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EXPERIMENTAL COPPER SMELTING AT AGIA VARVARA - ALMYRAS A CONTRIBUTION TO THE CONTROVERSY OF ANCIENT IRON PRODUCTION IN CYPRUS

Abstract

In October 1999 the last excavation was carried out at the site of Iron Age copper production at Agia Varvara–*Almyras*, leaving approximately 40% of the actual volume of soil on the small hillock of Almyras still unexcavated. Post excavation work is in progress and includes geochemical and archaeometallurgical analysis of all materials involved in the copper production.[1]

The experimental reconstruction of copper working activities at Almyras started in 1995 with ore dressing experiments[2]. Copper smelting experiments are now an established part of the Almyras Project. This is because actual work with authentic materials and techniques is as good a teacher of archaeometallurgy as any laboratory analysis. This is most certainly true concerning such factors as time, manpower, know-how and energy consumption.

Between September 1999 and May 2000, a total of five experimental copper smelting runs were carried out. The sequence of experiments at Almyras took place outside of the excavation perimeter and included ore crushing, the forming of ore pellets and their roasting, copper smelting in a single, free standing clay furnace, recharging of a slag/matte mixture in the same furnace for possible reduction and the casting of bronze objects in a separate casting hearth. Although bronze casting was never actually done at the site of Almyras in ancient times, we thought it important to go through the entire chain of operation and therefore include the ultimate goal of this huge endeavour — the production of an artifact!

The archaeological base for experiments in copper smelting

Immediately after the discovery of the ancient copper working site of Agia Varvara–*Almyras* in 1982 (pl. XVIIa), a rescue excavation of a badly damaged and eroded smelting furnace was carried out. This furnace is now stored in the Cyprus Museum in Lefkosia. The first two of fifteen field seasons since 1988 yielded most of the furnace finds, with the astonishing discovery that each furnace was different from the ones previously found. Roasting pits and double furnaces for copper smelting were unknown in Cyprus before these finds. Since then, the complete chain of operation has been unearthed at *Almyras,* from the mining pit to the refined copper metal.[3]

1. Generous support, financially and logistically, is acknowledged to the Swiss National Foundation for Scientific Research, SNF in Bern, and the Swiss Federal Laboratories for Materials Testing and Research, EMPA Dübendorf.

2. Connolly, A.: Some Preliminary Experiments in Copper Ore Benification, in: Fasnacht, W. *et al.*: Excavations at Agia Varvara – Almyras, Fifth Preliminary Report. *RDAC* 1996, 116-118.

3. For a review of twelve years of research at Agia Varvara-*Almyras* see: Fasnacht, W., *RDAC* 1999, 179-184

The archaeological evidence for the reconstruction of the copper working installations at *Almyras* consists of furnace fragments, tuyères, slags and copper metal and has provided enough information to make the following statements about furnace construction and operation:

- Smelting furnaces of Archaic, Classical and Hellenistic times were about 80 cm high and 30 – 40 cm in diameter.
- Roasting furnaces were open, oblong beds with side walls, with a length of below 2 meters and a width of about 70 cm. The ores were roasted prior to smelting to burn part of the sulphur off.
- Artificial air-induction took place through tuyères, i.e. cone-shaped clay nozzles of about 30 cm in length and 5 – 15 cm in diameter. We have no evidence, however, of how many tuyères were placed in a furnace and where exactly those tuyères were positioned.
- The ore used was chalcopyrite, finely crushed and mixed with limestone fluxes to form a highly liquid slag.
- The slag was periodically tapped and formed cakes in a pit next to the furnace. The slag cakes were about 30 cm in diameter and were discarded after cooling.
- Wood was used for fuel, either directly or in the form of charcoal. For our experiments, wood was used to preheat the furnaces and charcoal or a charcoal/wood mixture for the actual smelting process. Future experiments will have to test the direct use of dried wood for all steps of copper production.

