

Metallurgy of Zinc, High-tin Bronze and Gold in Indian Antiquity: Methodological Aspects

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(Received 18 August 2015; revised 19 December 2015)

Abstract

There are inherent challenges in attempting to explore the trajectory of knowledge production *vis-a-vis* the use of metals in antiquity. Metallurgical innovations, falling as they would have largely done in the domain of empirical knowledge and expertise, would not necessarily have left a systematic written record in the sense of knowledge production. This enquiry is perhaps even more convoluted in the Indian context where in the first place, there are not many detailed records that have readily come to light concerning mining and metallurgy and in the second place, not much systematic archaeometallurgical research has been undertaken. Nevertheless, this paper attempts to demonstrate the role of archaeometallurgical studies, coupled with ethnoarchaeological studies on continuing artisanal technologies, in such enquiries. The paper also seeks to explore the interplay between functional and cultural imperatives through which one may explain the preferential emergence of certain technologies with respect to debates on knowledge production. It restricts itself to selected case studies providing insights into the archaeometallurgy of high-tin bronzes especially from Iron Age Tamil Nadu, zinc smelting evidence at Zawar, Rajasthan, gold working with respect the Nilgiris, and the high-tin bronze mirror craft of Aranmula, Kerala.

Key words: Archaeometallurgy, Ethnoarchaeology, High-tin bronze, Iron Age, Megaliths

1. INSIGHTS FROM PROTOHISTORY: SKILLS IN MINIATURE AND STANDARDISATION

The earliest metallurgists of pre-history were probably the first experimentalists to whom the early foundations of science and technology may be traced. As pointed out by Trivedi (1998, p.29), 'the discovery of smelting was a very significant step forward in our manipulation of nature since it enabled the extraction of vast amounts of metal which could subsequently be shaped into weapons and agricultural tools'.

No doubt, such early discoveries, which were often accidental, were primarily driven by functional imperatives such as the need for tools and weapons. Nevertheless, there have also been arguments supporting the notion that aesthetic

factors may have also played a role in the early experimentation and discovery of metals and materials. For example, it is thought that the smelting of copper would have been discovered when it was found that brightly coloured copper ores such as green malachite and blue azurite could be reduced to copper (Gale et al 1990), which were used widely in pigments for example in ancient Egypt.

The use of gold and copper is reported from Neolithic times in the Merhgarh area of Baluchistan in Pakistan (c. 6000 BC). Fine gold artefacts such as diadems and a belt with intricate repoussé fish motifs and necklaces of micro-beads were uncovered from Mohenjodaro (National Museum, New Delhi). Harappan silver artefacts

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are reported from Kunal, in north-western India (Agrawal 2000, p.6). The copper-bronze repertoire (with the exception of a few figurines such as of dancing girls and bulls, and ornaments like copper beads and spacers) is rather starkly utilitarian. These include from pots, pans, razors, cobbler's tools, hairpins, sickles, blades, arrow-heads, axes, fish-hooks, chisels, spearheads, arrow-heads, straight and circular saws, mid-ribbed daggers and eye needles. Agarwal (2000, p.71) pointed to the Harappan primacy in developing certain types of instrumentation such as the needles with eyes on the pointed end, true saws, circular saws and drills. Above all, an outstanding feature that stands out in the Indus repertoire is the skill in working in miniature in a highly standardized way in a manner that has something approaching a contemporary industrial touch.

Apart from the gold micro-beads mentioned before, at Dholavira the spectacular limestone Harappan site in Kutch, miniscule gold beads were noted by the author. Some were tiny cylinders of diameters of no more than 1mm and others with octagonal facets no more than a centimetre long. All of this, taken together with the abundant evidence for lapidary working and beads exported to far of Oman and Mesopotamia, suggest that the Harappan sites functioned along the lines of thriving semi-industrial crafts outposts or hubs serving wider trading networks. One can certainly attribute something approaching a sense of 'method' in a scientific sense to the Indus artisans in their ability to so skilfully replicate and miniaturise. It is important to note that there are much smaller steatite micro beads, suggesting the efficiency of the Indus artisans and also their technological knowhow of a wide variety of raw materials. The Mohenjodaro dancing girl, all of 10 centimetres is a masterpiece in miniature with the armful of bangles uncannily recalling to contemporary Kutchi Rabari tribal women who wear shell bangles right along their arms.

