Figure 1: Hot forging of ingots at high-tin bronze vessel making workshop at Paridur, Kerala observed by Srinivasan and Glover in 1998.

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MEGALITHIC HIGH-TIN BRONZES AND PENINSULAR INDIA'S 'LIVING PREHISTORY'

Sharada Srinivasan

Introduction

It is generally understood that there was a hiatus and even a decline in the range or quantity of copper-bronze finds from the Indus Valley (third millennium BCE) to subsequent periods in the Indian subcontinent (Khandalavala 1988, Deshpande 1988). It has been noted that tin is a scarce resource in India (Dhavalikar 1988), which explains the fact that bronzes are perhaps not found in abundance in terms of size or quantity in Indian prehistory when compared to some other parts of the Old World. Scholars had tended to ascribe some of the skilled examples of bronze finds especially from the peninsular Indian 'megalithic' as imports (Leshnik 1974: 156; Rajpitak and Seeley 1979) and it had been thought likely that the Indian subcontinent would have received bronze technologies or traded tin or bronze from tin-rich southeast Asia (Craddock *et al.* 1989: 23).

However, this paper, based on the author's studies (including previously published and unpublished ones) on bronze vessels from Iron Age Indian sites and megalithic contexts of southern India (including from, for example, Nilgiri megaliths and cairns, the Adichanallur Iron Age burials, and the Megalithic excavation of Mahurjhari of the earlier part of the first millennium BCE), shows that sophisticated bronze working practices existed throughout these periods. In particular, specialised use is seen in the hot forged and quenched high-tin beta bronze vessels (21-24 wt% tin), with the predominant retention of martensitic beta phase of 23 wt% tin. These vessels rank amongst the earliest and most finely wrought examples known in the world, and also suggest that bronze metallurgy at the time was more advanced than previously suspected. Furthermore, ethnoarchaeological studies and archaeometallurgical studies made, first independently and then in collaboration with Ian Glover, since the early 1990s on surviving traditions for high-tin bronze working in Kerala helped to establish that the finds of the prehistoric/megalithic Indian high-tin bronzes need not have been imports but might represent a longstanding indigenous tradition. This paper touches upon some unreported aspects of the fieldwork by Srinivasan and Glover (1995, 1997, 2007) including the making of high-tin bronze cymbals, as well the author's explorations that also point to craft survival in parts of eastern and western India.

Investigations on megalithic and iron age high-tin bronzes

The Iron Age of peninsular and southern India represents an enigmatic aspect of Indian archaeology, with few burial-cum-habitation sites having been uncovered near cairns or burials. Studies (Srinivasan 1994) on vessels from the cairns of the Nilgiris and Iron Age burial complex Adichanallur (Breeks 1873; Rea 1915), in the collection of the Government Museum, Chennai

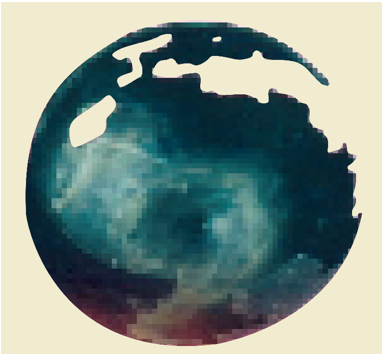

Figure 2: Knob-based Adichanallur vessel of wrought and quenched high-tin bronze, early 1st millennium BCE, Courtesy of the Government Museum, Chennai.

show the well developed use of wrought hammered and quenched high tin 23% beta bronze. Some of these bronzes, such as a vessel from Adichanallur (Fig. 2), could rank amongst the most finely wrought example known with a rim thinness of less than 0.2 mm. Previously it had been thought that the skilled technology of high-tin beta bronze working was developed in Southeast Asia or China and then spread to India (Rajpitak and Seeley 1979); its use is scarcely reported outside Asia. The technique seems to have flourished particularly at the fourth century BCE central Thai site of Ban Don Ta Phet (Bennett and Glover 1992; Rajpitak and Seeley 1979).

Despite the analyses reported in Breeks (1873: 63) of a few vessels from the Nilgiri cairns being of 20-25 wt% tin-bronze, and in Paramasivan (1941) of a microstructure of a bowl from Adichanallur of a high-tin content, it was generally believed that such artefacts were imported (Leshnik 1974: 156) and the possibilities of there being a local continuing tradition had never been explored. The author was the first to have identified such a continuing tradition of high-tin beta bronze vessel making from any part of the world, in the village of Payangadi in Kerala (first reported in 1991 for the 'Archaeometallurgy in India' conference at Benaras Hindu University, and published as Srinivasan 1998b) and to have correlated these with microstructures in vessels from the South Indian megaliths of Adichanallur and Nilgiris (Srinivasan 1994; Srinivasan and Glover 1995, 1997). This activity had already ceased at this village in Palghat district when Srinivasan and Glover revisited in 1998, although another workshop was identified and is discussed below.

