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Cast iron in ancient Greece: myth or fact?

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Abstract

Up to now all suggestions about the production of cast iron in antiquity were dismissed in the absence of solid archaeological evidence. Analytical work carried out in a number of archaeological finds from excavations in Messemvria-Zone, an ancient town in north Greece, demonstrates that the technique was known in the area as early as the 5th century B.C. The results presented here change completely our understanding about the history of ancient technology.

Keywords: *iron, cast, archaeology, Messemvria-Zone, analysis, archaeometallurgy.*

Introduction

Cast iron is the name used to describe an impure iron with 2-5% carbon in modern terms or with up to 1.9 % carbon and other impurity elements such as silicon and phosphorus in antiquity (Tylecote 1962, 312). The production of cast iron in Western Europe has been associated with the introduction of the blast furnace which has started c.1500 A. D. but it was not in general use before the 17th century A. D. (Tylecote 1962, 300). It is generally believed that the blast furnace technology was transmitted to Europe from China (Wagner 1999; Craddock 1995, 251; Tylecote 1962) where the earliest use of cast iron is well documented as early as the 4th century BC (Rostoker and Bronson 1990, 17). Although both experimental and ethnoarchaeological work suggest the possibility of cast iron production in pe-indusrial societies (for a discussion see Killick 1991), scholars did not accept it due to lack of archaeological evidence. They did carry experimental work in order to demonstrate that cast iron is not necessarily produced in a blast furnace (Wagner 1999). Cast iron was one of the products of African iron smelting and it was also re-produced in modern experimental smelting in bloomery shaft furnaces that were in general use in the ancient world (Killick 1991). Also, experiments have proved that the same furnace can produce wrought iron, steel, and cast iron depending on operation (Rostoker and Bronson 1990, 97-98).

The problem in question

Nevertheless, the question about the possible production of cast iron in antiquity has puzzled historians, archaeologists, and archaeometallurgists for many years. The historian of ancient technology Halleux (1974) recognised a description of producing cast iron in Aristotle; archaeometallurgists (Tylecote 1962, Photos-Jones 1987, Rostoker and Bronson 1990, Killick 1991) discussed extensively the possibility and have dedicated a lot of ethnoarchaeological and experimental work to prove it. The discovery of archaeological material which could provide the undisputed evidence remained the 'holy grail' of archaeometallurgy. The only similar archaeological evidence to authors' attention comes from the excavation of smelting sites in south Germany by Gassman (2001).

On the one hand, archaeometallurgists were lacking archaeological data and on the other, archaeologists made little or no attempts to engage with the study of the industrial and rural parts of ancient complex societies.

In the context of the debate about a more humanistic input into science based archaeology and the study of ancient metallurgy (Knapp 2000), a problem focused approach for the study of all industrial waste, by-products and products of ancient iron technology in Greece was adapted. The systematic recording and study of all excavated iron related material was followed by an extensive analytical programme and all the permits for sampling and studying the material were approved by the relevant authorities. The application of techniques such as metallography and Scanning Electron Microscopy (SEM with EDAX microanalyser) for the study of material from safe archaeological context made possible a series of discoveries that were unprecedented in classical studies (Kostoglou 2003).

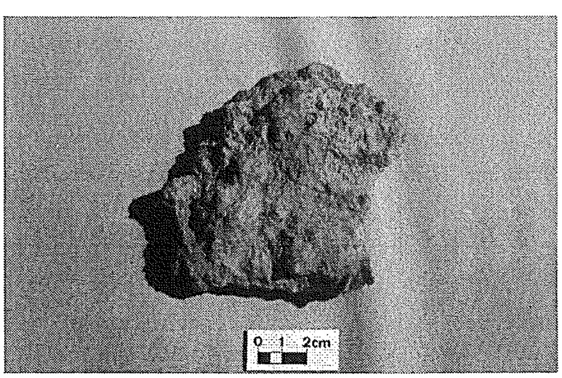

Figure 1. (a) Mass of cast iron, MES127, 5th century B.C.