2. HIGH-TIN BETA BRONZES OF THE SOUTH INDIAN IRON AGE

The aim of this section is to point out that the tradition of making unleaded bronze vessels of a high tin content by a specialized process of hot forging and quenched was established fairly early on in the Iron Age of South India. This process demonstrates a knowledge acquired over time the deliberate or intentional use of specific alloys based on the functional properties. Generally as-cast binary copper-tin alloys with over 15% are not widely reported in antiquity as bronze gets embrittled at higher tin contents due to the increasing presence of the intermetallic delta phase compound making it unwieldy at higher tin compositions. Even so, the unusual and skilled exploitation of a bronze alloy of a higher tin content is reported from some Iron Age sites, especially the megalithic sites, in peninsular India.

Metallurgical investigations by the author on very thin vessels from South Indian burials and cairns of Nilgiris (Fig.1) (*c.* 1000-500 BC) (Srinivasan 1994; Srinivasan and Glover 1995; Srinivasan, 2010) indicated that these were wrought and quenched binary high-tin beta bronzes, i.e. unleaded copper-tin alloys with 23-25% tin. These were fabricated by extensively hammering out such an alloy between 586-798⁰

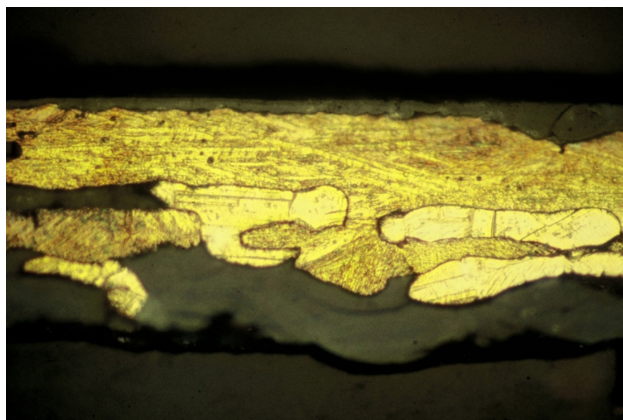


Fig. 1. Micro-structure of vessel from Nilgiri Cairns, Government Museum, Chennai, hot forged/wrought and quenched high-tin bronze structure of 23.9 % tin bronze

C when a plastic beta intermetallic compound (Cu_5Sn) of equilibrium composition of 22.9% tin forms. This was followed by quenching which resulted in the predominant retention of needle-like beta phase (as seen in the microstructure of a vessel from Nilgirs in Fig.1) which prevents the formation of brittle delta phase and takes a golden polish. In contrast low-tin bronzes have limited workability.

Interestingly, Strabo's 'Geography', referring to the north-western Indian region encompassing Taxila, mentions that there the vessels used broke like pottery when dropped on the ground, suggesting they were made of high-tin bronze (Rajpitak and Seeley, 1979). Indeed, a quenched high-tin bronze vessel with 21% tin from the Gandharan Grave Culture, circa 1000 BC was analysed by the author (Srinivasan and Glover, 1995). From the Bhir mound at Taxila, eight bronze vessels and mirrors with more than 20% tin, datable broadly from the fourth century BC to the first century AD were reported (Marshall, 1951, p.567). A century before a few vessels from the Nilgiri cairns of southern India with around 20-30 % tin-bronze were reported (Breeks, 1873, p.63). Due to the relative scarcity of tin in India, it was believed that these artefacts were imported ones (Leshnik, 1974, p. 156). The author made one of the first clear identifications of a continuing Indian tradition of high-tin beta bronze vessel making by the traditional hereditary community of Kammalar (or bronzesmiths) from the village of Payangadi in Kerala (first reported in 1991: Srinivasan, 1998). This activity has now sadly ceased to take place at this particular village, and while the craft still survives in other villages in Kerala vessels in Paridur (Fig. 2).

