

Fig. 2. Cross section of the iron plate ($\times 13$) found in The Great Pyramid of Gizeh. It shows a number of laminates that have been inexpertly welded together. The grain sizes, carbon contents and non-metallic inclusions are different in each laminate.

cant that the examined specimen contains no siliceous, slaggy, inclusions, nor does it contain more than a small trace of copper. Thus, it is most unlikely that the iron was produced as a by-product of a copper smelting operation.

The outer layers of the iron have been badly corroded and now form banded iron oxides. Significant proportions of gold were found in one of the oxidised layers and the plate may, originally, have been gold-plated.

The new data, coupled with the original, archaeological information, strongly suggest that the iron plate is contemporary with the building of the pyramid and that it is, therefore, one of the oldest known pieces of iron.

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[The Great Pyramid of Gizeh was built by the pharaoh Cheops (Khufu) of the Fourth Dynasty, c. 2560 BC. A fuller report of this investigation is to appear in *The Journal of the Historical Metallurgy Society*, vol. 23, pt. 2 (1989). Editor.]

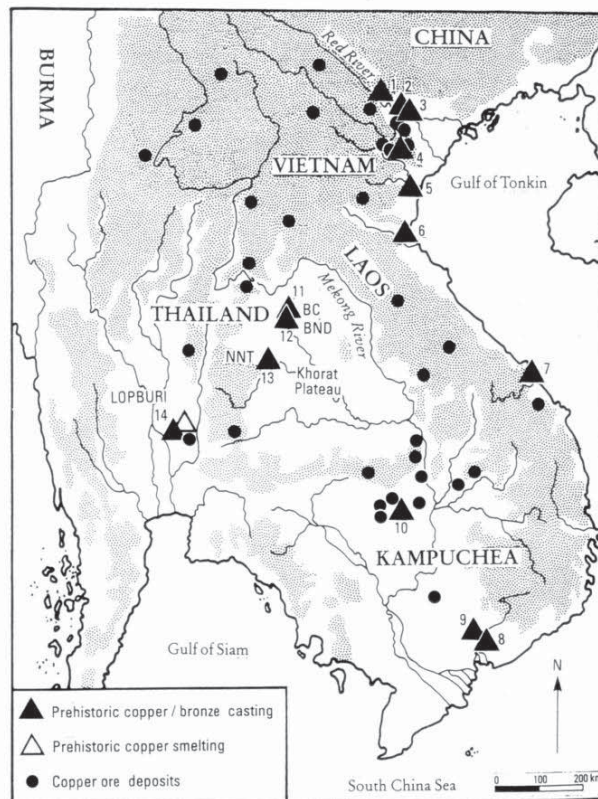
Crucible smelting in Prehistoric Thailand

In the neighbourhood of Khao Phu Kha mountain, an ancient copper mine near Lopburi town, in Central Thailand, there are extensive mounds of ancient slag at Non Mak La (NML), Non Pawai (NP), Nil Kam Haeng (NKH), Tha Khae (TK) and Khao Sam Yoi (KSY) (Fig. 1). These were visited in 1984 and 1985 in order to assemble samples of past metallurgical activities.

Although only a very small amount of copper metal was recovered from any of the smelting sites investigated, the large quantities of slag indicated that the area around Lopburi had been an important industrial complex and that smelting had been carried out on a large scale.

The metallurgists were using an efficient and standardised process, employing a crucible smelting technology rather than the more usual method of smelting in shaft and bowl furnaces. Large numbers of fragments of thick-walled, organically tempered crucibles were recovered at the smelting sites of Non Mak La and Non Pawai. Unfortunately, no complete crucibles were found and the fragments were all quite small, often only 10% of the rim remained. Because of the absence of complete profiles the proportions of the crucibles cannot be established with any degree of certainty, but the internal diameter seems usually to have been between 12 and 24cms. The thickness varied from about one centimetre at the rim, through 1–1.5cm. for the wall, to 4cm. at the base, and while the rim thicknesses could be accurately assessed, considerable thinning had occurred in some wall and base areas due to the internal

Fig. 1. Map of the prehistoric copper casting and smelting sites in the neighbourhood of Khao Phu Kha mountain.



dissolution during use. For example, one base fragment with an original thickness of at least 3.6cm. had been reduced in parts to 1.6cm.

