



Fig. 3. El Cerro de San Cristobal. Site No. 4. Bronze monkey or dog (?). Sos Baynat collection National Roman Museum, Merida. Scale 1:1.

able to melt this unique mineral into a very small natural bronze prill. A Spanish geologist (Felix Garcia, Minas de Rio Tinto) informed me that small ore veins of mixed copper/tin minerals were quite common in the past at the western side of the Iberian Peninsula. The majority of these deposits would most probably have been worked out in antiquity.

**No 20. Torre Romana Centumcellas** produced a small amount (about 15 pieces of surface and excavated Roman tin slag dated 1st to 3rd centuries AD). Iron slag fragments were also collected and analysed. The excavated tin slag of Torre Romana Centumcellas is only the third example of ancient tin slag that has been found and recorded within an archaeological context.

The Torre Romana Centumcellas tin slag, analysed in the laboratory of the Institute of Archaeology (SEM/EDS) not only contained tin in amounts varying from 2.2% to 20%, but also contained varying percentages of the elements

Niobium (Nb), Titanium (Ti), and Tantalum (Ta). These three minerals appear almost always with or alongside cassiterite in the granites of the central Iberian Peninsula.

The settlement and mining area of **El Cerro de San Cristobal** was planned (features and contours, 1:500 scale) during the 1994-95 survey seasons. It is hoped in the near future to enlarge the Logrosan planning survey to include the worked out mines on the lower north side of the Cerro and to plot in greater detail the cassiterite veins, mining shafts and galleries within the Late Bronze Age settlement area of the west Cerro.

The **Extremadura** tin survey project will be an on-going project involving the Prehistoric Department of the University of Caceres and it is hoped in the near future it will be possible to make some small excavation trenches at El Cerro de San Cristobal and at Mina de Berrocal.

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## High-Tin Bronze Mirrors of Kerala, South India

High-tin bronze (copper with 20-30% tin) has been used in various ancient cultures to make mirrors. This alloy, also known as speculum, has a bright reflective surface when polished. In Ancient China, decorated mirrors were widely made from the Chou dynasty onwards for cosmetic, decorative and other uses. Typical Han Chinese mirrors were often cast from leaded high-tin bronze with about 25% tin and 5% lead (Meeks, 1993). There are examples of mirrors from the Roman world which were also leaded high-tin bronze. A variation during Roman times utilized low-tin bronze alloys, but with a tin coating on the reflective surface. Mirrors in antiquity represent a special class of metal object requiring specific metallic properties. In addition to technical studies of ancient mirrors, observations of traditional metallurgical crafts may also be used to increase our understanding of mirror production using high-tin bronze alloys.

A distinctive traditional process for making cast, high-tin bronze mirrors exists in several small villages in South India. The process received little attention from archaeologists, anthropologists or metallurgists, until the first publication of the process by Mukherjee (1978). There are, however, many aspects of this specialized traditional craft which

were not considered at that time. As this traditional craft may yet vanish, the opportunity was taken to observe and document the process recently in the Allepey district of Kerala. There still remain several small, specialised groups of metals craftsmen utilizing the distinctive material properties of high-tin bronze to produce mirrors as well as bells, musical instruments and wrought vessels. Such utilitarian objects of high-tin bronze also appear to have been commonly used in Ancient India, so study of the traditional craft adds an additional perspective for the archaeological mirrors.

The metals craftsmen at the village of Aranmula in the Allepey District of Kerala, about 15 km from Changanur on the banks of the Pambiyar river, were visited on several occasions in 1992-93. Most helpful was a Mr A. Gopalakrishnan (Fig. 1), one of the few artisans who still carries on this traditional craft, which he claims has been in danger of dying out altogether. Economically, it was the interest of foreign tourists at a nearby *ashram* (religious commune) which has helped revive the craft. Mr Gopalakrishnan makes polished high-tin bronze mirrors mounted in brass handles. The high-tin bronze mirrors,

unlike modern coated glass mirrors, have the property of point image due to absence of refraction and although planar in form, the very slight natural convexity of the mirrors' surfaces are sufficient to give a somewhat reduced image. Some of the details of the process seemed guarded "secrets", but visits to the workshops, along with technical studies, helped better to establish certain properties of the mirrors. Mr Gopalakrishnan said the mirror compositions were "... pure copper with a high percentage of tin." The exact composition of which he would not say, but he indicated it could be close to 50%. Other workers also mentioned a similar composition. Samples of the mirror alloy provided by the craftsmen for analysis were actually not over 35% tin. Further samples were collected on a subsequent trip to Kerala. Another traditional metals craftsman, Mr M.S. Janardhanan Achary, from the nearby village of Malakkara in the Pathanamthitta District of Kerala, sold off some of his stock-in-trade. From these samples of alloys, moulds, and intermediate blanks, along with visits to the workshops, it is possible to document the steps of the process.