Discussion of the analytical data

This is the first time that archaeological material indicates that cast iron was produced during the 5th century BC in Greece changing completely our preconceptions about ancient technology. A number of finds generally described as rusty lamps of iron were discovered in 5th century BC layers during the excavations in ancient Messemvria-Zone, an ancient city on the northeast coastline of Greece (Kostoglou 2003). By using a number of analytical techniques (metallography, Scanning Electron Microscopy and X-ray analysis) we were able to determine that most of samples represent slag and other waste products of bloomery iron technology and five of these are positively associated with different steps of cast iron production from white (fig. 1) to grey cast iron (fig. 2). In white cast iron most of the carbon exists as cementite (iron carbide with the formula Fe3C) and it appears white under the microscope; in grey cast iron most of the carbon exists in the form of graphite, a soft plate or flake- like

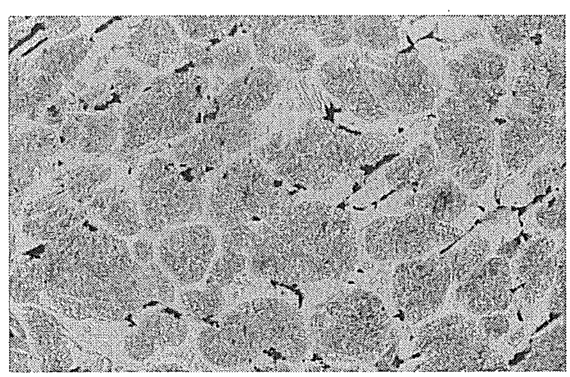

Figure 1. (b) Optical microscopy of MES 127 in magnification x132 sowing cementite surrounding islands of pearlite, a structure found in white cast irons. Black areas indicate air pockets.

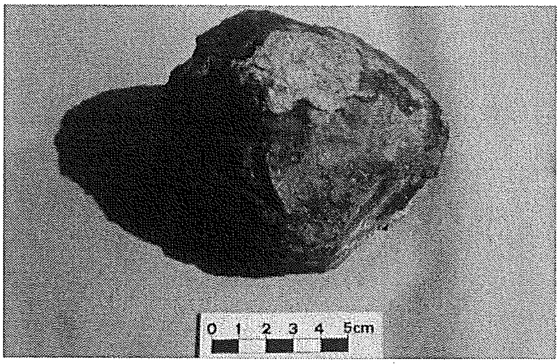

Figure 2. (a). Mass of cast iron, MES126, 5th century B.C.

Figure 2. (b). Optical microscopy x66 of MES126 showing transformation of graphite flakes (black) to cementite needles (white) due to decarburisation of grey cast iron. The matrix in both phases is pearlite.

structure (Tylecote 1962, 312-314). What happens is that iron under 1523°C is completely liquid and can be almost perfectly separated by the impurities of the ore. With the progressive addition of carbon this temperature can fall to a minimum of 1143°C (Rostoker and Bronson 1990, 16). Under highly reducing conditions, the iron, in a perfectly liquid state, gathers in the bottom of the furnace. The impurities of the ore along with the fluxes and charcoal also form a liquid slag, which since it is lighter sit on top of the iron. The smelter opens a hall on the furnace wall and first taps out the iron into halls where it is left to solidify. The same happens with the slag. The product of this operation is an iron containing up to 4% carbon. Iron on that stage is in a cementite form and surrounds island of pearlite. Holes are indicative of the casting process. This is called white cast iron and it is not ready for use because it is hard to work with. What follows is further re-heating of the mass of white -cast iron. During re-heating, iron absorbs more carbon that after cooling takes the form of long graphite flakes. The produced mass is ready to be used by the smith. This process is known as fining in modern metallurgy (Craddock 1995, 253) and leads to de-carburisation of cast iron. In a way, the process is the opposite of the one described as carburization which is the commonly accepted method for making steel in antiquity. Both processes aim towards a final product with a desirable amount of carbon and thus a good quality steel ready to be worked by the smith. It should also be noted that the region is extremely rich in mineralogical deposits and recent archaeological and analytical research has demonstrated that different technological traditions of smelting iron have developed side by side producing a number of high quality steel tools and weapons (Kostoglou 2003).