In Srinivasan and Glover (1995, 1997, 2007) and Srinivasan (2008), the processes of manufacture of unleaded specular 30-33 wt% high-tin 'delta' bronze mirrors at Aranmula in Kerala are documented, pointing to a wider high-tin bronze tradition. Evidence for slags from co-smelting copper and tin ores were found by the author from Kalyadi in Karnataka (Srinivasan 1997b) which did not rule out the possibility that, though minor, local tin resources in southern India may have been exploited in southern India's past.

Whereas the dating of the finds recovered from the Nilgiris and Adichanallur have been more problematic, there are further binary higher-tin bronze finds further from the megalithic burials at Mahurjhari in the Vidharbha region. The megalithic burials and associated habitations of the region, including Naikund and Bhagimori, have radiocarbon dates of the seventh to eight centuries BCE (Francis 2002: 114).

Figure 3: Fluted Nilgiri bowl of wrought and quenched high-tin bronze, early 1st millennium BCE, Courtesy of the Government Museum, Chennai.

As for elsewhere in the Indian subcontinent, Srinivasan and Glover (1995) report the analysis of a 24 wt% high-tin bronze vessel excavated from the Iron Age Gandharan Grave Culture in Taxila, Pakistan (attributed to 1000 BCE). This specimen was given to Glover by the Pakistan Archaeological Survey and the analysis was undertaken by Srinivasan using SEM-EDS at the Institute of Archaeology, University College London. Two samples excavated from the Indus Valley site of Mohenjodaro (c. 2500 BCE) had a composition of 22 wt% tin-bronze (Mackay 1938: 480). Although of course this may well be adventitious rather than intentional, it suggests a phase of experimentation with compositions of bronze.

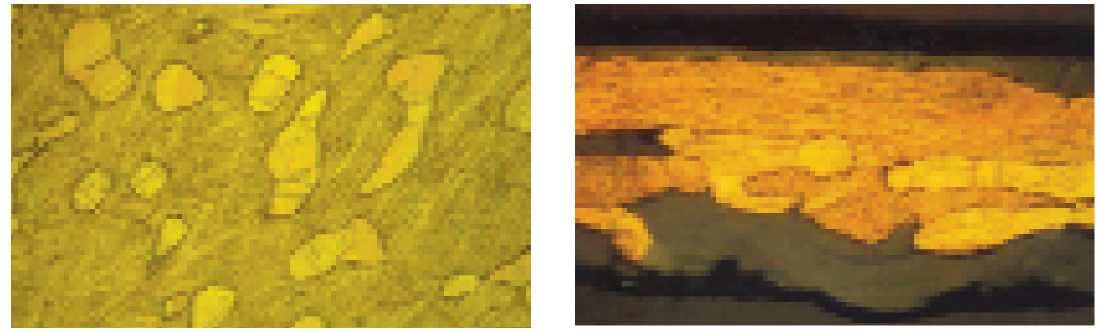

Fig. 4: (Left) Microstructure of wrought and quenched Adichanallur vessel with 22.9% tin showing predominant needle-like beta phase with some alpha phase islands. (Right) Microstructure of wrought and quenched Nilgiri bowl with 23.9% tin showing predominant beta phase with some alpha phase islands.

Datta *et al.* (2007) have also pointed to evidence for metal processing for high-tin bronze from Tilpi, West Bengal, from at least the second to first centuries BCE, as discussed further below. Such evidence might call for a departure from the notion (e.g. Craddock *et al.* 1989: 23) that the Indian subcontinent would have more likely received diffused bronze technologies or traded bronze from other parts of tin-rich Asia such as Southeast Asia.

