Sharada Srinivasan, *Man and Environment* XXXI(2): 1-8 [2006].

Megalithic High-tin Bronzes: Ethnoarchaeological and Archaeometallurgical Insights on Manufacture and Possible Artistic and Musical Significance*

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Abstract

The megaliths of peninsular and southern India represent one of the enigmatic aspects of Indian archaeology, with few burial-cum-habitation sites having been uncovered near cairns or burials. Archaeometallurgical investigations by the author on a range of thin vessel fragments from a range of megalithic sites such as Adichanallur and the Nilgiris in Tamil Nadu, and Mahurjhari in the Vidarbha region of the early to mid 1st millennium B.C. point to the use of binary copper tin alloys with a higher content of tin. The sites in the Nilgiris and at Adichanallur in particular, showed well developed use of wrought hammered and quenched high tin beta bronze (with around 23% tin) and rank amongst the finest earliest examples of this craft from anywhere in the world with extraordinary rim thinness of up to 0.2 mm. Although the provenance of some of the fine Nilgiri bowls was previously thought to be of foreign origin, original ethnoarchaeological and archaeometallurgical studies conducted by the author have established, partly in previous papers (Srinivasan 1994; Srinivasan and Glover 1995; Srinivasan and Glover 1997) and partly here, that these could well have been of indigenous manufacture. This is seen from comparisons with surviving rare crafts for making high-tin bronzes in Kerala which are amongst the very few well reported studies of such craft survivals in the world. Evidence of slag from co-smelting copper and tin ores was found by the author from Kalyadi in Karnataka, which suggests that there may have been minor local tin resources in South India which could have been exploited (Srinivasan 1997a). This paper explores some further aspects of the technology and related archaeological issues, and explores significance of this intriguing material culture. It is pointed out from ethnographic comparisons with high-tin bronze bowl making traditions in Kerala, that the rings, the knob-base, the polish and fluted shapes seen in the Nilgiri and Adichanallur bowls could have been part of a local tradition. Apart from artistic significance it is also pointed out that since the traditional high-tin bronze bowls from Kerala are known as *talavettu* or musical vessels, it is also possible that the megalithic high-tin bronze bowls could have had musical significance. Quenched high-tin beta bronze alloy (23% tin) is still used to make cymbals in parts of northern Kerala. A proclivity for musical materials in south Indian prehistory may perhaps be postulated given that Boivin (2004) has argued that rocks from Neolithic Kupgal had percussive functions. Thus the paper well demonstrates the usefulness of ethnoarchaeological approaches in archaeological and archaeometallurgical studies.

Introduction

Is generally understood that there was something of a hiatus and even regression in terms of the development of copper-bronze metallurgy between the Indus Valley (3rd millennium B.C.) and the subsequent Chalcolithic and megalithic cultures of the second and first millennium B.C. in terms of range or quantity of finds. Even so, this paper puts together results of investigations on some bronze vessels from Iron Age sites and megalithic contexts of southern India such as the Nilgiri megaliths and cairns and the Adichanallur Iron Age burials, to show that these reflect sophisticated bronze working practices with the use of a specialised alloy known as wrought and quenched high-tin bronze alloy (hot forged and quenched binary copper-tin alloys of about 23% tin resulting in the predominant retention of martensitic beta phase). These not only rank amongst the earliest such alloys known in the world but also suggest that bronze metallurgy at the time was more advanced than previously suspected.

* This paper was presented for the Malti Nagar Ethnoarchaeology Award at Bangalore and was selected for the award. The second paper by Anjana Reddy selected for this award, was published in the first issue of this volume.

It was previously thought that the skilled technology of high-tin beta bronze working was developed in South-east Asia or China and then spread to India, while its use is scarcely reported outside Asia. However studies by the author of surviving techniques for making wrought and quenched beta bronze bowls and high-tin delta bronze mirrors in parts of Kerala, together with analyses of finds from South Indian megaliths and Iron Age burials from other parts of India of the early to late first millennium B.C. suggest that the technique might have had indigenous origins (Srinivasan 1994, 1997a; Srinivasan and Glover 1995, 1997). Vessels from Adichanallur and the Nilgiris represent some of the finest examples of wrought and forged high-tin bronze vessels found with very fine rims of down to 0.2 mm thickness indicating extensive forging followed by quenching and fine decorations. If this is indeed so, it also remains a possibility that this technique could have in turn also spread to tin-rich southeast Asia, especially Thailand where well documented finds of high-tin bronzes are also known at Ban Don Ta Phet by the 4th century B.C. where the technique seems to have flourished to skilled heights (Rajpitak and Seeley 1979; Bennett and Glover 1992).

