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Research Article

INDIGENOUS METAL MELTING AND CASTING IN SOUTHERN AFRICA

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ABSTRACT

Metal casting involves melting a metal charge in a crucible, and pouring it into a mould with a predetermined shape. This is not generally thought of as an important aspect of metal working in pre-European southern Africa, but it played a role in the second millennium AD for producing ingots, blanks for rings and bangles, and rare objects of probable ritual significance. Casting was restricted to the non-ferrous metals, like copper and tin and their alloys, because indigenous bloomery iron technology could not produce large quantities of molten iron for casting. As far as we know, gold was not cast into moulds, although beads were fashioned by punching holes through spherical globules produced by melting. This paper presents metallographic and chemical analyses of the various products of metal casting, and summarizes what is known about indigenous casting technology in southern Africa.

Keywords: casting, melting, crucible, mould, ingot, copper, tin, brass, gold.

INTRODUCTION

Metal casting is the process of pouring molten metal into moulds with predetermined shapes. In the southern African context, this was restricted to metals which could be melted at temperatures achievable in an open crucible heated in a charcoal fire, with additional air provided by bellows. In practice, this meant casting was possible with locally produced tin and copper, and their alloy bronze, as well as imported brass (an alloy of copper and zinc) and other relatively low melting temperature alloys. There is evidence that gold was melted in crucibles to produce buttons and small spherical prills for further fabrication, but there is no evidence for gold casting by pouring into moulds. There is also no evidence for the systematic production of cast iron.

Despite the presence of metallurgy in southern Africa from early in the first millennium AD, all the evidence for indigenous casting in southern Africa comes from sites dated to the second millennium AD. These range in age from the 13th century AD levels at Mapungubwe (Vogel 1998; Meyer 1998) to 19th century AD sites at Phalaborwa (Miller *et al.* 2001), Marothodi near Rustenburg (Hall *et al.* 2006) and in KwaZulu-Natal (Maggs & Miller 1995) (Fig. 1). Research over the past 20 years has given us considerable insight into the technology employed by indigenous metal workers. This paper focuses on metal casting, to explore an aspect of indigenous metallurgy that may tell us something about technology transfer to southern African metal workers.

CASTING RESIDUES AND PRODUCTS

There are four principal kinds of evidence for casting technology recovered from southern African archaeological sites. In this context, crucibles are whole or fragmentary ceramic vessels in which metal was melted. No absolute distinction can be made between slagged potsherds and purpose-made crucibles, but there is no local evidence for specially formulated, highly refractory, clay-based crucibles. In some cases, broken domestic pottery sherds may have been used as skimmers, to remove slag or dross from the surface of molten metal. In either case, slag adhering to the ceramic often contains frozen droplets of metal, which allow chemical identification of the melt. Primary products of smelting can be metal that has solidified in the base of smelting furnaces, or spilled from them through cracks or air pipes. Casting spills are droplets of metal, either trapped in slag or loose, and dribbles of metal which have escaped from broken crucibles or been spilled during pouring, and then discarded. The object of pouring molten metal into moulds is to produce predetermined shapes. Ingots are destined for trade and remelting, eventually to produce cast blanks for forging or for final cast objects.

CRUCIBLES AND SLAGGED POT SHERDS

The earliest known southern African slagged sherds are from Mapungubwe, where large numbers of ceramic fragments with adhering slag have been recovered (Miller 2001a). A few of these have been investigated analytically. They consisted of ordinary low-fired pottery fragments which were used either as melting containers or as skimmers. It is difficult if not impossible to distinguish between the two. Both had adhering slag on inner surfaces and rims (Fig. 2), and portions of larger pottery fragments that originally may have been used as melting crucibles later could have been employed as skimmers. The samples analysed contained metal droplets, mostly unalloyed copper, but one contained iron droplets. This does not imply the production of cast iron at Mapungubwe. Iron droplets can form in the dross floating on molten copper, through the melting of iron inclusions in primary copper nodules remelted for purification or casting. These iron droplets become trapped in the slag-like dross when skimmed from the surface.

The analysis of slagged potsherds from Marothodi revealed the same process (Hall *et al.* 2006). Intensive production of copper took place at Marothodi, involving both primary smelting in earthen furnaces, and secondary refinement through melting in crucibles. There is no direct evidence of pouring into moulds at Marothodi, but the volume of production of copper makes it likely. We know from the excavation of secondary copper melting precincts at Marothodi that the crucibles were propped up on a circle of stones, with five to six of these crucible stands arranged in a circle (Hall *et al.* 2006: figs 8 & 9; Boeyens & Hall 2009: fig. 4). Presumably bellows driven charcoal fires were used to bring them to the melting point of the metal.

Slagged potsherds also constitute some of the evidence for gold melting. Sherds of domestic pottery with adhering slag containing droplets of gold have been reported from Great Zimbabwe and Thulamela (Fig. 3) (Miller 2002). Crushed gold-bearing quartz sand, or small granules of alluvial gold were melted in crucibles to consolidate the metal into usable

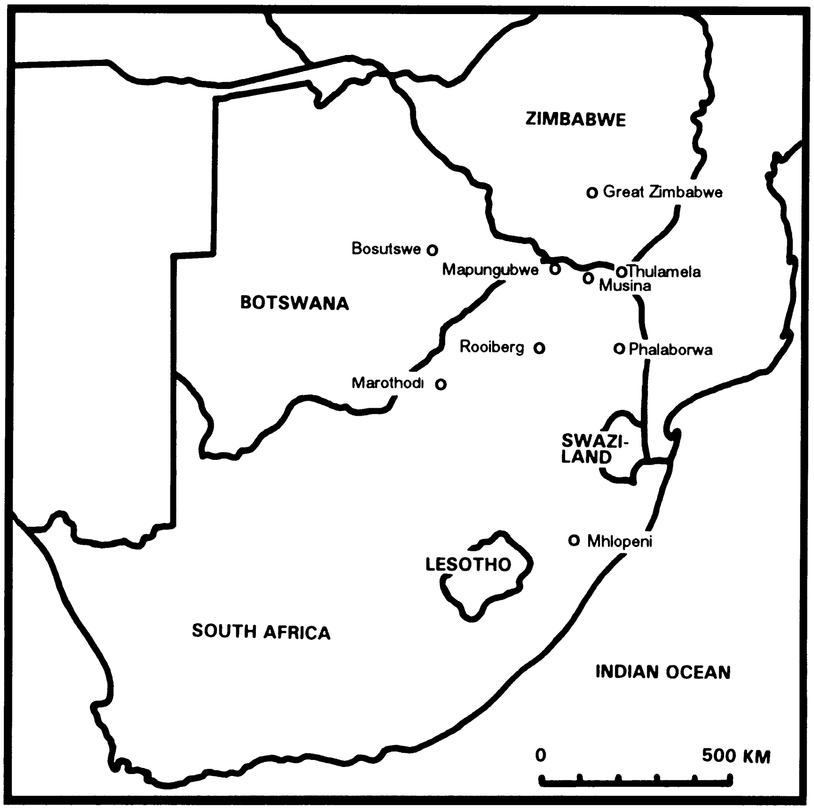

FIG. 1. *Map of southern Africa, showing the principal archaeological sites mentioned in the text.*

nodules or buttons. Such buttons have been found at Thulamela. There is no evidence though for casting molten gold into moulds, neither to make trade bars nor to cast ornamental items (Miller & Desai 2004). This may be because the temperature to melt gold was close to the maximum obtainable in an open charcoal heated crucible, which severely limited the volume of metal that could be melted at one time. At Mapungubwe and Thulamela some of the gold beads were made by producing small round prills, either by pouring molten gold into agitated water, or more probably by melting small pieces of gold wire in a crucible packed with charcoal to form small spheres. These were punched cold from both sides with a four-sided steel punch ground to a fine point, to make the holes, many of which have tell-tale cracks emanating from the corners (Miller 2001a; Miller & Desai 2004).

