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Pyrgos Mavroraki Smelting and Melting Experiments in a Metallurgical Workshop of the Second Millennium BC

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Interpreting the cultural influences of Cyprus in antiquity has posed an issue, depending on one's point of view or the different conclusions reached. Until the 1970s, in large part due to the extensive excavations along the northern coast of Cyprus, it seemed reasonable to recognise a plethora of Aegean traits in the island culture. Every element of the Cypriot Bronze Age was analysed and interpreted in a manner that led to comparisons with Aegean

civilisations (Buchholz and Karageorghis, 1973; Acts of the International Archaeological Symposium, 1979). However, after the political upheavals in 1974, most archaeologists moved their attention to the southern part of Cyprus, and a different historical landscape came into view (Karageorghis. 1986). Links found between Cyprus and other Levantine countries, with a strong influence from the seafront civilisations, (including Egypt) were recognizable (Michaelides, Kassianidou and Merrillees, 2009). These links confirmed the island played an important role in the commercial traffic of the Eastern Mediterranean, where copper was one of the most sought-after goods (Acts of the International Archaeological Symposium, 1982). This was likely the reason for the inhabitants of the island to learn of its extensive metal resources and led them to metallurgy, albeit centuries later than other Mediterranean civilisations (Erez, 2018, chapters 5, 10, 18, 19).

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Introduction

The question of when Cyprus began producing and exporting copper remained unanswered to this day and doubts concerning whether the copper ox-hide ingot was invented by the Cypriots (Hauptmann, Laschimke and Burger, 2016). While Cyprus was involved in the first attempts of small-scale copper production, the civilisations of the Aegean islands, of Anatolia and of the Near East Levant, possessed more advanced technology in smelting and casting copper alloys (Tylecote 2002, pp.18-34). The knowledge gap suggested trade between Cyprus and these regions wasn't as pronounced before the beginning of the second millennium BC, however, evidence of trading existed, as Neolithic Cyprus possessed Anatolian and Aegean obsidian (Moutsiou, 2019). Around the middle of the second millennium BC, the inhabitants of Cyprus learned to smelt sulphide ores, and started producing large quantities of copper for export, paid duty (at around 1470 BC Cyprus paid a tribute of 108 copper ingots to Pharaoh Thutmoses III) with ingots, that weighed approximately 30 kg (65 pounds) each (Kalyanaraman, 2017).

The shape of the ingots was the ox-hide and suggested a connection to a Cypriot religion (Knapp, 1986). However, the discovery of several ox-hide ingots made of non-Cypriot copper at the Ulu-burun shipwreck, sunk about 1300 BC, brought into question whether Cypriots were the inventors of this shape of ingot and whether perhaps the Mycenaeans, Phoenicians, Assyrians, Egyptians, Persians and Romans were as interested in the mineral resources of Cyprus, as scholars often claim (Stampolidis and Karageorghis, 2003). In this context, the excavations at the Pyrgos/Mavroraki site gained a greater significance, as a noteworthy relic of Cypriot metallurgical history. The structures and materials uncovered at Pyrgos/Mavroraki indicated a metallurgical site, positioned in a unique geological position, rich in copper outcrops and watercourses (Morel, 1964; Panthakis, 1967). The mines located in the surrounding area created an axis that ran parallel to the coastline, corresponded in alignment with the modern villages of Aghios Tychonas, Parekklisha, Pyrgos, Monì, Monagroulli, Asgata and Kalavassos. However, no other Early Middle Bronze age settlement of the extent of Pyrgos/Mavroraki had been found in the area, suggested the site was the district's main copper factory, where the minerals extracted from the different mines converged, possibly after being preliminarily roasted (Belgiorno, 2017, Fig. 4).

Pyrgos/Mavroraki was an archaeological site with a number of structures that aid in our understanding of ancient metallurgy. The industrial nature of the site had given it significance and it formed part of a landscape publicly accepted as having a special cultural meaning (Cyprus Today, 2008).

The area was full of resources with a special meaning to Cypriot history and held great potential to becoming an interpretive and public education instrument and a tourist attraction. The Bronze Age settlement was in a favourable position, situated on the slope of a low hill (Mavroraki) in the middle of a valley was formed by a stream crossing. In its proximity were both the largest ancient harbour Amathounte, and three smaller sheltered anchorages. Pyrgos aided us in understanding how the Limassol region developed and provided important findings for understanding the Early-Middle Bronze age (Belgiorno, 2017, pp.1-34, 45-93). The Pyrgos area had been classified as a protected area by the Department of Antiquities in 2002, due to its great cultural significance. A number of plots (almost 2 hectares) were expropriated to be used for further archaeological investigations. Evidence of the first settlement at the end of the Chalcolithic period was found along the ridge on the north-western side of the excavated area, the medium slopes of the Mavroraki hill (Belgiorno, 2017, p.15).