Investigations on Megalithic High-tin Bronzes

Generally, cast binary copper-tin alloys with over 15% were not much in vogue in antiquity as they become brittle due to the presence of the delta phase component. However investigations by the author from prehistoric, medieval and modern south Indian examples indicate the continued use of specialised binary high-tin beta bronzes with 22-5% tin to make artefacts such as vessels, coins and musical instruments (Srinivasan 1994; 1997b).

Metallurgical investigations by the author on very thin vessels from South Indian burials and megaliths of Adichanallur (Figs. 1-2) and the Nilgiris (Figs. 3-4) (*c.* 1000-500 B.C.) (Srinivasan 1994; Srinivasan and Glover 1995) indicated that these were wrought and quenched high-tin beta bronzes, i.e. copper-tin alloys with 23-25% tin (analyses reported in Table 1). 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% tin) forms, followed by quenching, resulting in the retention of a needle-like beta phase (Figs. 2, 4) which prevents the formation of a brittle delta phase. In contrast, low-tin bronzes have limited workability.

Despite the analyses reported in Breeks (1873: 63) of a few vessels from the Nilgiri cairns being of 20-25% tin-bronze, it was believed that these artefacts were imported (Leshnik 1974: 156) and the possibilities of there being a local continuing tradition were never 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

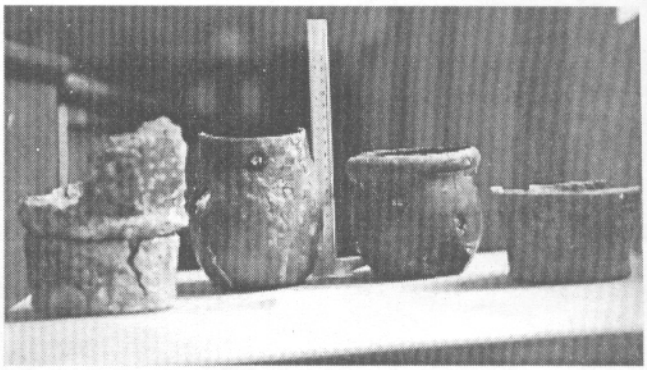


Fig. 1: Jug (acc. no. 61) from Iron Age Burials of Adichanallur, Tamil Nadu (c. 800 B.C.), Government Museum, Chennai, analysed by the author and found to be of wrought and quenched high-tin bronze (22.9% tin)

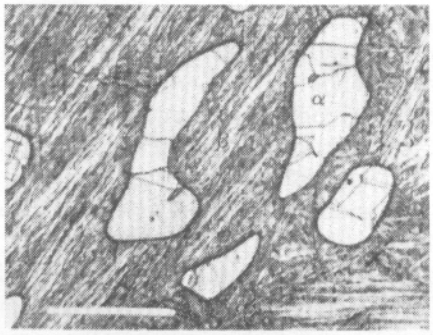


Fig. 2: Micro-structure of the above jug of high-tin bronze (22.9% tin) from Adichanallur showing elongated needles of beta martensite and some islands of twinned alpha phase indicating it was hot forged and quenched resulting in retention of beta phase.

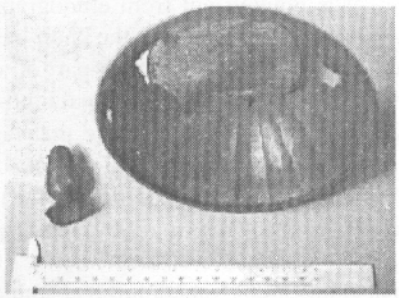


Fig. 3: Fluted high-tin wrought and quenched beta bronze bowl with 23.9% tin, Nilgiri cairns (c. 1000-500 B.C.), Tamil Nadu, Government Museum, Chennai. An incense burner is also seen.