The furnace used for the smelting experiments was built entirely of clay, with a solid mantle of clay and stone around the bottom and the tuyères being the only pre-fired elements. The size of this furnace was 80 cm in height and 35 cm in diameter at the inside (pl. XVIIb). The furnace was operated continuously for four to six hours, by means of two bellows from which clay pipes were connected to one or two tuyères. For air-induction, pot-bellows were used according to the Late Bronze Age find from Alassa, exhibited in the Cyprus Museum (Inv. No. Alassa 76). Usually, experimental archaeologists use two pot-bellows according to the Egyptian technique, where a person stands with one foot in each pot. A leather cover on the pots is alternatingly pressed down with the feet and manually lifted up with a string. We adjusted this system according to the hand-operated technique in Greece using goat skin-bellows (pl. XVIIIa), as well known from vase paintings of the Archaic and Classical Period.[4] It has to be mentioned that these paintings depict the ancient bronze casting technique and not the copper smelting process. As our team has ten years of experience in bronze casting experiments, we were eager to see whether the manual bellow operation also worked for the smelting process – and it did! For the demonstration of the casting technique, we choose bronze astragali as the objects to be cast (pl. XVIIIb). Bronze astragali served as dice, to play or to the read the oracle, and were part of funerary offerings already in the Bronze Age.[5] Numerous examples have been found in Cyprus.

The experimental furnaces for copper smelting were fed with consistent charges of charcoal and ore of 1.5 kg, alternating in a 20-minute rhythm. Charcoal was crushed to the size of a walnut and pellets of the

4. Weisgerber, G. and Roden, Ch.: Griechische Metallhandwerker und ihre Gebläse, in: Der Anschnitt 38, 1986, Heft 1, 2-26, especially Fig. 17.
5. Reese, D., in: *La nécropole d'Amathonte, Tombes* 113-367, p. 127ff. and especially footnote 59. *Études Chypriotes* XIV, Nicosia 1992.

ore/flux mixture were produced of the same size. We used a modern concentrate in the form of chalcopyrite, with a copper content of about 25%. Local limestone was added as a flux, because the original slag has been found to contain calcium and magnesium oxide up to a total of 12%.

A strict assignment of jobs kept throughout the entire run showed to be most successful. The bellow operators need to take turns of about one hour. Not so much physical strength as coordination, stamina and good senses to see, feel, hear and smell what is happening in the furnace is needed for this job. Historical records of women involved in mining and metal working are numerous and small scale operations like *Almyras* may well have depended on the work of women and even children.[6]

Accidental iron production during copper smelting

The result of all of the five smelting runs after several hours of charging and one hour of cooling was a lump of slag accumulated at the bottom of the furnace. This lump was always attached to the tuyere which mostly melted at it's tip. The slag was never liquid enough to be tapped. Matte-inclusions of up to 3 cm in diameter were trapped in the slag, with some accumulating at the bottom, which meant that the complete separation of the two phases was not achieved. The slag was too viscous and the matte could not find its way to the bottom of the furnace. The ultimate goal will be to assemble enough matte with which to then recharge the furnace and smelt this intermediate product to the actual raw copper metal. Our next step, however, will be the full chemical and metallographic analysis of all the experimental products. Preliminary results on polished sections on two of the slag cakes are available and are presented here. Upon close investigation under binoculars and the optical microscope, all five experimental slags consistently showed the following features:

- The slag matrix shows beginning crystallization to form fayalite laths in the centre of the slag cakes. This means that conditions for the slag formation come near the ancient ones.

- Within this slag matrix, numerous inclusions are visible with the naked eye:

  - a) rounded or polygonous matte inclusions, up to 3 cm in diameter, with beginning copper segregation;

  - b) globular copper sulphide inclusions of only a few millimeters in diameter, light blue in colour and sometimes with a core of solid copper metal;

  - c) minute copper prills, mostly of less than 1 mm in diameter, either isolated in the slag matrix or as part of the matte. These prills are rather pure, with only little copper oxide and/or sulphide inclusions.

  - d) Small bands of metallic iron, either incorporated into the matte inclusions or surrounding the numerous charcoal fragments in the slag.