The structures that emerged corresponded to laboratories and workshops, producing cosmetics, bronze, textiles and wine. The remains of thousands of copper reduction nuggets, fragments of crucibles, clay moulds, stone anvils, stone tools and pit furnaces dated to the first two centuries of the second millennium BC were found at the site and presented a unique opportunity to enrich our knowledge of ancient metallurgy and to arrive at new historical suggestions. The absence of a trunk-conical furnace at the site suggested that the copper ore was a mix of minerals, easily recognised due to its green colour on the upper outcrop stratification (Brown, Mackenzie and Gainsford, 1984, pp.23-32). To answer ongoing questions regarding the findings of the Pyrgos/Mavroraki site, the Perfume Theme Park Museum of Cyprus offered its premises and support in the context of an experimental archaeology season focused on proving the functionality of the Pyrgos furnaces using original Cypriot copper ores and replicas of the tools and implements discovered at the site. In order to recover just 400 grams of copper, 20-30 kilos of copper ore were used, just as in the Bronze Age (Rademakers, 2015).

Summary of the data from the excavations

In the summer of 2019, a series of experiments aimed to clarify a number of technical questions studying the materials and structures of the Pyrgos – Mavroraki site, attributed to metallurgical activities in the Early Middle Bronze age. The site represents an exceptional peculiarity in the Mediterranean archaeological landscape.

Data from the study of the structures and findings related to the site demonstrated the presence of an intricate manufacturing complex in which metalworking was only one of the specialized sectors connected to a polyhedral and complex production (Belgiorno, 2017, pp.18-29). Few other Mediterranean excavations have provided such complete data about the metallurgical technologies of the Middle Bronze age (Webb and Frankel, 2013). The experimental reconstruction of the archaeological evidences contributes to consolidate data that emerged, raise new questions and make accessing these technologies to students and scholars.

The data on the metallurgical sector of the Pyrgos site are dense (Belgiorno, 2017, p.18,29: Belgiorno, Ferro and Loepp, 2012). The main phases of the metallurgical processes of the period are well represented. Artefacts included finished products, equipment, infrastructures and processing waste of various types. Additional artefacts like stone tools used to treat minerals and the finished products appear in relation with different types of combustion structures and remains from both "smelting" and "melting". A considerable amount of slag, still rich in metallic copper, was found both in the remains of kilns (See Figure 1) and over a large area (map of copper reduction nuggets, slags, crucibles and clay vitrified fragments distribution, in Belgiorno, 2017, p.23, Fig.18).

Documented structural remains have been interpreted as smaller furnaces for the refining or the remelting of copper alloys, as well as technical ceramics such as crucibles, nozzles and casting moulds to produce heel-type axes with double rivets (See Figures 2, 3) (Belgiorno, 2009, Fig.51). A set of stone tools supported metal working process like sledge-hammer heads, hammers, anvils, sharpeners and abrasive whetstones (See Figures 4, 5).

The secondary working processes of Cu-alloys are archaeologically well represented, and the plastic and mechanical processes are now quite clear - especially following the discovery of two lithic anvils (Figs. 6 and7) shaped with a groove and of use traces left by forging the ribbed blades, typical of this chronological period.

However, despite the incredible amount of data and materials suggesting the general production-frame of the atelier, there is misinformation on the fundamental element, i.e. the type of ores used and the related processing technologies.

Many scholars, in reference to the rich deposits of Cypriot sulphides, hypothesized that they were exploited during the most ancient phases of local metallurgy. Other sources however, supported by archaeometric analyses (Stos-Gale and Gale, 2010), revealed that many of the oldest metal artifacts, initially believed to be indigenous, were instead imports. Semi-finished and finished products are chemically similar to the Anatolian, Cycladic and oriental sources of supply (Webb, et al., 2006; Stos-Gale and Gale, 2010; Düring, et al., 2018). This reduces the exploitation of the Cypriot deposits during the chronological period ranging the Early to the Late Bronze Age.

Another question concerned the minerals used and their treatment. While some sources (Hauptmann and Weisgerber, 1980; Bourgarit and Mille, 2007) supported the early use of sulphides -in analogy with ancient Balkan and Asian contexts-, the site of Pyrgos, despite of a vast variety of slag, returned neither traces of sulphides nor tangible evidence of their treatment before the reduction phases.

More recent metallurgical contexts have clarified what the amount of benefication residues were produced by the exploitation of sulphides. Mineral reduction with lithic tools, flotation, combustion structures for roasting, and a considerable mass of slag at such sites showed how invasive a similar activity would be and how easily it was recognized in the archaeological record. During this period some place names in Cyprus and the Cyclades refer to this significant environmental impact was a result of metallurgical activity. The name of Skouriotissa, an important and active mining district in Cyprus, referred to the accumulation of slag during the classical era and the name of the Cycladic site of Skouries on the island of Kytnos, with sulphide deposits documenting exploitation since ECII, which referred to a similar accumulation of slag (Gale, et al., 1985, p.82; Stos-Gale et al., 1998, p.724; Muhly, 2002, p.79; Stos-Gale, and Gale, 2003, pp.90-91; Stos-Gale and Gale, 2006, pp.316-319).

