METALLURGICAL PRACTICES IN EARLY ANATOLIA

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Two surveys were undertaken under the auspices of M.T.A. to gather information leading to an understanding of early metallurgical practices in this country (1). The essential goals were to locate ancient ore sources, investigate ancient copper mines, collect and analyze ancient slag, and to gather data on the ancient sources of tin. Due to the loftiness of some of our goals, it is not surprizing that our success in dealing with them was marginal. However, useful information came to light as a direct result of the surveys, and we now have some important insights into the practice of mining and metallurgy in early Anatolia.

INHERENT PROBLEMS IN INTERPRETATION

We encountered problems in interpretation, mostly regarding the date of the operations.

A. Mining

We located only a few mines, but in the absence of datable material we cannot place them into a definite chronology. In one case a wood sample was taken with the hope that eventually it will give us a C-14 date.

B. Smelting

Of the slags we collected and analyzed it cannot be determined in every case what the smelting methods were or from which stage of the smelting they came. It should be explained here that two methods of copper sulphide ore reduction may have been used by the ancient smelter and can be illustrated as follows:

1. *First method:*

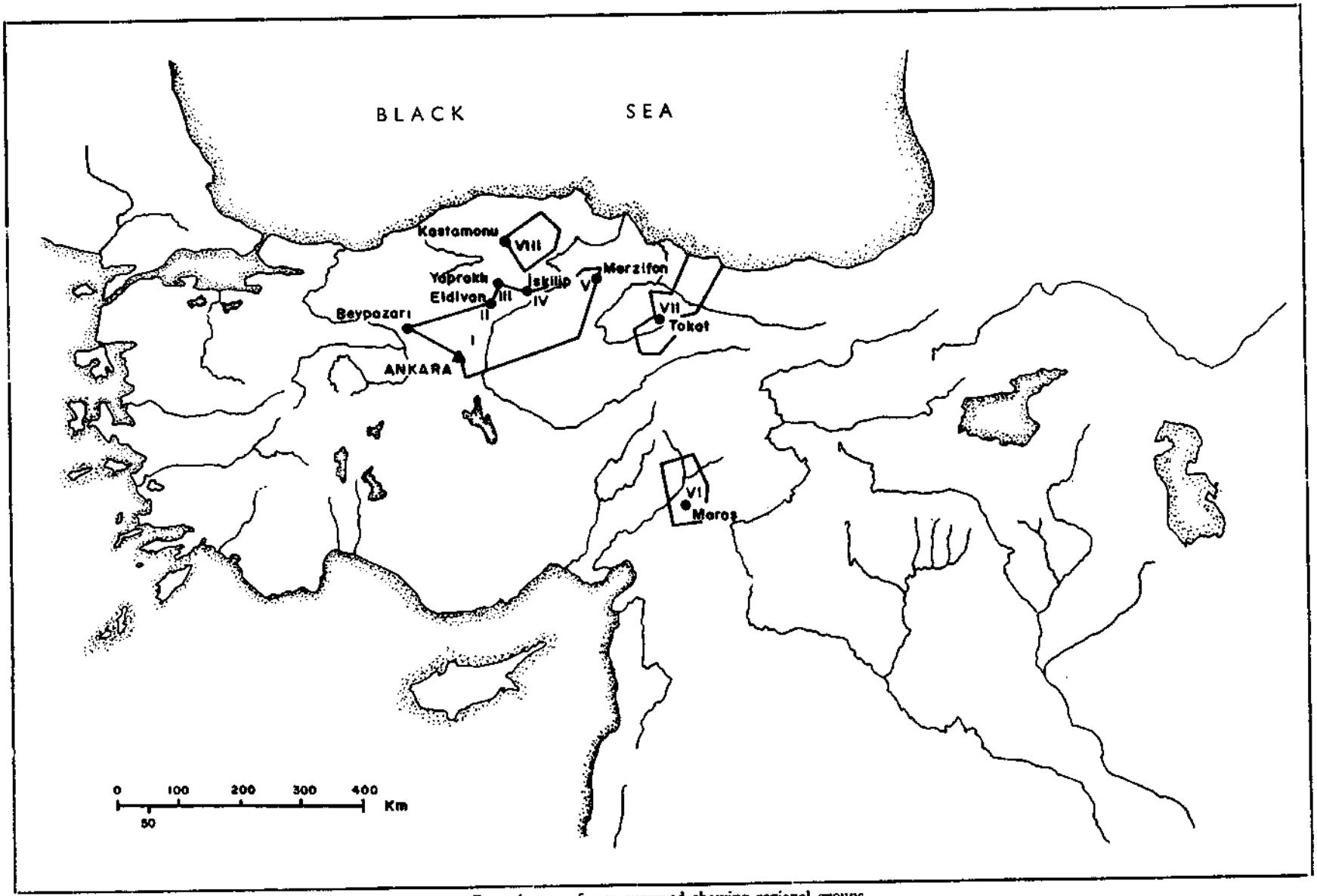
Dead roasting the copper sulphide (here chalcopyrite) until all the copper ore is oxidized:

$$CuFeS_2 + 3O_2 \rightarrow CuO + FeO + 2SO_2$$

The copper oxide is then smelted in a reducing atmosphere:

$$2CuO + 2C \rightarrow 2Cu + 2CO_2$$

(1) Reports are now filed at M.T.A.,P.S. de Jesus and E. Kaptan, *The Metallurgy of the Anatolians: A Survey,* M.T.A. Derleme Servisi R: 5226; *idem, The Metallurgy of the Ancient Anatolians: Second Preliminary Report 1974 (revised).* Complete analyses of the slags are given in these two reports plus maps, plans and specific details of each site. This present article summarizes the salient aspects of the two surveys.