Not only were the metallurgical structures of the hot forged and quenched high-tin beta bronze bowls similar to the megalithic ones, but the decorative styles were found to be similar (Srinivasan, 1994, Srinivasan and Glover 1995; Srinivasan, 2010). At Payangadi, concentric rings



Fig. 2. Vessels of wrought and quenched high-tin beta bronze (22-24% tin bronze) being made at Paridur, Kerala

were made by cold working using handmade lathes strikingly recalling to the megalithic vessels (Fig. 3). The artisans indicated that they were aware of the special properties of this alloy, as the vessels were described as *talavettu* or musical vessels. They mentioned that these vessels were used to store eatables such as curds as this alloy did not tarnish easily, but added that they should be handled with care.

The megaliths of peninsular and southern India, associated with the Iron Age, with a few burial-cum-habitation sites, have yielded some copper, bronze and gold artefacts. An extensive urn burial site at Adichchanallur in Tuticorin

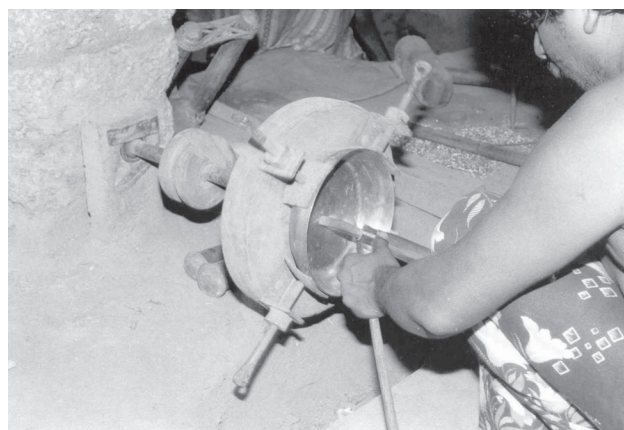


Fig. 3. Concentric circles on wrought and quenched high-tin bronze bowl being made by hand-turned lathe at Payangadi in Kerala (1991)



Fig. 4. Strainer fragments of high-tin bronze from Iron Age burials of Adichanallur, Tamil Nadu early to mid 1st millennium BCE, Government Museum, Chennai (Photo courtesy: Swaminathan Natarajan)

District (formerly Tirunelveli), which was excavated long ago contained some such objects. Alexander Rea had excavated several of the urns during 1910s and unearthed gold diadems, iron objects, bronze vessels, some with lids with fine finials depicting vegetal and animal motifs and thousands of potsherds of the characteristic black and red ware (A. Rea, 1915). The southern Indian Iron Age had been attributed to about 1000 BC (Allchin and Allchin, 1982).

A peculiarity of the south Indian megalithic high-tin bronzes studied and observed by the author, eg from Nilgiris, Adichanallur and Kodumanal in Tamil Nadu is that they seem to have been very heavily hot forged before quenching. There are also interesting stylistic parallels with recent examples studied in the workshop of Kammalar in Payangadi in Kerala as seen in the shapes and concentric rings at the centre. Some of the bronze vessels from Adichanallur and the Nilgiris have very fine rim thinness down to 0.2 mm representing the most finely wrought examples. This is also confirmed by the metallurgical structure of the vessel from Adichanallur and the elongated needles of beta phase of a composition approaching pure beta phase at 23% tin (measured by ICP-OES analysis). The lower tin alpha solid solution phase is present in much lesser amount. It is further indicated by

the annealed islands of alpha phase with annealing twins with the total absence of any remnant dendritic structure. The hardness of the martensitic beta phase needles was found to be 350 VPN and one may infer from the structure that it was hot worked, annealed and quenched in the alpha plus beta temperature range of around 680^o C close to the pure beta phase boundary for this composition. It is the property of high workability at higher temperatures of the beta phase which appears to have been very well exploited by the metalworkers of the Adichanallur high-tin beta bronze vessels.