Comparative insights on megalithic high-tin bronze vessels from Tamil Nadu & Maharashtra

Generally, as-cast binary copper-tin alloys with over 15 wt% were rarer in antiquity since they become brittle due to the presence of the delta phase component. However, investigations by the author from prehistoric, medieval and modern south India indicate the continued use of specialised binary high-tin beta bronzes with 22-25 wt% tin to make artefacts such as vessels, coins and musical instruments into the present day (Srinivasan 1994, 1998a). Metallurgical investigations by the author on very thin (0.2-1.0 mm) vessels from South Indian burials and megaliths of Adichanallur (Figs. 1 and 3) and Nilgiris (Figs. 3 & 4) of the early to mid-first millennium BCE and medieval Chola platters (tenth to twelfth centuries CE) indicate that these were wrought and quenched high-tin beta bronzes; i.e. copper-tin alloys with 23-25 wt% tin (Srinivasan 1994; Srinivasan and Glover 1995).

These were fabricated by extensively hammering out such an alloy between 586-798°C when plastic beta intermetallic compound (Cu_5Sn) of equilibrium composition (22.9 wt% tin) forms, followed by quenching resulting in the retention of needle-like beta phase (Fig. 4) which prevents the formation of brittle delta phase. In contrast, low-tin bronzes have limited workability at high temperatures (Hanson and Pell-Walpole 1951).

The use of unleaded higher tin bronze has also been identified by the author from investigations on samples taken from some vessel and finial fragments from megalithic excavations in the Vidarbha region at Mahurjhari (Fig. 5) and Boregaon. These are now in the Deccan College, Pune, and were uncovered from excavations made by S.B. Deo in the early 1970s (Deo 1973). The microstructure of a finial from Boregaon (Fig. 6) shows it to be a cast and quenched beta bronze with 21 wt% tin. A couple of wrought and quenched beta bronze bowls were also identified by the author from Mahurjhari (Fig. 5) with 18-21 wt% tin showing some martensitic quenched beta phase amidst alpha phase islands. However, in none of these high-tin bronze vessels from the Vidarbha megaliths was the composition range of formation of predominant beta phase of around 23 wt% tin fully reached.

The microstructural data confirms that they were not as heavily hot forged as the Iron Age period high-tin bronze vessels from the cairns of the Nilgiris and burials of Adichanallur in Tamil Nadu.

Links with surviving high-tin beta bronze bowl making in Kerala and India

In 1991 the author documented the making of wrought and quenched high-tin beta bronze vessels, gongs, cymbals and ladles in Payangadi in Kerala. Microstructural investigations of a bowl from Payangadi (Fig. 7) and Trichur respectively confirmed that the concave bowls were made by forging in cycles of hammering and annealing followed by quenching between 600-700°C, all in the alpha plus beta phase field (Fig. 8) (Srinivasan 1994, 1998b). This study is summarised below since the making of such large wrought high-tin bronze bowls has given way to much smaller ones.

At that workshop of Mr Kammalar Bhaskaran in Payangadi a flat ingot of 15 cm diametre and 1.0-1.5 cm thickness was used as the blank to be forged into the vessel. The plasticity of this bronze of composition around 23 wt% tin was exploited by forging it in the temperature range of formation of the beta intermetallic compound phase of about 600°C. The ingot was thus hot forged on a stone anvil and four craftsmen took turns in giving it massive blows with wedge-shaped iron hammers fitted into a wooden frame known as *cherangulam*. After about two cycles of over head hammer strikes, the ingot was annealed in the beta temperature range, and further cycles of hammering followed until the flat ingot took on a progressively concave shape. This work continued all afternoon, until the original ingot had attained a remarkable concave shape with a 25 cm diameter, 8 cm height and a rim thickness of only 1.5 mm (Fig. 7). This bowl had 22.5 wt% tin (Fig. 8), indicating that the degree of plastic deformation was more than twice that of the ingot, which is remarkable for bronze. In a collaborative study done with Oleg Sherby and S. Ranganathan it was found that the high-tin bronze alloy is quasi-superplastic (forthcoming). Finally, the bowl was annealed on a bed of charcoal and quenched in a tank of water to freeze the meta-stable martensitic beta phase. According to the craftsmen this prevented breakage of the vessels. A rounded wooden mallet was also used in the stage of final rounding and hammering of the bowl. The blackened surface of the as-quenched bowl was scraped with a scraper and files to remove the fire skin and expose the bright golden lustre of beta bronze, a characteristic that may well explain this alloy's popularity in ancient times. In parts of some vessels from Adichanallur and the Nilgiris, the original golden lustre still comes through, pointing to the strong corrosion resistance of the alloy. A fourth century Vishnukundin coin from the Deccan was also found to be of 24 wt% quenched high-tin bronze which seems to have been hot struck from this alloy, apparently for the same reason (Srinivasan 1998b).