To make the mould for casting, two oval, fine clay disc moulds about the size of the mirror were prepared and fired. The two disc moulds for each face of the mirror are spaced apart using three small cut pieces of the alloy. These alloy spacers would later melt into the cast metal and leave little trace in the finished mirror surface. The positioned discs are then covered with further layers of alluvial clay and bound with iron wire for strength. A plug of wax maintained a channel from the void between the discs to a cup-shaped cavity in the neck of the mould. These features are all evident in an X-radiograph made of an unfired mould with the wax still intact. Alloy fragments, sufficient to make the mirror, were then placed into the neck cavity and sealed with more clay to form a closed crucible attached to the mould. The whole assemblage was then put in a shallow pit filled with charcoal and kept vertical with the crucible downwards (Fig. 2). A small hand-cranked blower was used to achieve the required temperatures to melt the high-tin bronze alloy. The alloy would melt at about 750 C. When the crucible was observed to be red hot, the crucible-mould assemblage was turned over quickly so that the molten metal would flow through the neck cavity into the void between the two discs of the mould. After cooling, the mould was carefully broken to obtain the cast mirror blank. The use of the closed crucible-mould assemblage decreases oxidation and unnecessary loss of tin during casting. The ceramic discs could be carefully removed and reused.



Fig. 1. Mr Gopalakrishnan makes and sells high-tin bronze mirrors in the village of Aranmula in the Allepey District of Kerala. His foundry is one of the few remaining that make mirrors using traditional techniques.

The mirror blank was then mounted with wax onto a thick rectangular wooden polishing block with a rear handle. The blank was then carefully polished with even pressure against a hessian cloth placed on a wooden board, using coarse and fine polishing powders consisting of burnt mound material mixed with powdered mirror alloy and oil for lubrication. The polishing took several days. Final lapping was given with finely crushed red oxide (hematite) which is also used to clean the mirror face from time to time when it tarnishes. The oval mirror was removed from the polishing block by melting the wax. The polished mirror was fitted, using wax, into a handle frame made of brass. Mr Gopalakrishnan of Aranmula advised that to prevent tarnishing, the mirror should be given a polish occasionally using red oxide or vermilion, while grease was to be cleaned off by rubbing the surface with solidified coconut oil.

Metallographic sections of a finished mirror from Aranmula and an as-cast alloy fragment from Malakkara were examined using optical microscopy and the JEOL electron probe microanalysis (EPMA) in the Wolfson Archaeological Science Laboratory at the Institute of Archaeology, UCL. Structures of both show predominantly delta phase with the eutectoid matrix of alpha plus delta. EPMA confirmed the identification of delta phase with 32-34% tin, while the eutectoid had lower concentrations of tin. The microhardness ranged between 390-440 VPN. The high-tin alloy has a typical silver-white colour and it is hard, brittle and relatively corrosion resistant. When polished, it has optical effects which are responsible for the catoptric or mirror-like properties. It is noteworthy that craftsmen from both villages used approximately the same alloy compositions with 32-34% tin.

The contemporary mirror makers of Aranmula believe that their technique has indigenous local origins. Mr Gopalakrishnan said that his trade had a history of at least five hundred years passed down through generations, practised only by *acharis* (master craftsmen) who had the status of Brahmins. Reportedly, they had migrated from Sankarakoil in Thiruvallur, Tamil Nadu, to Kerala about 700 years ago. These *acharis* claimed Pandyan decent. Mr Gopalakrishnan said that the local technique for mirror casting had been divined by his ancestors through a vision of the Goddess.

There is a legend about the origin of the Aranmula mirrors which was told by Mr Janardhana Achary of Malakkara. In the 16th century, the Raja of Aranmula brought to the village some bronze craftsmen from Tamil Nadu in order to make ornaments and musical instruments for the temple. Growing fat and lazy on the products of the land granted to them, the



Figure 2. The mould and crucible are attached allowing the molten metal to be cast simply by inverting the assemblage. The mould may be seen above the crucible which is covered by burning charcoal in the front centre of the photograph.

# From the Director's Desk

Raja threatened to withdraw their privileges and evict them from his territory. After prayers and discussion, a widow Smt Parvaty Ammal had a dream in which Lord Parthasarathy revealed to her the secret of combining copper and tin in the right proportions to make a shining metal with a reflective crystal surface. They made a crown of this material for the Raja who relented and encouraged them to use the metal for Valkannadi (mirrors), one of eight articles in the Ashtamangalya sets. Traditionally this type of mirror was used only by royalty and brahmins because of its ritual associations and also in tantric worship in shrines such as Sabarimalai.