Conclusion

The results presented here change completely our understanding of technological innovation. It seems that both traditions, namely carburising wrought iron and decarburising cast iron, were used in antiquity. Further archaeological work will give us an inside in the different socio-cultural context of ancient metal technology. The advantage of cast iron against the wrought iron was not realized before the introduction of the blast furnace to Europe. Nevertheless, these finds prove that the technique was known in a European context since the 5th century BC and question our modern pre-conceptions about the technological capabilities of the ancient world.

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Metal production towards the end of Byzantine rule in eastern Macedonia

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Abstract

Throughout the Middle Ages the Byzantine Empire consolidated control over much of Northern Greece to secure sources of iron and precious metals. Although the trade in Byzantine metalwork is known to have been extensive and far-reaching there is little archaeological evidence for the production sequences followed by Byzantine metallurgists. This paper aims to evaluate the evidence for metallurgical operations in Eastern Macedonia through the late Byzantine period in order to promote an understanding of the relationship between political change and technological practice.

Keywords: *metallurgy, slag, speiss, microstructure, byzantine, iron, smelting.*

Introduction

Researchers and historians focusing on the study of economic systems in Medieval Europe have stressed the variance of a feudal, technically innovative western economy against a Byzantine free peasant economy sustained by inferior technological means (Guillou 1959; Runciman 1978). Such a dichotomy appears the more obvious after the political fragmentation of the early 13th century when Constantinople fell in the hands of the Frankish leaders of the fourth crusade. The loss of central imperial authority left a number of rival 'states' competing for succession through a process that caused severe economic disarticulation. In fact it is the period of emerging regional economies, which meant decentralisation of the monetary system, lack of unified fiscality and no market under the state's protection which subdued free peasants into serfs, dependent on rich landowners. The dominant role of foreign commercial powers such as Venice and Genoa led to a gradual decline of Byzantine industries while Ottoman expansion had catastrophic effects on population, agriculture and the economy of the 14th century. The Byzantine monetary system founded on the gold solidus which had never suffered devaluations at least up to the mid 11th century was now under increased pressure (Harvey 1989). All the major rival states formed after the collapse of central power, namely the Nicaean and Epirus Empires and the

Frankish kingdoms of Constantinople and Moreas had to rely on local resources for sustaining their economies. It was a time of decentralisation when resources were concentrated in the hands of a few rich individuals or monastic institutions that stimulated production.

Technology in context

Although Byzantine economics have recently attracted better attention with the role of production in understanding economy being increasingly acknowledged (Laiou et al 2002; Nikoloudis 2004) technological studies, or more broadly, material culture studies relating to innovation and production have not been well represented in the study of this period. Often technology in the Byzantine world is seen as devolving or stagnating, hence it has tended to neither attract the attention of Byzantine scholars or indeed historians of technology who are particularly focused on documenting instances that support ideas of endless technological progression.

Such attitudes to Byzantine technology as described above are exaggerated in the study of the period after the fragmentation of the Byzantine Empire following the events of the thirteenth century (Laiou 2002, 6). Prior to this the pivotal political role of metal procurement is widely accepted but virtually no studies have been undertaken to better understand this area. Work proposed here intends to readdress this imbalance. For instance it is argued by some scholars that the rich gold deposits in the border regions of Armenia were "*...so important to the early Byzantine state that the conflicts with the Persians/Sassanids, which dominated political events from the fifth to the seventh century, at times took on the character of economic wars*" (Matschke 2002, 116).

