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Precious Metals Extraction in Palaia Kavala, N. E. Greece

An Archaeometallurgical Attempt to Locate Skapte Hyle

Abstract

The aim of this long-term study is to identify the precise location of Skapte Hyle, an area in Macedonia famous in antiquity for its gold and silver mines. Skapte Hyle is known to have been situated in the Thasian Peraia[1], the colonies of Thasos on the coastal stretch of the mainland, opposite the island, from the 7th century BC to the Roman period. Recently re-evaluated documentary and archaeological evidence has suggested that the region of Palaia Kavala, north-east of the town of Kavala, was probably the main metalliferous zone of the Thasian Peraia and thus Skapte Hyle should be sought there.

The attempt to locate Skapte Hyle will be achieved in two stages. The first involves the evaluation of the type of extractive metallurgical practices through the analysis of extensive metallurgical waste, ores and artefacts found at Palaia Kavala. In the second, the excavation of selected metal-working sites and the dating of a number of slag heaps will be undertaken.

This report concentrates on the preliminary results of the analytical investigation of the metallurgical waste and reveals an elaborate procedure for retrieving precious metals from mainly Mn-rich iron ores. The date of these operations (antiquity and/or Ottoman) is not yet known. The results presented here have shed considerable light on the extractive pyrometallurgical processes at Palaia Kavala, but at the same time have given rise to new questions concerning the precise location of that renowned metals-producing area.

Introduction

Palaia Kavala is the region encompassing the southern flank of the Lekani mountain range, taking its name from one of the villages included in it (Fig. 21.1–2). It does not constitute a geographical region. The name has been used by the Institute of Geological and Mining Exploration (IGME) to denote an area with Mn-rich iron mineralisation. The region is delineated clockwise from the west (Fig. 21.1) by the Plain of Drama, north the Falakron mountain and the interlying valley, east the River Nestos, and south the delta of the same river and the Gulf of Kavala. Archaeometallurgically, Palaia Kavala is renowned for abundant evidence of "ancient" mining and large, as yet largely undated, slag heaps. These activities can be attributed either to antiquity or to the Ottoman period or both.

The long-term aim of this project is to discover the location of Skapte Hyle, a "village or town opposite Thasos"[2], famous in antiquity for its precious metals, particularly gold. Herodotus reports that in the 5th century BC Skapte Hyle was included within the Peraia, the colonies of Thasos on the coastal strip of the mainland[3], and that the Thasians were benefitting considerably from its mineral wealth to a far greater extent than from their own mines. In the next section it is argued that Skapte Hyle should be sought within Palaia Kavala. However, the task of locating Skapte Hyle, and thus the metal-working activities of the Late Classical and Hellenistic periods, is a particularly difficult one in view of the size of the area and the enormous volume of metal-working remains. Therefore, before excavation and dating of one or more sites is undertaken, it is essential to establish whether Palaia Kavala was indeed a precious metals producing area and thereby a candidate region from the point of view of mining and metal-working. With that aim in mind this report presents the preliminary analytical investigation of the archaeometallurgical remains of that region as well as the documentary/archaeological evidence (both in antiquity and later periods) which support the argument that Skapte Hyle should be sought in Palaia Kavala.

The morphology of Palaia Kavala consists of summit ridges (max. height 1300 m) which alternate with deep valleys criss-crossing the region. The geology of the area is crystalline schists with marble intercallations and granites with pegmatic and applitic offshoots penetrating the metamorphic rocks[4]. The iron ore deposits of the Lekani range are of hydrothermal origin and occur as fissure veins between marble and schist. They are present in as-

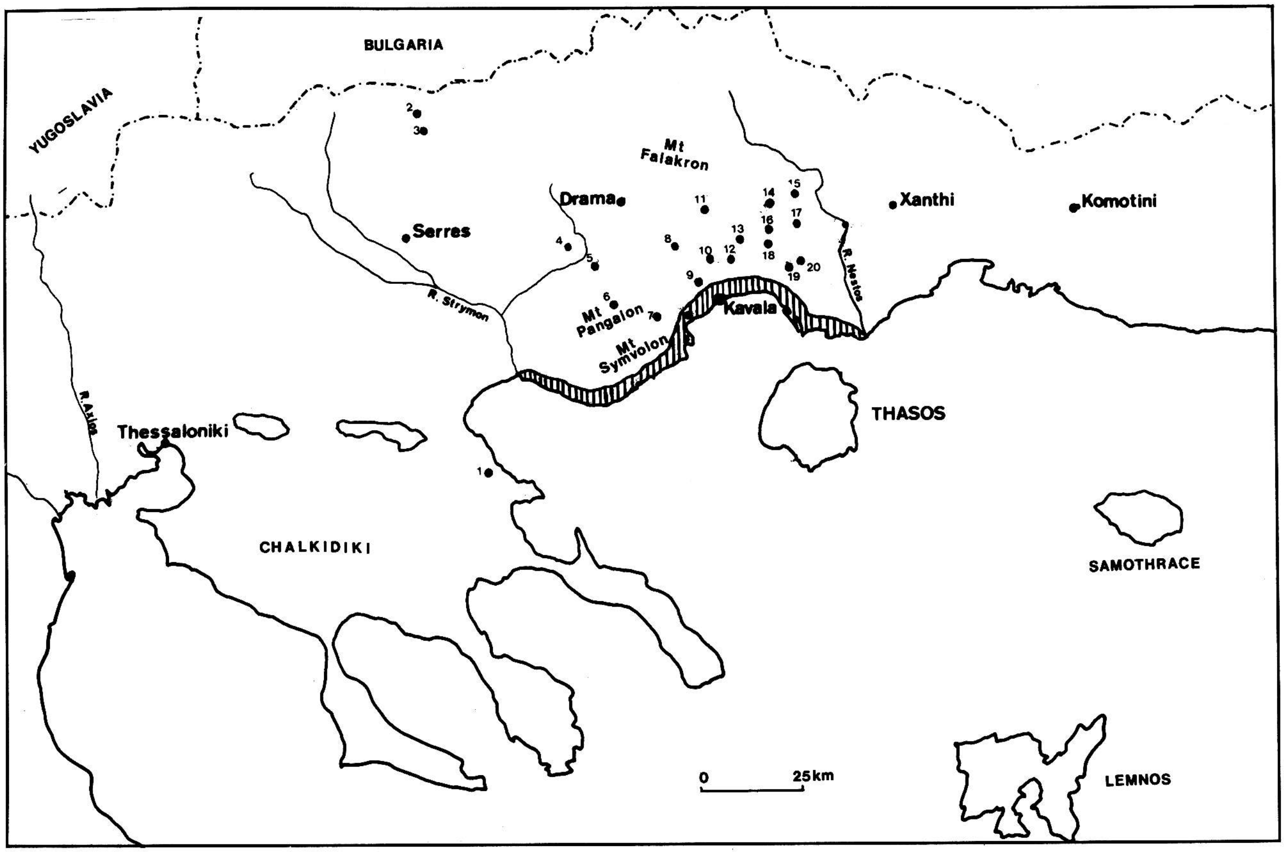
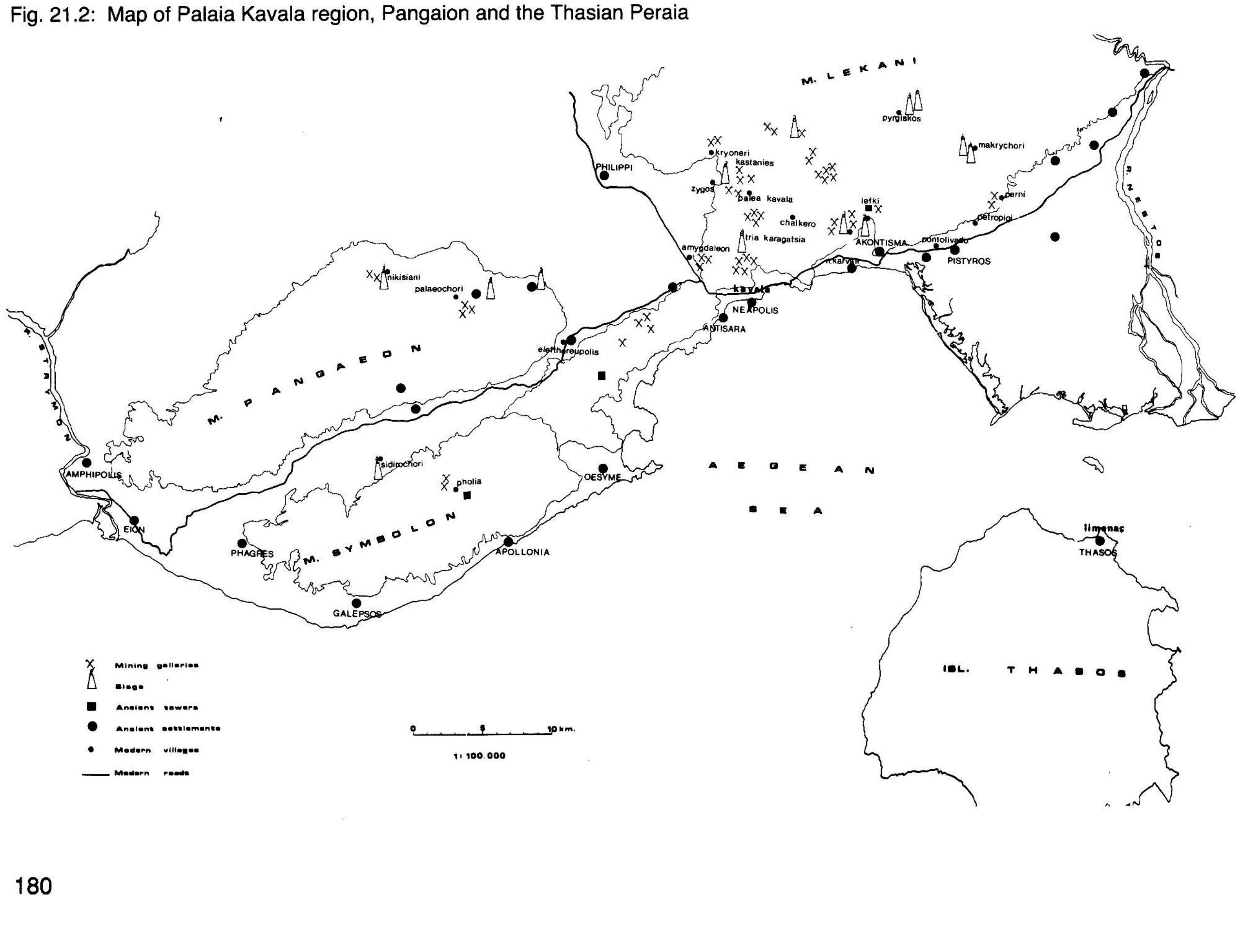