Another most interesting aspect of some of the vessels associated with the South Indian Iron Age is prevalence of very fine perforations in some of these very finely wrought vessels which have led to descriptions of 'strainers'. This is seen for example in a 'strainer' vessel from Adichanallur (Fig.4) which was studied metallurgically by the author and also found to be of two-phase wrought and quenched high-tin bronze of 24% tin. From the megalithic site of Kodumanal as well, vessels with perforations have been found. Such 'strainers' do not seem to have been reported from Taxila or Southeast Asia. It is thus possible to see the Adichanallur and Nilgiri high-tin bronze vessels of the Iron Age as representing a somewhat distinctive local tradition when compared to examples from elsewhere.

High-tin bronze structures in some vessels from the Nilgiri cairns, now in the British Museum as the Brecks collections, have been reported (Craddock et al, 2007).

It is worth noting that there seems to have been a longstanding familiarity with the use of unleaded bronze in the Indian subcontinent going back to the Indus Valley. The compilation of some 140 analyses of objects from Indus Valley contexts reveals the interesting trend that some 30 objects from Mohenjodaro have tin contents over 5% but contain no lead (Chakrabarti and Lahiri, 1996, pp. 45-8). An exceptional sample of unleaded bronze of 22% is also reported from the Indus Valley site of Mohenjodaro (c. 2500 BC) although without micro-structural study it cannot be inferred if this was just an accidental as-cast bronze of this composition or an intentionally alloyed and quenched high-tin beta bronze (Mackay, 1938, p.480, Srinivasan 1997a). However, what may be inferred from the above is an early engagement with the use of unleaded bronzes.

Another interesting conundrum is the question of the source of tin. It seems logical to speculate that, since tin is relatively scarce in most of India, it could have been imported from tin-rich areas such as Southeast Asia. It is true that the possibility of some exploitation of minor local resources cannot be ruled out altogether. For one, a few analyses of high-tin beta bronzes from southern Indian megaliths showed patterns of trace elements sufficiently different from those of Ban Don Ta Phet in Thailand, suggesting diverse sources of metal for the Indian examples (Srinivasan and Glover 1995). The author's investigations threw up more preliminary evidence for local sources of tin than previously suspected. Investigations by the author on slags from the ancient mining region of Kalyadi within the Hassan district of Karnataka indicate that these are bronze smelting slags with up to 7% tin from co-smelting copper and tin ores due to the presence of metallic iron, rather than casting slags from

alloying copper and tin, which could suggest the exploitation of indigenous sources of tin (Srinivasan, 1997b). Actually tin is considered to be one of the items sent out of the Karnataka coast in Solomon's times along with peacocks and naves (Maloney, 1975, p.36). Thus there is room for speculation about the early sources of tin for the south Indian Iron Age/early historic high-tin bronzes.