  - e) large charcoal fragments, having been trapped in the viscous slag.

6. Our artistic drawing of the copper working activities at Almyras shows a family operated scene, in: Fasnacht *et al. RDAC* 1996, Fig. 5.

   Further reading about women and mining in: Frauen und Bergbau. *Veröffentlichungen aus dem Deutschen Bergbau-Museum Bochum,* Nr. 45, Bochum 1989.

During the third experiment, where the same charcoal, ore, tuyères and bellows were used and the rhythm of charging was kept as with all other experiments, a lump of several kilos of slag was produced. Back in the laboratory, this piece was sawn in two. It showed a much higher amount of iron metal than all other slag cakes. We obviously had reduced the iron in the chalcopyrite mineral directly to clearly visible metallic iron — and this result stirs up the controversy of iron being produced in ancient Cyprus.[7] The author himself has always been sceptical about the theory of local iron production,[8] and still is. The main arguement was that it is too difficult with prehistoric means to reduce the iron in the chalcopyrite instead of the copper. Now as we accidently produced iron ourselves, it seems appropriate to have metallurgical analyses carried out on the samples of this iron by a specialist in ancient iron technology. The results of investigations carried out by Marianne Senn are the following:

Metallic iron has formed predominantly in direct contact with charcoal inclusion (pl. XIXa). In these places, iron is present in dendritic form and dominant over copper metal. This dendritic iron is confined to copper matte. The same dendritic iron also occurs in samples from other smelting runs, but less dominant. Besides the dendritic iron in the matte, small iron inclusions also occur in the slag, or in the form of little droplets in globular matte inclusions (pl. XIXb).

It is highly unlikely that any of these iron inclusions could be isolated from their surrounding material and then used for smithing.

The formation or even dominance of metallic iron in the products of experimental copper smelting shows that the conditions were highly reducing. Much less reducing atmospheres would be sufficient for the formation of a copper matte. There are different ways to reach an lower oxidation level: reduce the immediate air-flow, change the rhythm of bellowing and charging, use different fuel, work at different temperatures, change the position of the tuyères or change the furnace construction. Detailed analysis of more experimental products will have to follow the present one in order to systematically assess the influence of each of these parameters.

Conclusions

Already in the Bronze Age, iron was not an uncommon by-product of the copper smelting process,[9] but it was not used in any way at that time. But how much of the new metal, the iron, did the Iron Age copper smelter know? In fact, some of the *Almyras* copper metals contain up to 10% of metallic iron, clearly visible under the microscope as dendrites in the copper matrix. This "useless impurity" was burnt off during the refining process. It is questionable, therefore, that the Iron Age copper smelter knew that this impurity was the same metal as the one of his mining tools he paid a high price for.

As shown by our experiments, iron production out of chalcopyrite ore with the ancient copper technology is possible but does not make sense. Although metallic iron is omnipresent in all copper smelting products, be it slag, matte or copper metal, it is too small to be isolated physically, i.e. by crushing and

7. Kassianidou, V.: Could iron have been produced in Cyprus. *RDAC* 1994, 73-79.
8. Fasnacht, W. *et al.* Excavations at Agia Varvara - Almyras, Fifth Preliminary Report. *RDAC* 1996, 98.
9. Pickles, S. and Peltenburg, E.: Metallurgy, Society and the Bronze/Iron transition in the East Mediterranean and the Near East. *RDAC* 1998, 79 and 90.

hand-picking, and too difficult to be isolated chemically, i.e. with a consecutive smelting step that would burn off the copper related minerals and leave the metallic iron. Iron could not be brought to the liquid state like copper; archaeologists tend to ignore the fundamental difference between the ancient copper and iron technology: Iron was never smelted to a liquid metal before the Middle Ages, it was always intermixed with the slag and only reached the viscous state. Copper technology, on the other hand, was based on complete separation of the metal and slag phase for thousands of years before iron was "invented".