Metal mirrors were also one of the *asthamangalayam* or eight auspicious items which were important for the prosperity of each household. Mirrors were also one of the *asthamangalayam* which formed the wedding trousseau of Nambruthri and Nair brides of Kerala. Mirrors as an item in the *asthamangalayam* as described by the achari are depicted as early as the Kushan period in a Jain votive tablet of the 1st-2nd centuries AD (Czuma, 1985).

Different types of mirrors are also commonly depicted in Indian sculpture as being held by deities, celestial maidens and dancers from the early historic periods into the medieval period in North and South India. Stone sculptural panels and friezes depicting such mirrors include the Sunga Yakshi from Barhut (3rd century BC), the Kushan Yakshi or Tree Goddess from Sanghol (1st century AD) and several from the medieval period such as a Hoysala dancer and a deity from Konarak and two *apsaras* (celestial maidens) from Khajuraho (Keay, 1981). A few archaeological finds of mirrors are reported from widely separated contexts such as the tanged planar mirrors from the Indus valley civilisation (c. 3000 BC), others from the Nilgiri megaliths (mid to late 1st millennium BC) in southern India, and from Satavahana hoards (1st century BC – 2nd century AD). However, scarcely any analytical work is reported, except for two mirrors from the Gandharan grave culture of the 1st millennium BC found at the important archaeological site of Taxila. The reported compositions of the two mirrors are 22% and 24.8% tin (Marshall, 1951).

One suspects that the use of high-tin bronze has a long history in the Indian subcontinent, particularly in Southern India, to make wrought and quenched bowls, gongs, cymbals, coinage, mirrors and other items. The accounts by traditional craftsmen agree that mirror making from Aranmula has certainly some local antiquity. The numerous iconographic representations of mirrors in Indian art represent use and associations of distinctive metallic products. When viewed from a metallurgical perspective, however, the investigation of high-tin bronze mirrors reveals fascinating insights into technical accomplishments and fine craftsmanship.

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The Director and the Trustees of IAMS welcome our new Trustee, Professor Peter Ucko, the recently-appointed Director of the Institute of Archaeology, University College London.

In the light of the changes to the *IAMS Newsletter*, which in the past concentrated on work done within our research group, members of the Scientific Committee of *IAMS* proposed to widen the orbit of *IAMS* to become a refereed journal of archaeometallurgy starting with the next issue, No. 21. *IAMS* will publish compact reports on ongoing research and we are inviting our colleagues to contribute papers. Peter Clayton and John Merkel will continue to be the editors of *IAMS*, assisted by members of the Scientific Committee.

Subscriptions will be invited for Volume 3 (parts 1 and 2) of *Researches in the Arabah: The Ancient Copper Mining and Smelting in the Western Arabah*, edited by Beno Rothenberg and C. Tim Shaw, which is now going to press. These volumes will contain the final reports of all excavations carried out by *IAMS* between the years 1964 to 1990 on the mine and smelting sites, dating from the Late Neolithic period to medieval times, of the south-western Arabah. These reports also contain numerous specialist reports on all the finds, plus hundreds of photographs, drawings and maps. Subscriptions received for Vol. 3 (parts 1 and 2) before the date of publication will entitle the purchaser to a 50% price reduction, and for a similar reduction for Vol. 1 (*The Timna Mining Temple*, 1988) and/or Vol. 2 (*The Ancient Metallurgy of Copper*, 1990).

During the past few years, *IAMS* has been involved in co-operative projects with the Supreme Council of Antiquities (SCA) and Cairo University in Egypt. Along with the SCA, in April 1995 *IAMS* co-sponsored the first International Conference on Ancient Egyptian Mining and Metallurgy and Conservation of Metallic Artefacts. In the following summer, *IAMS* presented a summer course in archaeometallurgy at the El Tabbin Institute of Metallurgical Studies (TIMS). In the summer of 1996, along with conservation staff from the SCA and Cairo University, the Institute of Archaeology at UCL presented a summer programme on archaeological conservation at the Tabbin Institute. Dr Merkel lectured on the conservation of metallic artefacts. The second conference on Ancient Mining and Metallurgy and Conservation took place on 14-16 April 1998. *IAMS* was again a co-sponsor for the conference. The Institute of Archaeology UCL and the Royal School of Mines, Imperial College, were also sponsors from the UK.