None of these are present in Pyrgos, except for small combustion structures interpretable like furnaces and scarce remains of fuel, despite of a fair amount of cupriferous slags.

Metallurgical slag a starting point

Slags are derived from smelting ores that are rich in copper, which was present in the form of globular masses known as “prills”. Although their number was significant (a few thousand), they could have been discarded in ancient times because they were judged as not rich in metal, or as fragments that escaped the crushing process that was necessary for recovery of the metallic copper

The extensive literature suggests ways the slags can shed light on the extraction process, on pyrotechnology and on the minerals used (Burgarit, 2019). Often present in the slag are fragments of the fuel, parts of the furnace as well as traces of ore not completely reduced by the extraction process. Although archaeometric investigations are capable of revealing information on the chemical-physical aspect of the slags, the inferred data can be misleading in the absence of a clear picture of the extraction processes. Post-depositional or taphonomic processes (Rehren, 2009), Reuse of the slag as a part of the construction of furnaces, crucibles or clay tools (Queixalos, et al., 1987) or post-depositional or taphonomic processes (Rehren, 2009), compositional heterogeneity of the minerals and techniques constitute notable variables for the research for which some authors, in contradiction to others, hypothesized the use of slagging agents (Craddock, 1999; Burgarit, 2007).

Faced with a polyhedral issue and a systematic study of the archaeological slags pending, we decided to undertake a series of preliminary extractive experiments with the intent of becoming familiar with the materials and with the process of reinterpreting the archaeological record in a practical way. We hope to validate some of the hypotheses made during the excavation. From the data collected, we would provide a basis for comparison, and redirect future studies by excluding some hypotheses while posing new questions. We remained open to the possibility of rediscovering copper metallurgy in a completely empirical way, while staying true to the archaeological data.

Outline of mining archaeology

For the evidence of non-slagging techniques, we have suggested that the use of carbonates and oxides produced only a small amount of slag when compared with the treatment of sulphides. In Cyprus, it was hypothesized one of the likely traces of use of copper silicates and sulphates was at the site of Ambelikou Aletri (Dikaios, 1946), where evidence relating to reducing activities contrasted with the scarcity of slags (Zwicker, 1982, p.67).

In different contexts we found similarities with the Iberian techniques in reducing carbonates and cupriferous oxides inside large crucible-furnaces, known as ”vases-furnace” (Giardino, 1998, p.126). Following archaeo-metallurgical research, we were initially prompted to consider, the massive Pyrgos slag was a by-product of sulphide extraction.

In that case, the slags would have been derived largely from the silicate gangue, constituted by the encasing lava rock (pillow lava formations), the quartz and silicate veins formed as hydrothermal phenomena that led accumulation of sulphides in secondary mineralization. The study of Cypriot mining geology led us to consider the massive mineralization associated with the geological “pillow lava” formations at the Troodos ophiolitic complex (See Figure 8).

In fifty years of mining research, more than thirty deposits, located in different stratigraphic horizons, were classified and exploited in the mining districts of Skouriotissa, Tamassos, Kalavassos and Limni. Characterized by a vertical sedimentation, these deposits had their upper part composed of lenticular deposits of copper and iron sulphides, followed by enrichment zones and veins of secondary mineralization of mixed sulphides between the basaltic groups. It is important to note that, even in this case the geo-mining studies leave no doubt, denying the presence of significant carbonates or silicates in association with the main sulphide deposits. In other cases, however, scarce traces were described in the secondary enrichment zones or in the Cretaceous limestone formations as a by-product of the leaching of the main mineralization (Constantinou, 1982).

Although there was evidence of exploitation attributable to the Greek and Roman period, there did not appear to be concrete evidence of previous exploitations. This missing mosaic tile of ancient metallurgy would shed light on minerals used by ancient communities of metalsmiths. Intense exploitation, during the historical period probably erased traces of older and superficial mining. Therefore, we took into account that we would come across minerals poorer than those found in ancient times, with the probability of obtaining significantly different results.

Data evaluation and choice of experimental strategies

Putting together the data collected from years of research, we came to the following conclusions.

1. The Cypriot geo-mining literature considered the secondary formations of carbonate oxides and copper silicates almost absent or of very little value. These were listed in ancient Roman and medieval sources as usable for alchemical purposes and in the production of pigments.
2. Scholars agreed that Cypriot metallurgy was based from the very beginning, on sulphide deposits of the Troodos ophiolitic complex. With some exceptions, such as Ambelikou Aletri, it was believed that the metallurgical communities of the second millennium BC were able to obtain copper from sulphides using non-slagging technologies.
3. The ancient slags, massive and rich in metallic copper, were the product of sulphide reduction, and the vitreous matrix was due to fusion of the silicates derived from the quartz veins and encasing lava rock.