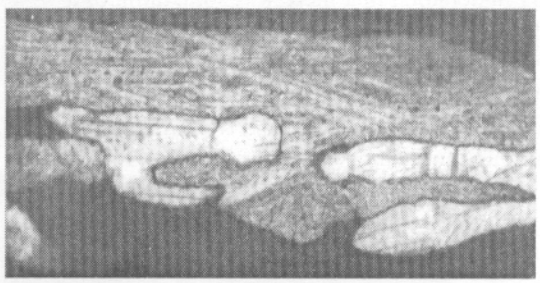


Fig. 4: Micro-structure of the above high-tin wrought and quenched beta bronze bowl (23.9% tin) from the Nilgiris, Tamil Nadu (400X)

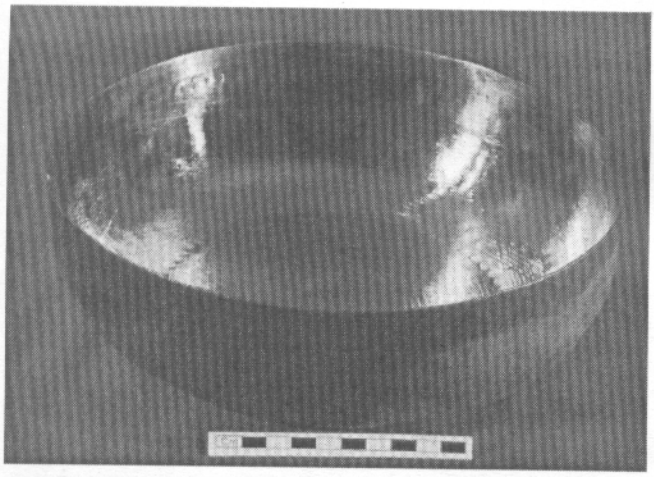


Fig. 9: Recent high-tin bronze vessel, Payangadi, Kerala made in 1991

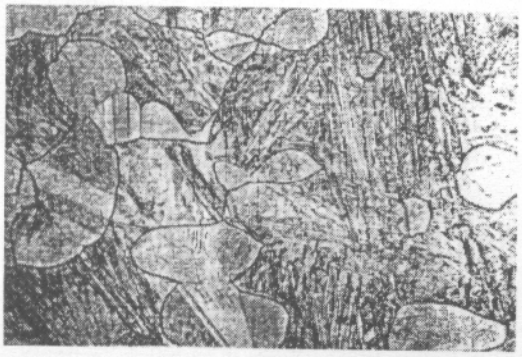


Fig. 10: Micro-structure of the above high-tin bronze vessel made in 1991, in Payangadi, Kerala of wrought and quenched high-tin bronze (22.5% tin)

attained a remarkable concave shape with an ingot of 15 cm diameter and 1-1.5 cm thick being transformed into a thin concave bowl of diameter 25 cm, 8 cm height and rim thickness of only 1.5 mm (Fig. 9). This indicates that the degree of plastic deformation was more than twice that of the ingot, which is remarkable for bronze. In a collaborative study done by the author and Oleg Sherby it was found that high-tin bronze is quasi-superplastic.

Finall, the bowl was annealed on a bed of charcoal and rapidly quenched in a tank of water which would have frozen 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 shears and files to remove the fire skin and expose the bright golden lustre of beta bronze. The micro-structure of this bowl shows a typical structure of quenched beta high-tin bronze with martensitic beta and an alpha plus beta structure (22.5% tin) (Fig. 10). This would explain why this alloy was in vogue in ancient times. It is remarkable that in one Iron Age example from Adichanallur, and a few from the Nilgiri megaliths, there is no dark patination rich in tin oxides, which is often found, and the original bright golden lustre still comes through. Some Vishnukundin coins were also struck of this alloy, apparently for this reason. Another interesting aspect of the high-tin bronze bowl-making process observed in Payangadi was the striking similarities with megalithic vessels from the Nilgiris in the shape and the use of circular rings for decoration. The latter were made by mounting the vessel on a lathe with clamps on a wall and hand-turning it, using a set of files like a compass (Figs. 11-12). Thus, it was possible to see the legacy of the Nilgiri bowls in these processes in Kerala (Fig. 12).