Smelterskop at Rooiberg is littered with the remains of tin production, including vast numbers of slag-encrusted ceramic fragments (Chirikure, Hall & Miller 2007; Miller & Hall 2008; Chirikure *et al.* 2010). Most of these are slagged tuyere tips, although some appear to be pieces of furnace lining. No crucibles from Rooiberg have been identified, but two slagged potsherds from the nearby mid-17th century AD site of Rooikrans have been analysed. One contained copper droplets only, and the other contained droplets of both iron and tin bronze (Miller & Hall 2008). These mixed droplets represent either alloying or remelting of tin bronze at Rooikrans; the iron in this case originating in either the copper or the tin. Again, there is no direct evidence for casting the metal into moulds at Rooikrans, but melting metal in crucibles is well attested there.

The final example of melting crucibles is from the 17th century AD site of Mhlopeni in KwaZulu-Natal (Maggs & Miller 1995). These are crucibles ground out of sandstone (Fig. 4). Chemical analysis of the glassy slag adhering to their interiors and rims indicated that they were used for melting imported brass. This process was continued into the 19th

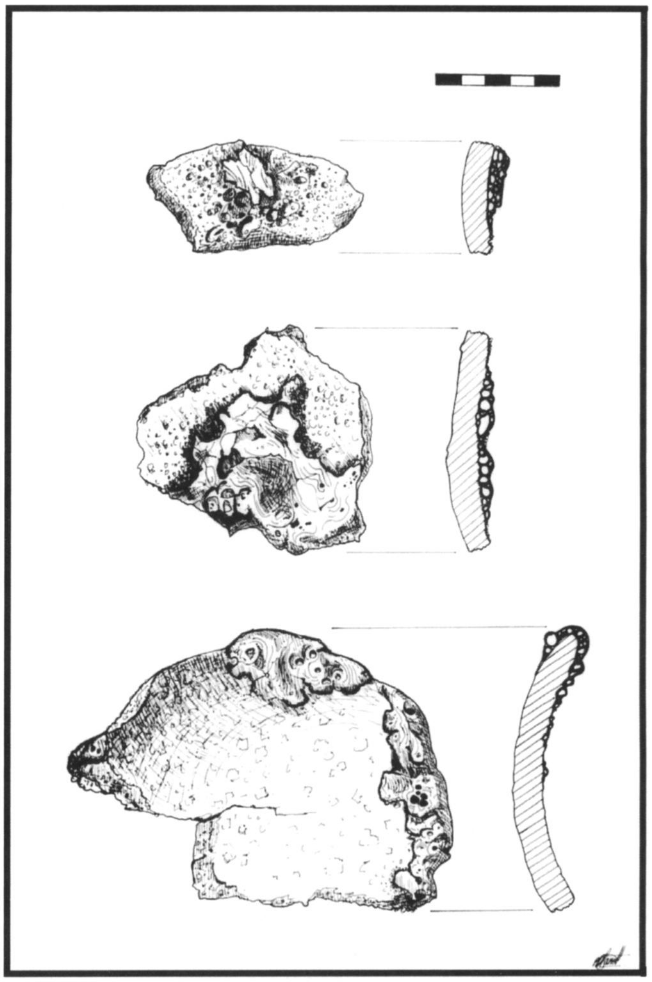

FIG. 2. *Drawing by Philip Barrett of three pottery sherds from Mapungubwe, showing slag adhering to the inner surfaces and in one case to the rim (scale divisions 10 mm).*

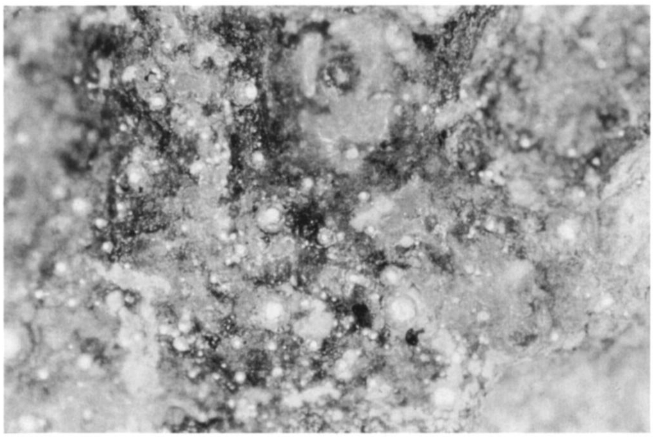

FIG. 3. *Gold droplets in a glassy slag adhering to the inside of a ceramic sherd from Thulamela (width of field of view 7 mm).*

century. At the Zulu royal capital of Mgungundlovu (1829–1838) similar sandstone crucibles were used to melt imported brass. This was then poured into variously shaped moulds to make high status ornaments for the court of the Zulu king, Dingane (Maggs & Miller 1995; Roodt 1993).

PRIMARY PRODUCTS OF SMELTING

Primary bun- or dish-shaped metal objects are known from numerous localities, many of them surface collections with no direct archaeological association. Exceptions are from Mapungubwe, SPK3 at Phalaborwa, and Thulamela (see Table 1). The Mapungubwe primary copper dish (M1234) (Fig. 5) was one of several described by Gardner (1963) from the lower levels of Mapungubwe Hill. The microstructure of a metallographic section was typical of such items, consisting of coarse dendritic copper grains with blue copper sulphides decorating the grain boundaries and forming some fine eutectic networks (Fig. 6).

The Thulamela copper bun (TM22) was recovered from between the stones of the wall of the principal compound. In section it was fairly dense, with very little porosity. The microstructure consisted of typical large primary dendrites of copper with dark blue, inhomogeneous, two-phase grain boundary sulphide inclusions which also formed areas of eutectic intergrowth with the copper. The copper grains also enclosed small bright spots, which could be exsolved iron.