Another interesting aspect of the high-tin bronze bowl making process observed in Payangadi, Kerala in 1991 was the striking similarities with megalithic vessels from the Nilgiris in the shape and the use of circular rings for decoration. These circular rings were made by mounting the vessel on a lathe with clamps on a wall and hand turning it and using a set of files like a compass (Fig. 9). Thus it was possible to see the legacy of the Nilgiri bowls in these processes in Kerala.

Figure 5: High-tin bronze vessel from Mahurjhari (Vidharbha megaliths) with finial, & finial fragments from Boregaon with 21% tin. Early 1st millennium BCE.

In 1998 when the author and Glover re-visited Kerala, these craftsmen from Payangadi had given up their trade. However, another set of craftsmen were observed who made smaller high-tin bronze vessels in Paridur, Kerala. The bowls made here were raised far less than those seen at Payangadi in 1991. In this context, the term 'raising' is the process of working a flat circular ingot into a bowl shape. The use of traditional handheld buffalo skin bag bellows could still be seen. Unlike what was seen in Payangadi where a single bowl was being forged, here to speed up the process a set of four ingots were piled on one another and forged all at once (Fig. 1). Then, after some degree of forging had been done, the final forging, quenching and post-quenching tooling was undertaken.

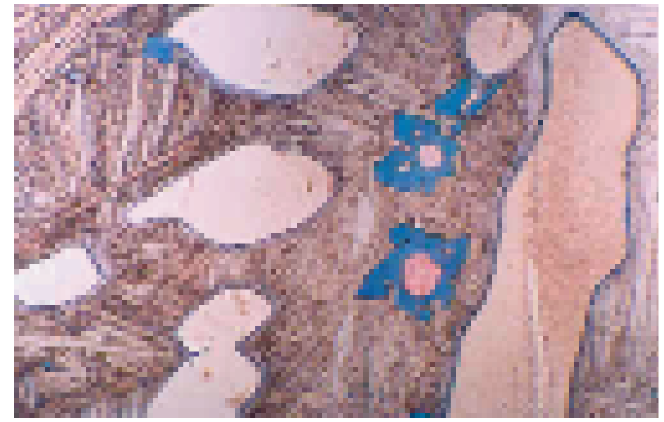

Figure 6: Microstructure of cast and quenched beta bronze finial from Boregaon, with 21% tin.

Craddock and Hook (2007) have observed high-tin bronze bowl making activity in Palghat district, and Pillai *et al.* (2006) described the shaping of an 'eating bowl' from Kaduvaloor in Kerala of 21.6 wt% tin, further confirming the survival of South Asia's wrought and quenched high-tin bronze bowl making tradition. However, the degree of shaping described in these publications is again far less than that observed by the author in 1991 in Payangadi, perhaps indicative of declining abilities in shaping high-tin bronze. At a 2004 crafts fair in Bangalore, the author documented craftsmen from Kantilo, Orissa who made small shallow vessels which could be identified as high-tin bronzes from their tonality, lustre and from the existence of a blackened face from quenching, while the process of manufacture described with them also tallied. Here, as in some older vessels from Kerala, the edge of the rim is given a flared effect or sometimes a fluted effect which recalls the Nilgiri vessels which were nevertheless much thinner and hot forged much more. Mukherjee (1978: 89-91) also described the making of 'wrought bell metal' which perhaps referred to high-tin bronze. The author also visited a workshop in Anjar, Gujarat in 2005 where small cups were made of high-tin bronze, although these were mostly cast to shape and only lightly forged before quenching. Flat plates with raised rims were also made by them known as *Kasher thala*.

Casting and forging of musical cymbals of high-tin beta bronze in Kerala

During a fieldtrip to Mallapuram district, Kerala by the author and Glover in 1998, it was observed that traditional cymbals were also still made using wrought and quenched beta high-tin bronze. The cymbals were not as extensively hot forged as the bowls, since the main aim seems to have been to quenching the 23 wt% tin beta bronze alloy so as to get the martensitic transformation of the metastable beta phase, which has significant musical properties of high tonality. However, the cymbals were roughly cast to a concave shape by the open casting process in a sand mould. Thereafter they were hot forged in the temperature range of formation of the plastic beta phase to a fine concave shape of about 10 cm diameter and 1 cm thickness. A hole in the centre was made by hot hammering with a long chisel to enable the two hand cymbals to be strung together for musical playing. Fig. 11 shows the quenching process at this workshop. Filing followed by final hand polishing with abrasive powders was used to bring out the bright golden lustre (Fig. 12). The cymbals are used for traditional Bharata Natyam performance and are known as *tala* or *nattuvangam*. Cymbals such as these are depicted for example in a bronze Nataraja from Melaperumbulam (c. twelfth century CE) and *tala* is mentioned in Chola inscriptions. Flat circular gongs are also made of high-tin bronze in Kerala and used in performances related to the dance theatre of Kathakali. Given the tonality of high-tin bronze it is possible that the musical effects of the alloy were known in antiquity.