The fact that the crucibles were used for smelting is demonstrated by the bulk chemical composition of the slag lining the inner surfaces of the fragments, which is similar to that of slag cakes found at the sites. Petrographic and electron microprobe analysis showed that the slag lining, unlike the cakes of slag, contained appreciable amounts of magnetite, resulting from oxidation of the thin layer of molten slag by air entering the crucible during the pouring process. None of the crucible fragments showed any evidence of holes which might have been used for inserting tuyères, or for tapping off slag. It seems likely, therefore, that these were externally heated, and the slag and metal removed by pouring at the end of the process. While there is no evidence of the intentional use of the roast reaction, the mineralogy is such that this would have occurred naturally to a certain extent, and would thus have contributed to the heat requirements of the charge.

No evidence of the heating process survives but, in the absence of any tuyères (the few fragments of tuyères which were found at Non Mak La were associated with iron smithing there), it is probable that the crucibles were supported on fires blown either by a channeled natural draft or by bellows feeding through a perishable organic material such as bamboo. However this was done, it seems inescapable that the ancient metallurgists of the Lopburi area were able to achieve temperatures of 1200°C in these crucibles using a technology not previously encountered elsewhere.

The pouring operation is similarly unclear. Many of the rim fragments show evidence of slag being poured out (Fig. 2), and slag lumps were found of approximately the same size and shape as the cup moulds found on these sites (Fig. 3). These moulds, unlike the crucibles, show no evidence of direct heating, and some have a projecting foot which would possibly allow them to be held in a stand or frame. Fragments of heavy clay rings were found, slightly larger in internal diameter than the crucibles themselves, and these could have been used to protect the crucibles from damage while being gripped with green bamboo for pouring.

Clearly an important further step in the investigations of copper smelting in this area would be to build such a crucible and operate it under simulations of conceivable field methods.

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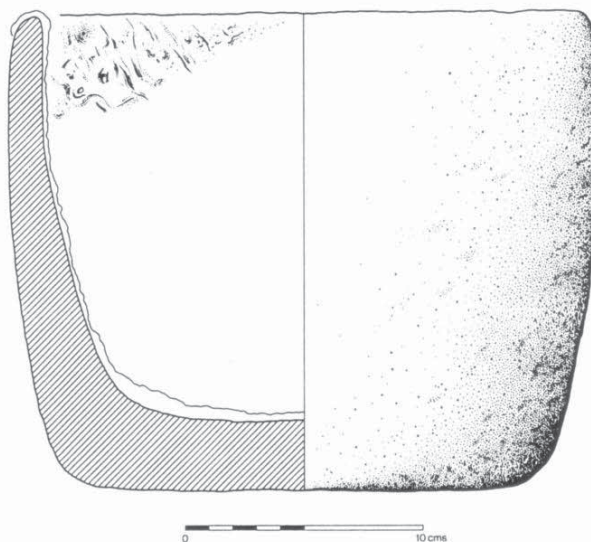


Fig. 2. Reconstruction drawing of a crucible used for smelting at Non Pawai. Many of the rim fragments showed evidence of slag having been poured out of the crucibles.

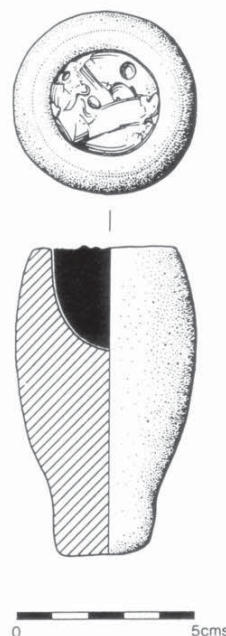


Fig. 3. Ingot mould found at Non Pawai together with a lump of slag the same size and shape as the mould.

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