It should be noted however, that these points still have aspects that have not been fully explained. Firstly, although we hypothesized that the Millenary and intensive exploitation of Cypriot mining formations may have erased the traces of pre-protohistoric outcrops, it could also be assumed that this exploitation had eliminated the traces of surface areas of alteration, where carbonates and silicates were more abundant in ancient times. Secondly, the exploitation of sulphides encompassed complex technology that was not reflected in the archaeological traces of Pyrgos, and demonstrated a simpler and more direct metallurgy that was mainly concerned with the treatment of oxides, carbonates and copper silicates. In designing a first cycle of experiments, we therefore started with the consideration of a simpler technology, closer to the archaeological data in our possession.

The search for the mineral

In order to limit the variables involved and to be able to have geologically certified mineral to be supported with any local minerals, we turned to a Cypriot mining company, Skouriotissa mine, the only mine active in Cyprus. We asked for minerals from surface outcrops, more likely to be in line with ancient prospecting, rather than chalcopyrite extracted from the main deep deposits. In the collaboration, we received several kilos of limestone and chalk veined with azurites and leaching malachite and six kilos of pure copper electrolytically produced by the plant.

Although these litho-types were a carbonate matrix and therefore not suitable for obtaining a silicate slag, the slight blue-green mineralization in these formations encouraged us to undertake some reconnaissance in the disused mines of the Kalavassos (Limassol) territory (See Figure 9) of finding, among the waste materials from centuries of excavations and cuts to the rocky fronts, some minerals of little significance for industrial exploitation but of great significance for our experiment.

We were surprised to see a consistent greenish outcrop among the igneous formations of pillow lava that demonstrated cupric carbonates and silicates.

The geological literature, did not mention the presence of carbonates or silicates at this level. This is probably due to the search for more advantageous deposits, The analysis of this find linked a part of the data and pushed the experiment in a new direction.

Collection and treatment of the mineral

The mined mineral appeared as bright green rock, interspersed with quartz veins and dark areas. The friability of the mineralized rock, as was probably the case in ancient times as well, was quarried with the use of simple tools (See Figures 10 and 11). The best portions of the rock were macroscopically selected on the site, trying to separate the most visually significant minerals from the less mineralized rock. The use of water helped to bring out the colours and allowed us to focus on the greener portions (See Figures 12 and 13).

Once it was transported to the Experimental Park, the rock was crushed into fine gravel and collected in terracotta bowls. Basaltic millstones, experimentally reconstructed according to those found in large quantities at the archaeological site of Pyrgos aided the process (See Figure 14).

Crushing the mineral was simple, and water was used periodically to wash the sands compacted on the millstones and to eliminate the lighter gangue, slowly immersing and emptying the cups full of mineral in a larger container full of water (See Figure 15). At this point, a surprising fact emerged, the wet millstones appeared greenish after being left in the sun, exactly as the archaeological millstones found in the excavation.

Since first investigating the colour of the millstones, we considered the tools for the treatment of the mineral. We had associated it with the alteration products of sulphides or slags, but that view should be reconsidered (See Figure 16).

It could be that the millstones of Pyrgos had never crushed sulphides, of which there is no trace at the site, but rather carbonates and silicates, whose light sands are difficult to distinguish on the ground, but have dyed the millstones through prolonged contact causing their green appearance (See Figure 17).

Choice of combustion structure

The ore was laid out to dry, and we then concentrated on the construction criteria for the reduction furnace. Among the various types of combustion structures found in Pyrgos, we found a well that contained both the remains of a probable tuyere and fragments of slag in the immediate vicinity. We had chosen this structure due to its generous dimensions of about 40 cm, the depth was 30 cm, suitable to accommodating the intended modest load of mineral.

We reconstructed something similar by digging a pit and lined it with stones and clay, in accordance with what was found in situ (See Figure 18). The tuyere was made simply by wrapping some local clay around a piece of marsh reed of a diameter of 2.5 cm used like mandrel (See Figure 19). The whole structure was then covered with a layer of finer clay to smooth its surface and filled the cracks formed due to the shrinkage of the first layer. A small crucible furnace was built next to this furnace for casting experiments (See Figure 20). The structure was similar to the previous one, although of considerably smaller dimensions: a diameter of 25cm and a depth of about 10 cm, to accommodate the crucible of copper mixed with fuel.

For the reconstruction and the sizing of the tuyeres, we referenced the various finds made during the excavation, with some of them being intact. These had variable dimensions and were sometimes vitrified, in direct connection with the furnaces and altered by the heat. For the positioning of the feeding point, we opted for a ventilation system placed just above the crucible (See Figure 21) and secured to the edge of the furnace with pebbles and clay.

Examples of such a type of system was iconographically known in the Egyptian world as they were found in the tomb paintings of *Rek mi Re* and *Puyem Ra* (See Figure 22). The study of the Pyrgos crucibles, discoloured and vitrified exclusively from the inside and apparently intact on the outside, suggested the use of this type directly in contact with the walls of the furnace and not immersed in coal. The mainly internal fire was therefore fed from above.