FIG. 4. *Sandstone crucible from Mhlopeni, used for remelting brass (scale divisions 10 mm).*

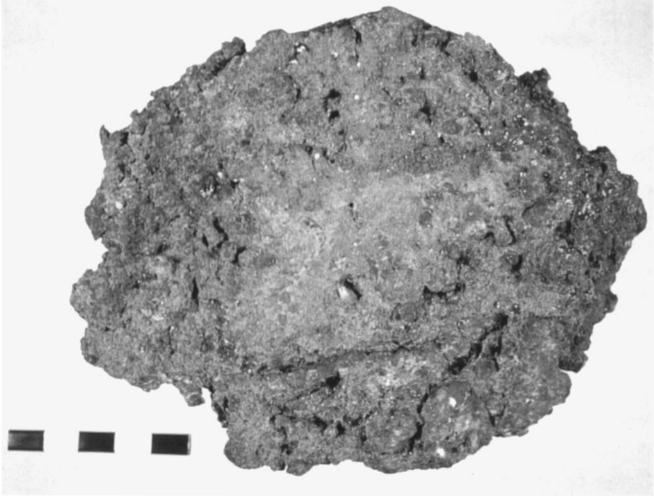

FIG. 5. *Copper dish from Mapungubwe (M1234) (scale divisions 10 mm).*

At SPK3 at Phalaborwa, two copper dishes (SPK3.A and SPK3.B) were excavated from an 11th to 12th centuries AD house floor, associated with a pot containing copper slag (Miller & Killick, in press; Miller *et al.* 2001). Both solidified on the concave floor of a smelting furnace and had adhering fragments of ceramic furnace lining, charcoal, and smelting slag. The microstructure consisted of coarse dendrites of pure copper with interstitial and grain boundary copper sulphide inclusions with a composition approximating chalcocite (Cu_2S), as well as a Cu-Cu_2S eutectic network. The presence of sulphide inclusions in this and other similar specimens does not imply the smelting of sulphide ores. The sulphide inclusions commonly seen in southern African smelted copper must derive from minor residual sulphides in the predominantly oxide and carbonate ores.

The Phalaborwa copper bun (University of Pretoria 22/99/1) measured 125 × 133 mm, and had been found on the surface of Kpololoane, a low ridge near Kgpolwe (J.C.C. Pistorius, pers. comm. 1992). In section it had considerable porosity and the edges of the sample were extensively corroded, with the devel-

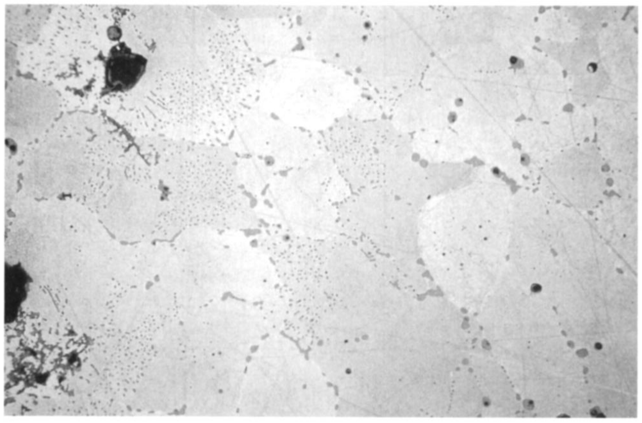

FIG. 6. *Polished section of copper dish from Mapungubwe (M1234), showing large copper grains with scattered globular copper sulphides, mainly along grain boundaries but also forming fine eutectic intergrowths with the copper (width of field of view 0.6 mm).*

TABLE 1. *Metal artefacts sampled and analysed metallographically.*

Provenance	Metal and object	Mass (g)
Great Zimbabwe (Z334)	tin/lead bar	98
Great Zimbabwe (Z335)	copper 'nail head'	124
Great Zimbabwe 2030 BD, Z4 5/D/2 (Z581)	tin bar	1545
Lekhona (Zimbabwe)	copper *musuku*	720
Lillie (IL-8.1220)	bronze nodule	–
Malaboch, Potgietersrust (Wits 14/47/1)	tin rod	110
Malaboch, Potgietersrust (Wits 14/47/2)	tin rod	110
Malaboch, Potgietersrust (Wits 14/47/3)	tin bar	1907
Mapungubwe (M1234)	copper dish	797
Musina	tin *lerale*	509
Mooihoek 381KS, Pietersburg (Arg 5175)	zinc bun	–
Phalaborwa (UCT PHA)	copper *lerale*	823
Phalaborwa (SPK3 A)	copper dish	1137
Phalaborwa (SPK3 B)	copper dish	1077
Phalaborwa (Verwoerd A)	iron & copper nodule	–
Phalaborwa (Verwoerd D)	copper rod	–
Phalaborwa, University of Pretoria (22/99/1)	copper bun	660
Pretoria rubbish dump (PRE)	copper *lerale*	1138
Rooiberg (Wits 21/39/1)	tin bun	796
Rooiberg (Wits 21/39/2)	20% As copper dish	1609
Rooiberg (Wits 21/39/3)	tin bun	2143
Rooiberg, 'Blaauwbank' (Wits 21/39/6)	9% As copper nodule	–
Soutpansberg, Vogelstruis farm (MU1)	copper *musuku*	2227
Thulamela (TM22)	copper bun	2407
University of Pretoria (22/99/2)	cast iron bun	2660
University of Pretoria	tin bar	–
Phalaborwa (Wits 55/45)	copper *lerale*	574

opment of secondary cuprite. The microstructure consisted mainly of a coarse dendritic network of copper, with sparse, exsolved iron droplets. There were dark inhomogeneous two-phase grain boundary sulphide inclusions with an internal eutectic structure. Dispersed within the copper grains there were also lighter blue primary dendrites forming clusters of rounded globules, which were isotropic and single phase. These were probably cuprite. Neither the microstructure nor the chemistry was significantly different from the SPK3 dish-shaped items.

Phalaborwa has also produced a remarkable bimetallic nodule (Fig. 7), first described by Verwoerd (1956). It has been reanalysed and described by Miller & Killick (in press):

> It is layered, with a copper layer about 16 mm thick and an iron layer about 6 mm thick. The iron layer is brittle, with cracks extending into the iron from the copper/iron interface. The bottom of the copper layer has open porosity and encloses quartz grains and blobs of slag. The slag inclusions contain small fragments of partially reacted magnetite ore, silicate laths, and patches of glass containing silicate and leucite dendrites with a few copper droplets. Both the quartz grains and the slag were probably detached from the floor of the furnace, and were trapped by solidification while rising through the denser molten copper. The copper layer contains about 3% iron, 1.5% sulphur, and 0.5% phosphorus, with three different types of inclusions. The first are dendrites of a copper-iron sulphide which forms a eutectic with the copper; the second are globular blue copper-iron sulphide inclusions showing mesh-like exsolution textures; and the third type is light blue and is iron phosphide (Fe_3P). The copper/iron interface is irregular, with interfingering of the copper and iron. The iron layer contains 12% phosphorus. The microstructure shows large dendrites of iron, and copper in a eutectic. The continuous phase of the eutectic is a copper/iron sulphide, while the discontinuous phase is iron phosphide. The iron also contained some primary dendrites of the same copper/iron sulphide phase described above for the copper layer. This unique object appears to be the accidental product of co-smelting copper ore with a magnetite flux and a phosphate mineral, probably the bright blue-green apatite typical of the Palabora ore body. The consequence was to form a liquid iron/phosphorus alloy immiscible with molten copper; these separated into a lighter iron-phosphorus layer and a denser copper layer. The hybrid nodule, with iron too brittle for use and copper heavily contaminated with iron phosphide, was evidently discarded as useless.