General map of area surveyed showing regional groups.

2. *Second method:*

a) In the first step the copper ore (here chalcopyrite) is roasted just long enough to separate the iron sulphide from the copper sulphide. This operation results in a copper matte (ca. 40-60 % Cu) collecting at the bottom of the furnace. A slag which forms at the top is tapped off:

$$2CuFeS_2 + 3O_2 \quad 2CuS + 2FeO + 2SO_2*$$

b) After roasting, the copper sulphide (still somewhat mixed with impurities) is sorted by hand from the rest of the gangue and is put through an oxidizing stage:

$$CuS + 2O_2 \quad 2CuO + SO_2$$

c) Finally the copper oxide is smelted, as above, in a reducing atmosphere:

$$2CuO + 2C \quad 2Cu + 2CO_2$$

The advantage of the first method over the second is that it is simpler, and indeed, it was probably used very late in our metallurgical history. Its principal disadvantage was the tremendous loss of potential copper in the form of dust and smoke during the roasting stage, whence comes the advantage of the second method. If the temperatures and mixtures are properly controlled, more copper would be smelted per load, since little copper ore is lost in smoke and dust.

Our problem in interpreting the analyses was that we could not be certain from what phase or from what method the slags came. Not enough comparative data on ancient slags is available to us to make valid interpretations, using analyses alone. According to R. F. Tylecote of the University of Newcastle the ratio of Cu to S in a matting slag (second smelting method) is 100:4. Unfortunately only a few of our samples were analyzed for % S. We had thought that it would not be necessary to determine this element in our slags. This opinion turned out to be a methodological error on our part.

What is the difference between a copper and an iron slag? Colleagues dealing with the subject of ancient metallurgy have often claimed that to distinguish a copper slag from an iron slag the copper content must be in the neighborhood of, or more than, ca. 0.1 %. In view of the data compiled in our survey and from the analyses, we cannot fully agree with this claim. The copper content of slag from the same site (and sometimes from the same sample) occurred in varying percentages. These percentages would vary from, tor example,

.004 - .1 % (Dedeköy)

0.91 - 3.11 % (Hisarcıkkayı)

.004 - 0.4 % (Asarcık Yaylası)

This disparity, admittedly, could be due to a certain extent to the relatively small size of the samples (generally less than 50 grams) submitted for spectrographic analysis. But this is not certain, for the greater portion of the samples analyzed showed less than 0.1 % Cu. It is unlikely that any of our slags are the result of iron smelting (except for a few salient examples), for they occurred in or near zones known to be copper-bearing. Hence, in order to distinguish copper slag from iron slag standards other than spectrographic analyses will have to be used.

* In this step some of the CuS is actually oxidized, but it can be reconverted to CuS by adding FeS: CuO + FeS CuS + FeO. This copper sulphide, will then rejoin the bulk of the matte. The reaction which drives the iron into the gangue is: FeS + 3 Fe_2O_3 + 7 SiO_2 7 FeO, SiO_2 + SO_2. This is a relatively sophisticated copper-saving measure and may not have been used by the prehistoric smelter.

C. Historical interpretation

The scarcity of archaeological data at the mining and smelting sites did not allow us to make even rough guesses as to the age of many of the ancient workings. In some cases we collected carbonized wood for C-14 dating, but only a few results are available at this writing. Wood was available at practically all of the sites, but we did not collect it in every case for essentially three reasons: 1) the site was very small, hence inconsequential in historical terms, 2) we did not feel that the means available to use would permit us to have more samples analyzed, and 3) the time available to us did not allow for extensive sample collecting.

The sites of the two surveys are grouped by region. The boundaries of these regions are somewhat artificially established for convenience in comparison. It will be noted, however, that to a certain extent the groupings do constitute entities.

I. THE ANKARA GROUP

1. Karaali area
2. Beypazarı area

A. Mining

The presence of a large slag dump at Karaali Village suggests mining activities over a long period. However, we did not locate any mines in the area. At Karaboyalık just north of Karaali there seems to be evidence of an adit, now caved. Ore available in this region is chalcopyrite (2).

B. Smelting

At Karaali the copper in the slag varied from 0.07 to 1 %. Iron was >10 %. No outstanding features could be seen in this slag.

C. History

Due to the great amount of slag (70,000 t) former working in this area must have lasted for a considerable time. Near the slag mound at Karaali evidence goes back to at least Byzantine times. Earlier evidence may also come to light with further investigation. To the south of Karaali (ca. 5 km) there is a large höyük. The latest occupation on this ancient settlement is Late Phrygian, i.e. ca. 5th century B.C. The size of the mound indicates occupation going back perhaps as far as the Early Bronze Age. The ancient settlement may have been established to exploit the copper mineral deposits of the area. In earlier times agriculture may also have been in practice as it is today.