Nicolas (2009: 62-82) points to the finds of flat gongs in the maritime archaeological record from shipwrecks in Southeast Asia from the ninth to thirteenth centuries CE, which had links to the Hoysala region of southern India. Flat gongs with raised rims of quenched high-tin bronze have also been reported from the Philippines (Goodway and Conklin 1987). The degree of working reported does not seem to have been very extensive in comparison to the making of high-tin bronze vessels in Kerala.

Re-examining the milieu of megalithic high-tin bronzes

Finds from megaliths in southern India point to long distance exchange networks even in an era slightly preceding the true early historic period. Berenike in Egypt principally traded in stone and quartz beads from sites in Tamil Nadu, such as the megalithic burial-cum habitation site of Kodumanal (c. 300 BCE), and in glass beads from Arikamedu until the second century BCE (Francis 2002). Finds of carnelian and of lapis lazuli from megalithic Kodumanal probably had their sources in western India and Afghanistan respectively. To the author, a copper alloy tiger figurine from megalithic Kodumanal inlayed with carnelian and lapis lazuli seems to share stylistic affinities with a late prehistoric carnelian lion/tiger found at Ban Don Tha Phet in Thailand (published in Glover 1990).

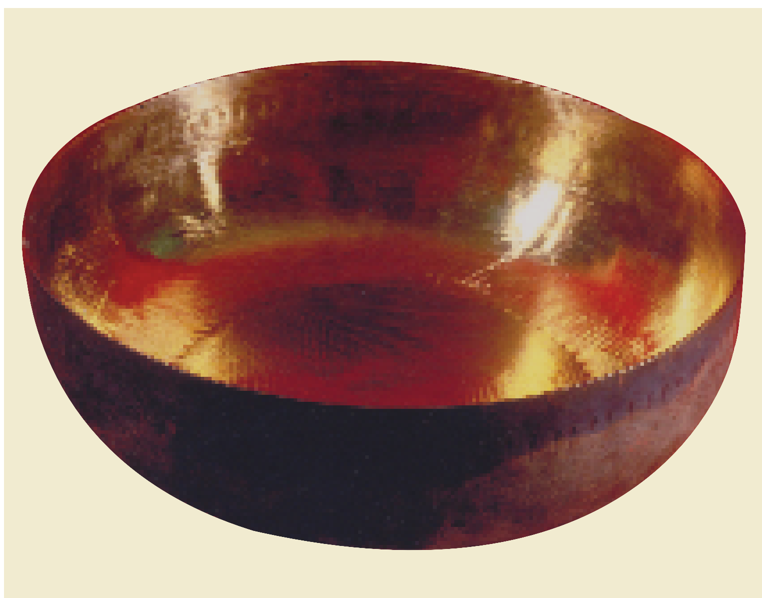

Figure 7: Large wrought and quenched bowl made at Payangadi, Kerala obtained by Srinivasan in 1991.

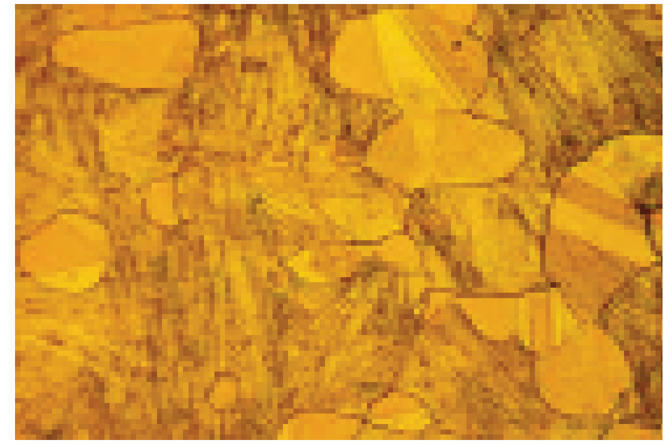

Fig. 8. Microstructure of Payangadi bowl confirming wrought and quenched structure. Scale bar represents 100µm..