Although there are several thorough studies of various aspects of the Byzantine economy, there remains no single synthetic work that would provide a global view of the subject (Laiou 2002, 7). In part this is understandable since the Byzantine world is characterised by regional variation and difference, something which has not been reflected in accounts of technology (see for instance Matschke 2002). However there now exists a need for a work where the economy can be understood as a whole but such an understanding can only come from a synthesis based on focused regional studies, something that is lacking in many approaches to innovation and production in the Byzantine world. Much is known about some aspects i.e. agrarian economies or pottery but only in certain regions whilst mining and metallurgy within Greece remains scarcely understood at all (c.f. Pernicka et al 1981; Meyer et al 2000; but see also Weisgerber and Wagner 1988; Werner 1985; Edmondson 1989). It is attempted here to evaluate diverse evidence for mineral exploitation and smelting in Eastern Macedonia so that issues of production within a defined region could be unravelled.

Smelting sites in the Region

Fieldwork commenced with a geological-archaeological correlation in terms of metalliferous deposits, smelting sites and settlement distribution (figure 1). Previous analyses on ore samples from the mineralised regions of Angistro, Vrontou and Palea Kavala undertaken at the laboratories of IGME in Xanthi were also taken into consideration (Spathi et al 1982; Epitropou 2004). What follows is a report of the evidence encountered across the three prefectures of Serres, Drama and Kavala.

Serres

Two sites of smelting activity have been located around the village of Faia Petra about 7 km northeast of Sidirokastro. The first consists of scattered material close to a monastery situated 300m west of the village. Charcoal entrapped within slag fragments is a common occurrence and a few typical Macedonian pottery sherds belonging to Classical and Hellenistic times have been noted. The second slag concentration is about 100m west of the village covering a slope facing eastwards at a site with natural springs. Except for slag, tuyere fragments of greyish clay, furnace lining and a charcoal layer were found associat-