Fig. 21.1: Map of Eastern Macedonia with sites referred to in the text: 1 = Olympias, 2 = Katafyto, 3 = Vathytopos, 4 = Dikili Tash, 5 = Sitagroi, 6 = Nikisiani, 7 = Eleftheroupolis, 8 = Philippoi, 9 = Amygdaleonas, 10 = Zygos, 11 = Kirgia, 12 = Palaia Kavala, 13 = Tria Karagatsia, 14 = Lekani, 15 = Kechrokampos, 16 = Pyrgiskos, 17 = Kastanies, 18 = Makrychori, 19 = Petropigi, 20 = Perni

Fig. 21.2: Map of Palaia Kavala region, Pangaion and the Thasian Peraia



sociation with Mn (27–43% iron oxide, 18–43% manganese oxide) with the added presence of other elements like Pb, Zn, As and also Au and Ag. The iron-manganese ores derive from the oxidation of sulfides (pyrite, galena, chalcopyrite) which are included in small amounts[5]. Two zones of mineralization (one with a north-eastern, another with north-western direction) are evident in the area and seem to be distinct on both chemical and mineralogical grounds[6]. This distinction may prove to have some bearing on the archaeometallurgy of the region. The north-eastern mineralization, which includes the occurrence at Korizo Lofos (1 km south of the slag heaps at Tria Karagatsia, Fig. 21.2), consists of iron-manganese ores associated with Pb, Zn, and Ag. The north-western, which includes the occurrence at Chalkero, is associated with Cu and Au and occasionally Bi with low contents of Mn, Pb, Zn and absence of Ag. Arsenic is present in both[7].

Analyses of Palaia Kavala ores revealed the following mean values for main elements: 26.4% Fe (range 0–52%), 8.8% Mn (0–33%), 3.8% Pb (0–57%), 2.9% As (0–18%), 1.2% Zn (0–6%), 0.35% Cu (0–4%). The mean silver and gold values were 56 ppm Ag (range 0–420 ppm) and 1 ppm Au (range 0–42 ppm). Among other trace elements measured, the following were included: Ba, Sb, Sr, Cd, Sn and Bi[8].

Evidence for underground mining in the region abounds. Ancient galleries are concentrated in the area outlined by the villages of Amygdaleonas, Zygos and Palaia Kavala, in addition to others in the region of Chalkero, Perni an Petropigi (Fig. 21.2)[9]. The metal-working sites lie either on mountain plateaux or slopes or the foothills of the Lekani mountains. The volume of the slag heaps ranges from a few hundred tons (Makrychori, Tria Karagatsia, Dipotamos) to a few tons (Pyrgiskos, Kastanies) (Fig. 21.2). Lead systems for channelling water to as yet undiscovered furnaces are occasionally evident.

Apart from slag, speiss – a metallic "waste" product consisting of iron arsenides – was recovered from the slag heaps but in smaller quantities[10]. Speiss[11] is usually present in the form of plates or shapeless lumps of various sizes or prills caught within the slag (Fig. 21.3). Speiss has also been found at Nikisiani on Pangaion (Fig. 21.2)[12].

Historical and Archaeological Background

The archaeometallurgical remains of Central and East Macedonia and the island of Thasos, Greece's richest metalliferous province, have been the subject of a number of investigations into metals technology[13] as well as provenance-related questions[14]. In East Macedonia there are indications of indigenous metals production spanning a period of nearly sixty-five centuries, from the Late Neolithic (second half of the 5th millennium BC) at Sitagroi[15] and Dikili Tash[16], to the turn of this century. At Sitagroi, there is

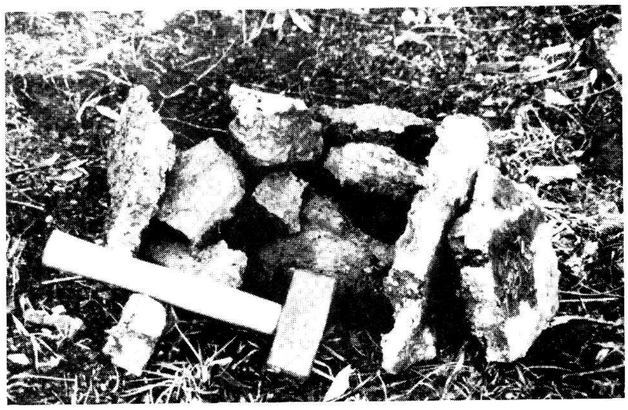


Fig. 21.3: Dipotamos. Plates of speiss

evidence for gold and copper working, slag fragments (melting?) and crucibles[17], while at Dikili Tash, the occurrence of copper slag points to attempts to smelt copper ores as early as the 5th millennium BC[18]. The smelting of copper at the Early Bronze Age phase of this settlement is currently being verified by analytical investigation[19]. On the other hand, at Vathytopos (Fig. 21.1), there are eye-witness accounts of bloomery iron smelting furnaces, blown by water-powered bellows, in operation at the turn of this century[20]. Thus, the situation in Macedonia presents a unique opportunity for a diachronic study of ferrous and non-ferrous ore mining and metals extraction which has only recently begun to be sorted out.

