EXTRACTIVE IRON METALLURGY ON THASOS AND THE EAST MACEDONIAN MAINLAND

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The island of Thasos and its colonies on the coast of the East Macedonian mainland (Fig. 12) were renowned in antiquity for their sources and exploitation of precious metals and the minting of silver coinage. Recent investigations have established the location of some of these mines (Wagner *et al*, 1980 and 1981).

Little is known about the equally important iron ore deposits which seem to have been worked on Thasos from the 9th century BC onwards. In this study a unified approach has been taken in the investigation of raw materials and waste products of iron smelting operations as well as analysis of iron artefacts from Thasos and the East Macedonian mainland. The methods of examination involved elemental analysis by X-ray fluorescence and atomic absorption spectrometry of ores and slags, and chemical analysis of mineralogical phases in slags by electron probe microanalysis (EPMA). The purpose of this study is to establish the type of iron ore sources used at particular periods, as well as to shed light into aspects of extractive iron metallurgy, namely furnace conditions. In the absence of any evident furnace remains, slags are the only "artefacts" to provide information on the latter. On the other hand, in order to establish the preferential use of one ore type versus others, the slag inclusions commonly found in archaeological iron artefacts are examined with the electron microscope and the results correlated with those obtained from the investigation of slag remains.

Extractive metallurgy refers to the reduction processes involved in the extraction of iron from its ore (primarily oxides and carbonates). In the bloomery process this reduction takes place in a bowl-shaped or shaft furnace by the liquefaction around 1200°C of the earthy (gangue) constituents of the ore. The iron does not become molten due to the relatively low temperature in the furnace (melting point of iron *c.* 1550°C). The product of the reduction is the bloom, a spongy metallic iron mass enveloped in slag and composed of varying carbon contents ranging from wrought iron (less than

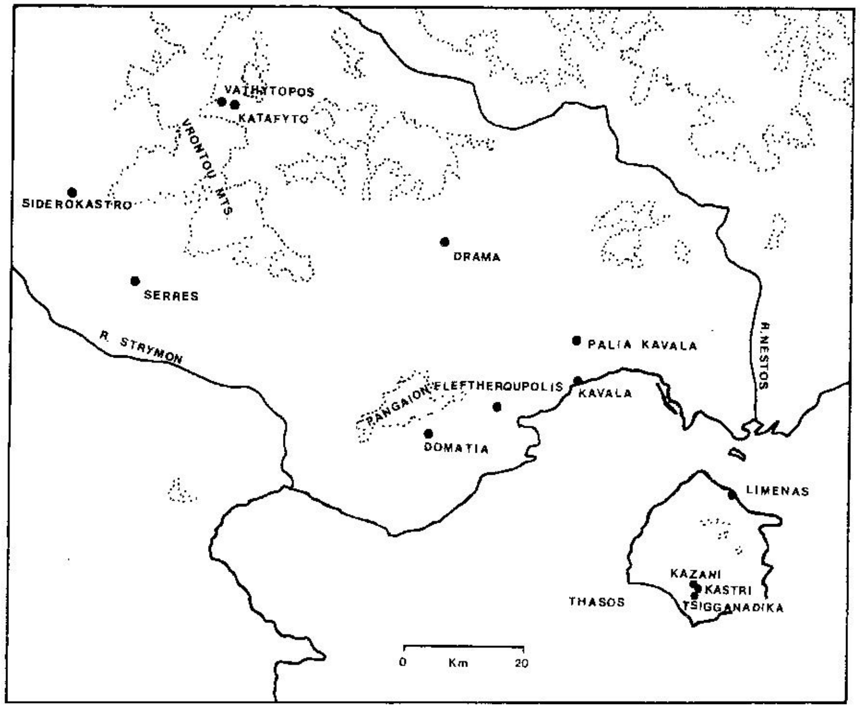

FIG. 12. Map of eastern Macedonia and Thasos. Dotted line indicates contour at 1000 m.