In 1998 when the author and I. Glover re-visited Kerala these craftsmen from Payangadi had given up their trade, however, another set of craftsmen were at work making rather smaller high-tin bronze vessels in Paridur in Kerala. Here, to speed up the process a set of four ingots were piled on one another and forged (Fig. 6, please refer inside front cover) and then final forging done on each before quenching.

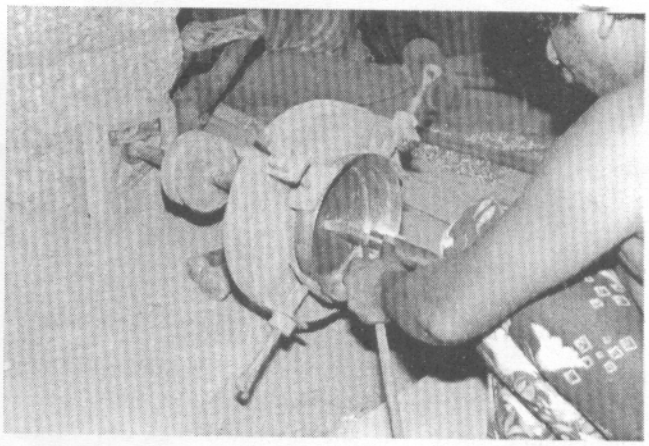


Fig. 11: Making inner rings as decoration on polished high-tin bronze bown in Payangadi, Kerala using a hand-turned lathe

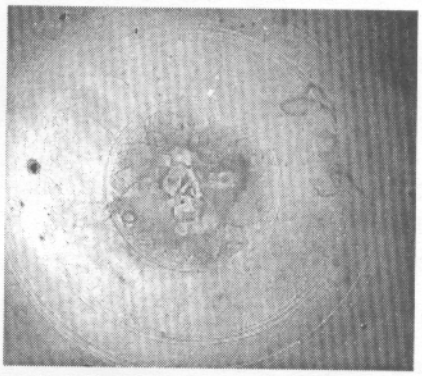


Fig. 12: Inner rings in vessel from Nilgiri megaliths, Government Museum, Chennai

world, in the village of Payangadi in Kerala** and to have correlated these with micro-structures in vessels from the South Indian megaliths of Adichanallur and the Nilgiris (Srinivasan 1994; Srinivasan and Glover 1995). At Payangadi, high-tin bronze vessels were made by extensively hammering out (in cycles of annealing and hot forging) an alloy close to a composition of 23% C around 600 °C in the temperature range of formation of the plastic beta intermetallic compound, followed by quenching, resulting in the retention of needle-like beta phase (Figs. 5-7, please refer inside front cover). At the workshop, the author also found that the resultant alloy has musical properties and acquires a very bright golden polish which would explain its significance in antiquity (Fig. 8, please refer inside front cover). Figure 9 is a finished and polished wrought and quenched high-tin bronze bowl made at Payangadi of 22.5% tin with analysis reported in Table 1.

Prior to these studies, non-Indian sources had been suggested for the bowls from the Nilgiri megaliths to be located in West Asia (Leshnik 1974: 156) or East Asia (Rajpitak and Seeley 1979). However, it now seems likely that they were made in ancient Kerala since they closely resemble the wrought and quenched high-tin beta bronze bowls from Payanagadi. The resemblance is not only metallurgically, but also stylistically, in the use of concentric rings in the centre of the bowls made in 1991 by using a hand-turned lathe. This is consistent with local lore where the Todas, the original inhabitants of the Nilgiris, claimed that such vessels came from Kerala (personal communication with Evam Piljian of the Toda community). The author is currently also investigating vessels from megaliths in Kerala. Allchin and Allchin (1982) also postulate indigenous developments for the south Indian megaliths.