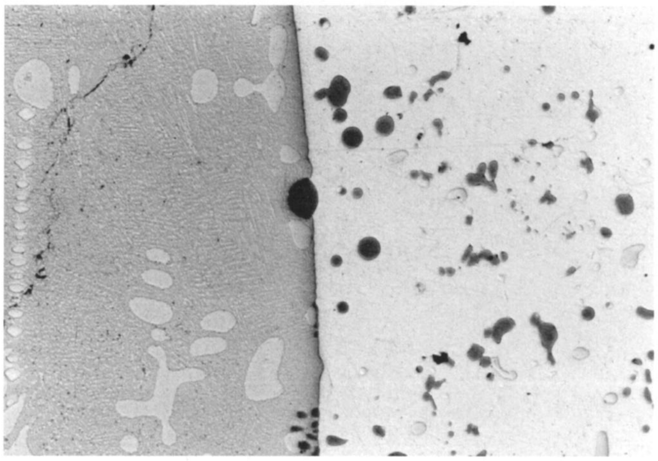

FIG. 7. *Polished section through the bi-metallic interface of Phalaborwa nodule 'Verwoerd A', showing darker iron and lighter copper, with iron phosphide inclusions in the former and copper sulphide in the latter (width of field of view 0.7 mm)*

Experimentation, and the production of accidents, was also happening at Rooiberg (Grant *et al.* 1994; Chirikure *et al.* 2007; Miller & Hall 2008). The remains of copper smelting in Blaauwbank Donga included slag waste from the production of arsenical copper, including an irregular finger-like nodule of 9% arsenical copper (Wits 21/39/6) (Fig. 8). Given its volume, it must represent leakage from a smelting furnace.

An arsenical copper dish-shaped object from Rooiberg (Wits 21/39/2) has been the subject of much analysis and speculation (Grant *et al.* 1994; Miller & Hall 2008). This is plano-convex, with an ochreous brown exterior (Fig. 9). It is about 35 mm deep, and about 105 mm by 130 mm in plan, with numerous sampling holes, two of them drilled right through. Broken surfaces reveal a very coarse grained structure, silvery white, rapidly tarnishing to a light yellow. The mass before the

FIG. 8. *Arsenical bronze nodule from Rooiberg (Wits 21/39/6) (photograph courtesy of Simon Hall).*

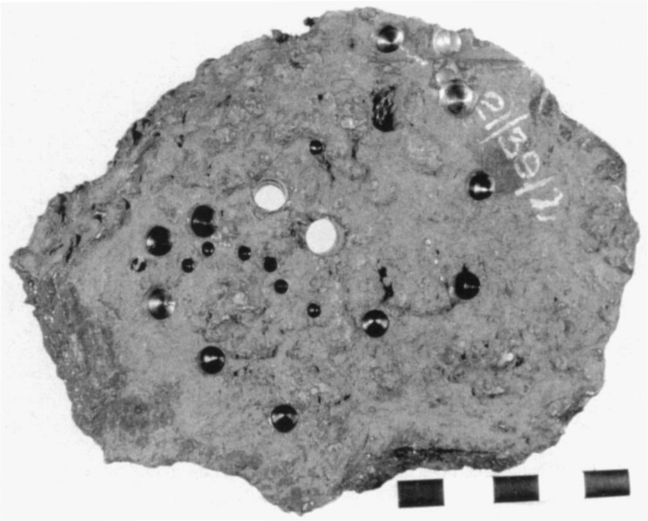

FIG. 9. *Rooiberg arsenical bronze (Wits 21/39/2) (scale divisions 10 mm).*

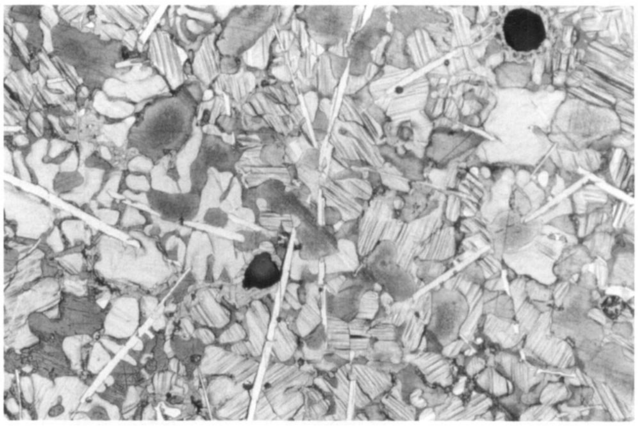

FIG. 10. *Polished and etched section of Rooiberg arsenical bronze (Wits 21/39/2) showing its complex, poly-phase microstructure (width of field of view 0.5 mm).*

most recent metallographic sampling was 1608 g and a 15.8 g sample was removed.

The chemical analysis of two 2 mm squares by energy dispersive X-ray fluorescence spectroscopy (EDS) showed that this was arsenical copper with a measured bulk composition of about 24.7% arsenic. (Published analyses of this object vary considerably, due to its inhomogeneity and very coarse crystallization.) The composition is close to the copper-arsenic eutectic of 21% at 685°C (Scott 1991: 124), representing the minimum melting point. The microstructure was dominated by very coarse dendritic crystals, best seen under crossed polarized light, and occupying 45.4% of the volume, based on a 500 point count (Fig. 10). They were anisotropic and a pale pinkish brown in reflected light. Etching with $FeCl_3$ solution showed them to be cored and in the scanning electron microscope they appeared granular with small brightly reflective dot inclusions which may be exsolved iron. This phase was the copper-rich alpha phase. The primary dendrites were coarser towards the edges of the object, due to preferential copper segregation in the first parts of the melt to freeze. Two small area analyses of this phase gave different values, as would be expected from these large cored and inhomogeneous dendrites, with arsenic ranging from 12% to 17.5%. The other major phase occupied 44.8% of the volume, was blue with strong bireflectance, and strongly anisotropic from light yellow grey to deep blue. In the optical microscope twinning was visible at high magnification, and when etched in $FeCl_3$ solution these grains displayed pervasive twinning, or possibly martensitic transformation. This was the arsenic-rich beta phase with about 33% arsenic. In addition to these two dominant phases there were numerous thin lath-like crystals, possibly of two different types, together occupying 9.8% of the volume. The thinner were purplish violet, with a light blue through purple blue bireflectance in air, distinct anisotropy from steel grey to dark brownish purple, and parallel extinction. They were partly resorbed, fractured and embayed, and must represent a high temperature phase. The thicker laths were more irregular. These appeared a slightly lighter purple, with more subtle bireflectance and a strong deep purple to slightly lighter purple blue anisotropy. In reality these are probably the same phase and the difference in appearance is due to the relative size of the crystals. Two spot analyses revealed that these were a copper/iron/arsenic phase; possibly a cupriferous form of leucopyrite (Fe_3As_2) which is orthorhombic, white, and strongly anisotropic with polarization colours of greenish yellow, purple and dark brown, and is inert in $FeCl_3$ (Short 1940: 162). There were very minor amounts of another phase, which appeared to be intergrown with the beta phase, and was distinguished by a distinct pinkish to yellow birefringence. This was a copper-rich phase containing a few percent tin, which is not surprising since Rooiberg was a tin mining area.

Analysis of ores from the Blaauwbank Donga at Rooiberg has revealed the presence of arsenical malachite and the arsenic/copper mineral olivenite, presumably the original ore from which this object and the Blaauwbank smelting spill were produced (Miller & Hall 2008). At an eutectic composition, the arsenical copper would have been too hard and brittle to have been of any use, and evidently was discarded.

CASTING SPILLS

The material recovered from the lower levels on top of Mapungubwe Hill included numerous prills or nodules of copper (Miller 2001a). These were heavily corroded, but the metallographic analysis of the cores of eighteen of them showed that they consisted of copper with minor cuprite and copper sulphide inclusions. Chemical analysis by EDS showed no detectable alloying elements in any of them. Sulphide inclusions in two of them were found to contain up to 4% selenium and 1% tellurium. (This should provide a traceable geochemical signature, but the actual source of this copper remains unknown.) Early in the occupation of the hill-top, copper was melted and worked on the site.