Production of technical ceramics and lithic tools

During the drying phases of the fournaces, we dedicated ourselves to the reconstruction of technical ceramics: molds, crucibles and tuyeres using archaeologically documented examples. The Troodos massif offered secondary clays mixed with volcanic sands, particularly suitable for the production of fire pottery.

Our choice to improving resistance to thermal shock was add more sand in the in the mixture of the crucibles according wit the archaeological examples. All the sun-dried pottery was fired in a large open fire (See Figure 23).

Some basalt lithic tools were reproduced in accordance with the archaeological finds. Two peen hammers obtained from flat pebbles were readjusted by abrasion and subsequently mounted on a handle. The two lithic anvils with a flat surface and V-shaped groove (See Figures 6, 7) were reproduced, by working two large basaltic pebbles (See Figure 24).

A multiple melting mould was made from a block of calcarenite. Although such a find does not appear in Pyrgos, it was necessary to complement the moulds (which are of clay at Pyrgos) in the experiments in order to limit their wear (See Figure 25).

Smelting tests

The main furnace was preheated with a wood fire (See Figure 26) and once the tuyeres and bellows were attached, it was checked to observe if the ventilation dynamics were correct.

There was no certain data regarding the power supply of the melting furnaces at the time, however, some information stemming from the aforementioned Egyptian iconographies, suggested the shape and size of the bellows used.

It could be inferred from iconographies, bellows were constructed with wood and leather (See Figure 27).

At the end of the heating phase of the furnace, and once combustion was stabilized, a handful of ore was added. The ore slowly fell towards the coals at the hottest point of the hearth, and the first data collected. The flame turned from orange to green, the charcoal became covered with a greenish-yellow patina and the combustion vapours became pungent and displeasing (See Figure 28).

*When the flame reverted to an orange colour, we added more mineral and charcoal until the observations became apparent again. We continued with this method for an hour until a first portion of mineral about one kg was completed and seven kgs of coal were used (See Figure 29)

At this point the furnace showed a noticeable drop in performance, inferred from the colour of the flame and from feeding difficulty was probably due to an obstruction in the tuyere under the embers. Once the bellows were unhooked, part of the charcoal was removed in order to evaluate what had happened. We observed a large incandescent mass of slag had formed around the tuyere and that many small drops of molten and incandescent copper shone in the mass (See Figure 30).

After waiting for its temperature to drop, we removed the charcoal and exposed the slag adhering to the furnace wall. With the help of a pick and a firing pin we removed the slag and cooled it with water. Among the vitreous concretions of molten rock stood clear drops of metallic copper (See Figures 31, 32)

Melting experiments

The same preliminary operations used for smelting tests were carried out, namely: heating with a wood fire and setting up the ventilation line. The tuyere was positioned at the upper edge of the furnace (Pontieri and Trojsi, 2008 p. 161; Sheel 1989, fig. 14,15) and connected to wood and leather bellows (See Figures 33, 34). The crucible was loaded with pieces of copper at the centre of the pit-furnace, immediately below the tuyere, the entire structure was covered with embers and fresh charcoal. During this phase, we used 400 grams of pure copper, was which donated by the Skouriotissa mine. This was used in order to avoid affecting the previously experimentally obtained copper that would be used for archaeometric analyses.

Twenty minutes of bellow working and using three kilos coal, the copper completely melted, and was poured into stone moulds to obtain semi-finished products (See Figures 35, 36).

Although experimental casting had already been done during previous educational campaigns at the Pyrgos site, this time we were able to focus on other technical aspects as well, such as refractory stability of the clays used to reproduce the crucibles and the comparison of data with the numerous archaeological fragments in our possession. In this experiment we found the small combustion structures, present in large numbers in Pyrgos proved extremely effective and rapid in the melting process.

Because the heat was exclusively concentrated within the crucible, the wear was limited and allowed greater fuel savings. It would not be far-fetched to imagine a very busy workshop environment, in which several furnaces operated simultaneously, casting larger items or refining the copper obtained from slag (See Figure 37).

Recovery of copper prills from slag and quantitative analysis of mineral usage

In the laboratory, the large slag was cleaned, and a portion of the metal content removed for archaeometric investigations (See Figures 38, 39, 40).

To preserve the slag obtained, we conducted additional smelting experiments in the laboratory to empirically verify the actual yield of the mineral used in the experiments. For these analyses, we used a gas-oxygen torch, a ceramic crucible of the semi-open type, about 42 g of mineral and some pieces of coke.

The ceramic crucible was necessary to avoid possible interference of commercial graphite crucibles with the mineral. The coke carbon, more effective than charcoal, was used to neutralize the oxidizing flame of the torch and guaranteed the conditions of redox.