The high sophistication of numerous vessels and gold jewellery uncovered from the Nilgiri cairns (loosely dated from about 1000-500 BCE) and Iron Age Adichanallur burials (c. 1000-800 BCE) had previously led scholars to speculate that they were imported (Leshnik 1974; Knox 1985; Rajpatik and Seeley 1979). However, the possibility of these being of south Indian provenance is now better supported by the ethnoarchaeological and archaeometallurgical evidence summarised here, and there is a possibility that they were even made in Kerala.

The collection of vessels, at least forty, from the Nilgiri hoards in the British Museum comprises elegant fluted, knob-based and carinated vessels with concentric rings. In addition to the analysed high-tin bronzes from the Nilgiris previously mentioned, there are five high-tin bronze bowls with around 22-23 wt% tin, dated from the fifth to second centuries BCE, reported from the Breeks collection of vessels from the Nilgiri cairns at the British Museum (Craddock and Hook 2007). From the microstructures indicated before, the elongation and degree of hot forging in these south Indian examples from Adichanallur and the Nilgiris (evidenced in the elongated needles of beta phase and annealed alpha phase islands) seems greater than that detected in many of the microstructures of the high-tin bronze bowls from Ban Don Ta Phet, Thailand illustrated in Rajpitak (1983). These often show dendritic patterns in the alpha phase suggesting that they were mainly cast and quenched and not substantially hot forged, even if they were cold worked. This further suggests a greater mastery of the exploitation of the quasi-superplastic properties of high-tin bronze in the south Indian megalithic high-tin bronzes. At any rate, evidence for long-distance contact with Southeast Asia is suggested in the stylistic similarities that knob-based and ringed bowls from the Nilgiri cairns showed with vessels from Ban Don Ta Phet in Thailand (fourth century BCE).

The finds of quenched high-tin bronze from the Vidarbha megaliths of Mahurjhari and Boregaon are also significant as these can be more securely placed to the earlier part of the first millennium BCE. The typologically similarity is also noticeable with the finds from Adichanallur, especially in the styles of the bowls with finials although as previously noted these also show less hot forging. Francis (2002: 115) described the bead making complex of Mahurjhari as a 'Pandukal habitation site', after Leshnik's (1974) classification of the South Indian megaliths as 'Pandukal complex'. Both Francis (2002) and Deo (1973: 32) have pointed to the similarities of the beads of Mahurjhari to those from southern India. The Vidarbha megaliths in the Nagpur area are not too far from the ChotaNagpur plateau where some small scale pre-industrial mining of tin by local people has been reported (Mallet 1874).

Ray (1996) has suggested that rather than primarily attributing social change in peninsular India to Mauryan intervention alone, the impetus from coastal and maritime interactions should also be taken into account. A major trade route in the early historic period was the route from the Malabar coast in the west through the Palghat pass, and moving east to the Kaveri delta with its settlements and including sites such as Kodumanal, Karur, Arikamedu, Korkai and Alagankulam (Thapar 2002: 237). Parasher-Sen (2000) also points to the significance of local developments in the Deccan in terms of origin of settlements. The existence of skilled metallurgical or craft techniques need not necessarily be linked with settled urbanism and indeed, even until recently in India many crafts such as metal crafts were practiced as itinerant or migrant trade.

The possible ritual aspect of the high-tin bronze vessels of the pre-Common Era from the Nilgiris and Thailand has been speculated upon by scholars such as Glover (1992). Ritual associations with Buddhism are suggested by the floral and lotus patterns and the raised knob-base surrounded by rings suggestive of Mount Meru. The raised knob could also have been facilitated by the forging technique working outwards in a spiral. Even in recent times in the Nilgiris, the Toda and Badaga communities often have high-tin bronze platters (decorated with rings) which are for ritual use and are usually said to come from Kerala. Such high-tin bronze vessels with raised bases/knobs may still be found on sale in shops in Kerala. The use of high-tin bronze vessels for storage of food items also makes scientific sense due to the lower corrosive properties. The tonality of high-tin beta bronze as seen in its continued use in musical gongs and cymbals in Kerala is also significant.