3. HIGH-TIN BRONZE WATER-CLOCK AS AN EXAMPLE OF INSTRUMENTATION

While there is a relative scarcity of actual physical evidence of scientific instruments related to empirical observation from within the Indian context, there are a few examples. The author found some intriguing evidence for the use of high-tin bronze in a skilfully made wafer-thin water clock from Kerala which fits the description of a *ghaṭi yantra*. The *ghaṭi yantra* is a sinking water clock with a hole at its bottom. As it floats, water flows into the bowl and it sinks after a certain time interval. It is possible that its use related to rituals of the Namboodri Brāhmins of Kerala, who in late medieval period made significant contributions to mathematics. It has been pointed out that Brāhmanical rituals required stop watches to regulate their course (Sarma, 1997: p. 978). He gives a description of the type of *ghaṭi* or sinking water clock frequently used in India at least from the early 11th century until the arrival of mechanical clocks from Europe. Here, a hemispherical copper vessel (*kapāla*), six digits high and with a capacity of about 3.1.3 litres (60 *palas*) with a hole at the bottom to admit a gold pin four digits long and weighing approximately 0.183 gms (3.33 *maśa*), was placed on water (Sarma *ibid.*). The vessel sank in one *ghaṭi* or *ghaṭikā* sixty times a day. There were water clocks and sand clocks used in Kerala, primarily to measure time for medication, particularly *dhara*. One of the popular instruments used by the Ayurvedic physicians is known as *nazhikavatta*. One *nazhika* is equivalent to 24 minutes and two

and a half *nazhikas* form one hour. The temple related rituals begin seven and a half *nazhika* before the sunrise.

4. GOLD AND MINING PRACTICES IN THE NILGIRIS AMONGST THE MARGINALISED

Gold mining seems to have had a long history in the region of Karnataka going back to third millennium BC (Allchin and Allchin, 1982, p.337). Preliminary field surveys made by the author in north Karnataka in the Hutti-Maski region in 1991 indicated extensive old workings of gold. Nearly every outcrop visited had old mining galleries with large mullacker fragments indicating ore crushing activity in antiquity. Timber from an old mine over 200 metres deep in Hutti was carbon dated to indicate that such deep hard rock mining was carried out by the mid 4th century BC (Radhakrishna and Curtis, 1991, pp.23-4). This ranks among the deepest of old gold mines known in antiquity. The Jalagarus of the Dambal region had carried out alluvial washing and panning for gold, after the rainy season when the heavier gold got washed downstream from the auriferous hills (Foote, 1874, p. 140).

Sparse placer tin had been reported along with alluvial gold in the Dambal region of Karnataka (Mukherjee and Dhaneshwar, 1978, pp.345-50; Foote, 1874, p. 140). Given the extensive evidence for ancient exploitation of gold in north Karnataka, one cannot totally rule out the possibility of the exploitation of some local tin ores (Srinivasan, 1997b). Coincidentally, the high-tin bronze vessels from South Indian burials such as Adichanallur and Nilgiris (1st millennium BC) also occur with intriguing finds of gold ornaments. Bronson (1992) states that: 'the traditional tin and gold mining seem to have many similarities. Owing to its density and chemical resistance, tin oxide ore could practicably be recovered from alluvial deposits by panning and ground-sluicing methods like those used for mining gold. Deposits with a tin content in the 0.1 percent range could

therefore be worked profitably. The multiplicity of these deposits within the tin-bearing areas, along with the simplicity of equipment needed to sluice out and smelt the ore, meant that productive units stayed numerous and small. As late as the 1880's the bulk of the tin in world commerce was produced by small firms using methods that were essentially preindustrial'. Interestingly, eastern India also has some tin deposits in the Hazaribagh region (Chakrabarti 1979, 1985-6), where Mallet observed the pre-industrial smelting of tin by local tribals in furnaces resembling shaft furnaces for iron smelting. Thus it is possible that tin mining in antiquity could have been undertaken on a small scale even on deposits which are considered sparse in modern terms.

The rich finds of gold jewellery from the Nilgiri cairns represent an unusual hoard which has been dated from the early or mid 1st millennium BC to AD by some commentators (Knox, 1985). Some general Etruscan/Hellenistic influences can be detected in the techniques such as gold granulation whereby surface tension was used to turn melted gold filings into spheres. This Hellenistic feature is also found in the jewellery from early historic Taxila. The sophistication of finds from the Nilgiri cairns has led to legitimate speculations that they were imports (Leshnik, 1974). However, there is enough that is distinctive or diverse in them to suggest 'local' styles (Knox, 1985). Knox points out that in the earrings pendants and other ornaments from the Nilgiri graves the local style becomes apparent, whereby these are 'well made objects, probably made of local gold, constructed with skill and imagination, neither of which qualities need have been beyond the reach of a people who were original and talented enough to produce the unique Nilgiri ceramic assemblage, the iron tools and, if our imagination can run to it even the bronze vessels'. The evidence for old workings in the region of the Nilgiris and ethnoarchaeological evidence for continuing practices of extraction of sparse local gold resources is significant.