There have been two periods of intense activity in the exploitation of precious metals in Central and East Macedonia: in antiquity and during the Ottoman period (1453–1912)[21]. In antiquity the classical sources refer to two metals-rich areas, namely Pangaion[22] and Skapte Hyle[23]. Both areas are known in the classical sources as both silver and gold producers. Although there are few doubts as to the location of Pangaion, the position of Skapte Hyle has been the subject of much debate and extended controversy. For the location of the latter, two areas have been favoured:

a) on or near Pangaion[24],

b) on the southern slopes of Lekani mountain[25].

The most important arguments against the first hypothesis have been set out by one of us[26] and include the following:

a) in no classical source is Skapte Hyle located on Pangaion. The connection and subsequent confusion with the latter came about by some historians and archaeologists, based on the fact that both areas were precious metals producers.

b) Herodotus states clearly that at the time of Xerxes' invasion (490 BC) the Pangaion mines were being exploited by Thracians. The Thasians did not penetrate inland in that region until a century later, 360 BC, when they found-

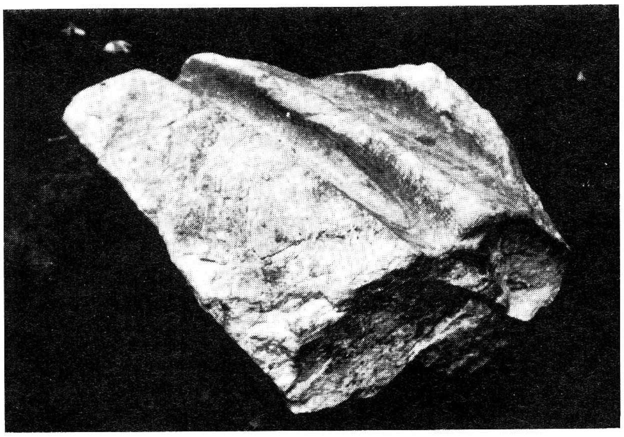


Fig. 21.4: Anestias. Fragments of ore-washing installations (?)

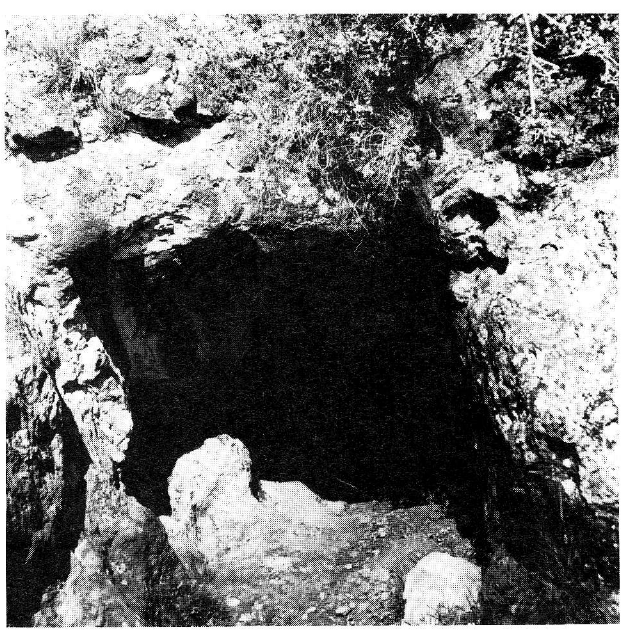
ed Krenides (subsequently Philippoi) and even then, their stay in the area was rather short-lived (360–356 BC). Thus, since Skapte Hyle was certainly Thasian territory during the 5th century, it could not have been situated on Pangaion (a Thracian territory) at that, or any later, time. In brief, it is argued that the classical sources are quite clear that Skapte Hyle was not to be found on or near Pangaion.

What, then, is the archaeological and historical evidence which argues in favour of Palaia Kavala? The Thasian colonial state (Peraia) stretching between the Rivers Strymon and Nestos was a series of walled settlements founded with the purpose of exploiting the natural resources of the mainland. While most of these settlements were economically and politically dependent on Thasos, Neapolis (modern Kavala) gained its independence and minted its own coinage[27]. It can thus be assumed that part of the metalliferous Peraia would have been ceded to Neapolis to provide the metal resources for its mint. The Thasian metalliferous territory should therefore have been restricted to the area east of Neapolis, and it is there that the mines of Skapte Hyle should be sought[28].

The present investigators' field surveying in the region has revealed many galleries and slag heaps a few km north of the coastal Thasian settlements on the mainland. For example, the mining galleries of Lefki and Anestias (Fig. 21.2) and the remains of metal-working (slags and possible fragments of ore washing installations) to the west of Anestias (Fig. 21.4) could have been the *ergastiria* of two Thasian settlements, one of which has been identified as the ancient Akontisma[29] (Fig. 21.2). In addition, the mining galleries and shafts of Perni and Petropigi (Fig. 21.5) could be associated with a walled settlement, thought to be ancient Pistyros (Fig. 21.2). The great slag heaps of Makrychori could also be associated with yet a third Thasian settlement, near modern Pontolivado. At the south-east end of the Makrychori slag heap, fragments of Thasian amphoras, black painted pottery and Megarian skyphoi were found (Figs. 21.6–7), the last of which allowed that section of the heap to be dated between the 4th and the 2nd centuries BC[30].

It is the proximity of metal-working sites to Thasian coastal settlements which suggests that a number of slag heaps in the area may date to antiquity, as the sherds from Makrychori indicate[31]. However, the sheer size of the slag heap at this site, as well as at other sites within Palaia Kavala, could suggest that, although exploitation may have taken place in antiquity, the same or neighbouring mines were reworked at later periods (ie. Ottoman). Until now, relevant Byzantine[32] or Ottoman documentary/historical evidence has not been very forthcoming. The survival of a place name "Madem Tsiflik" near Amygdaleonas and the mining galleries nearby suggest some activities on the eastern flank of the Lekani range during the Ottoman period, but no other information is available. On the other hand, it is well established that there were significant metal-working activities on Pangaion in the Ottoman period. This is documented both from the accounts of the 16th century French traveller, Belon, and also from Ottoman firmans which talk of extensive silver production in Eleftheroupolis (Pravi)[33]. In addition, there is archaeological evidence of a furnace at Livadia, Nikisiani which has also been dated to the 16th century[34]. In view of the activities on Pangaion, the operation of silver mines near Serres and the attempt to revive the silver mines on Thasos[35], similar endeavours should be expected in Palaia Kavala particularly since the presence of large slag heaps would have betrayed earlier metal-working activities.

Fig. 21.5: Petropigi. Entrance to the mining gallery



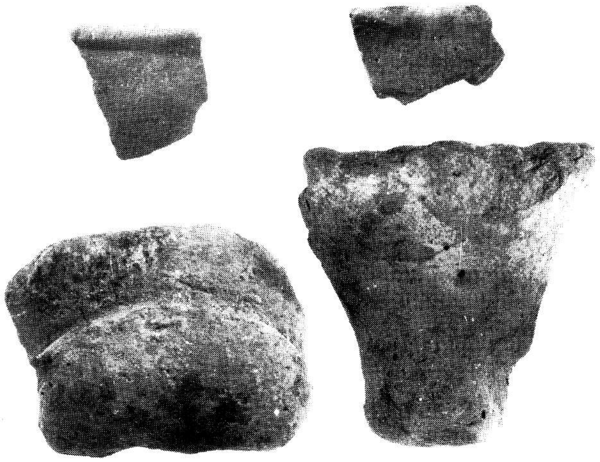


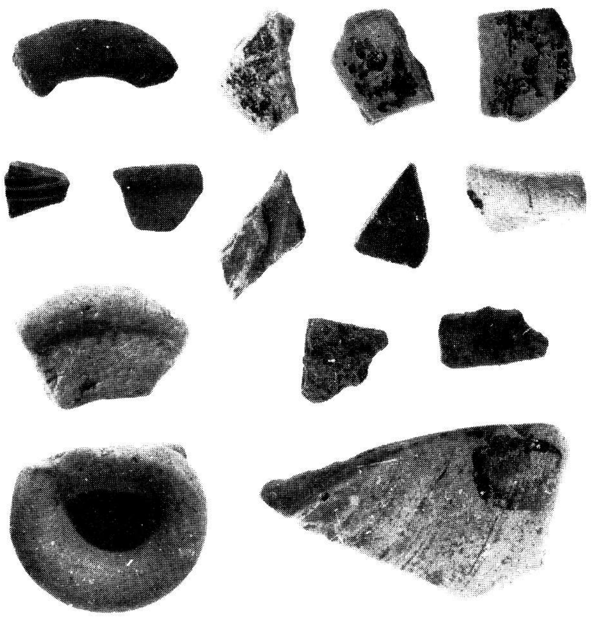
Fig. 21.6: Fragments of Thasian amphoras and pithos jars

The present review of the archaeological/documentary evidence has inevitably been biased towards antiquity because of the preponderance of presently available historical evidence relevant to that period, as well as the long-term aim of this project, namely to locate Skapte Hyle. Nevertheless, it is likely that with further research into Ottoman records additional evidence for contemporary exploitation will be revealed.