The fragmented mineral was mixed with coal, placed in the crucible and heated with a small oxidizing flame (See Figures 41, 42). In a few minutes, a nice lump of slag was formed, physically identical to the one obtained experimentally. After cooling, the copper prills emerging from the silica matrix appeared clearly.

The slag was crushed in a mortar. The copper prills were recovered and melted in the crucible into a single drop weighing 0.6 grams.

We deduced the geological ore sample that was analysed had a copper content equal to 1.4%. This data must take the context into account. This was a single experiment carried out with a secondary mineral found in the external area of an abandoned mine exploited for years. It was likely that ancient secondary mineralization was much richer and more visible.

Final considerations

The first experiment was successfully completed, and new experimental campaigns can be considered. Aside from the chemical-physical data still being evaluated, it was interesting to see and take note of the practical information acquired in the course of the experiment: the approach with mineral formations not considered previously, the chromatic aspect of the minerals considered suitable, related geological indicators, exploitation, tools needed in the past, and the phases related to treatment and enrichment with possible archaeological implications.

Our furnace work was as ideal as possible, and delivered significant important information on smelting that were not taken into account: temperature, air flow, quantity of coal and mineral size, showing how interconnected they were and as factors worth empirically evaluating.

It was clear to us how such an approach was valuable for studying ancient technologies.

Such reconstructive experiments helped to bring a variety of factors to light, that would only rarely emerge from archaeological excavations.

PYRGOS MAVRORAKI SMELTING AND MELTING EXPERIMENTS IN A METALLURGICAL WORKSHOP OF THE SECOND MILLENNIUM BC | PERFUME THEME PARK OF CYPRUS PRESENTS PYRGOS-MAVRORAKI METALLURGY EXPERIMENT

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FIG 1. SLAGS OF PYRGOS/MAVRORAKI IN SITU. PHOTO BY ANTONIO DE STROBEL

FIG 2. MOULDS OF HEEL-TYPE AXES WITH DOUBLE RIVET, FROM PYRGOS/MAVRORAKI. PHOTO BY ANTONIO DE STROBEL

FIG 3. MOULDS OF HEEL-TYPE AXES WITH DOUBLE RIVET, FROM PYRGOS/MAVRORAKI. PHOTO BY ANTONIO DE STROBEL

FIG 4. MACE HEADS, HAMMERS, ANVILS, SHARPENERS AND ABRASIVE STONES FROM PYRGOS/MAVRORAKI. PHOTO BY ANTONIO DE STROBEL

FIG 5. MACE HEADS, HAMMERS, ANVILS, SHARPENERS AND ABRASIVE STONES FROM PYRGOS/MAVRORAKI. PHOTO BY ANTONIO DE STROBEL

FIG 6. LITHIC ANVILS EQUIPPED WITH A GROOVE AND TRACES OF USAGE MADE BY THE FORGING OF THE RIBBED BLADES TYPICAL OF THE EARLY-MIDDLE BRONZE AGE. PHOTO BY ANTONIO DE STROBEL

FIG 7. LITHIC ANVILS EQUIPPED WITH A GROOVE AND TRACES OF USAGE MADE BY THE FORGING OF THE RIBBED BLADES TYPICAL OF THE EARLY-MIDDLE BRONZE AGE. PHOTO BY ANTONIO DE STROBEL

FIG 8. “PILLOW LAVA” FORMATIONS OF THE TROODOS OPHIOLITIC COMPLEX. PHOTO BY ANTONIO DE STROBEL

FIG 9. DISUSED MINES OF THE KALAVASSOS (LIMASSOL) TERRITORY. PHOTO BY ANTONIO DE STROBEL

FIG 10. BLUE-GREEN ROCKS INTERSPERSED WITH QUARTZ VEINS AND DARKER AREAS. PHOTO BY ANTONIO DE STROBEL

FIG 11. BLUE-GREEN ROCKS INTERSPERSED WITH QUARTZ VEINS AND DARKER AREAS. PHOTO BY ANTONIO DE STROBEL

FIG 12. SOME WATER HELPED US IN FOCUSING EXCLUSIVELY ON THE GREENER PORTIONS. PHOTO BY ANTONIO DE STROBEL

FIG 13. SOME WATER HELPED US IN FOCUSING EXCLUSIVELY ON THE GREENER PORTIONS. PHOTO BY ANTONIO DE STROBEL

FIG 14. CRUSHING AND WASHING THE MINERALS. PHOTO BY ANTONIO DE STROBEL

FIG 15. CRUSHING AND WASHING THE MINERALS. PHOTO BY ANTONIO DE STROBEL

FIG 16. THE WET MILLSTONES APPEARED GREENISH AFTER BEING LEFT IN THE SUN. PHOTO BY ANTONIO DE STROBEL

FIG 17. MILLSTONE OF PYRGOS/MAVRORAKI WITH A GREENISH SURFACE. PHOTO BY ANTONIO DE STROBEL

FIG 18. DIGGING AND LINING A PIT WITH STONES AND CLAY. PHOTO BY ANTONIO DE STROBEL

FIG 19. ARRANGING NOZZLE WITH A REED. PHOTO BY ANTONIO DE STROBEL

FIG 20. A SMALL CRUCIBLE FURNACE WAS ALSO BUILT NEXT TO THE FIRST FURNACE WITH A VENTILATION SYSTEM PLACED JUST ABOVE THE CRUCIBLE. PHOTO BY ANTONIO DE STROBEL