From the perspective of both natural history and aesthetics, it is worth noting the strong sense of botanical observation reflected in the early jewellery from Tamil Nadu. An outstanding early example of this idiosyncratic 'three-dimensional' gold jewellery from Tamil Nadu is a ear-ring from Souttoukeny of the 2nd century BC which depicts a typical local spiked prickly fruit, now in the Musee Guimet in Paris (Postel, 1980, p. 130). Nature motifs from the Nilgiri gold finds include an intricate pendant with crescent moon motifs, a granulated flower motif and a peepul leaf motif. These do bring to mind the rich Sangam poems generally dated back to *c.* 1st century BC to 3rd century AD, which are evocative of local fruits and flowers such as *kurinji*.

The Nilgiri hills and Wynad bordering the present states of Tamil Nadu, Kerala and Karnataka comprise some sparse hard rock and alluvial gold deposits. In recent times they have been illegally mined/panned by local Kurumba tribes. In Gudalur they are engaged in hard rock mining for gold and panning from associated streams for alluvial gold. Large wooden pans are used to pan the alluvial sand and to concentrate fine specks of sand rich in gold. Then a blob of mercury is added to create an amalgam with the gold that gets turned into a small globule of gold by sublimating the mercury through heating. In this way they are able to retrieve trace quantities of the metal.

5. EARLY ZINC SMELTING

It is of great significance to history of science that the earliest firm evidence for the extraction of metallic zinc and use of high-zinc brass alloys in the pre-industrial period comes from India. Zinc is one of the most difficult of metals used in antiquity. In order to smelt the zinc ore and isolate the zinc metal, heating up to 1000°C is needed. It would form as a vapour in the furnace and get re-oxidised immediately. Hence finds of metallic zinc are not often reported from early

antiquity. Finds of early historic alcohol distillation vats of Hellenistic influence at Gandharan Taxila, point to one possible inspiration for the zinc smelting process. Notions of 'distillation' and 'sublimation' seem to have also had deep ritual and aesthetic pre-occupations going back to ancient times in India. The abundance of perforated jars from the Indus period has raised speculation about their use as incense burners involving the sublimation of materials. The distillation and extraction of materials for ritual purposes is also seen from descriptions of the soma drink associated with Vedic sacrifice. There is unique evidence for the extensive, semi-industrial extraction of metallic zinc at the Zawar area of Rajasthan by at least the 12th century AD (Craddock et. al. 1998).

Zinc was smelted by an ingenious method of downward distillation of the zinc vapour formed after the reduction of zinc ore. Specially designed retorts with condensers and furnaces were used, so that the zinc vapour could be drastically cooled down to about 500^o to get a melt that could solidify into zinc metal. The furnaces excavated at Zawar consisted two chambers, top and bottom, separated by a thick perforated brick plate. The top portion would be packed with charge and fired. The bottom separated as it was from the top by the perforated grill, would be much cooler and hence would be the part where the smelted zinc vapour would be condensed. The aubergine-shaped retorts were stuck vertically through the perforations such that the top parts were filled with charge. The stem forming the condenser led into the bottom cooler chamber so that the vapour could condense through the stem and drip down to be collected in vessels placed at the bottom (Craddock et. al. 1998). Extensive zinc mines with huge mining galleries were reported at Zawar, some of which have been carbon dated back to the turn of AD.