What traces of ancient iron production have been substanciated in Cyprus so far ? No iron bloomery furnace and no iron slags have been found yet. The simple use of iron objects in a very early stage, so to speak in the *statu nascendi* of the technology itself, is not enough evidence of local production.

A possiblility of indigenous production of iron on Cyprus exists theoretically: from the geological point of view it is possible that iron-rich gossans rather than pyrites were used for systematic iron production.[10] Gossans had been thrown away as waste for thousands of years of copper production. At an initial stage of the iron technology, these gossans may at least have been tested for their possible use for iron production. After the initial stage, there may have been no need for local production any more, because once the iron technology was established, the metal was produced ubiquitously and cheap, all over the Mediterranean, the Balkans and Central and Western Europe. Cyprus would then have taken back its traditional role from the Bronze Age, the role of a producer of excellent copper. The copper produced in the advanced Iron Age, at places like *Almyras,* was among the purest on the market.[11] "Aes cyprium" could keep this reputation until Roman times, and more than that: it even gave the name to the island up to this day.

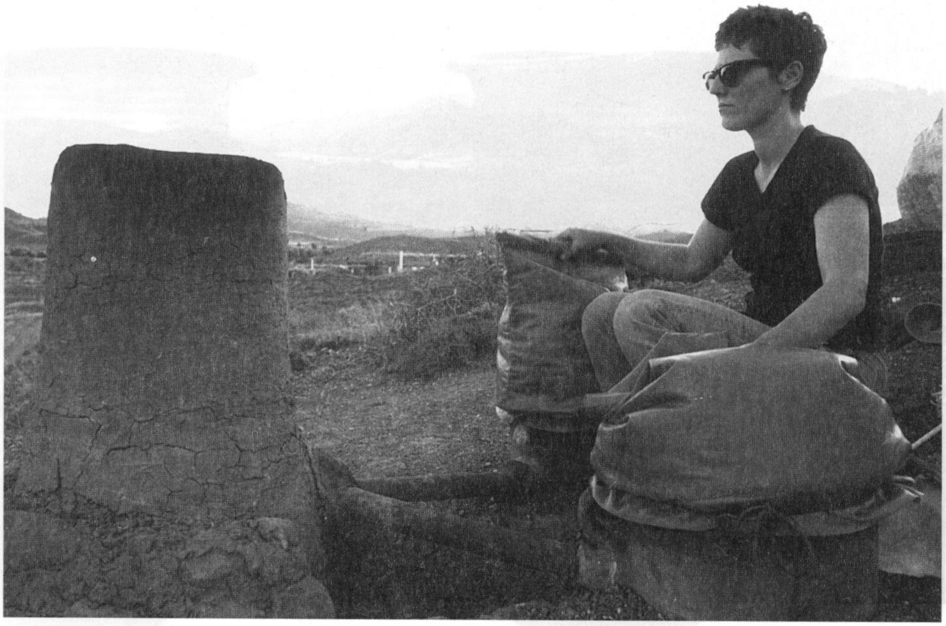
To prove a possible exploitation of gossans for iron production on Cyprus, systematic field research to detect iron production waste in the well know ancient copper production areas will have to be caried out. This task, accompanied by iron smelting experiments, will have to be initiated by a new crew of specialists, the ones for the ancient iron technology.