Methodology

Analyses of samples taken from slag heaps have been carried using the Electron Probe Microanalyser (EPMA), a Cambridge Scientific Instruments Mark V, attached to a Link 860 X-ray microanalyser. The principal mineralogical phases of samples of slag and speiss were analysed with that instrument in polished sections. Speiss prills were often found trapped within the slag and analysed by the same method. Apart from slag, samples of ore were also collected (Petropigi, Fig. 21.2). This ore was rich in iron and contained an appreciable amount of As but little Mn. Twenty kg were smelted in an experimental bloomery furnace. The resulting arsenic-rich bloom and associated slag were also analysed with the Electron Microprobe for purposes of comparison with the archaeological material[36].

Fig. 21.7: Sherds dating to the 4th–2nd century BC



Metallurgical Waste: Slag and Speiss

Slags from Palaia Kavala were, on average, large in size (10 cm diameter) and compact (no pores). Analyses revealed that the main characteristic is the presence of manganese (Table 21.1). Slags from Kechrokampos, Makrychori, Tria Karagatsia, Pyrgiskos and Eleftheroupolis (East slopes of Pangaion) consist of three phases: a) a manganese-rich wustite, b) a calcium-rich olivine (kirschsteinite) reported here as "fayalite" and c) a matrix consisting of either a potassium, aluminium silicate of melilitic composition or, less often, a eutectic of melilite and kirschsteinite. Polished sections of analysed slag samples are shown in Fig. 21.8. The olivine constitutes the predominant phase, the matrix making up the interstitial material. Manganese partitions in all three phases, zinc in the olivine and the matrix and lead only in the matrix. Lead and zinc are present in small amounts in only some samples (Table 21.1). An iron aluminium oxide phase has been detected in one sample and is reported as a spinel. Arsenic occurs in the slag phase of only one sample (Makr 13), a fact which is not surprising since As normally partitions in the metallic phase.

Speiss is found in slag heaps from all the sites mentioned above either in the form of plates (Fig. 21.3) or as prills in the slag (Fig. 21.8 c). Table 21.2 gives the composition of two phases for a number of speiss samples. The low arsenic phases correspond to about 8–10 % As, the higher ones to about 60 % As. It is clear from Table 21.2 that Palaia Kavala speiss does not consist only of iron and arsenic but contains a number of other elements which either form solid solutions with one or the other of the main elements (like Sb in As) or are present as matte inclusions (iron arsenic sulphides with small amounts of copper and antimony). These two distinct phases are evident in metallographic sections of speiss (Fig. 21.1) and can be interpreted in terms of the As-Fe binary phase diagram (Fig. 21.9). The two phases include a) long laths and, occasionally, large dendritic globules, consisting of alpha-iron with about 10 % As, and b) a eutectic of alpha-iron and Fe_2As (composition 35 % As and 65 % Fe) as the interstitial material.

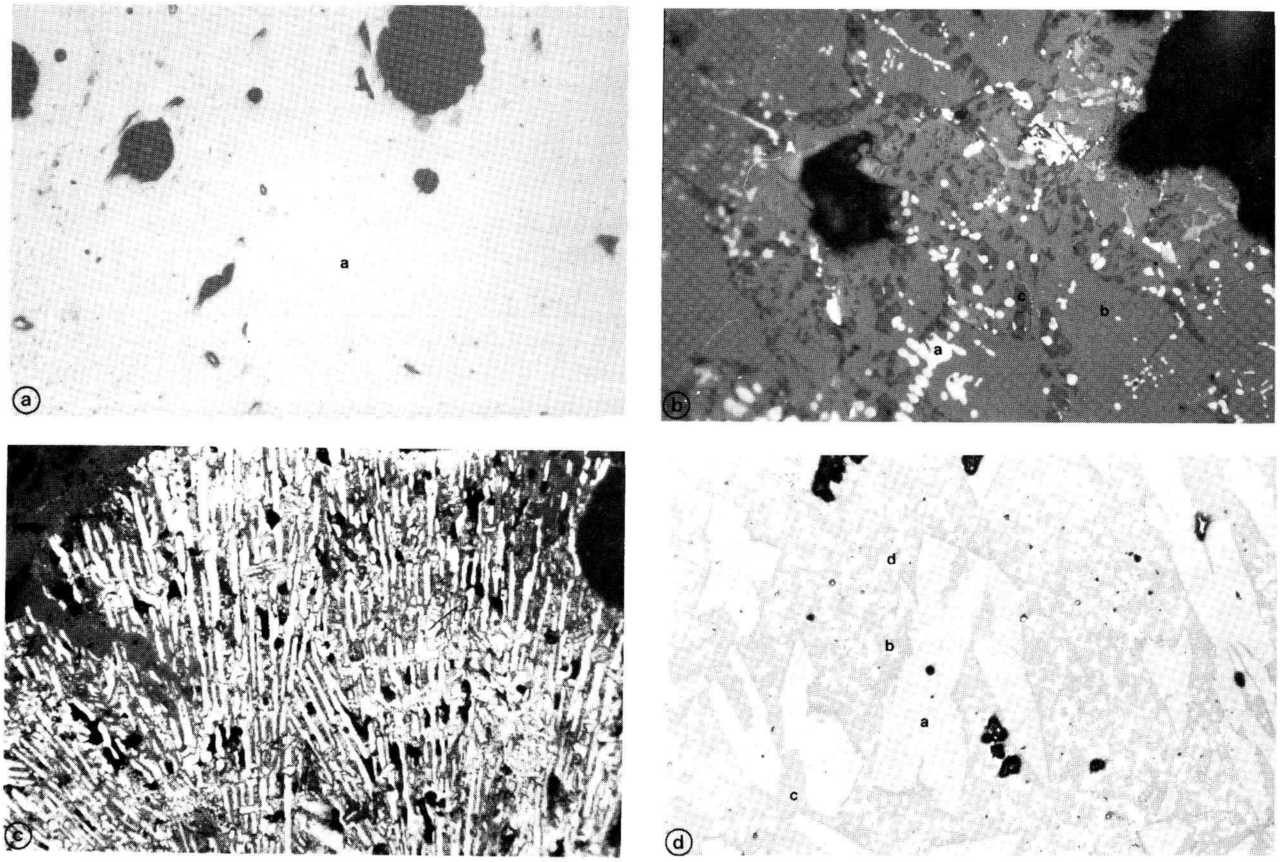
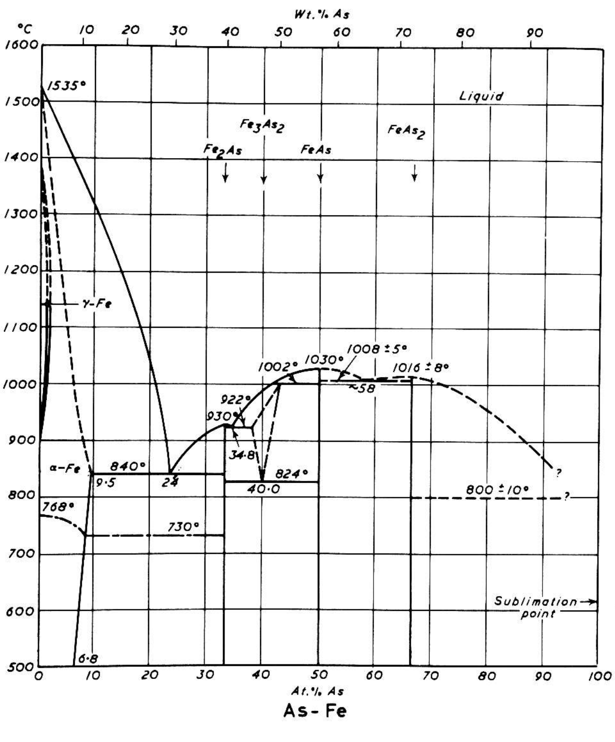