No evidence for metallurgical activity in the way of mines or smelting could be located in the Beypazarı area.

II. THE ELDİVAN GROUP

1. Dar Yer Mevkii
2. Gemilik Mevkii
3. Demir Boku
4. Sarı Pınar
5. Çakmak Tepe
6. Cuma Camii Tepesi
7. Domuz Deresi
8. Hisarcıkkayı

A. Mining

A recent sounding at Dar Yer Mevkii yielded traces of malachite. Copper mineralization (cuprite, chalcosite, malachite) in the Eldivan Mountains has been noted in other reports (3). Native copper has been found at Domuz Deresi but in small quantities. No former mining activities were detected.

B. Smelting

At Gemilik Mevkii the copper content in the slag varied considerably in three samples:

	(1)	(2)	(3)
% Cu	5.52	1.04	1.56
Co	0.1	0.004	0.003
Fe	15.97	11.43	9.46
S	0.44	0.14	0.14

Due to the high ratio Cu-S of the first sample we might suspect that this is an example of reducing slag. This is by no means certain, especially in view of the other two samples which could be examples of matting slags.

Demir Boku gave analyses more characteristic of other slags in the area:

		(1)	(2)
%	Cu	> 1.0	0.7
	Ni	0.07	0.15
	Fe	>10.0	10.0

Hisarcıkkayı provided us with valuable information regarding ancient smelting techniques, for not only did we find slag, but we located an ancient smelting furnace (Figs. 1-3). Analysis of the slag is given below:

		(1)	(2)
%	Cu	0.91	3.11
	Pb	0.003	0.003
	Ag	n.d	0.0007
	Zn	0.80	0.49
	Co	0.03	0.03
	Fe	40.94	27.39
	S	0.14	0.55

These slags show appreciable percentages of Zn and S (in addition to Fe which is always present in copper slag). They could be examples of matting slags as we shall see below. At another part of the site a zinc slag was found and gave the following analysis:

%		
	Cu	0.3
	Pb	0.04
	Ag	0.0002
	Zn	> 10.0
	Co	0.002
	Fe	> 1.0

In a second analysis of this slag it was found that the Zn content was on the order of 80 % and S was 1.7 %. These analyses indicate some kind of separating phase where the ancient smelter evidently was trying to extract the copper mineral (chalcopyrite ?) from a very complex metallic ore, possibly sphalerite (zinc blende, ZnS). The zinc slag represents that which the smelter had slagged off. He then would have taken his remaining enriched copper ore, presumably still in the sulphide state, and subjected it to a matting process which we see reflected in the first two analyses. Here the Zn is still strongly present (0.80 and 0.49 %, respectively) as well as S (0.14 and 0.55 %). In view of the analyses of the slag related to the furnace we feel that the latter was used for matting copper. No blast air equipment was found at the site, but we must point out that it had been recently pillaged by locals. Hence, much of the information about the furnace in its original state was destroyed. In the reconstruction included here (Fig. 1) bellows have been added, but only on a theoretical basis. A pit in front of the furnace was provided, but it is not certain that this is a tapping pit. Temperature in this furnace may have reached 900-1000°C. It was used several times as seen by the successive layers of mortar and slag on the inside of the furnace wall (Figs. 2 and 3).

C. History

Hisarcıkkayı does not seem to have been an important metallurgical center due to its modest size, but it was probably typical of metallurgical traditions of the Late Roman-Early Byzantine period. The date is provided by a fair number of sherds a few meters to the north of the furnace. No archaeological material was found in relation to the furnace, so its date is only inferred by the presence of the near-by surface sherds.

It is surprizing that such a small operation would deal with processes such as isolating copper ore from complicated mineral structures and then proceed methodically through at least two more stages to produce copper.

Carbonized wood samples were collected at Hisarcıkkayı, but no C-14 dates are yet available. Paleomagnetic samples were taken of the furnace to determine former magnetic orientation and intensity. Results of the magnetic reading have been filed with the General Directorate of M.T.A. and are now catalogued for future comparison with other data. If and when other ancient furnaces are located, the Hisarcıkkayı magnetic readings will become particularly useful.

