



Fig. 4. Smelt process model.

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## Clay Moulds for Copper Ingots — a first discovery

For a long time metallurgists and archaeologists assumed that bun-shaped and similar copper ingots often found in ancient hoards and shipwrecks are the primary product of the copper smelting process, i.e. the plano-convex shaped ingot was assumed to be a 'replica' of the furnace bottom. The smelting process model was thus presented: after pre-heating the bowl-shaped smelting hearth, the ore mixture was charged into it and there reduced to metallic copper prills; these sank through the liquid gangue material, the 'slag', to form a plano-convex copper ingot on the concave furnace bottom. In advanced process models the slag was then tapped out of the furnace and the copper ingot, remaining at the bottom, could then be simply recovered.

Experimental and theoretical research into copper smelting carried out during the last few years by IAMS's metallurgical research group and its students established that this model was an over-simplification.

Most of the copper ingots were, in fact, secondary products, i.e. cast into shape after the conclusion of the primary smelting process in an additional operation and from raw copper, not necessarily from one and the same smelting operation. In other words: most of the common ingots and, of course, ingots of more elaborate shapes like the 'ox-hide' ingots of the Mediterranean, are the product of a casting operation not directly connected with the primary smelting of copper. However, the essential piece of missing evidence was a casting mould for ingots.

In the collection of our Arabah and Sinai research unit (The Institute of Mining and Metallurgy in the Biblical World, Tel Aviv) are a large number of furnace fragments, lining parts, clay tuyères and other refractories which were uncovered in the excavations of the Timna smelting camps in 1962–83. As part of the current preparations for the definitive publication of

these excavations, all these process-related finds were recently meticulously reinvestigated, measured and recorded by Craig Meredith (the member, since 1969, of IAMS's permanent field team in charge of finds), in order to establish the essential data on the dimensions and shapes of the different furnace types represented by these fragments.

Working patiently through masses of very dusty furnace fragments, Craig noticed and separated a small number of flat, grey-burned, saucer-shaped clay objects, very thick-walled and brittle, for which there was no immediate explanation. These were obviously heavily fired, showing heat stratification in the sections. The bottoms are flat and the top mildly concave, bordered by a vertical rim several centimetres high. All these fragments came from Layer 1 of Timna Site 30 which related to Egyptian 22nd Dynasty activities during the 10th century B.C. These latecomers to Rameside Timna (14–12th centuries B.C.) introduced a new and much advanced copper smelting technology, involving tempering the clay furnace lining and tuyères with tiny bits of crushed slag (Bachmann and Rothenberg, in *Antikes Kupfer im Timna-Tal*, ed. Conrad and Rothenberg, 1980, p. 220). Craig's enigmatic objects showed the same slag temper but otherwise they could

not be fitted into the furnace model of this period (see Rothenberg, *Copper Smelting Furnaces in the Arabah, Israel: the Archaeological Evidence*, in British Museum Occ. Papers No. 48, 1985, pp. 129–30, Figs. 12–13). There was simply no way in which these saucer-like objects could be parts of the wall or bottom of a furnace. Further close inspection established that these 'saucers', which were not slagged must have been used in a horizontal position and that the heat was mainly concentrated on their inside, observations confirmed subsequently by the British Museum Research Laboratory.

At the end of his task, Craig presented his detailed report, including a surprise chapter: Casting Moulds. Subsequent measurements and comparisons resulted in the final definition: Casting moulds for ingots, the first ever identified.

The identification of casting moulds for bun-shaped ingots provides essential additional archaeological evidence for the historic reality of our newly proposed copper smelting models.

The detailed results of this research programme are due to be published in *The Ancient Extractive Metallurgy of Copper*, Researches in the Arabah, Vol. 2, IAMS, London, 1988. Beno Rothenburg

## The Production and Trade in Copper in Medieval Times

Underwater and land-based sites have produced evidence of extensive Bronze Age trade in metals, and this continued into the Roman period with lead, tin and copper all finding their way across the Mediterranean in the general direction of Rome. Until we come to Venice in about A.D. 1000, it is difficult to find much evidence of trade in the 1st millennium A.D. but, by the Early Middle Ages, Venice had an extensive trade, obtaining her raw copper from Italy and Central Europe. The arsenal at Venice processed this and exported it to various sites in the Mediterranean and beyond. Later, this trade was taken over by the Portuguese who extended it into Africa.

In the elucidation of trade and production of copper, archaeology is our only tool up to medieval times, as detailed descriptions of technique are lacking and trading records confined to tablets which rarely give a clue as to place of origin.

In the medieval period we begin to get written records of how things were done, paintings of furnaces and equipment, and we can say that the prehistoric period of metallurgy comes to an end. We not only have technicians such as the twelfth-century monk, Theophilus, and others like Biringuccio and Cellini, but also writers and theorists like Agricola and Leonardo da Vinci. Their technical treatises are more than supplemented by trading archives which begin to give us details on prices and quantities, although it is not easy to get accurate data on the output of metal as these often pass through several hands.

### Venice

Venice was one of the earliest trading centres after the Roman period, and it is useful to take it as an example. It imported copper at first from the area south-east of Bolzano, and Tuscany and later from Central Europe generally and Turkey (Kastamonu). Some of this copper was refined and stamped in Venice and its environs, like Treviso. The rest was sent onwards as part of Venetian trade, mainly with the East.

This work was done in the *getti* the area near the arsenal on the east end of Venice (*gettando* = casting) and the term 'Ghetto' is said to have originated from the fact that in 1516 the sites of the old and new foundries, Ghetto Vecchio and Ghetto Nuovo, were assigned to the Jews.

Venice got its refined copper mainly from the Harz and Tuscany. Copper was refined in the arsenal in Venice and was stamped with the shield of St Mark (probably like those so often seen in Venice today). It was made in two grades: hard and soft. The former was used for bells and mortars; the latter for malleable applications such as wire and sheet and it was sold as buns, masses, etc. The ductile yellow copper came from Poland through Bruges and, up to the fourteenth century through Krakow (probably from Slovakia?). The copper office in Venice – the Getto – refused to refine the hard copper, presumably because it needed too much fuel.

Lots of copper came from the north Italian mines