Fig. 21.8: Polished sections of mineralogical phases in slag from Palaia Kavala: a = DYP 1. Glassy silicate slag of kirschsteinitic composition (a) from Dipotamos, very different from slags from other sites. 50×; b = MAKRO 7sp. Slag associated with lump of speiss. Fine inter-growth of dendrites ([a], light grey), calcium-rich olivine ([b], medium grey), glassy matrix ([c], dark grey) and black pores. 200×; c = KEHRO 2sp. Speiss prill in slag. 100×; d = PYRG 3. Calcium-rich fayalite ([a], angular grains) with fine crystals of the same, (b), dispersed in the silicate matrix (c); very fine wustite ([d], bright, sparkling constituent), black holes. 400×

Fig. 21.9: As-Fe binary phase diagram



The presence of the two phases, namely As and a eutectic of alpha-iron and Fe_2As, together with the higher percentage of the former phase with respect to the latter suggest that the As content in the melt must have been hypoeutectic, i. e. between 10 % and 24 % As (Fig. 21.9). Thus, speiss must have cooled from a relatively low temperature in the Palaia Kavala furnace, c. 900 °C.

Gold and silver contents in the slag and speiss were below the detection limit of the Electron Microprobe, so they were analysed by Atomic Absorption Spectrometry. Table 21.3 shows that gold and silver partition in both speiss and slag, gold being present in substantially smaller amounts than silver. The same relative concentrations were observed in the analyses of the ore samples. The precious metals must have been associated with the lead included in the slag and speiss. The presence of precious metals in both slag and speiss and the absence of evidence for any substantial amounts of base metals in the slag suggests that precious metals extraction must have been the main metallurgical activity in the region.

Sample no.	Phase	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	FeO	ZnO	Sb_2O_3	PbO	As_2O_3
Kara-3I	wustite	0.87	0.58	1.12	0.39	0.00	0.00	0.00	0.17	0.43	10.05	85.97	0.00	0.00	–	–
	matrix	0.61	0.85	0.77	10.26	0.49	0.00	0.12	6.35	0.34	11.35	68.65	0.66	0.00	–	–
	matrix	0.00	0.66	1.05	29.65	0.00	0.00	0.65	21.97	0.31	14.35	14.35	0.00	1.94	–	–
Kara-3II	wustite	0.63	0.00	1.44	0.57	0.00	0.14	0.00	0.40	0.00	7.26	85.70	0.00	0.00	–	–
	matrix	0.60	0.98	0.96	30.87	1.58	0.00	0.56	22.35	0.17	13.14	28.44	0.00	0.00	–	–
EL-IV	wustite	0.00	0.56	0.52	0.57	0.00	0.00	0.00	0.24	0.51	2.97	94.63	0.00	0.00	–	–
	matrix	0.00	0.70	5.46	34.57	1.14	1.07	2.44	18.53	0.32	4.51	31.25	0.00	0.00	–	–
	matrix	0.00	0.50	6.17	35.52	1.05	1.45	2.85	18.40	0.31	4.22	30.43	0.00	0.00	–	–
EL-1	"fayalite"	0.00	0.51	0.00	31.92	0.69	0.00	0.17	19.53	0.28	4.46	45.48	0.00	0.00	–	–
	matrix	0.49	0.00	19.04	47.41	0.34	0.23	17.28	1.00	0.31	0.34	14.65	0.00	0.00	–	–
	wustite	0.75	0.00	0.39	0.50	0.00	0.00	0.15	0.20	0.68	1.14	93.74	0.00	0.00	–	–
Kehro-3	spinel	0.00	0.81	20.15	0.93	0.00	0.00	0.00	0.43	2.89	1.09	70.80	1.11	0.00	–	–
	matrix	0.00	1.59	17.19	26.01	0.00	0.00	0.11	13.29	2.61	0.96	39.15	0.42	0.00	–	–
Kehro-6	"fayalite"	0.00	1.51	0.79	32.21	1.07	0.00	0.63	26.99	0.30	4.96	32.73	0.00	0.00	–	–
Kehro-4	„fayalite"	0.00	1.33	0.00	29.09	0.49	0.00	0.11	18.03	0.24	6.01	35.17	0.58	0.00	–	–
	matrix	0.00	1.01	10.58	32.39	0.84	0.19	0.49	15.58	0.79	2.14	28.41	0.00	0.00	0.8	–
	matrix	0.00	1.67	14.04	27.99	0.50	0.00	0.00	14.32	1.88	2.17	30.40	0.00	0.00	0.	–
Dyp 1	matrix	–	0.95	11.58	47.76	0.60	–	2.90	9.38	0.72	12.83	14.70	–	–	2.4	–
Makr 13	matrix	–	–	12.28	37.63	1.63	–	2.92	18.86	0.59	7.90	10.23	–	–	4.7	1.9

Table 21.1

Table 21.2

Sample no.	Phase	Fe	As	Sb	Cu	S	Mn	Ti	Pb	Ag
Kara-3I	speiss	60.92	32.39	1.02	2.08	1.69	0.25	0.00	0.00	–
		49.42	43.07	1.83	0.67	2.89	0.32	0.00	0.00	–
Kara-3II	speiss	56.18	35.37	1.01	3.17	1.45	0.00	0.00	0.00	–
		47.79	43.04	1.89	1.64	1.26	0.00	0.00	0.00	–
EL-III	speiss	59.77	36.32	1.27	0.48	0.17	0.00	0.17	0.00	–
EL-II	speiss	91.73	6.58	1.11	0.49	0.00	0.00	0.31	0.00	–
		59.28	21.75	16.54	1.37	0.85	0.00	0.11	0.00	–
		85.13	9.75	5.14	0.46	0.00	0.00	0.23	0.00	–
EL-I	speiss	53.72	33.11	3.92	2.01	3.99	0.18	0.14	1.23	–
Kehro-1sp	speiss	51.89	33.69	2.92	3.24	0.00	0.00	0.16	0.00	–
		79.23	9.38	0.40	0.83	0.00	0.00	0.31	0.00	–
Kehro-2sp	speiss	58.23	37.26	1.75	2.71	0.21	0.00	0.23	0.00	–
		86.19	11.08	0.31	0.74	0.00	0.00	0.37	0.00	–
Kehro-4sp	speiss	55.66	35.05	0.00	0.00	0.83	0.00	0.19	0.41	–
Dyp-3sp	speiss	55.27	32.81	8.05	2.16	1.38	0.00	0.25	0.00	–
		86.57	10.14	1.09	0.51	0.00	0.00	0.29	0.00	–
		77.03	10.37	7.03	0.74	0.18	0.00	0.00	0.00	–
		43.63	23.68	18.63	1.82	3.94	0.00	0.21	0.00	–
Dyp-5sp	speiss	87.61	10.19	1.34	0.40	0.00	0.00	0.39	0.00	–
		55.72	31.33	9.49	1.89	2.07	0.00	0.00	0.00	–
		51.41	23.01	14.09	1.81	4.04	0.00	0.18	0.60	–
Dyp. H. Me	speiss	85.85	9.89	1.62	0.50	0.13	0.00	0.10	0.00	–
		57.14	35.15	4.42	1.83	0.19	0.00	0.22	0.00	–
Dyp-4sp	speiss	89.36	9.38	1.15	0.64	0.00	0.00	0.32	0.00	–
		40.09	10.99	46.26	2.26	0.00	0.00	0.00	0.00	–
		56.54	34.34	6.82	1.86	0.15	0.00	0.28	0.00	–
Makro. 9sp	speiss	55.32	38.08	5.86	0.97	0.47	0.00	0.30	0.00	–
Makro. 7sp	speiss	86.39	10.23	1.36	0.27	0.17	0.00	0.28	0.00	–
		57.59	35.19	3.78	0.19	0.18	0.00	0.30	0.00	–
		61.62	10.49	2.43	0.69	24.96	0.00	0.19	0.00	–
	matte	62.43	0.00	0.00	0.58	36.01	0.00	0.22	0.00	–
Makro. 8sp	speiss	56.13	34.36	6.17	3.17	0.30	0.00	0.22	0.00	–
	matte	57.31	3.13	7.65	1.85	26.33	0.00	0.25	0.00	–
	speiss	63.29	16.44	7.69	2.63	2.04	0.00	0.29	1.74	–
Makro. 6sp	speiss	87.14	10.47	0.95	0.39	0.00	0.00	0.29	0.00	–
	speiss	57.53	35.69	4.51	1.42	0.21	0.00	0.20	0.00	–
	"speiss"	50.11	11.56	5.14	0.79	16.05	0.00	0.16	0.00	0.72
Pyr. Gr. 3	speiss	54.67	38.11	1.09	5.78	0.14	0.00	0.13	0.00	–