Two C-14 dates are available for the Eldivan group:

Gemilik Mevkii	427 A.D. ± 150
Demir Boku	4 B.C. ± 129

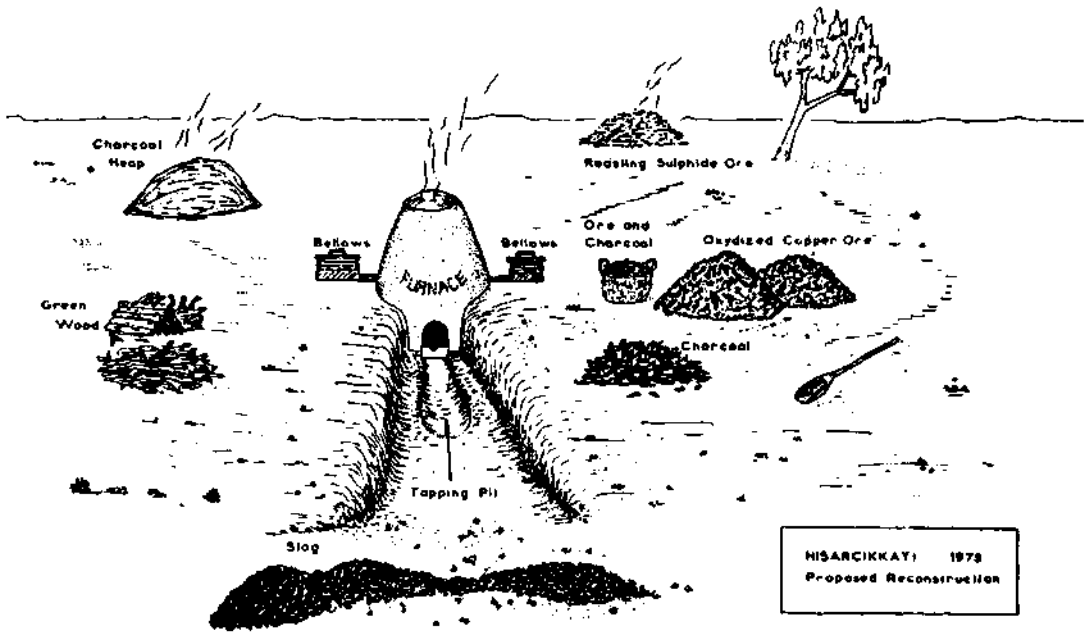


Fig. 1 - Reconstruction of the Hisarcıkkayı furnace.

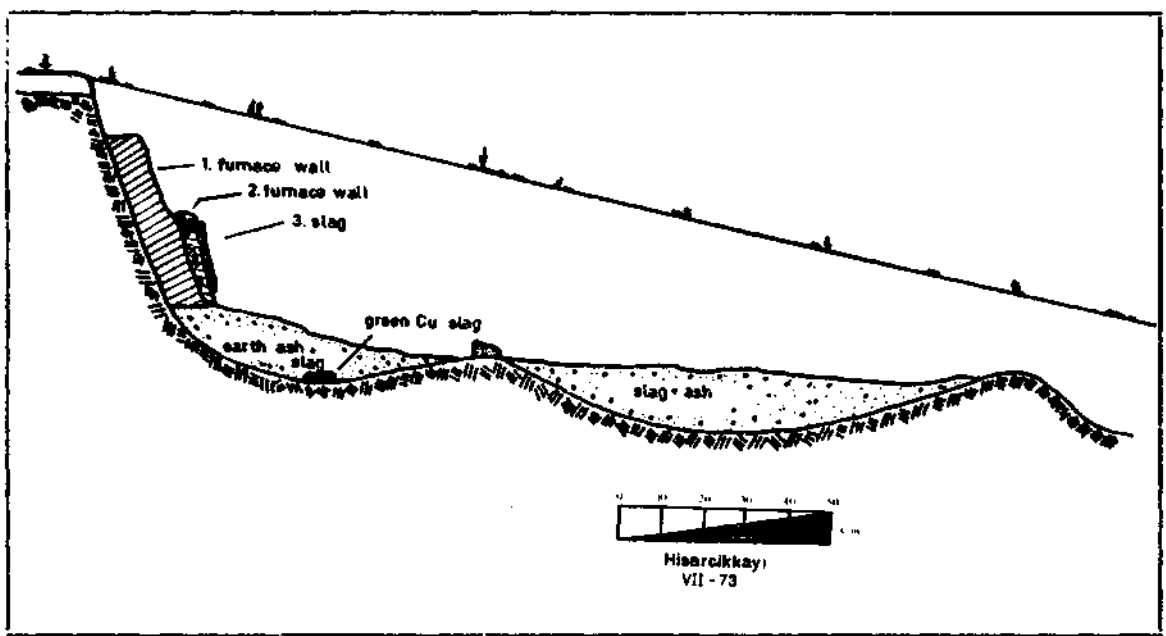


Fig. 2 - Section of the Hisarcıkkayı furnace. Side view.

Although we see that the two sites were never contemporary according to these dates they were nevertheless close. Taking into account the error factors the closest that these two dates can come