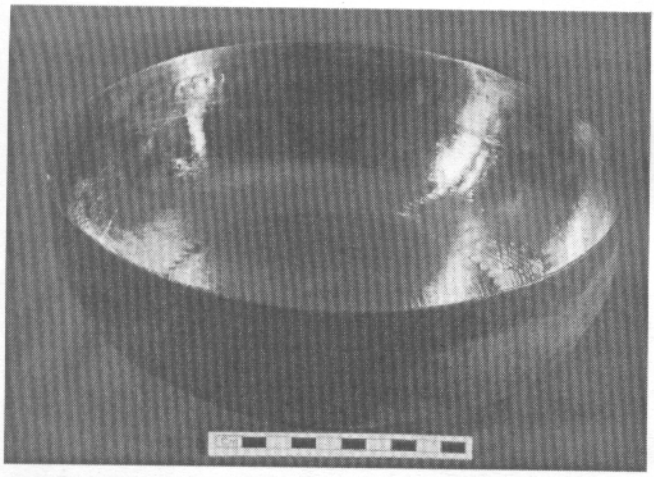
The author is currently investigating a few vessel fragments and artefacts from the Vidarbha megaliths of Maharashtra, where some sites are dated to the 8th *c.* B.C. The micro-structure of a finial from Boregaon shows it to be a cast and quenched beta bronze with 21% tin, while some wrought and quenched beta bronze bowls from Mahurjhari have 18-19% 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% tin fully reached. They were not extensively worked or hot forged as the high-tin bronze vessels from the Iron Age megaliths of the Nilgiris and Adichanallur which show a stage of true mastery of the plasticity of the martensitic beta phase. Paramasivan (1941) published a photograph of a microstructure of a bowl from Adichanallur which is comparable to a quenched high-tin bronze. Two samples excavated from the Indus Valley site of Mohenjo-daro (*c.* 2500 B.C.) also had analysed of 22% tin-bronze (Mackay 1938: 480), although micro-structural data is not available. These finds may predate those hitherto known from elsewhere in antiquity. This may suggest a departure from well entrenched ideas (e.g. Craddock *et al.* 1989: 23) that the Indian subcontinent would have more likely received diffusionist bronze technologies or traded bronze from tin-rich Asia, especially Southeast Asia.

Links with Present-day High-tin Beta Bronze Bowl Making in Kerala

In 1991, the author documented the making of wrought and quenched high-tin beta bronze vessels, gongs, cymbals and ladles in Payangadi. Microstructural investigations on two bowls from Payangadi and Trichur confirmed that the largest concave bowls, of 25 cm diameter, 8 cm depth and 1.4 mm rim thickness (Fig. 9), were made out of a flat circular ingot of 22.5% tin of a diameter of only 15 cm, and 1.5 cm thick. This was done by forging in cycles of hammering and annealing followed by quenching between 600-700 °C, all in the a+b phase field (Figs. 5-8, please refer inside front cover). The inner surface of quenched bowls are often polished bright golden, to contrast with the exterior quenched skin (Fig. 9). My late grandmother, a householder interviewed in 1991, said that the *talavettu* (i.e. musical vessels due to the tonality of the b-martensitic alloy) were preferred to brass for storing food, very likely due to the non-toxicity of a high tin content and the alloy's corrosion resistance. She added that food was not heated in such vessels, probably due to the formation of an embrittling lower temperature phase upon cooling. Moreover, the inner part of the wrought bowls was decorated using hand-turned lathes creating concentric rings very similar to the megalithic bowls from the Nilgiris and Adichanallur. Thus, it was possible to extrapolate how the south Indian megalithic high-tin bronzes could represent a long standing local metallurgical tradition.

At the workshop of Kammalar Bhaskaran in Payangadi, an ingot was cast with an alloy of 10 kg of copper with 2.75 kg of vellium or tin, into a flat ingot with around 500 g extra tin added to compensate oxidation losses. The composition of the cast ingot has approximate 23% tin. The plasticity of the bronze with around 23% tin was exploited by heating it in the beta temperature range of about 600 °C following which it was placed on a stone anvil. Four craftsmen took turns in powerfully hitting it with wedge shaped iron hammers fitted into a wooden frame known as *cherangulam*. After about two cycles of hammering by high intensity blows, the ingot again was annealed in the beta temperature range. Further cycles of hammering followed till the flat ingot took a progressively concave shape. This continued all afternoon, until the bowl

** First reported in 1991 this activity has now sadly ceased to take place at this village.



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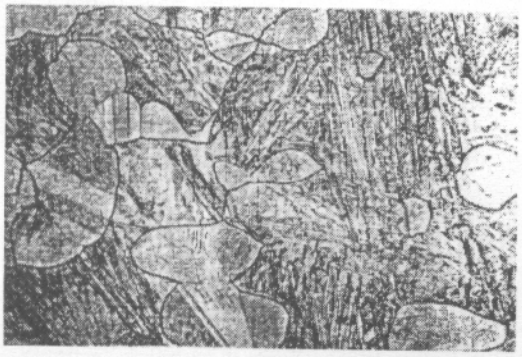