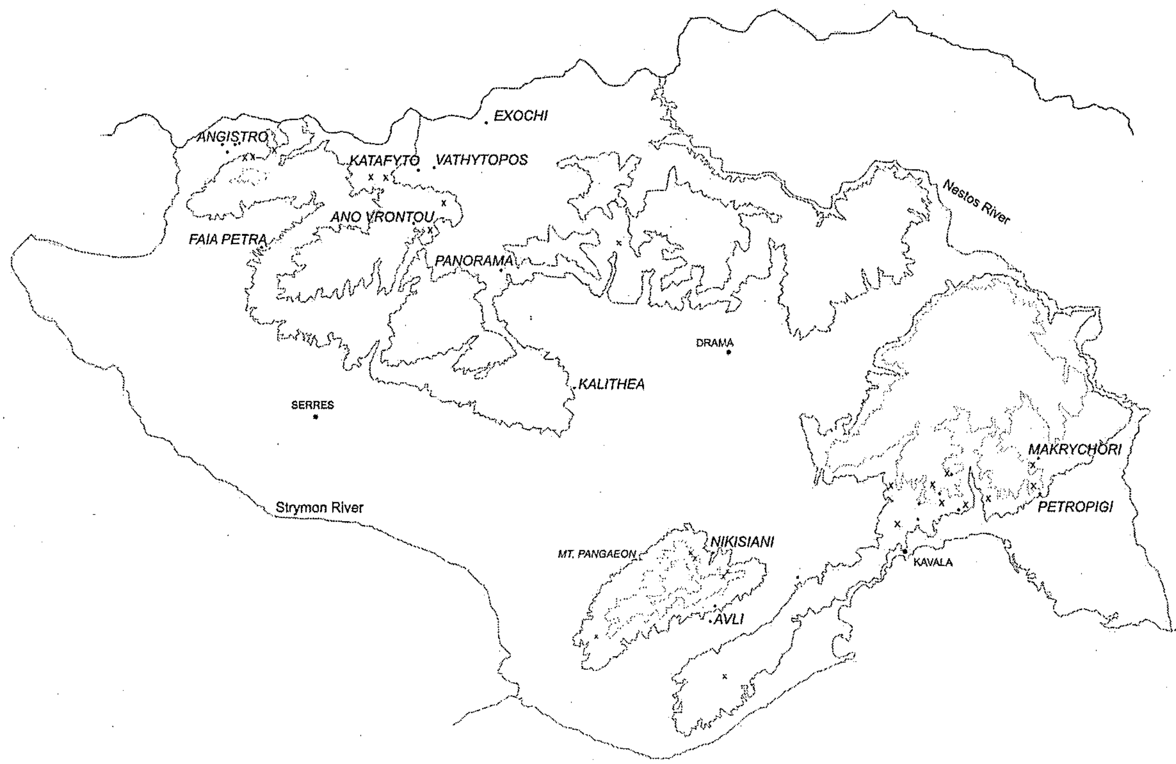

Figure 1. Map of Eastern Macedonia (smelting sites: l, mines: x)

ed with undated pottery sherds.

At the environs of Ano Vrontou the remains of a substantial watermill by the banks of Durvitsa River, employed for the bloomery and forging of iron have been recorded. Metallurgical debris is rare as limited slag fragments were counted found in a thin deposit within the current bank of the river. After construction of the dam it appears that rise in the water level caused severe destruction of the slag heaps. According to locals the village of Ano Vrontou had a long tradition in iron smelting and forging since Ottoman times and possibly even earlier. They mentioned the water generated forge producing iron utensils outside their village and they also referred to bell founding for the needs of the village church. The installations consist of a substantial tower about 12 m in height with two arches supporting the water flue and large rectangular rooms extending on both sides.

Angistro was a major centre of metallurgical activity with waste accumulations reaching roughly 150.000 m² in form of substantial slag heaps and scattered material. Hundreds of tons of metallurgical slags have been accumulated through centuries of smelting operations that probably started some time in the Byzantine period or earlier. Chiotis et al (1996) recorded eleven slag heaps and remains of two furnaces 40 m NW of Aghia Paraskevi chapel. Three major occurrences exist, one to the northwest entrance of the village west of Aghia Paraskevi extending for about 170m parallel to the road up to the site of the granaries, a second at the site of Katomero to the northeast close to the fisheries and the third to the south close to natural springs at Loutra. Smaller heaps were found near the mines of Aghios Konstantinos and Prophitis Elias.

Drama

About 3 km south of the village of Kalithea, within a landscape of low hills in the Drama plain, remains of former buildings associated with metallurgical waste have been located. Locals refer to numerous mills that were in operation through most of the last century in the area. The evidence that survives today consists of accumulations of stone masonry among which numerous slag fragments and ceramic sherds can be found. Three such accumulations have been recorded though many more exist in the area. It is not clear whether the structures had been directly associated with metallurgical practice but examples of water-mills for the crushing of ore and operating water driven bellows are known from Ottoman times.

The monastery of Agios Dimitrios at Panorama is situated on the southwestern flanks of Mt. Falakro on the Kalapoti passage connecting the plain of Drama with that of Nevrokopi. Slag fragments were found scattered within a radius of around 500m around the monastery. Other finds include Byzantine pottery sherds, marble architectural fragments and parts of a baptistery. Signs of a skarn deposit, were found close by consisting of malachite and magnetite but no firm evidence for their exploitation occurs.

Close to the village of Exochi north of Kato Nevrokopi several small slag heaps were noted with an approximate overall volume of 50-100 m^3. The heaps are mostly scattered across farming fields and derive from extraction of the iron bearing deposits of the region. As part of a wider region of decentralised iron production sites Exochi was incorporated in a network of raw and semi-finished materials circulation. In order to sustain production, charcoal and raw ore as well as smelted blooms from upland zones would have been transported in those lowland intermediary locations where the final stages of smithing would have taken place. Furthermore such locations would effectively pass the products over to consumption centres of the surrounding villages.

At the southern foots of Mt. Orvelos about 1 km northwest of Katafyto a large concentration of metallurgical waste has been located. Smelting activities left behind large accumulations of metallurgical waste in the order of 100-200 tons. Bloomery iron slags cover an extensive mound stretching parallel to a stream with a lower eastern side and a conical peak to the west. Entrapped tuyeres within slag cakes (largest: 20x10cm) and other baked clay fragments were also found suggesting the existence of a furnace on the slopes of the mound.