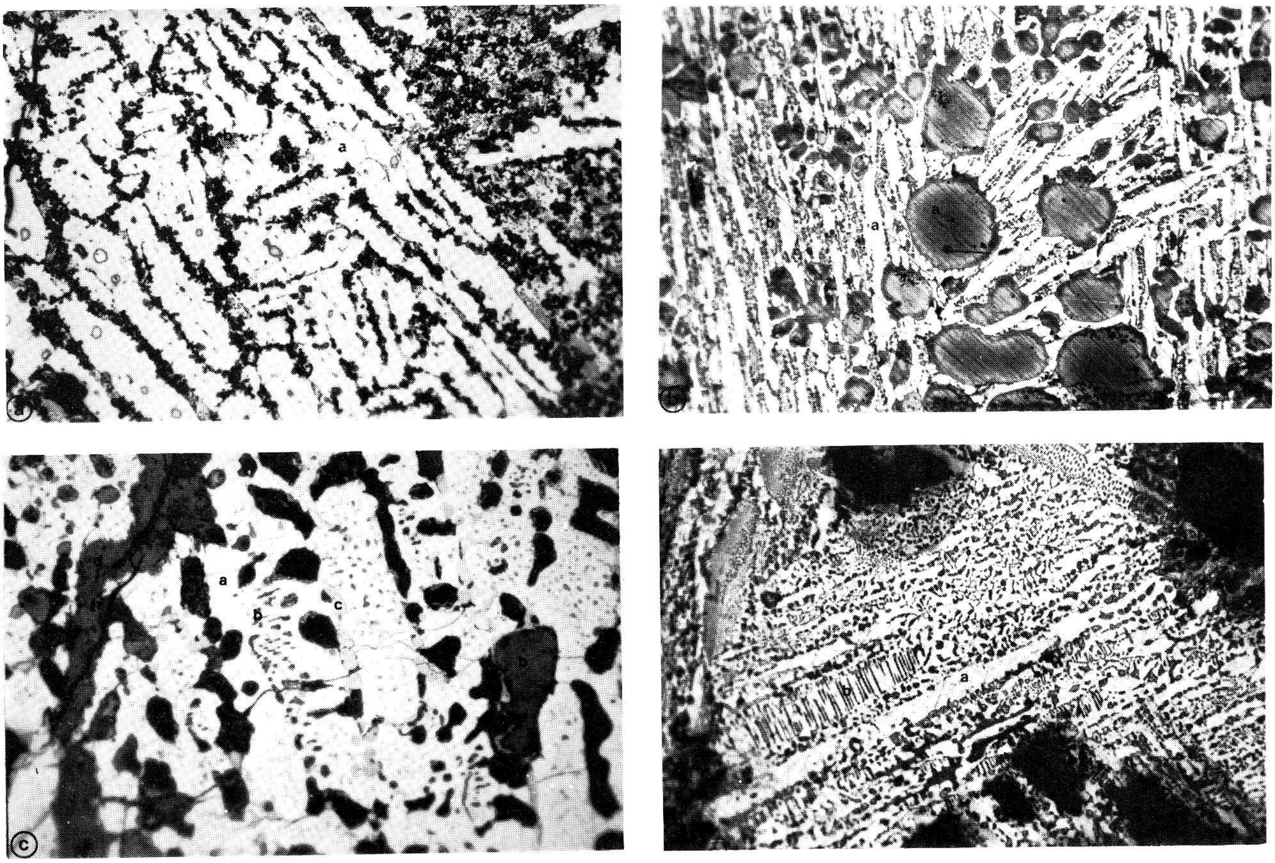


Fig. 21.10: Polished sections of mineralogical phases in Palaia Kavala speiss: a = DYPME. Low As ([a], white-grey laths), high As ([b], grey-black interstitial material. 200×; b = KEHRO 1sp. Low As ([a], white-grey laths and grey round globules), high As ([b], grey interstitial material). 200×; c = MAKRY 7sp. Low As ([a], white-grey areas), high As ([b], fine interstitial material and some larger areas), Matte grains ([c], light grey areas), corrosion (d). 200×; d = KEHRO 3sp. Similar to KEHRO 1sp. Large black areas and pores. 100×

There were scarcely any artefacts to be found associated with the slag heaps at Palaia Kavala. The only evidence was a cannon shot and a gun stone of basalt lava found next to each other near the Lekani slag heap (Fig. 21.1). They both had a diameter of 7.58 cm, and the cannon shot weighed about 2 kg. Electron Microprobe analysis (Table 21.4) of the latter revealed two phases similar to those observed in the speiss. The characteristic dendrites suggest, as might have been expected, that the cannon shot was cast.

Table 21.3:

Site	*Ag (ppm)*	*Au (ppm)*
Dipotamos (sp)	1.2	0.0
Kechrokampos (sp)	62.0	32.0
Kechrokampos (sp)	36.0	2.9
Eleftheroupolis (sp)	70.0	9.9
Makrychori (sl)	119.0	0.4
Kechrokampos (sl)	45.0	12.1

sp = speiss; sl = slag

Table 21.4:

Site	*Fe*	*As*	*Sb*	*Cu*	*S*
Dendrites	88.03	10.07	0.55	0.31	0.12
Interstitial	58.35	37.25	1.33	1.69	0.31
Matte incl.	70.77	15.67	2.25	0.83	4.63

Fig. 21.11: Cannon shot (left) from Lekani and gun stone (right) of same diameter

Suggested Mechanism of Precious Metals Extraction in Palaia Kavala

Analyses of the Palaia Kavala ores have indicated that apart from Mn and Fe, the ores contained As, Pb, Ag, Au and Zn, the relative concentrations varying according to the direction of mineralisation. The Au content was in general very low. Although Mn varied considerably, As was consistently present as a minor element. Mn and often Pb were to be found in the slag, while As occurred consistently in the speiss, as did Cu and Sb (Tables 21.1 and 2). The presence of Au and Ag in both slag and speiss indicated that the ores did contain precious metals, thereby demonstrating that the archaeometallurgical evidence supports the archaeological proposition argued above that Skapte Hyle should indeed be located within Palaia Kavala.

What was the extractive process by which precious metals were recovered from the Palaia Kavala ores? A key to the process involved may lie in the presence of Pb in some slag samples. In view of the small quantity of Ag and the even smaller amount of Au in slag and speiss (Table 21.3), it is possible that Pb was added during smelting to act as a precious metals collector. A suggested mechanism for the process is the following: Mn-rich iron ore with varying amounts of Pb, Zn, As, Au and Ag was charged in the furnace with PbO/PbS. The product was Pb with Au and Ag collecting in the bottom of the furnace, speiss floating on top of the Pb layer and slag floating on top of both (relative specific gravities in gm/cm^3: Pb (11), speis (5–8), slag (4). Au and Ag would also collect in speiss, but the affinity of the precious metals for Pb is greater than for speiss. In addition, some of the Au-rich or Ag-rich lead would find its way into the slag. No matte layer would be produced due to the absence of sulphur in the ore.