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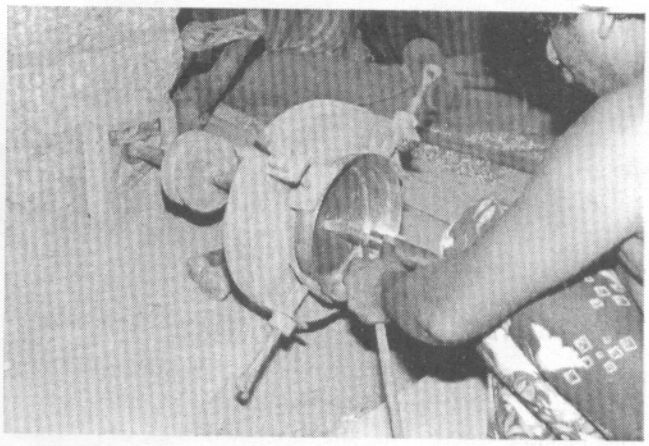

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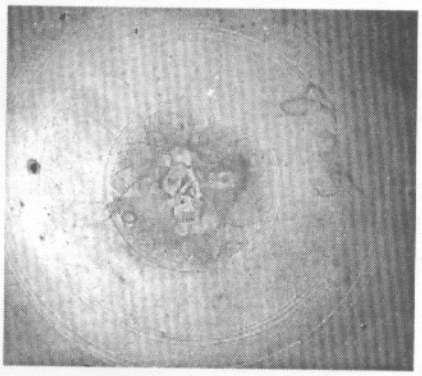

Fig. 12: Inner rings in vessel from Nilgiri megaliths, Government Museum, Chennai

At a crafts fair in Bangalore, the author also documented craftsmen from Kantilo in Orissa, who made smaller and shallower vessels which could be identified as being of high-tin bronze from the tonality, lustre and existence of one blackened face from quenching. The manufacture process described by 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 also recalls the Nilgiri vessels which are nevertheless much thinner and subjected to greater hot forging. Mukherjee (1987: 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 where small cups were made of high-tin bronze, although these were mostly as-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 subsequent field trip to Kerala in 1998, in Mallapuram district, it was found that traditional cymbals are still made using wrought and quenched beta high-tin bronze. Here the cymbals are not as extremely hot-forged as the bowls. The main aim seems to have been to quench the 23% 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 are roughly cast to an approximate concave shape by the open casting process in a sand mould. Thereafter they are finessed to a fine concave shape of about 10 cm diameter and 1 cm thickness after annealing the alloy and hot forging them in the temperature range of formation of the plastic beta phase. A hole in the centre is made by hot hammering with a long chisel to enable the two hand cymbals to be strung together for playing. The final polishing to bring out the bright golden lustre is done by filing following by hand polishing with polishing powders (Fig. 13-15). The cymbals used for traditional Bharata Natyam performance and other dances known as *tala* or *nattuvangam*. Cymbals such as these are depicted, for example, in a bronze Nataraja from Melaperumbulam (*c*. 12th century A.D.) and *tala* finds mention in Chola inscriptions. Flat gongs are also made of high-tin bronze. Given the tonality of high-tin bronze, it is possible that the musical effects of the high-tin bronze alloys were known in antiquity.

Re-examining the Milieu of Megalithic High-tin Bronzes

The emergence of urbanism in southern India and the factors leading to it are perhaps less well understood. The process of urbanisation from Neolithic or Megalithic stages seems to have come about later by about the 3rd century