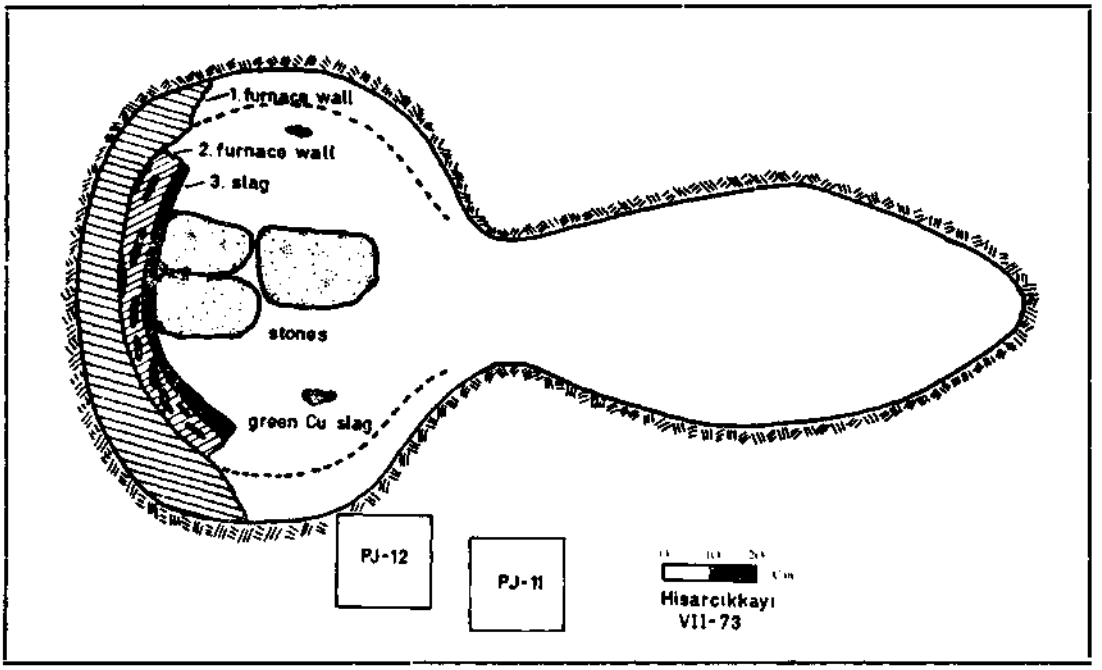


Fig. 3 - Section of the Hisarcıkkayı furnace. Top view.

together is 152 years (i.e. when Gemilik is 277 A.D. and Demir Boku is 125 A.D.) (4). The other undated sites in this general area may fill this gap, but this is only a suggestion. There is no evidence against placing the other sites earlier or later. One has the impression that the Eldivan group does somehow constitute a whole and may reflect small-time smelting operations during the Late-Roman-Early Byzantine Period.

III. THE YAPRAKLI GROUP

1. Armutlu Yelet
2. Panayır Tepe
3. Akyolun Tepe
4. Kireçlik Mevkii
5. Dipyurt
6. Dedeköy
7. Eyriceova
8. Damluyurt Başı
9. Damluyurt Deresi
10. Kapaklı Mevkii
11. Katırçıteni Mevkii
12. Kara Tepe
13. Sabonunu Tarlası
14. Kıyıaltı Mevkii
15. Ahmet Burhan Tarlası I
16. Ahmet Burhan Tarlası II
17. Asarcık Yaylası
18. Kaş Yaylası
19. Yan Yaylası

A. Mines

Again, no actual mines were discovered in this area, though judging from the quantity of slag on some of the sites there were no doubt worthwhile deposits. At Armutlu Yelet we may have come across an ore-processing site on the right bank of the small stream. Evidence of the structures were much destroyed by the stream's waters. Copper ore (carbonates) were detected in some of the rubble. Again at Ahmet Burhan Tarlası II we may have evidence of an ore-processing site. The large serpentine hill to the left of the road seems artificial (Photo 1), perhaps formed by the rubble and gangue of the ore. Smelting seems to have been intense here. Malachite, azurite, chalcopyrite and bornite have been noted in this area, but we saw no surface evidence of these ores (5).

B. Smelting

In the analyses of the slag there does not seem to be any outstanding features except that at Dipyurt and Dedeköy we found iron prills in the slag. Although iron content in copper slag is normal, iron prills are not so common. Their presence may be explained by the high temperatures employed in smelting the copper ore and may have at the same time smelted the iron in the gangue or flux. This must mean that the temperature reached at least 1000° C.

At Kireçlik Mevkii we found nothing but carbonized wood. This could have been the remains of a charcoal making site. This wood was sampled for C-14 dating, but no results are yet available.

C. History

We located two possible ore-sorting sites, and the abundance of slag in this area showed that here were many deposits rich enough in copper to make smelting worthwhile to the ancient smelter. No dates are available at this time, nor can we suggest any general guidelines. But it may be noted that probably the operation in the Yapraklı group spanned over a long period, perhaps 1000 years. It must be added that smelting could only take place during the summer months, as from September onwards the weather is much too damp.

We have identified Panayır Tepe as. the fairground mentioned by the early traveller W.F. Ainsworth. This annual fair was important enough to be visited by the Pasha of Ankara (6). Remains of stone walls and a stone staircase can still be seen there. We are at a loss to explain the presence of a small deposit of slag at this site.

IV. THE İSKİLİP GROUP

1. Hamdi Efendi Çiftliği
2. Fındıkoğlu Deresi
3. Hasan Karaman Tarlası
4. Astar Deresi,

A. Mines

It has been reported in other studies that native copper is available in this area (7). It is interesting also that we found very few slag dumps. This would seem to agree with previous surveys that claim that there is, in fact, little copper ore in this area. No mines were located, but we were able to confirm the presence of native copper in the Astar Deresi.