If the zinc content exceeded about 34% or 35% there are grounds to believe that the artefact was made by alloying metallic zinc to copper. The

earliest likely evidence for brass made by alloying zinc metal to copper comes from brass objects with about 34% zinc comes from the excavation of the Buddhist site of Taxila (ca 4th c. BC), now in Pakistan (Marshall, 1951). A metallic zinc ingot with a Brāhmi inscription from the collection of late Nigel Seeley was studied by the author using lead isotope ratio finger-printing and was found to fit a 5th c. AD attribution from the Andhra region (Srinivasan, 1998). The shape of the ingot/coin was also interesting akin to a solidified globular droplet with a flat bottom as it could have been collected at the bottom of the furnace by downward distillation. Brass images and votive artefacts of Hindu, Buddhist and Jaina affiliations are found from different parts of the Indian subcontinent.

The use of zinc metal had an exciting trajectory with the coming of Islamic influence in India following which the functional properties of the metal and its alloys seem to have been substantially exploited. A remarkable artistic innovation inspired by Persian inlaying traditions developed under the Sultanate rulers of the Bidar region of Karnakata was the use of metallic zinc to make the highly elegant *bidri* ware, a patinated high-zinc alloy with 2-10% copper inlaid in silver, used to make *hukka* bases, ewers and other artefacts. Lahore was a renowned centre for the making intricate brass astrolabes under instrument makers such as Shaikh Allah-Dad (1570-1660) (Smith, 1997, pp. 74-5). The ease of castability of high zinc brass could have ensured that precise and minute details required for astrolabe making could have been picked up.

6. CODIFIED KNOWLEDGE IN TEXTS

There some prescriptive texts in Sanskrit which are related to zinc and brass production. Nāgārjuna, the famous Buddhist scholar (c.200 AD), believed to have been born in a southern Indian Brahmin family and later accepted Buddhism, was a renowned alchemist to whom

Rasaratnākara, the Sanskrit text devoted to the extraction and purification of metals is attributed. *Rasaka* mentioned in this text can be construed as referring to zinc ore (V.J. Deshpande, p. 158). Nāgārjuna's comment – 'What wonder is that calamine...roasted thrice with copper converts the latter into gold?' – seems to refer to the manufacture of brass by the cementation process. A few other iatrochemical texts relating to *Rasāyanaśāstra* of the 11th-14th century AD period are reported to be containing procedural knowledge of zinc metallurgy. *Rasendracūḍāmaṇi* of Somadeva of the 12th or 13th period, mentions the *vraṇṭaka mūṣa*, a brinjal-shaped covered crucible of clay with a hollow tube should be used in the distillation of *kharpār* (zinc ore), which recalls to the kind of retorts found at Zawar (Craddock, 1998; Ray, 1956, p.191). The *Rasaratnasamuccaya* of Vāgbhaṭa attributed to the 13th-14th century AD is another landmark text, addressed to Bhaiṣajyaguru or Buddha as physician. This text describes contemporary method of production of zinc, namely the *tiryakpātana* (downward distillation). This text yields valuable and extensive information on the process of zinc smelting which, astonishingly, correlated well to the archaeological evidence for the process of zinc smelting at Zawar observed by the team of Hegde, Craddock and others (Craddock et. al, 1998). Although the organic prescriptions in *Rasaratnasamuccaya* may sound scientifically improbable, they have been found to correlate quite well with the finds at Zawar down to the description of the retort as being aubergine-shaped and the use of salt which would have served as a sintering agent and so on (Craddock et.al., 1998). It appears that the Indian metallurgists had pioneered the difficult technology of zinc smelting and championed the introduction of metallic zinc into the modern world. The method of production adopted by downward distillation found at Zawar is almost what Europe expanded in the 18th century (Craddock et al., 1989).