Tin sources and bronze metallurgy in the South and Southeast Asia

It appears that by the earlier half of first millennium BCE the use of high-tin bronzes, with certain stylistic similarities, had come into vogue at various Iron Age sites in the Indian subcontinent, including Gandharan Grave Culture of Taxila, the Vidharbha megaliths of the Northern Deccan, and the Nilgiri

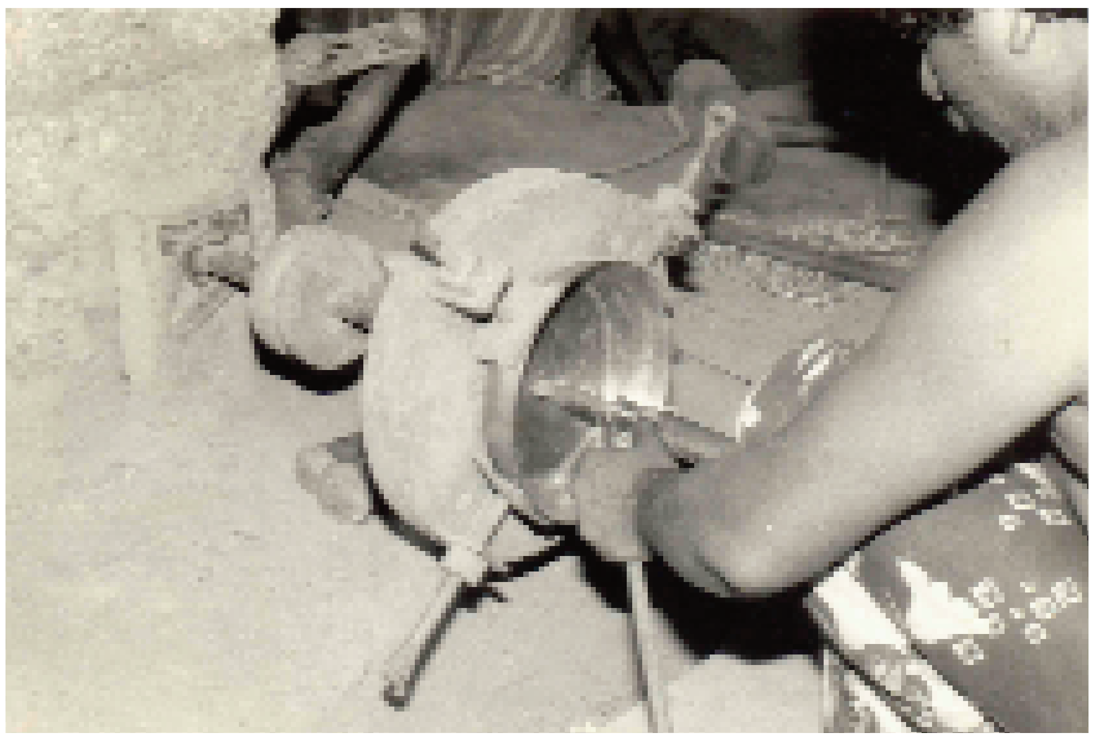

Figure 9: Hand-turned lathe at Payangadi observed by Srinivasan in 1991, where rings are made at the base of the wrought and quenched high-tin beta bronze vessel, similar to megalithic vessels.

Figure 11 (left): Quenching of high-tin bronze cymbal observed in 1998 by Srinivasan and Glover. Figure 12 (right) Polishing of high-tin beta bronze cymbals observed in 1998 by Srinivasan and Glover.

cairns and Adichanallur burials of the extreme south of India.

The sources of tin for the Indian subcontinent are an enigma since tin is a relatively scarce commodity in India today. However, it must be remembered that deposits which would be termed as uneconomical today could have been sufficient for small scale, labour intensive mining. It is probable that mining placer tin deposits would leave relatively few traces when compared to hard rock mining, although it could leave behind a disturbed landscape that might endure for a while. For bronze finds from the Indus Valley and Taxila, it has been postulated that Afghanistan might have been a plausible source of tin (Muhly 1985: 281). Afghanistan has some stannite and cassiterite deposits, while Misgaran in Herat shows some evidence of early exploitation (Reedy 1992: 244). Jarrige (1995) points to the links in terms of late Bronze Age Bactria and Magria in Afghanistan on the later Indus Valley. A better understanding of the material culture of the Gandharan Grave Culture of Taxila, dated to 1000 BCE, from which a high-tin bronze vessel has been investigated and published by the author (Srinivasan and Glover 1995), would help clarify developments in the north-western Indian subcontinent. From the Bhir mound at Taxila, Marshall (1951: 567) reported eight 20+ wt% tin vessels and mirrors, datable broadly from the fourth century BCE to the first century CE. Strabo's *Geography* mentions that in the northwestern Indian region encompassing Taxila, vessels were used that broke like pottery when dropped on the ground; Rajpitak and Seeley (1979) have interpreted these vessels as made of high-tin bronze. The finds reported by Ravich (1991) of Scythian and Sarmatian hot-forged high tin bronze mirrors of the sixth to fifth centuries BCE from Central Asia also adds an intriguing dimension in terms of the proximity to this geographical cluster.