B. Smelting

Judging from the three slag dumps found we can say that they were generally concerned with copper smelting. No outstanding features are reflected in the slag analysis.

C. History

The few smelting sites located point to minimal copper exploitation in this group. Hasan Karaman Tarlası, situated near the confluence of the Astar Deresi and the Koca Çay, may have been a regionally important site in Byzantine times. Some sherds suggest occupation of that period. The archaeological deposit seems to be aboul one meter thick. Slag from the field points to copper exploitation as a secondary industry.

V. THE MERZİFON GROUP

1. Gümüş
2. Subaşı
3. Bakır Çay (Kağnı Dere, Saka Pınar, Bahçelidere, İnkaya)
4. Suluyalak
5. Şamelik Deresi

A. Mining

In the Bakır Çay area mining was no doubt done right on the banks of the stream, this area being relatively abundant in copper ores. Some tunneling was seen at İnkaya in the bank of the Bakir Cay. The ore extracted was generally malachite and some copper carbonate. Chalcopyrite seems to be more in abundance and occurs near or on the surface.

B. Smelting

Slag dumps line the banks of the Bakır Çay and indicate copper smelting over a long period. At Subaşı earthenware tuyeres were uncovered in the slag, unequivocal evidence that blast air was used here (Photo 2). The Subaşı slag gave the following analyses:

	(1)	(2)
% Cu	>1	>1
Sn	0.004	0.007
Pb	0.004	0.01
Ag	0.001	0.001
Ni	0.03	0.03
Bi	0.0015	0.001
Co	0.001	n.d.
Fe	>10	>10

The high number of tuyeres (ca. ten in all) in such a small dump may indicate that small furnaces were used in smelting. Although we did not encounter any furnaces, a few pieces of hard baked clay incrusted with slag were found. These could be pieces ofclay wall from furnaces (cf. reconstruction, Fig. 4).

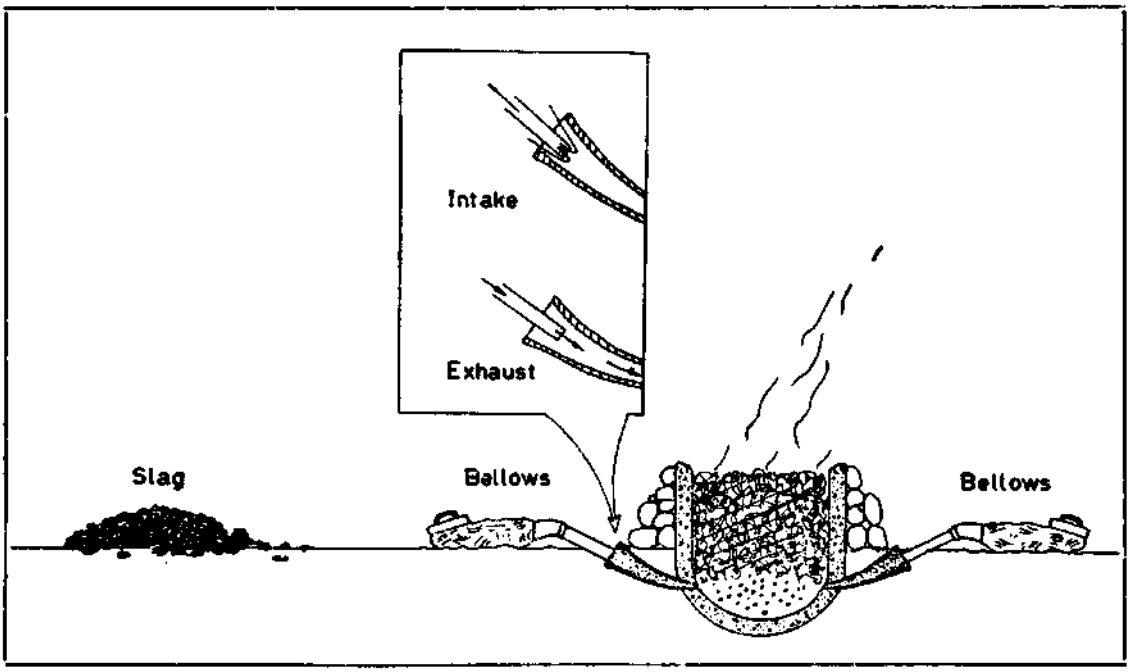


Fig. 4 - Reconstruction of a Subaşı furnace.

The area of Gümüş is known to be lead-bearing (8), and in view of a large amount of slag (esl. 500,000 - one million t), would seem to have a long history of smelting. Copper ore is not present in abundance, but it does occur in the slag. Analyses of the slag gave the following results:

	(1)	(2)	(3)	(4)	(5)	(6)
Cu	0.74	0.15	0.93	0.36	0.04	0.04
Pb	2.16	>1	0.87	0.44	1	0.01
As	27.76	>1	31.5	20.97	>1	n.d.
Sb	...*	0.1	...	...	0.04	0.01
Ag	...	0.015	...	...	0.015	n.d.
Ni	...	0.015	...	...	0.04	n.d.
Zn	n.d.	>1	n.d.	n.d	>1	n.d.
Co	...	n.d.	...	...	n.d.	0.002
Fe	54.46	>10	59.71	64.45	>10	10.0

* Dots (...) indicate that the sample was not examined for this element.