About 2 km west of Vathytopos where the remains of a water mill still stand today a significant amount of slag and coarse-ware pottery was recorded. Small patches of trampled slag pieces lay on a plateau formed between the water mill and the current course of the stream. The slag fragments resemble macroscopically in texture and colour the denser samples from Katafyto and might have been formed from a common ore. The evidence from both sites suggests the use of furnaces operating by the aid of water driven bellows as the one reported by Georgiev (1971) in Samokovo, Bulgaria.

Kavala

The southern Lekani foothills overlooking the modern village of Makrychori became a focus for establishing a metallurgical centre that yielded large-scale output in metals mainly iron and most probably silver and gold. It is part of a large number of smelting sites in the region of Palaea Kavala including Pyrgiskos, Dipotamos and Petropigi all of which were active during Classical and Hellenistic times. At the site of Platania, south of Makrychori surface scatters of metallurgical waste spreading across 80-100 hectares deriving from substantial, severely damaged slag heaps have been located. On the highest levels of the slopes where slag deposits do not occur, tailings within some of the terraces have been noted. This fine sorted rubble rich in iron oxides might represent the remains from ore crushing activities which were taking place in crushing floors defined by the terrace walls. Remains of ore washing facilities in form of rectangular marble surfaces and architectural fragments have been recorded close to the terraces while a marble capital deriving from a column might suggest that some short of shed existed. The smelting furnaces although not located would have been on these upper levels between the terraces and remains of the two substantial slag heaps both of which have been quarried for the use of slag in road openings.

Mt. Pangaeon stretching to a total length of 50km divides Eastern Macedonia into north and south and

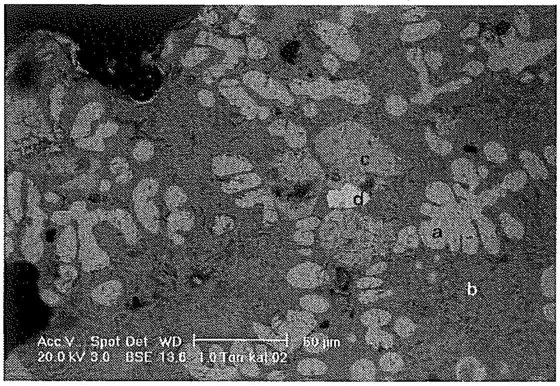

Figure 2. Kat06 SEM micrograph: a) wustite dendrite; b) fayalitic matrix; c) spinel crystal (Ti-rich); d) metallic inclusion (Fe-rich)

slag heaps have been recorded in numerous sites such as Livadia, Giannaki Vrisi, Avli, Valtouda, Lofos Sina, Antiphilippoi, Moni Analipseos and Proti. The estimated volume of slag from all the above sites is in the order of 35.000-40.000 m^2 and in most cases high As levels and speiss fragments have been reported (Papastamataki 1985). A comparison of the chemical data from Palaea Kavala and Pangaeon speiss showed the same composition suggesting similar methods for precious metals extraction (Photos 1987).

In most cases described above the organisation of working space is dictated by a gravitational axis according to which furnaces are built on top of hills and slag is discarded on the slopes. The process was in constant movement due to rapid formation of large volumes of unwanted material that constrained operations. Once the accumulated debris reached the heights of the hilltops the furnaces moved upwards and newly formed slag covered the older deposits. Although through such practice stratigraphy might appear to have formed in a straightforward manner disturbance complicates the picture. Levelling of slag heaps or dumping of material in more than one heap was common and succession of layers through time was often interrupted. In worksites like these described above artefacts of daily use are restricted and they rarely become entrapped in the deposits, hence the almost complete absence of pottery. Scatters of sherds however could indicate specific dates for restricted areas of the contexts where they belong. Untangling the history of production merely through pottery spanning almost 14 centuries is a very hard task but careful sampling from stratified deposits would appear rewarding for future studies.