The process of image casting by lost wax processes is described in certain prescriptive texts. The *Mānasōllāsa*, or *Abhilaṣitārtha-cintāmaṇi* written by the Chālūkyan king Sōmeśvara of the 12th century AD from south-western India gives a detailed description of the process of making metal icons by the lost wax casting process known as *Madhuchisthavidhāna*. This is still practised in Swamimalai in the Tanjavur district, which harks back to the famed Cōla bronze (Reeves, 1962; Srinivasan, 1996).

7. ETHNOARCHAEOLOGY OF HIGH-TIN BRONZE MIRRORS

A mirror uncovered by Breeks from the Nilgiri cairns was reported to have 30% tin (Breeks 1873: 63, 156). There is a surviving tradition in Kerala, well known as *Ārammula kaṇṇāṭi* (the mirror of Ārammula). Although it is not possible to gauge the antiquity of the craft, the mirror making *ācāris* interviewed generally believed they had been practicing for at least 300 years. It is also interesting however, that they were rather secretive and reluctant to reveal fully the details in the initial encounters as they had a strong sense of the tradition being a trade secret. This is also gives an insight into why the dissemination through codification of practices may not have been widely encouraged if they were jealously guarded as hereditary trade secrets. One may add the *ācāris* are generally a literate community.

A case study of this surviving high-tin bronze craft at Ārammula for the making of 'delta' bronze mirrors revealed the following facts. The author's field investigations going back to 1991 and technical investigations (Srinivasan and Glover, 1995, 1997) were the first to establish that the properties were due its specific composition correlating to high-tin delta bronze, i.e. of 33% tin-bronze, so-called because of the match with the composition of pure delta phase, an intermetallic compound ($\text{Cu}_{31}\text{Sn}_8$) of 32.6% tin. The studies also identified that the mirror-effect

was obtained by optimizing its presence since it is a very hard, stable and silvery compound of hardness close to 500 VPN which can hence be polished with the best possible reflectance and mirror effect. Analyses by the author using SEM, EPMA and AAS techniques confirmed the alloy to be closer to 32-34% tin bronze nearer to the delta phase composition. Although the high-tin delta bronze alloy is highly brittle and shatters almost in the manner of glass, this is offset by casting a very thin (no more than 3 mm thick) flat oval blank in a two-piece closed crucible-cum-mould (Srinivasan and Glover, 1995; Srinivasan and Glover 2007; and Srinivasan 2008). The level of detail in making the crucible-cum-mould in a manner to optimize the casting can be gauged from the fact that though the crucible-cum-mould was made as a closed crucible to minimize oxidation losses from exposure to the air, a very small hole or passage was left in the neck through which the remnant gases could escape otherwise they would contribute to a defective casting. The technological processes suggest that this mirror making tradition was a fairly unique one, distinct from those found elsewhere in the world.

8. CONCLUSION

The above survey stresses the fact that the use of specialized metals and alloys such as beta high tin bronzes and delta bronzes besides zinc indicates an appreciation of functional properties. We have also sought to underline aesthetic/ritual/symbolic considerations. There are instances from archaeometallurgical and ethnoarchaeological studies of highly skilled metallurgical practices carrying on for generations as seen in the case of the hereditary Kammalar of Kerala carrying on practices of high-tin bronze vessel making which correlate well with finds from the Indian and south Indian Iron Age and early historic periods. We have also pointed to the example of skilled practices of gold extraction among the Kurumba tribe in the Nilgiris. It is harder to trace even

ethnoarchaeology of such technologies, the practical aspects of which were transmitted through the oral than the written tradition. However, the history of zinc smelting in India, for which the earliest details come from the Zawar region of Rajasthan, has supporting traditional textual material correlated by archaeological findings indicating metallurgical practices of zinc in antiquity. There seems to have been an attempt at documenting technological knowledge as prescriptions and procedures. It may be the fascination with the distillation process, which accounts for the prominent textual base of the smelting practice. Ethnoarchaeology of the Ārammūla metal mirror working tradition of Kerala exemplifies metallurgical practices totally bereft of any textual support.

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