An irregular bronze-coloured nodule of copper alloy from Mapungubwe (Fig. 11) was a casting spill with a composition of 66% copper, 25% lead, 6% zinc and 3% tin by weight (Miller 2001a). This is very similar in composition to a cast *'kohl stick'* from the Swahili site of Ungwana in Kenya, with approximately 64% copper, 28% lead, 3% zinc and 7% tin, presumed to be imported from outside sub-Saharan Africa (Kusimba *et al.* 1994). Because there is no archaeological evidence for the primary production of zinc or lead in southern Africa, four copper bangles and another casting spill from Mapungubwe were analysed to compare with the leaded brass nodule. They consisted essentially of pure copper with no other detectable elements.

The site of Bosutswe, in central Botswana, has also produced evidence of bronze melting (Miller 2003a,b). This was in the form of a small nodule of dross or metal oxide scum (B481, mass 10.2 g, Sn 30%) from the top of a metal melting crucible. It consisted of large droplets of tin-free copper associated with cuprite (Cu_2O), and containing skeletal crystals of cassiterite (SnO_2), both formed by oxidation of the heated metal exposed

FIG. 11. *A nodule of leaded brass alloy from Mapungubwe (Wits collection B.7 S.6 14.17.7) (scale divisions 10 mm).*

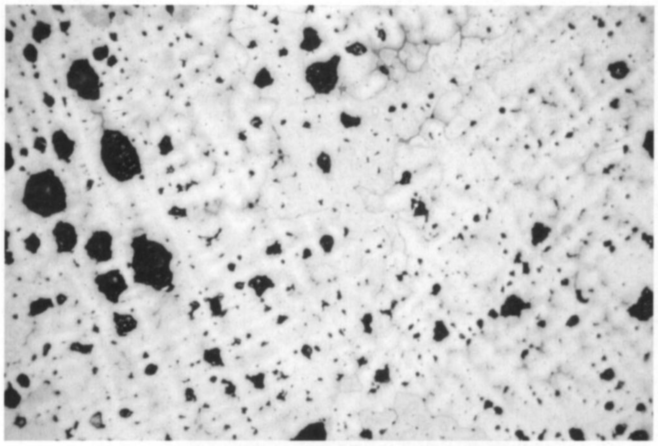

FIG. 13. *Polished and etched section through a bronze nodule from Bosutswe (B3), showing the coarse dendritic structure and dark holes due to gas porosity (width of field of view 2 mm).*

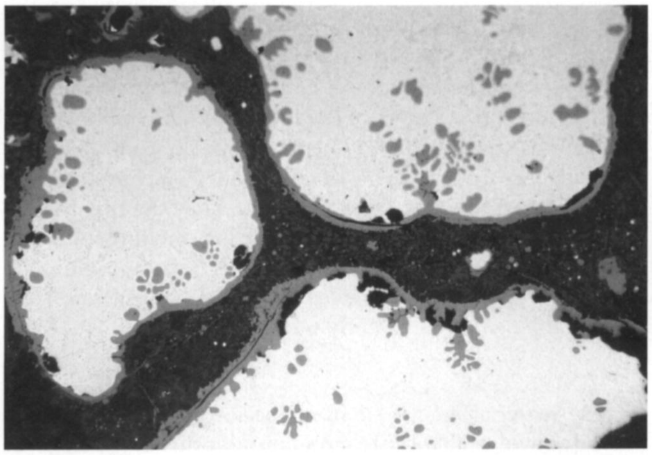

FIG. 12. *Polished section through a nodule of bronze melting dross from Bosutswe (B481), showing light copper droplets containing dark globular dendrites of cuprite, in a felted matrix of cassiterite, cuprite, delafossite and black glass (width of field of view 1 mm).*

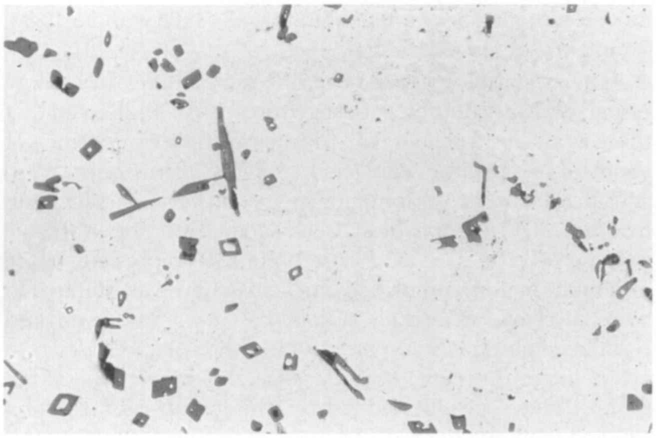

FIG. 14. *Polished section through a bronze nodule from Lillie near Phalaborwa (IL-8), showing dark skeletal cassiterite crystals (width of field of view 0.7 mm).*

to air (Fig. 12). There was also a fine grained intergrowth of cassiterite and delafossite ($CuFeO_2$), associated with copper, cuprite, and black glass. This was evidence that the bronze had been melted in a crucible. The product was represented by a bronze nodule (B3, mass 4.2 g, Sn 8%), with large dendritic alpha grains, some delta eutectoid between the dendrites, and a few rounded dark blue sulphide inclusions (Fig. 13). This was a normal unworked, cast microstructure, presumably a discard or spill from melting and casting bronze, which may have been produced locally or originated elsewhere (Miller 2003a,b).

A similarly isolated small bronze nodule (IL-8.1220) was found in 1972 on the farm Lillie, in the Mashishimale Hills in the Lowveld near Phalaborwa (Miller & Killick, in press). This was a 5.5% tin bronze, with a coarse primary cast dendritic structure, and inclusions of skeletal crystals of cassiterite which had formed by oxidation of the bronze when molten in an open crucible (Fig. 14). With no other evidence of bronze production in the area, this probably represents an import from the tin production centre of Rooiberg.

The mid-13th century site of SPK3 on Kgpolwe hill near Phalaborwa has produced two copper prills (SPK3.3) with a combined mass of 2.73 g. They were greenish brown, smoothly globular on one side and irregular on the other, and not magnetic. The larger one, about 28 mm long, 12 mm wide and 3.5 mm thick, was analysed and found to consist of very pure copper dendrites in a copper/cuprite eutectic characteristic of melting in an open crucible (Fig. 15). These prills were probably spilled during the remelting of copper in a crucible. During melting of a relatively small quantity of copper in an open crucible exposed to air, the sulphide inclusions float to the surface and can be skimmed off, while some oxygen dissolves in the molten copper to form characteristic cuprite grain boundary inclusions and the cuprite/copper eutectic on cooling (Miller & Killick, in press).

INGOTS

Rectangular section copper bars with projecting heads on one side, so-called 'Schroda-type' or 'nail head' ingots and reminiscent in shape of modern coco-pan rail nails, have been found at several sites in the Limpopo Valley and further north. A metallographically studied example from Great Zimbabwe (Z335) weighed 124.4 g (Fig. 16). It had a primary cast microstructure with large copper dendrites with sulphide inclusions, and contained 3% iron. This was made out of unrefined copper, and presumably was destined for trade (Miller 2002).