Eastern India also has some minor tin deposits in the Hazaribagh region with some evidence for pre-industrial exploitation (Mallet 1874). Singh and Chattopadhyay (2002-3) have pointed to the find of a knobbed vessel with about 19 wt% tin from sixth century BCE Agiabir in the Gangetic Valley. Datta *et al.* (2007) have pointed to evidence related to high-tin bronze metal processing including an ingot and crucible fragments from Tilpi dating at least to the second or first centuries BCE. The finds of the quenched high-tin bronze vessels mentioned here from the Vidharbha from Mahurjhari and Boregaon of about the eighth to seventh centuries BCE may be significant in terms of the relative proximity to the aforementioned deposits of the Hazaribagh and Chota Nagpur areas.

Alhough the dating of the bronze vessels from Adichanallur and Nilgiris are less secure, there are marked stylistic similarities with the Mahurjhari assemblages which have been radiocarbon dated to the eighth to seventh centuries BCE. Raymond Allchin (pers. comm.) opined that the date of the Adichanallur assemblages could be put around 800 BCE. It has been pointed out here from the microstructural comparisons that the degree of forging in the Tamil beta high-tin bronze examples seems to be the most extensive when compared to the other regions discussed here including Southeast Asia. This is also consistent with the significant degree of hot forging seen in extant crafts for high-tin bronze vessel making from Kerala in southern India. In comparison, the surviving ethnographic crafts of forged and quenched high-tin bronze vessels reported from the Philippines show less hot forging (Goodway and Conklin 1987), and this also seems to be the case with the Southeast Asian high-tin bronzes from archaeological contexts (e.g. Bennet and Glover 1992; Murillo-Barosso *et al.* 2010).

The Southeast Asian finds of high tin bronzes from sites such as Ban Don Ta Phet and Ban Chiang dating from about the fourth century BCE have been well discussed by other authors (Bennett and Glover; Pigott 1992; Rajpitak and Seeley 1974, 1983) and some comparisons have been made with South Asian material. Although a more detailed comparative study of South Asian with Southeast Asian material is called for, it is outside the scope of this paper. However, exciting finds from Khao Sam Kaeo in the upper Thai-Malay Peninsula have thrown further light into the issues of metal processing of high-tin bronze (Murillo-Barraso *et al.* 2010). Investigations of slag and ceramics suggest that by the mid to late first millennium BCE, a casseterite cementation or co-smelting process of copper and tin ores was possibly used to produce high-tin bronze ingots that may have been for export or local use. It is most intriguing too that the photomicrograph of crucible slag from sample TC17 (*ibid.*) possibly evidencing manufacture of bronze from cementation of iron-rich casseterite with copper metal from the Khao Sam Kaeo assemblage is markedly similar to that reported by Srinivasan (1997b) in undated slags from surface collection from Kalyadi in Karnataka southern India, previously interpreted as bronze smelting slags from co-smelting copper and tin ores. The Kalyadi slag had bronze prills of a composition of 7 wt% tin and the marked presence of metallic iron in them could also be explained as being due to iron-rich alluvial cassiterite. In this connection the sparse tin reserves of the Dambal region of Karnataka may have significance as well.

It is also significant that Pryce *et al.* (in press) have pointed out that Khao Sam Kaeo's distinctive 'nippled' moulds for high-tin bronze ingots are very similar to crucibles found in relation to a high-tin bronze ingot from the broadly contemporary site of Tilpi in West Bengal (Datta *et al.* 2007) and other such South Asian technical ceramics such as the nippled crucibles found at Dariba in Rajasthan of the late 1st millennium BCE. They conclude that these findings lend support to Bellina's (2001) thesis that already by the first millennium BCE there was a long-distance network in place whereby highly skilled South Asian artisans may have settled in Southeast Asia or trained Southeast Asians. The evidence pieced together in this paper lends more plausibility to the notion that the technology of high-tin bronze production could well have travelled from South Asia to Southeast Asia, rather than the reverse as previously more widely believed.

Acknowledgements

The author would like to acknowledge the late Dr Nigel Seeley, Dr Ian Glover, Dr Anna Bennett, Dr Tom Chase, Prof V.N. Mishra, Prof S. Ranganathan, the late Prof R. Balasubramaniam, Digvijay Mallah and the Government Museum, Chennai, for their kind support in these research endeavours.

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