0.05% C) to steel (approx. 0.5% C). The bloom will subsequently be forged to remove residual slag and then hammered into shape.

The iron ores on Thasos are plentiful. At present the indications are that two types were exploited in antiquity and later times. They are the common limonite and hematite ores and on the other hand, the magnetite-rich beach sands containing *c.* 7% TiO_2, evident on the southern shores. The presence of substantial amounts of Ti (9–18% TiO_2) in slags also from the southern part of the island can lead to the obvious assumption that they were the waste product of the smelting of this Ti-rich magnetite sand. Thus, titanium has most fortunately played the role as a marker of ore type. Combining the results of analyses of Ti-rich slags and the slag inclusions in archaeological artefacts, the metallurgical developments involving the transition from one ore type to the other can provisionally be assessed.

The earliest iron-ore extraction dating from the Early Iron Age (EIA) to the 7th century BC involved limonite/hematite ores, judging from the analysis of slags from a EIA grave at the Larnaki cemetery and from a 7th century BC context at Artemission in

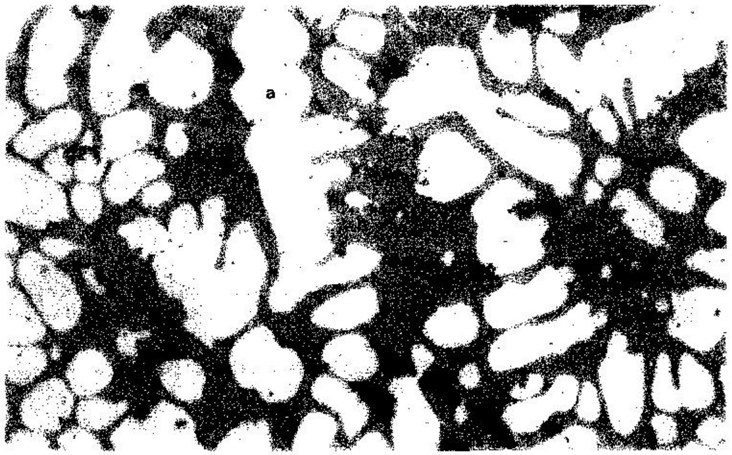

FIG. 13. Typical bloomery slag with (a) dendrites of wustite (FeO), (b) needles of fayalite (Fe_2SiO_4), and (c) silicate matrix. Polished section, x136.

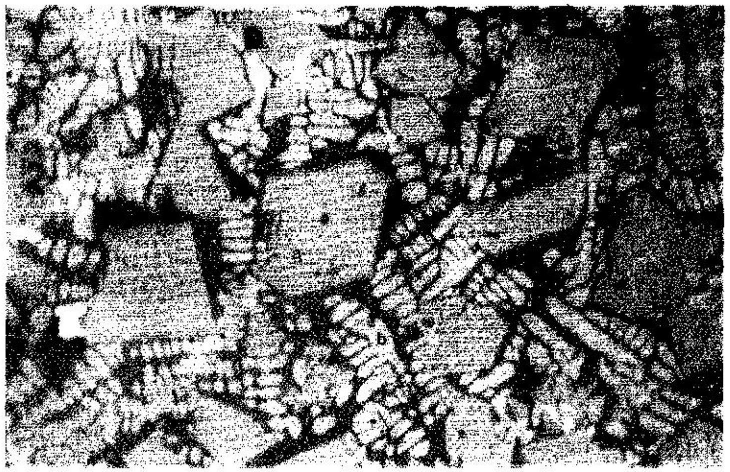

FIG. 14. Titanium-rich bloomery slag from Thasos with (a) plates of ulvospinel (Fe_2TiO_4), (b) dendrites of wustite (FeO) and (c) silicate matrix rich in calcium. Polished section, x275.