The major production at Rooiberg and its vicinity was tin (Chirkure *et al.* 2007; Miller & Hall 2008; Chirikure *et al.* 2010). Several tin ingots, from Rooiberg, Musina, and Great Zimbabwe, have been analysed metallographically (Table 1). They all display very similar microstructures and their trace element chemistry suggests that they all originate at Rooiberg

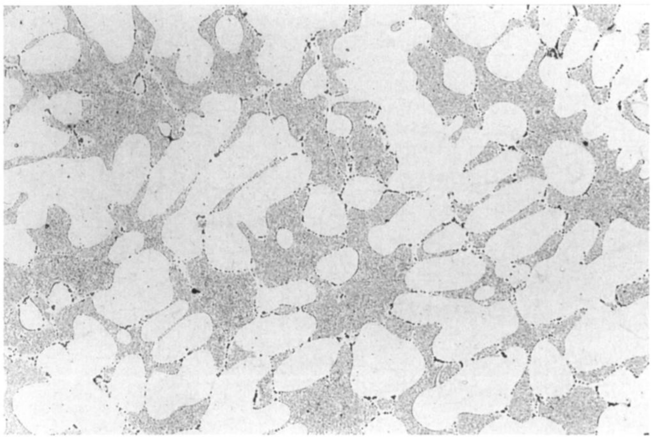

FIG. 15. *Polished section through a copper nodule from SPK3 (SPK3.3), showing globular copper dendrites in a matrix of copper/cuprite eutectic (width of field of view 1 mm)*

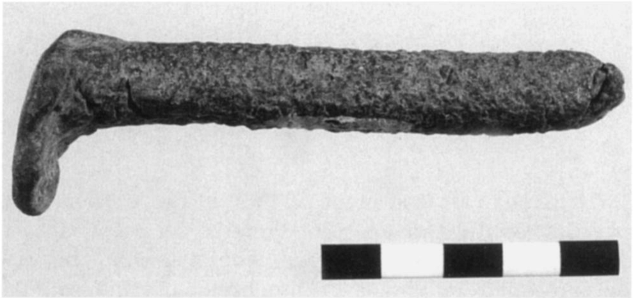

FIG. 16. *A nail head copper ingot from Great Zimbabwe (Z335) (scale divisions 10 mm).*

FIG. 17. *Rooiberg tin bun ingot (Wits 21/39/3) (scale divisions 10 mm).*

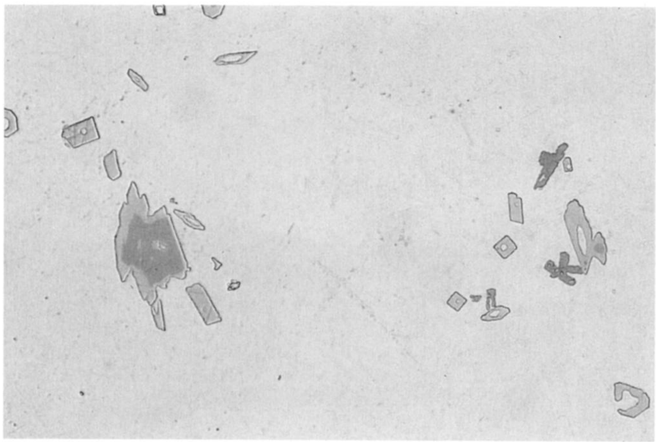

FIG. 18. *Polished section of Rooiberg tin bun ingot (Wits 21/39/3) showing typical microstructure of the tin matrix with darker tin/iron intermetallic compounds known as 'hardhead' (width of field of view 0.15 mm).*

(Grant 1999; Miller & Hall 2008; Chirikure *et al.* 2010). In shape they differ considerably. The two tin ingots from Rooiberg itself (Wits 21/39/1 and Wits 21/39/3) are plano-convex bun ingots, slightly longer than wide and presumably solidified in a bowl-shaped crucible (Fig. 17). The microstructure of Wits 21/39/3 exemplified that of all the tin ingots, consisting primarily of tin, with variable amounts of the tin/iron intermetallic compounds collectively known as 'hardhead' (Fig. 18; Table 2). The Malaboch rods (Wits 14/47/1 and Wits 14/47/2) found near Potgietersrust are nearly identical to each other in weight and shape, being long slender rods, rounded on the bottom and flat on top, which must have been cast into prepared moulds. The Malaboch bar (Wits 14/47/3) is a sturdy bar with two projecting horns or studs, one at each end (Fig. 19). This is similar to the Great Zimbabwe bar ingot (2030 BD), but this one lacks the terminal projections (Fig. 20).

Several other ingots studied, two of lead pewter, one of zinc, and one of cast iron, have been presumed to be imports, simply because of the lack of any primary evidence of the production of zinc, lead, or cast iron in pre-European southern Africa. At Bosutswe, a corroded lead ingot (B483) was recovered from an early Zimbabwe period level (Fig. 21). It was a small cylindrical slug with a mass of 24.1 g, containing 84% lead, 12% tin, 3% silicon (probably sand trapped in the corrosion product), and somewhat less than 2% copper. This is a lead solder composition and is comparable with the lead finger ingot recovered from Great Zimbabwe (Z334) with 77% lead and 23% tin (Miller 2002) (Fig. 22). Their provenance is unknown. A superficially similar cast bar from the Swahili site of Ungwana on the Kenya coast has the inverse composition of about 80% tin and 20% lead (Kusimba *et al.* 1994).

A locally unique zinc ingot (Arg 5175) was found in a cave on the farm Mooihoek 381KS in the Pietersberg district (currently Thabamoopo district), and presented to the National

TABLE 2. *Point count analyses, in per cent, conducted on tin ingots under the optical microscope, with 500 points at 0.05 mm increments (from Miller & Hall 2008).*

	White tin matrix	Dark FeSn	Light $FeSn_2$	Arsenical inclusions	Speckled eutectic
Rooiberg bun ingot (Wits 21/39/1)	97.2	0.6	2.2	–	–
Rooiberg bun ingot (Wits 21/39/3)	97.2	–	2.2	0.6	–
Malaboch rod ingot (Wits 14/47/1)	98.6	0.2	1.2	–	–
Malaboch rod ingot (Wits 14/47/2)	99.6	–	0.4	–	–
Malaboch bar ingot (Wits 14/47/3)	99.8	–	0.2	–	–
Zimbabwe bar ingot (Wits 2030 BD1)	94.8	–	0.2	–	5.0
Musina *lerale* (from Killick 1991)	83.8	5.2	11.0	–	–

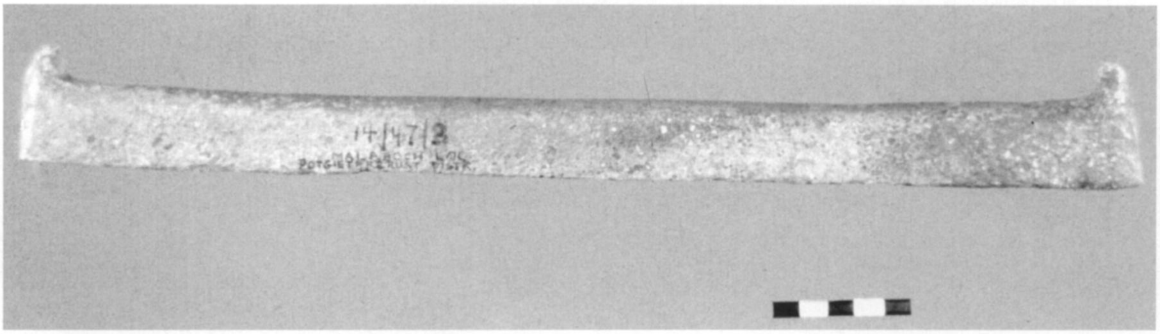

FIG. 19. *Tin bar ingot from Malaboch, near Potgietersrust (Wits 14/47/3) (scale divisions 10 mm).*