FIG 21. A SMALL CRUCIBLE FURNACE WAS ALSO BUILT NEXT TO THE FIRST FURNACE WITH A VENTILATION SYSTEM PLACED JUST ABOVE THE CRUCIBLE. PHOTO BY ANTONIO DE STROBEL

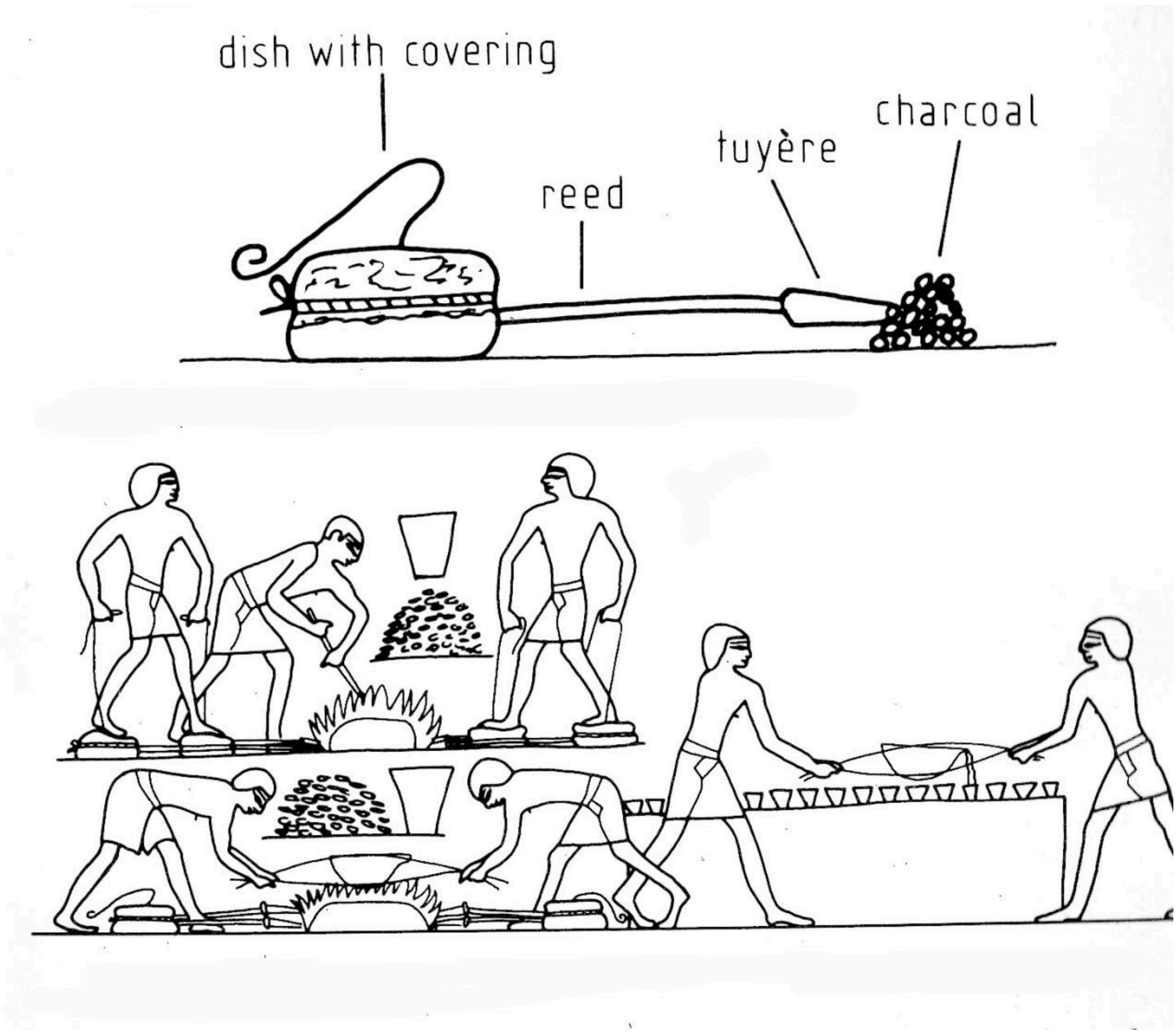

FIG 22. THE TOMB OF REKH-MI-RE AT THEBES, THE MELTING AND CASTING OF METAL, AFTER DAVIES 1943. PL. 52. NEW YORK.