Speiss and slag would subsequently be tapped out of the furnace, slag being discarded while speiss was either thrown away or collected for reuse. Pb containing Au and Ag must have subsequently been cupelled in a cupellation hearth, the resulting litharge being collected and probably charged back in the smelting furnace. A flowchart of the suggested mechanism is presented in Fig. 21.12.

Documentary corroboration of the extraction scheme given in Fig. 21.12 comes from a passage of Belon (1553) describing his observations of the metallurgical activities at Siderokapsia (Olympias) in Chalkidiki (Fig. 21.1) at the beginning of the 16th century. In the furnaces ("fourneaux"), roasted pyrite and charcoal were charged in a layered form together with galena. Belon does not explain the reasons for the addition of galena and seems to assume that this was a well-known practice. Galena seems to have been roasted before being added to the furnace. The products coming out of this furnace were gold, silver and lead as well as "dross". Belon mentions that dross was useless and that the workers lifted it little by little with

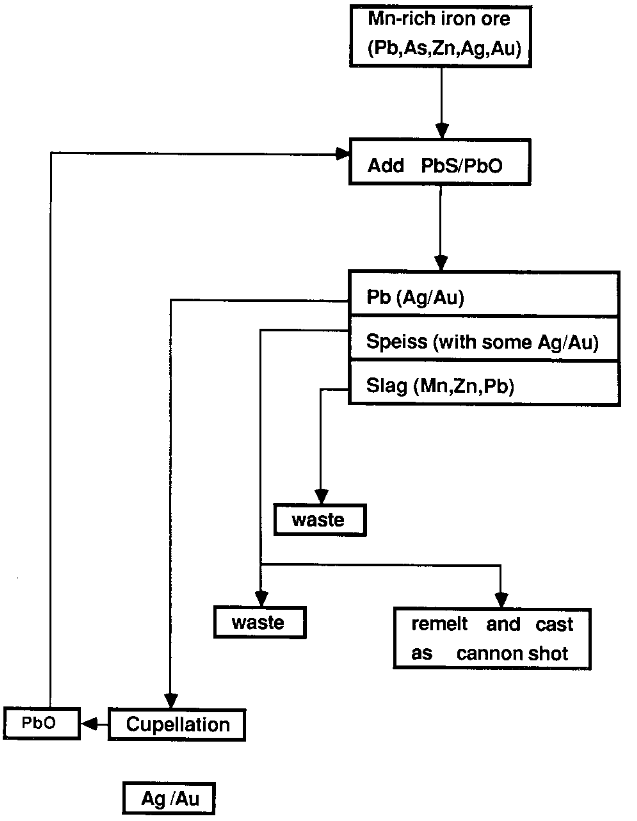


Fig. 21.12: Flowchart of precious metals extraction in Palaia Kavala

an iron rod and threw it away before it solidified on the metal. This dross was most probably speiss since the author differentiates it from silver slag which he calls "scoria"[37].

In brief, it is suggested by Belon that co-smelting of pyrite and roasted galena was taking place in one furnace and that slag and speiss were tapped out of the furnace first and then the precious metals-rich Pb layer[38].

Agricola[39] describes a similar process for the smelting of Au/Ag-containing pyrite, but employing two furnaces. In the first, the roasted pyrite was smelted resulting in speiss, matte and slag. In the second, Pb was added and mixed with the speiss; the product was not slag but only Pb, rich in gold and silver and some speiss forming from the arsenic which did not evaporate as oxide. The slag tapped from the first furnace in Agricola's scheme would have contained no Pb apart from the small amounts included in the ore. Since some of the Palaia Kavala slag contains Pb, it is more likely that the lead was mixed with the iron oxides in one furnace as opposed to the two described by Agricola and that the Palaia Kavala extractive practices resembled more closely those given by Belon.

Evidence for the remelting of speiss for cannon shot comes from the specimen found at Lekani (Fig. 21.11). It is documented that a foundry for cannon balls and iron for construction material was established in 1698 at Eleftheroupolis (Pravi), the goods being shipped to the naval base at Constantinople[40]. There is no suggestion what the Pravi cannon balls were made of, namely speiss or cast iron but if it were speiss then the raw material was most probably coming from Pangaion rather than Palaia Kavala. The analytical investigation of the archaeometallurgical data and the flowchart of the extractive practices presented here raise two important questions:

a) The extractive metallurgical practices by which Pb was used as a precious metals collector were common practice in the 16th century AD. However, at Makrychori the evidence of sherd typology suggests that metal-working activities may date as early as the 4th–2nd century BC. Is it possible that the same extractive processes were used as early as the Hellenistic period in Macedonia? If that is indeed the case, Mn-rich iron oxides must then have been smelted in a furnace similar to those of the Ottoman period. The extent to which such technology was available in antiquity must remain for the present a matter of debate.

b) It has been argued above that on the basis of archaeological evidence, it can now be safely assumed that Skapte Hyle lay within Palaia Kavala. Furthermore, the classical sources refer to Skapte Hyle as both argentiferous and auriferous, and oral tradition has kept the memory of gold more alive. However, at this preliminary stage of the archaeometallurgical investigation it is apparent that the region was primarily a Ag-producing area since the Au content of the analysed ore, speiss and slag appears to be very low. Where, then, is the gold of Palaia Kavala? It is possible that either the gold-bearing veins of Skapte Hyle were situated along the north-eastern zone of mineralisation of Palaia Kavala or gold-bearing pyrites were preferentially selected from the manganese-iron oxide mineralisation through some type of enrichment process[41] not yet evident.

The long-term aim of this project will have to answer both these questions. The results presented here constitute only the preliminary stages of the project. The bulk of the work, namely the excavation and dating of a selected slag heap, lies ahead.

Conclusions

In this report it has been argued that the location of Skapte Hyle should be sought archaeologically within Palaia Kavala, the region extending East of Kavala to the River Nestos and in the North into the Lekani mountains. The same region is archaeometallurgically very rich with extensive iron ore deposits containing Mn, As, Pb, Cu, Ag, and some Au, and abundant evidence for as yet undated mining and smelting activity. Analytical investigation of ore, slag and occasional artefacts (cannon shot) revealed that the archaeometallurgical remains are related solely to silver extraction. It is proposed that PbO/PbS was co-smelted with iron ore in one furnace, Pb acting as a precious metals collector. Hellenistic-Roman sherds collected from the slag heap at Makrychori suggest that this process may have been known as early as the 4th–2nd century BC. Scientific dating of the slag heaps is pending.