Laboratory work

Microstructural characteristics of the 40 samples examined show a pattern of a predominant vesicular matrix with occasional wüstite, rare fayalite and some metallic phases present (figure 2). The latter represent isolated or clusters of Fe prills and speiss in some instances. Glassy phases were noted in a limited number of samples. Leucite which is a feldspar rich in potassium has been found in one of the samples from Katafyto. The presence of that mineral may indicate a high furnace wherein K condensates as there is space to rise up, circulate and end up in the slag. Occasional spinels rich in Ti were noted in samples from the same site.

The major mineralogical phases present in E. Macedonian slag are wüstite (FeO), spinel (Fe_2TiO_4) and a glassy crystalline matrix which is made up of kirschstenitic ($Ca.FeO.SiO_2$) composition and a K-Al-Fe silicate known as mellilite (Photos 1987; Vavelidis et al 1996). Previous chemical analyses conducted on slag from Thasos and sites in northern Serres and Drama namely A. Vrontou and Katafyto showed appreciable Ti contents ranging between 4.96 and 17.80% in Thasos specimens and 2.15-3.70% in Katafyto slag (Photos 1987, 161). The importance of Ti in the slag analysed lies on the fact that it acts as a potential tracer element for ore provenancing. Experimental data on reducing iron sands from known locations to give rise to ulvospinel phases with similar composition to archaeological slag have enhanced the possibility of provenancing the ores that were exploited in the past.

A second group of slags based on mineralogical composition concentrates at sites of the Lekani range in the Palaea Kavala region namely at Pyrgiskos, Dipotamos, Tria Karagatsia, Petropigi and Makrychori. Their main characteristic is the presence of Mn which is distributed among the wüstite phase. Other major phases include a Ca-rich olivine (kirschstenite) and a matrix which consists of either an Al-K silicate of mellilitic composition or a eutectic of mellilite and kirschstenite (Photos 1987, 192). Speiss fragments were also recovered from sites mentioned above deriving from the smelting of complex ores and also within the slag in the form of prills. Speiss acts as a precious metals collector due to its high contents of As and/or Sb which are close to Au and Ag in valance and are usually closely associated within a smelt.

Atomic absorption spectroscopy (AAS) analyses at IGME revealed high levels of precious metals in speiss and slag from Palaea Kavala (Photos 1987). Slag and speiss fragments from Petropigi and other sites fall within homogeneous typological groups suggesting a uniform picture of the processes practiced at most sites in Palaea Kavala. It is therefore highly likely that the Mn-rich ores of Palaea Kavala have been the ore source of the speiss but could not have been used for bloomery practices, due to embrittlement caused by the presence of Mn. The ore introduced in a blast furnace would have produced combined As-Fe entering the speiss and slag while the precious metal contents would have been easily extracted.

Based on the above Photos (1987, 204) concluded that the Palaea Kavala iron ores, rich in precious metals were not utilised primarily for iron but for their Au-Ag contents. What followed in the process was the addition of lead to collect silver since smelters could not have known the properties of speiss. After Pb was tapped, slag and speiss were discarded or re-melted the final stage of cupellation of the metal would produce litharge and metallic Au-Ag.

Conclusion

The investigation of material residues from metallurgical activities such as the smelting of iron and extraction of gold made possible a glimpse of Byzantine technology in Eastern Macedonia. The small-scale mining practiced during late Byzantine times was closely associated with an agriculturally based economy. Landowning farmers and monastic institutions were often the only candidates with the resources available to exploit mineral deposits. Alternatively rich estate holders were able to lease contracts to operate mining shafts in imperially owned mining districts. In such political conditions a conservative strategy with no margins for experimentation would appear ideal for optimising production to benefit the estate holders. At times when taxation intensified and herding would not supply sufficient income, metal production increased but the reward to those engaged in the activity was redefined. And yet despite the unfavourable political conditions, metal production continued to supplement the economic fabric of the region for some four hundred years to come.

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