10. Kassianidou, V.: Could iron have been produced in Cyprus. RDAC 1994, 76,771994

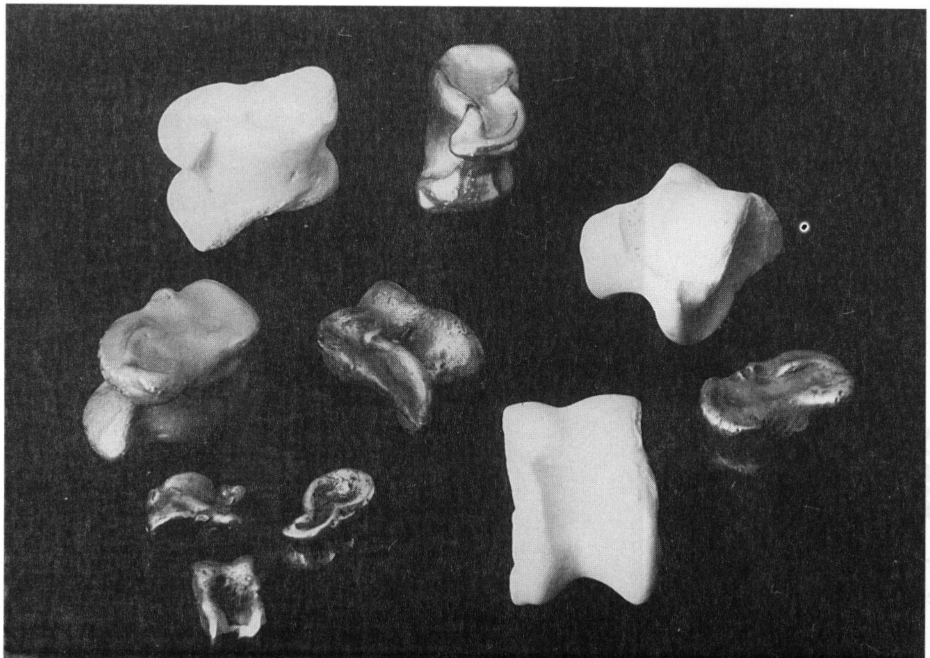
11. Fasnacht, W.: Excavations at Agia Varvara - Almyras, Fifth Preliminary Report. RDAC 1996, 98.

a: Agia Varvara – *Almyras* before excavation, looking south into the Sia-Valley: All finds and installations except the copper mine are hidden under the sediments on the small hillock in the foreground.

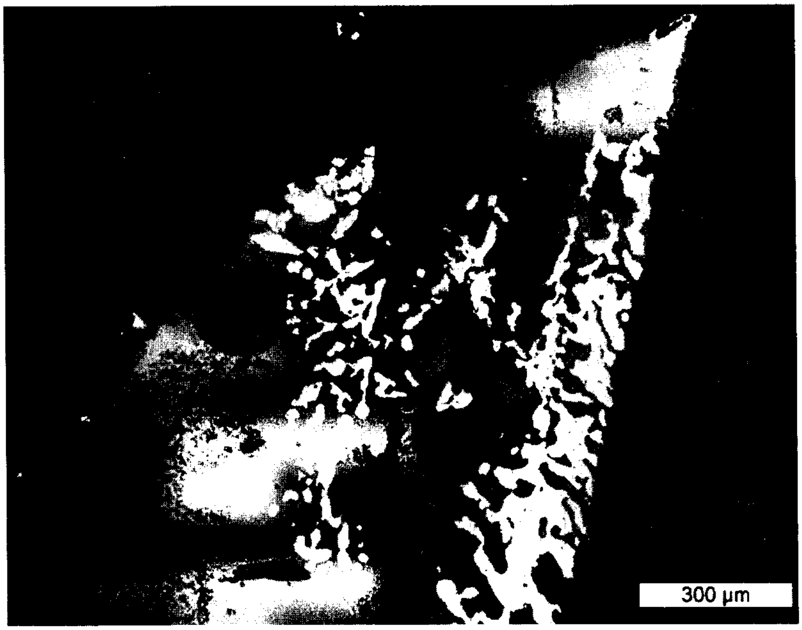
b: Copper smelting furnace reconstructed for experimental use. One big tuyère is placed in the central hole above the tapping pit in the foreground.



a: Two bellows for artificial air-induction into the smelting furnace. Manual technique as used in Archaic and Classical Greece.



b: Original sheep bone astragali and experimental copies in bronze, lead, silver and guilded bronze. Astragali have been used as dice since antiqity.



a: Micrograph of a polished piece of matte with metallic iron as the dominant inclusion (bright dendrites). Metallic copper is present in small particles.

b: Micrograph of a piece of slag with a large globular matte inclusion. It contains metallic iron (bright drops) and slightly more metallic copper (in the cracks and at the periphery).