FIG 23. CRUCIBLES AND NOOZLES FIRD IN AN OPEN FIRE. PHOTO BY ANTONIO DE STROBEL

FIG 24. TWO LITHIC ANVILS WITH A FLAT SURFACE AND V-SHAPED GROOVE WERE ALSO REPRODUCED, AND ONE MOULD OF CALCARENITE. PHOTO BY ANTONIO DE STROBEL

FIG 25. TWO LITHIC ANVILS WITH A FLAT SURFACE AND V-SHAPED GROOVE WERE ALSO REPRODUCED, AND ONE MOULD OF CALCARENITE. PHOTO BY ANTONIO DE STROBEL

FIG 26. THE MAIN FURNACE WAS PREHEATED WITH A WOOD FIRE. PHOTO BY ANTONIO DE STROBEL

FIG 27. WORKING ON BELLOWS CONSTRUCTED WITH WOOD AND LEATHER. PHOTO BY ANTONIO DE STROBEL

FIG 28. THE FLAME BEGUN TO TURN FROM ORANGE TO GREEN AND WE ADDED MORE MINERAL AND COAL. PHOTO BY ANTONIO DE STROBEL

FIG 29. THE FLAME BEGUN TO TURN FROM ORANGE TO GREEN AND WE ADDED MORE MINERAL AND COAL. PHOTO BY ANTONIO DE STROBEL

FIG 30. A LARGE INCANDESCENT MASS OF SLAG HAD FORMED AROUND THE NOZZLE AND THAT MANY SMALL DROPS MOLTEN AND INCANDESCENT COPPER SHONE IN THE MASS OF MOLTEN ROCK. PHOTO BY ANTONIO DE STROBEL

FIG 31. AMONG THE VITREOUS CONCRETIONS OF MOLTEN ROCK STOOD CLEAR DROPS OF METALLIC COPPER. PHOTO BY ANTONIO DE STROBEL

FIG 32. AMONG THE VITREOUS CONCRETIONS OF MOLTEN ROCK STOOD CLEAR DROPS OF METALLIC COPPER. PHOTO BY ANTONIO DE STROBEL

FIG 33. TUYERE POSITIONED AT THE UPPER EDGE OF THE FURNACE AND CONNECTED TO THE USUAL WOODEN AND LEATHER BELLOWS. PHOTO BY ANTONIO DE STROBEL

FIG 34. TUYERE POSITIONED AT THE UPPER EDGE OF THE FURNACE AND CONNECTED TO THE USUAL WOODEN AND LEATHER BELLOWS. PHOTO BY ANTONIO DE STROBEL

FIG 35. THE COPPER MELTED IN THE CRUCIBLE WAS POURED INTO STONE MOULDS IN ORDER TO OBTAIN SOME SEMI-FINISHED PRODUCTS. PHOTO BY ANTONIO DE STROBEL

FIG 36. THE COPPER MELTED IN THE CRUCIBLE WAS POURED INTO STONE MOULDS IN ORDER TO OBTAIN SOME SEMI-FINISHED PRODUCTS. PHOTO BY ANTONIO DE STROBEL

FIG 37. MULTIPLE FURNACES IN THE CORNER OF ONE OF THE METALLURGICAL WORKSHOPS OF PYRGOS / MAVRORAKI. PHOTO BY ANTONIO DE STROBEL

FIG 38. PURE COPPER NUCLEI EXTRACTED FROM THE GLASS MATRIX. PHOTO BY ANTONIO DE STROBEL

FIG 39. PURE COPPER NUCLEI EXTRACTED FROM THE GLASS MATRIX. PHOTO BY ANTONIO DE STROBEL

FIG 40. SMALLER DROPLETS AND PRILLS AFTER CRASHING THE SLAG. PHOTO BY ANTONIO DE STROBEL

FIG 41. THE MINCED MINERAL MIXED WITH COAL WAS THEN PLACED IN THE CRUCIBLE AND HEATED WHILE TRYING TO MAINTAIN A SMALL OXIDIZING FLAME. PHOTO BY LIVIO PONTIERI

FIG 42. THE MINCED MINERAL MIXED WITH COAL WAS THEN PLACED IN THE CRUCIBLE AND HEATED WHILE TRYING TO MAINTAIN A SMALL OXIDIZING FLAME. PHOTO BY LIVIO PONTIERI

FIG 43. ONCE THE SLAG WAS CRUSHED IN THE MORTAR, ALL THE COPPER PRILLS WERE RECOVERED AND MELTED IN THE CRUCIBLE INTO A SINGLE DROP WEIGHING 0.6 GRAMS. PHOTO BY LIVIO PONTIERI

FIG 44. ONCE THE SLAG WAS CRUSHED IN THE MORTAR, ALL THE COPPER PRILLS WERE RECOVERED AND MELTED IN THE CRUCIBLE INTO A SINGLE DROP WEIGHING 0.6 GRAMS. PHOTO BY LIVIO PONTIERI