Limenas. These were bloomery slags with no more than trace levels of Ti consisting of three phases (Fig. 13): wustite, fayalite and a glassy silicate matrix. The Limenas slag has the typical mineralogical slag composition produced from this type of ore and is in fact similar to the other early iron slag found at Vardaroftsa in western Macedonia (Davies 1939. 254–5).

On the other hand, the Ti-rich slags are mineralogically different (Fig. 14). They include ulvospinel as well as wustite but also a matrix rich in calcium. It is not yet established whether this calcium was added intentionally or was part of the charcoal and/or furnace lining composition. However, the estimated free running temperature of these slags is well within the temperature range achieved in a bloomery furnace. This implies that a different furnace construction would not have been necessary for the smelting of the sands, although the fuel to ore ratio may have varied.

During which period did the magnetite sands come into use? Presently all that can be said is that this source of iron probably post-dates the hematite/limonite ores, and there are strong indications that they were used as early as the Roman and even Hellenistic times. Preliminary TL data ascertain that the sands were smelted in the late Byzantine period.

Moving over to the mainland, magnetite sands with Ti (*c.* 5% TiO_2) are also present in the Vrontou region. These are to be found in stream beds and crevasses where they have naturally concentrated. These sands are the weathering product of granite rather than gneiss, as in Thasos, and contain radioactive compounds like uranium and thorium. Iron slags found at sites like Katafyto and Vathytopos near the Bulgarian border were similar in composition to those of Thasos with the added presence of vanadium and chromium. There is the possibility of using these two elements as markers for the differentiation of objects coming from the mainland. The three elements were indeed found in the slag inclusions of a nail from Katafyto known to have been manufactured in the same village at the turn of the century.

In reference to antiquity, analysis of archaeological artefacts from the 7th century BC cemetery in Drama and 6th century BC graves at Aidonochori suggested the use of the local hematite deposits as opposed to other sources. It is not clear at this stage of the investigation when the transition to magnetite sands took place on the mainland.

Very little information can be discerned from the analysis of slags concerning the metallurgical operations on both Thasos and the mainland. The location of slag heaps near a stream at Katafyto points to the possible use of water power to drive bellows and/or a forge hammer, but such arrangements would not have existed until more recent times. On the contrary, the Thasos sites are situated (with one exception) on remote hill tops close to good sources of fuel, if not water. Some of these centres are in the vicinity of prehistoric settlements such as Tsigganadika in Kastri and Kazani, Tragi and Kato Larnaki in the neighbourhood of Pyrgos. The physical conditions and exposed nature of the hill tops have not been favourable to the preservation of furnaces; a proton magnetometer survey at Kazani did, however, locate the fragmentary remains of a furnace bottom buried in 20 cm of soil above the limestone bedrock.

Turning to the literary sources, extractive iron metallurgy was certainly practised in E. Macedonia from late Byzantine times onwards, as is documented in a manuscript from Aghion Oros dated to 1347 AD (Photos *et al*, in press). The practice has continued within living memory until the beginning of this century. Elsewhere iron production is documented in the Eleftheroupolis district, where a blast furnace was built for the

manufacture of cannon balls which were subsequently shipped to the naval arsenal in Constantinople. In the same district, blast furnaces seem to have been in use from the 17th to early 19th century AD. Iron production is also recorded at Domatia in the Pangaion.

To conclude, the exploitation of magnetite sands is of particular interest in connection with the controversial Chalybian iron mentioned in Pseudo-Aristotle (*De Mirabilibus Ascultationes*), produced from river sands in the Pontos region of the Black Sea (Tylecote, 1981; Bryer, 1982). The practice must have been quite common in other parts of the northern Aegean from the 10th century AD onwards, as a Byzantine exiled official noted (Westerink, 1973) and as our own work on Thasos and the eastern Macedonian mainland suggests. On the basis of our results to date, the earliest magnetite sand iron production could have been in late antiquity, namely the Hellenistic times. Details concerning the difficulties encountered in the reduction of magnetite sands are currently under investigation in a set of experimental smeltings.

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