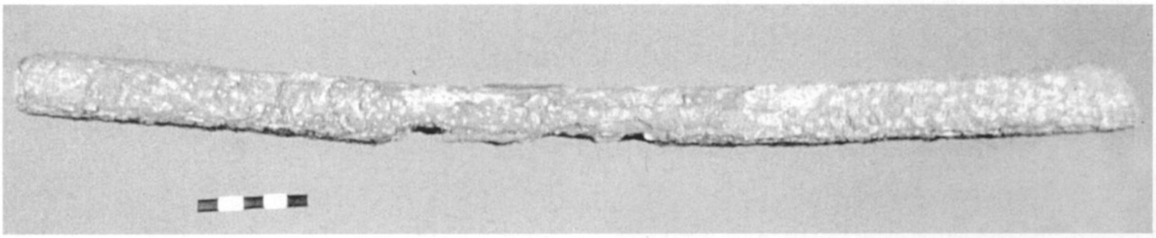

FIG. 20. *Tin bar ingot from Great Zimbabwe (2030 BD) (scale divisions 10 mm).*

FIG. 21. *Lead pewter ingot from Bosutswe (B483) (scale divisions 1 mm).*

Cultural History Museum around 1930 (J. van Schalkwyk, pers. comm. 1997). It is 330 mm long, 105 mm wide, 43 mm thick, and the original weight unknown because of prior sampling (Fig. 23). According to Paul Craddock, then of the British Museum, the dimensions are 'identical to Chinese ingots recovered from the EIC Diana sunk off Malacca in 1816 en route to Calcutta' (P. Craddock, pers. comm. 1997), pointing to China as the source of this ingot too. An EDS analysis revealed no detectable elements apart from zinc.

There is a cast iron ingot (22/99/2) in the archaeological collection of the University of Pretoria. Its provenance is unknown (J.C.C. Pistorius, pers. comm. 1992). This is a concavo-convex bun ingot, 155 mm by 130 mm in maximum dimensions, and with a mass of 3.01 kg. There are shallow radial grooves on the upper surface due to cooling contraction. A metallographic sample showed that this was an ingot of unworked grey cast iron, with normal flake graphite in a matrix of ferrite and nodules of pearlite. Apart from its shape and size which were similar to those of indigenous buns of tin and copper it had no features that allowed it to be distinguished from material of modern European or South African manufacture. If this is indeed a pre-European archaeological artefact, it indicates that not only zinc and copper based alloys were being imported into southern Africa.

CAST OBJECTS OF SPECIAL INTEREST

At both Mapungubwe and Phalaborwa copper was cast into small bars for further working into rings and bangles. Examples from the Kgpolwe sites at Phalaborwa are small copper bars (Fig. 24) with cast microstructures consisting of large, rounded copper dendrites, with globular interdendritic cuprite inclusions. In some cases the copper/cuprite eutectic network was deformed by subsequent cold work, but is still clearly visible (Fig. 25) (Miller & Killick, in press).

Copper castings in the form of the golf club-like *marale* (singular: *lerale*) characteristic of copper production in the Lowveld and in the form of the top hat-like *metsuku* (singular:

FIG. 22. *Lead pewter ingot from Great Zimbabwe (Z334) (scale divisions 10 mm).*

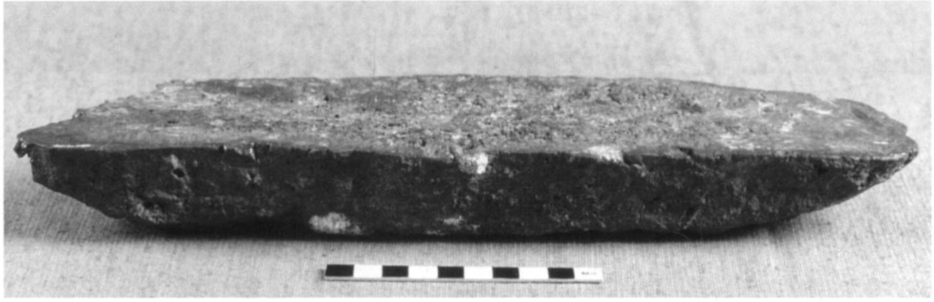

FIG. 23. *Zinc ingot from the Thabamoopo (Pietersberg) district (Arg 5175). Photograph courtesy of J. van Schalkwyk (scale divisions 10 mm).*

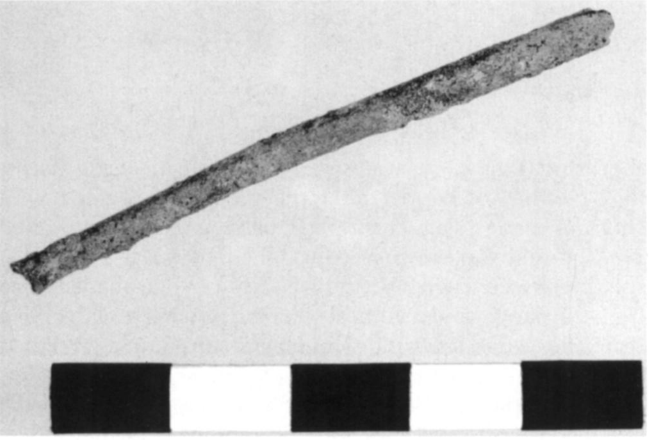

FIG. 24. *A small cast copper bar from Phalaborwa (MN5.1) (scale divisions 10 mm).*

musuku) typical of the Musina area have been found in the Soutpansberg and along the northern Transvaal trade routes used in the early historical period (de Vaal 1984, 1985; Miller 2003c). There has been much speculation about the meaning and function of these castings and they have been seen variously as trade goods or ceremonial objects (Virchow 1893; Stow 1905; Haddon 1908; Hemsworth 1908; Stanley 1910, 1929; Trevor 1912; Dicke 1926; Lindblom 1926; Stayt 1931; Thompson 1938, 1949, 1954; van Warmelo 1940; de Vaal 1984, 1985; Bloomhill 1963; Friede 1975; Steel 1975; Ackerman 1983; Eloff 1990; Killick 1991). Little is known about the age or social function of these artefacts, or the range of variation in their design, structure, or composition, despite the numerous descriptions of them (Miller & van der Merwe 1994).