It is net uncommon (or arsenic to occur with lead ores, but we are struck by the very high quantities of it in our slag. Arsenic is normally very volatile when heated to high temperatures, but the large amounts detected above would seem to have remained in the slag only if the ore that was being smelted contained extremely high quantities of it.

Copper is present in the slag in appreciable quantities, but in view of the high quantities of other elements it is doubtful that it was the metal smelted. From the analyses enargite (Cu_3AsS_4) is suggested as being present in the original ore, but this is by no means certain. Arsenopyrite (FeAsS) may also have been a constituent in the principal ore body.

We did not find any documents which could give us an indication of the beginnings of workings at Gümüş, but we did locate in the village an inscription dated to 1866 which mentions metallurgical activities of that time. The ancient geographer, Strabo, mentions the Roman mines in the area of Pimolisa, now Osmancık. He goes on to say that

> «the air in the mines is both deadly and hard to endure on account of the grievous odour of the ore, so that the workmen are doomed to a quick death.» (9)

He adds that the Romans acquired slaves locally to work these mines. Although Strabo mentions only mining, we suspect that the cause of death was due to the arsenical smoke from the smelting operations. The high content of As in the slag from Gümüş has allowed us, then, to identify this town with the Roman mines of Strabo's time (64 B.C. - 21 A.D.). This identification is supported not only by the analyses but by the physical features of the area that Strabo describes. He mentions that under Mt. Sandaracurgium the mining took place in the form of «great caveties». We point out that the present-day İnegöl Dağ overlooks the town of Gümüş and the ancient workings, just as Strabo's Mt. Sandaracurgium would have and in which today mine tunnels may be found. It is not certain that arsenic was in fact the metal that the Romans were exploiting. They would seem to have had little need for it, though it has been found in various forms in earlier archaeological sites in the Near East and in Greece. Lead would seem to be a more likely metal, and we know that galena is particularly rich at this deposit. Arsenic may have been present in the galena and constituted an unwanted mineral. Iron may also have been one of the metals exploited in Roman times here, as bits of high-carburized iron were found mixed in with the slag.

For a smelting site in the Bakır Çay area we have one C-14 date:

Subaşı . . . . . 223 B.C. + 300

Since this site and others produced tuyeres we may conditionally say that blast furnaces were in use in this area somewhere around 530 B.C. - 70 A.D. This would be the period of Late Phrygian to Roman. Due to the error factor of the C-14 date we cannot come to a dating much more precise than this. However, we did not notice any pottery or other artifacts which could definitely be attributed to the period between Late Phrygian and Late Hellenistic. Hence, we tend to place the smelling complex in and around the Bakır Çay to Roman - Early Byzantine.

VI. THE MARAŞ GR

1. Süleymanlı
2. Ericek

A. Mining

No examples of mining could be found in this area. Only small occurrences of copper to the south have been noted in previous studies (10).

B. Smelting

Only two small smelting sites were located in this area. Slag analyses turned out to be rather low in copper content but otherwise featureless.

C. History

At Süleymanlı a couple of Late Byzantine coins (Romanus III and Michael IV) were said to have come from the village. Smelting could date from that period, but the operation was an extremely modest one and could not have lasied for more than a few years.

VII. THE TOKAT GROUP

1. Ağacaağaçlı
2. Bakımlı
3. Gevrek Köyü
4. Kozlu
5. Arpalık

A. Mining

A mine at Ağacaağaçlı (Karaoluk) was uncovered then filled up again by a local villager. From his description it was a straight shaft mine with a sloping gallery. The mine is said to have been lined with wooden supports which the villager removed and used in building himself a small shack across the stream from the mine. The wooden beams are in good condition, and a piece was obtained for C-14 dating (11).

B. Smelting

Three sites in this group gave concrete evidence of smelting. The analyses of the slags stayed fairly close to established patterns. Only at Arpalık did we notice a fairly high content ot zinc (0.15 %).

C. History

This area is important as it is said to have been the region where the Early Bronze Age cultures began their metallurgical development. The history of the area goes back at least as far as the Kozlu mine, recently reported and dated to 2800 B.C. by C-14. (12). This mine would seem to have supplied Early Bronze Age cultures with copper ore. Although no smelting sites have been reported near the Kozlu mine, further research may locate some. There are at least two known Early Bronze Age sites in this region, one called Kayapınar near Artova and the other Horoztepe near Erbaa. Bronze work is known at both of these sites. One might postulate here and say that it is quite possible that Tokat province was the home of Early Bronze Age metallurgy in the sense that it was a main supplier of copper ore. The fact that tin-bronzes are commonly known in the Early Bronze makes Tokat a candidate for the supplier of Anatolian tin. If tin did exist in this province the deposits must have been very small.