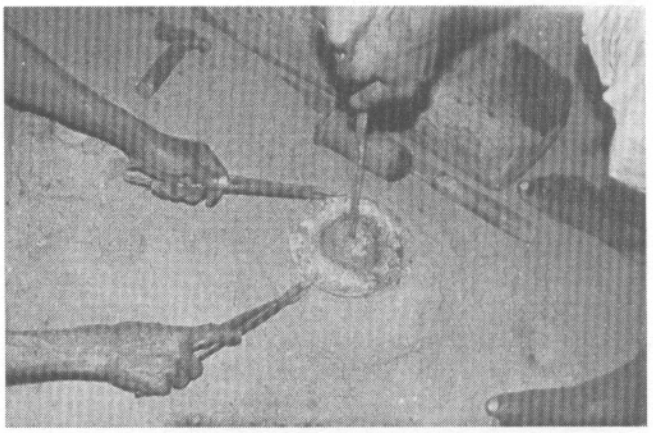

Fig. 13: Making of high-tin bronze cymbals, Mallapuram, Kerala: hammering of central hole of high-tin beta bronze cymbal when heated to temperatures of formation of plastic beta phase (c. 650 °C–750 °C)

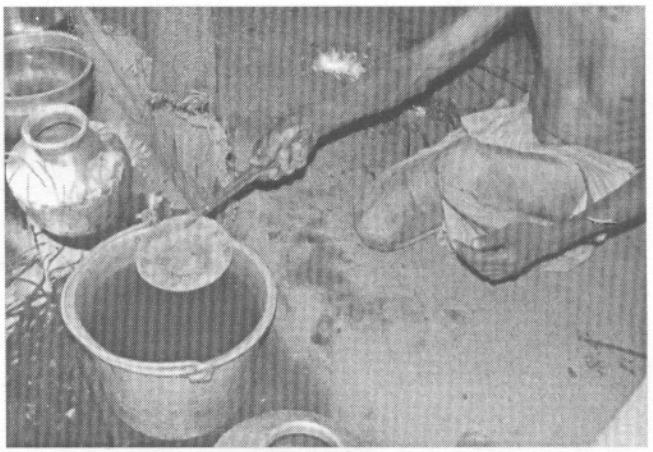

Fig. 14: Quenching of high-tin beta bronze (23% tin) cymbal, Mallapuram, Kerala

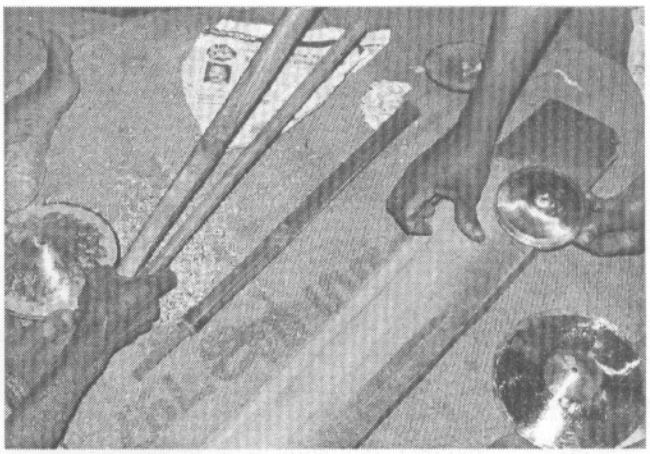

Fig. 15: Polishing and scraping of quenched high-tin bronze musical cymbals, Mallapuram, Kerala

B.C. with relatively few habitation sites having been found close to megalithic burials. However, it is interesting that even in the absence of typical urban characteristics such as structural remains, there is some evidence for other features associated with urbanism such as writing, literature and evidence of long distance exchange. For example, forms of graffiti or writing thought to be related to Tamil Brahmi are claimed to be found on potsherds from sites such as Kodumanal. Intriguingly, finds of writing resembling Tamil Brahmi were reported from three urns excavated in 2004 by T. Satyamurthy, ASI, Chennai, from the impressive urn burial site of Adichanallur that may date back to the 7th or 8th century B.C., and which may throw new light on the origins of writing in South Asia according to S. Deraniyagala of ASI, Sri Lanka (Subramanian 2004). Such finds may also have significance with respect to understanding the emergence of the fine but enigmatic corpus of Tamil Sangam literature, loosely dated to the 5th century B.C. to 5th century A.D. That the early Sangam era may have coincided with the iron age megalithic period (first millennium B.C.) is suggested by references to stone megaliths, including urn-burials and cist-burials (Narasimhaiah 1980: 188).

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 with sites in Tamil Nadu such as the megalithic burial-cum habitation site of Kodumanal (*c.* 300 B.C.) and in glass beads from Arikamedu until the 2nd century (Francis 2002). Finds of carnelian and of lapis lazuli from megalithic Kodumanal probably had their sources in western India and Afghanistan respectively. A copper alloy tiger figurine from megalithic Kodumanal inlayed with carnelian and lapis lazuli may be seen to share affinities with an early historic carnelian tiger found in Thailand and reported in Glover (1990).