NOTES

1 Herodotus VI, 46.
2 Stephanus Byzantius 573, 19.
3 Lazaridis 1971.
4 Gialoglou/Drymonitis 1983.
5 Maratos/Andronopoulos 1966; Anastopoulos/Koukouzas/Hatziyannis 1976; Gialoglou/Drymonitis 1983.
6 Spathi/Kouvelos/Perdikatsis 1982, 107.
7 Ibid.
8 Spathi/Kouvelos/Perdikatsis 1982, Table 25. IGME is currently expanding its chemical data bank by sampling extensively various deposits in the region with a view to establishing the potential for possible future exploitation of these ores for their precious metals values (A. Papavassiliou and V. Perdikatsis, pers. comm.).
9 Ancient galleries have been surveyed and mapped by Krikelas (1979) and Favas (unpublished). Others have been investigated by the Greek Spelaeological Society particularly in Kryonerion (Hatzilazaridis 1981, 347). A project is currently being formulated to date and survey the mines in detail.
10 Speiss is iron, copper or nickel arsenides or antimonides produced in the smelting either of complex ores or of a copper ore containing substantial amounts of iron and arsenic. Speiss is hard, grey, brittle and magnetic. The fractured surface is bright and crystalline and resembles cast iron. Speiss can be argentiferous or auriferous or even contain members of the platinum family. Platinum and gold have higher affinities for speiss as opposed to matte (a copper-iron sulfide), while silver has the same affinity for both (Rosenquist 1983, 343). These three metals have a higher affinity for lead compared to speiss and matte. Concentrations of precious metals in speiss have been reported at levels in excess of 1000 gm/ton (Lupu/Dragan 1961, 196).
11 The earliest evidence for speiss occurs in Mycenean Greece at Tiryns (13th century BC), as a sample kindly provided to us by the excavator has testified (Kilian 1983, 306). The analysis (Photos 1987, 311) showed two phases: a high arsenic (64.90% Fe, 31.05% As, 2.29% S, 1.03% Cu) and a low arsenic one (86.14% Fe, 12.39% As, 0.18% S, 0.34% Cu) suggesting that it was produced from the local smelting of complex copper ores.
12 Papastamataki 1986a. The nature of precious metals deposits on Pangaion has been a matter of controversy primarily due to the lack, until recently, of geological and archaeological data. However, ancient galleries as well as smelting sites have recently been discovered on Pangaion, in the course of a collaborative programme of research between the Archaeological Service (East Macedonia Division) and IGME. A number of slag heaps have been surveyed and sampled by Papastamataki and her co-workers (1975, 1986a, 1986b). She has published important chemical analyses for ores and slags but unfortunately did not make an attempt to elucidate the metallurgical processes involved. Some analyses of Pangaion slags and speiss have been carried out in the course of this work (Photos 1987).
13 Pernicka/Gentner/Wagner/Vavelidis/Gale 1980: Wagner/Pernicka/Vavelidis/Baranyi/Bassiakos 1987; Photos/Koukouli-Chrysanthaki/Gialoglou 1987; Photos 1987.
14 Gale/Gentner/Wagner 1980.
15 Renfrew/Gimbutas/Elster 1987.
16 Theocharis/Romiopoulou 1961.
17 Theocharis 1973, Fig. 120.
18 Seferiadis 1983, 647.
19 Photos/Koukouli-Chrysanthaki forthcoming.

20 Photos 1987.
21 Various sections of Macedonia came under Ottoman occupation about two decades earlier than the fall of Constantinople in 1453. However, this date is used as a general starting point for the occupation of Byzantium and the Greek lands in Europe and Asia minor alike. On the other hand, 1912 is the date of the liberation of Thessaloniki by the Greek army, which together with the treaty of Bucarest (1913) signify the end of the Balkan wars and the annexation of Macedonia with its present borders to the Greek state. It should be added here that Macedonia is a geographical rather than a political unit spreading over Greece, Bulgaria and Yugoslavia. It was the Treaty of Bucarest (10 August 1913) which ceded 10% of the region to Bulgaria, 51% to Greece and 39% to Yugoslavia (Sakellariou 1982, 482).
22 Herodotus V, 23 and VII, 112; Aeschylus, frg 12; Euripedes, Ressus 921 and 970; Aristotle, Athenaeus 15 and 11, 42b; Strabo, Geography XIV, 5, 28 and VII, 31, frg 34; Plinius, Historia Naturalis VII, 56 and 1987; Clemes of Alexandria, Stromat. I, XVI, 75, 8.
23 Herodotus VI, 46; Thucidides I, 100, 2 and I, 101, 3; Plutarch, Kimon XIV; Diodorus Siculus XI, 70, 1; Lucretius VI, 808, 810.
24 Pedrizet 1910; Casson 1926, 77; Collart 1934, 40; Lazaridis 1971, 40; Samsaris 1978, 37; Tsekourakis 1981, 76; Unger/Schütz 1982, 163.
25 Meiggs 1943, 21; Hereward 1965; Hammond 1979; Koukouli-Chrysanthaki 1980.
26 Koukouli-Chrysanthaki 1980. The author has reevaluated her arguments in a more recent publication, Koukouli-Chrysanthaki (in press).
27 Bakalakis 1936; According to archaeological and literary evidence, Neapolis, Oesyme and possibly Galepsos were founded by the 3rd quarter of the 7th century BC. Other colonies such as Antisara, Apollonia and possibly Phagres and the small colonies to the east of Neapolis seem to have been founded later at the end of the 6th century BC. See Fig. 21.2 for the spread of the Thasian colonies on the mainland.
28 The region west of Neapolis/Kavala encompassing the Symvolon range (Fig. 21.1) has not yet provided any indications of gold and silver and so can be excluded as a precious metals producing area. Manganese-iron deposits have been identified in the Symvolon near the village of Pholia (Maratos and Andronopoulos 1966, 61) and slag and metal-working remains at the site of ancient Apollonia (Fig. 21.2). Analyses of slag from the latter site showed it to be that of bloomery smelting.
29 Koukouli-Chrysanthaki 1980. The remains of an "ancient" tower at Lefki brings to mind similar towers located on Thasos near metal-working and marble quarrying sites (see Fig. 21.2 for the distribution of these towers on the mainland).
30 It is not clear how far to the north the frontiers of the Thasian Peraia extended. An inscription dating to the Roman period found near the village of Petropigi defines these frontiers between the Thasian Peraia and the Thracians. It is possible that in the Classical period, the border could have extended up to Pyrgiskos. By the same token it cannot be excluded that many of the metallurgical sites inland could have been exploited by the Thracians instead.
31 The characterisation of some sherds in the Makryhori slag heaps as possibly Roman may corroborate the Roman literary sources (Lucretius VI, 808–810, and Festus, 442–443) which point to Skapte Hyle as a silver producing area in the Classical period.
32 Vryonis 1962.
33 Belon 1553; Murphey 1980.
34 Papastamataki 1986b.
35 Anhegger 1943, 178 and 335.
36 The experimental smelts were carried out in field conditions at Ashdown Forest, Sussex, with the generous assistance of Mr R. Adams (Photos 1987). The purpose of the experiment was to establish whether slag picked up near Petropigi mine was indeed produced from the smelting of Petropigi ore. This was confirmed, the only difference being the end products. Our furnace was built and operated to make bloomery iron, which indeed it produced, while the Petropigi furnace must have been made to produce lead which would subsequently be cupelled for its silver values. The operating conditions for our furnace were more reducing, while these of the Petropigi furnace were more oxidising. Nevertheless, it was the arsenic-rich bloom (c. 10% As) produced by the solid state diffusion of As in the iron and the known conditions of operation of our furnace which elucidated the mechanism of precious metals extraction in Palaia Kavala.
37 There is a similar passage in Agricola (Translators Hoover and Hoover 1950, 408) about white silvery "dross" being picked from the metal with an iron rod after the slag layer was removed and before the silver disappeared in it. Although no particular name was given to this crust, Agricola was most probably referring to speiss.
38 Belon mentions a number of other minerals apart from pyrite being present at Siderokapsia. All these names are not mineralogically accurate and could only serve as a broad description of the ores available. Nevertheless, pyrite was the main ore used, first roasted in a pit to remove the sulfur. Belon uses two words "cheminèes" and "fourneaux". The first could be translated as hearths or chimneys according to the narrative. While pits for roasting of pyrite were built in the open air, furnaces/hearths were constructed indoors in the middle of the workshop, and of thick masonry, particularly their back wall. Furnaces and hearths were situated along streams and were operated by water power. They had an arch in the front. "Spodos", the precipitate of probably arsenious oxide, condensed on the outside of the arch of the furnace, while "pompholix", probably zinc carbonate, also produced in the smelting was usually collected.
39 Agricola (Translators Hoover and Hoover, 1950, 556).
40 Anhegger 1943, 206.
41 Parenthetically and in reference to pyrites, it should be mentioned that there is the interesting reference in Lucretius (VI, 808–810) to "smelly" Skapte Hyle. Upon hammering, pyrites can give off a smell of sulfur as can, to a larger extent, arsenopyrite, although this alone may not be sufficient to have given the mine its appelation. A more critical factor may have been the spontaneous combustion that pyrites can undergo when broken up. With time, evolution of H_2S occurs followed by subsequent sintering of the pieces.

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