VIII. THE KASTAMONU GROUP

1. Cozoğlu
2. Örencik

A. Mining

At Cozoğlu Mahallesi near Hocavakıf a mining and smelting complex was located. The copper deposit is said to be mediocre in the form of azurite, malachite and chalcopyrite (13). Tunnels can be seen in the mountain side just behind the village. Others are said to be caved and hence no longer visible. The quantity of slag suggests that operations could have lasted more than 100 years.

B. Smelting

Slag dumps litter the ground behind the village of Cozoğlu indicating that a series of smelting furnaces were used, not just one or two. There is a fair possibility of locating these furnaces with a minimum of field work. The remains of a smelting furnace was located at a second site, Örencik Köyü (Kargı). It was represented by fragments of baked clay — probably the mortar lining of the furnace. A plan of this furnace could not be reconstructed from the fragments which may be due to the type of construction. The furnace may have been built on top of the ground and not a bowl furnace dug into the ground.

C. History

This area may have played a peripheral role in early metallurgy, but the extent of our historical data does not yet allow us to ascribe any dates. The mining complex at Cozoğlu may eventually give the best account of the metallurgical history of the area, since mining and smelting was performed at the same place.

CONCLUSION

It is interesting to note that relatively sophisticated techniques were known at early periods of metallurgical development. Copper sulphide smelting was in practice by 2800 B.C., as seen by the Kozlu mine. The depth of this mine indicates that mining technology itself had developed to the extent that miners could deal with the problems of ventilation and water seepage. The smelting furnace at Hisarcıkkayı shows that by the Late Roman Period copper matting was a common practice. It is also possible that this technique had started long before. The tuyeres from the area of the Bakır Çay show that blast air equipment was in use by Roman times, again possibly earlier. At Gümüş the ancient Roman lead-arsenic mine and smelting complex has been located. The metallurgical history of this country is indeed a rich one. Although much still remains to be done in this field, we have been able to have a brief look at the techniques employed in former times, and they are a credit to the ingenuity of the early Anatolian metallurgist.

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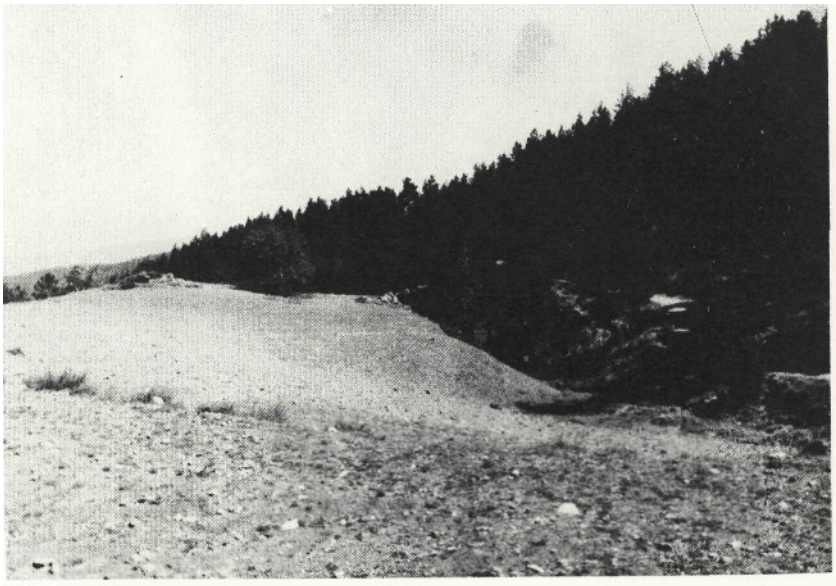

Photo 1 - Serpentine hill, Ahmet Burhan Tarlası II.

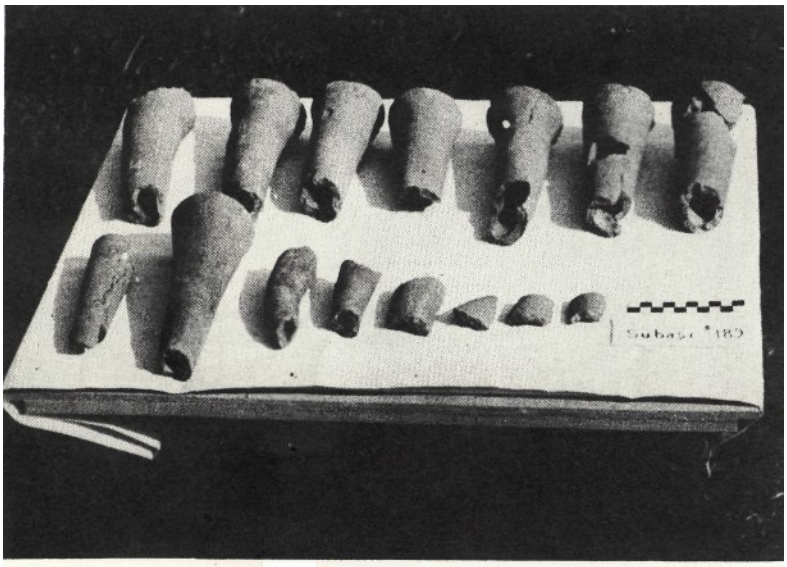

Photo 2 - Tuyères from Subası.

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