The high sophistication of numerous vessels and gold jewellery uncovered from the Nilgiri cairns (loosely dated from about 1000-500 B.C.) and Adichanallur burials (*c.* 1000-800 B.C.) led scholars to speculate whether they were imported (Leshnik 1974, Knox 1985; Rajpatik and Seeley 1979), especially since the best documented studies on high-tin bronzes come from Ban Don Ta Phet in Thailand, *c.* 4th century B.C. However the author has argued (Srinivasan and Glover 1995, Srinivasan 1997b), as also indicated in this paper, that technical studies now suggest that it is most likely that the analysed vessels, which were of high-tin beta bronze, were of local provenance. This is also supported by evidence of a long standing local tradition continuing to the present-day especially in Kerala. In fact, the Nilgiri and Adichanallur vessels rank amongst the most elegant and early examples of high-tin bronze metalware. The collection of vessels from the Nilgiri hoards in the British Museum numbers no less than 40, and in particular comprise elegant fluted, knob-based and carinated vessels with concentric rings, etc. The elongation and degree of hot forging in these samples is far greater than that seen in the high-tin bronzes from Thailand suggesting a greater mastery of the technique 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 (*c.* 4th century B.C.). This suggests that maritime interactions between southern India and southeast Asia were prevalent even in an era predating the better documented Roman maritime trade.

Although it was previously thought that due to the scarcity of tin in south India, skilled bronze traditions may have not been supported, the analyses of old slags from Kalyadi, Karnataka by the author suggest otherwise. In fact Maloney (1975) suggests that a reference from Solomon's time concerns the export of tin from the coast of Karnataka. The Dambal region of Karnataka is reported by GSI-Bangalore Circle to have had sparse tin reserves and it may be noted that if alluvial tin had been mined completely, it would not leave many traces.

Ray (1996) has suggested that rather than primarily attributing social change in peninsular India to Mauryan intervention, 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 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 the origin of settlements. Tamil Sangam works such as the *Ettuttokai* refer to a prosperous people living in Tamil Nadu and Kerala who had seafaring trade with the Yavanas or Mediterranean people and with the island of Savakam, thought to be Java in Southeast Asia (Marr 1985). The above discussion also suggests that the existence of skilled metallurgical or craft techniques need not necessarily be linked with settled urbanism and indeed, even till recently in India, many crafts such as metal crafts were practiced as an itinerant or migrant trade.

Postulating a Musical Significance for the Megalithic High-tin Bronze Vessels

While the megaliths themselves, not to mention the megalithic high-tin bronze bowls, remain an enigma, another matter for speculation is that of the function of these highly specialised bronze bowls. One possibility could have been ritual function, and indeed the notion of the raised knob-base surrounded by rings and the floral

lotus patterns seen on some Nilgiri bowls and links with bowls from Thailand, have made some commentators such as Glover (1990) speculate on ritual associations with Buddhism. This is seen from the decorations especially the raised knob-base and rings representing mount Meru in the centre. Of course, in practical terms, the functionality of high-tin bronze for storing food due to its less corrosive properties, has been observed by the author in Kerala.

However, a third possibility postulated by the author is that the vessels may have been used for their musical significance even as far back as the megalithic period. This is because the quenched high-tin bronze alloy is found to have good musical properties and is used for making cymbals even today. The grounds for suggesting that its musical properties may have appealed even in megalithic times comes from recent publications by Boivin (2004) that clusters of rocks with depressions from the Neolithic site of Kupgal in Karnataka in southern India could have been used for making ringing or percussion sounds.

Acknowledgements

The author would like to acknowledge the late Dr. Nigel Seeley, Dr. Ian Glover, Dr. Anna Bennett and Tom Chase for the valuable inputs and assistance, the Government Museum, Chennai and Prof. V.N. Misra, Deccan College for providing samples and assistance. The analyses reported in Table 1 by Electron Probe Micro-analysis was done at the Institute of Archaeology, London, and that on a vessel from Mahurjhari, at Freer Gallery of Art, Washington DC.

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