FIG. 25. *A longitudinal polished section through the cast copper bar MN5.1, showing the residual cuprite grain boundary network deformed by subsequent cold work (width of field of view 0.7 mm).*

Marale are rods about 0.5 m long with cranked heads, some carrying variable numbers of projecting studs (Fig. 26). They are mostly associated with copper production at Phalaborwa and were cast into inclined hollows in sand, produced by burying and extracting an approximately 15 mm diameter stick and scooping out a shallow bowl at the top into which to pour the copper. The inclined hole allowed air to escape as the copper filled the rod. The bowl filled with copper to produce the off-centre heads, some of which were ornamented by projecting studs. Three copper *marale* were available for metallographic sampling. The Pretoria example was found by Dr Udo Küsel in a 19th century rubbish dump outside Pretoria (Fig. 26). This *lerale* had a shaft 500 mm long, 55 mm in circumference and about 15 mm in diameter. The head was about 55 mm in diameter and devoid of ornamental studs. The sample consisted of fairly dense cast copper dendrites with very little porosity. There was a grain boundary network of dark blue, isotropic sulphides, with a two-phase internal eutectic structure. There were also numerous other dendritic clumps of a light blue, homogeneous, isotropic phase, similar to the Phalaborwa copper bun (Pretoria 22/99/1).

The Phalaborwa *lerale* in the University of Cape Town collection was collected in the vicinity of Phalaborwa by Professor Nikolaas J. van der Merwe. This *lerale* had a shaft 495 mm long, 35 mm in circumference and about 13 mm in diameter (Fig. 26). The flattened conical head was about 60 mm by 40 mm across and 65 mm deep, and bore five ornamental studs each about 25 mm long and 8 mm in diameter. These were arranged symmetrically with four in pairs on the narrow sides of the head, and the other one on the 'inside' above the attachment of the shaft. The sample taken at the end of the rod was very porous, with large interdendritic porosity with secondary cuprite lining the open holes. There was a very low density of primary sulphide inclusions, and a network of sparse isotropic blue grain boundary sulphides.

The University of the Witwatersrand specimen was recovered from Phalaborwa by Dr Angus Armstrong of Westphalia, in the then Northern Transvaal. This *lerale* had a shaft 345 mm long, and about 40 mm in diameter, with a shallow squarish head about 55 mm by 44 mm without ornamental studs. The sample was very dense, with very low porosity. It had large primary copper dendrites, with a grain boundary network and eutectic areas consisting of single phase dark grey sulphide inclusions intergrown with the copper.

The Musina tin *lerale* is unique, being the only known example made of tin (Killick 1991). It has two projecting studs on the head (Fig. 26). A further tin ingot example, not analysed, is a sturdy tin bar with a keyhole cross-section, shown to David Killick and Nikolaas van der Merwe in 1978, and reportedly found on the farm Rooiwater in the Murchison Range, near Gravelotte (Miller & Killick, in press). Both of these probably originated at Rooiberg.

One of five copper rods found at Phalaborwa, previously

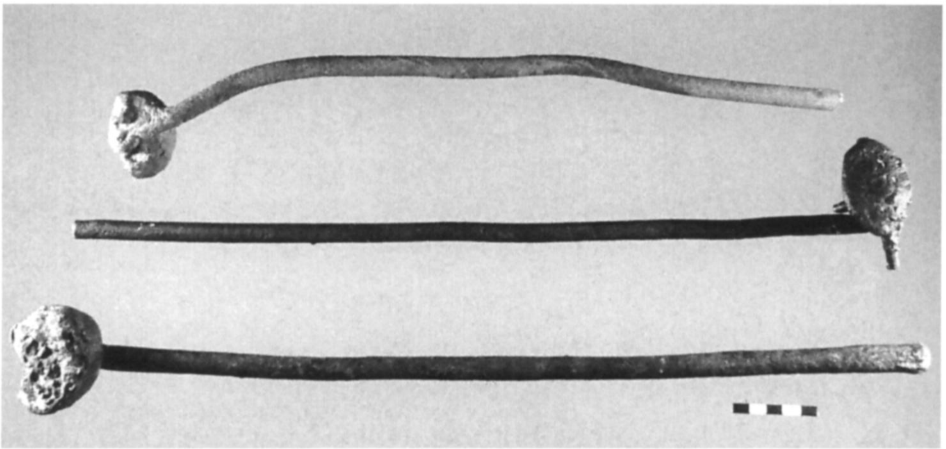

FIG. 26. *Three marale with long shafts and typically cranked heads. The upper one is made of tin and comes from Musina. The middle one is copper and was found near Phalaborwa. The lower copper one was found discarded in a 19th century Pretoria rubbish dump (scale divisions 10 mm).*

published by Verwoerd (1956), was analysed by Miller & Killick (in press). This was like a *lerale* rod, without its head. It consisted of coarse dendrites of copper with numerous grain boundary droplets of inhomogeneous copper sulphide or copper-iron sulphide inclusions. It contained about 2% iron and some of the copper-iron sulphide inclusions contained a few percent of selenium (Miller & Killick, in press). (If this can be shown to be a signature of Lowveld copper, then it has implications for the source of some of the Mapungubwe material). All *marale* have been surface finds, lacking any meaningful archaeological context. This includes those in museum collections, and despite voluminous speculation almost nothing is known about the age or social function of these artefacts (Miller & van der Merwe 1994; Miller *et al.* 2001; Miller 2003c; Miller & Killick, in press).

Metsuku are shaped like top hats, with the crown decorated with erect stubs, sometimes also present on the flange (Fig. 27). They also are of unknown social significance (Miller 2003c) but metallographic study ruled out the speculation that the mass was a casting raiser or essentially the waste product in manufacturing copper rods. The ends of the studs revealed a cast microstructure in section, so they were not residual; and most if not all the examples known are hollow, or filled with sand, pebbles, or slag. This points to their being deliberately designed and manufactured, presumably as ceremonial objects rather than trade goods. They were cast using successive pours of molten metal, and often fractured along the horizontal joins. The first pour filled the bottom of the sand mould, into which the impressions of the studs had been made with a small stick.

Successive pours encapsulated whatever filler was put in place in the shaft or body of the casting, and it was finally capped with a pour that formed the flared flange. In some cases this too was ornamented with studs. The numbers of studs correlate roughly with the size of the *musuku*: smaller ones weighing only a few hundred grams contain few studs, the larger ones of over a kilogram may have several rows with up to ten studs each.

The Soutpansberg copper *musuku* was collected by Dr B.J. de Vaal from the Farm Vogelstruis (22°50′S, 29°15′E) while he was inspector of schools for the former Transvaal Education Department. The casting had been broken into two pieces by the farm labourer who found it near the salt pan after which the Zoutpansberg is named (A. Meyer, pers. comm. 1990). The total height of the object was 120 mm, with a flange with a diameter of about 140 mm, and a squarish column tapering from a diameter of about 80 mm near the flange to about 67 mm by 72 mm near the top, which was ornamented with four rows of short studs (Fig. 27). The *musuku* had been made using at least four castings of copper, and the interior was filled with charcoal-bearing slag. The top half bearing the studs weighed 1137.9 g and the lower piece weighed 1089.5 g. Two metal specimens were sawn from the *musuku* – a wedge-shaped piece from the flange, and a vertical section down the length of one stud. The wedge, sawn into a number of sub-samples, weighed a total of 10.17 g and the stud section weighed 1.47 g. In addition seven pieces of slag with a total mass of 7.64 g were removed for polished thick and thin sections. A further 36.52 g of slag was removed to extract the charcoal for identification and AMS dating. The rest was ground for X-ray fluorescence analysis. The charcoal was identified as *Terminalia prunioides* (E. February, pers. comm. 1991). An AMS radiocarbon date calibrated to AD 1220–AD 1410 was obtained on the charcoal (Hedges *et al.* 1991). The artefact must have been manufactured

FIG. 27. *A copper musuku from the Soutpansberg (scale divisions 10 mm).*

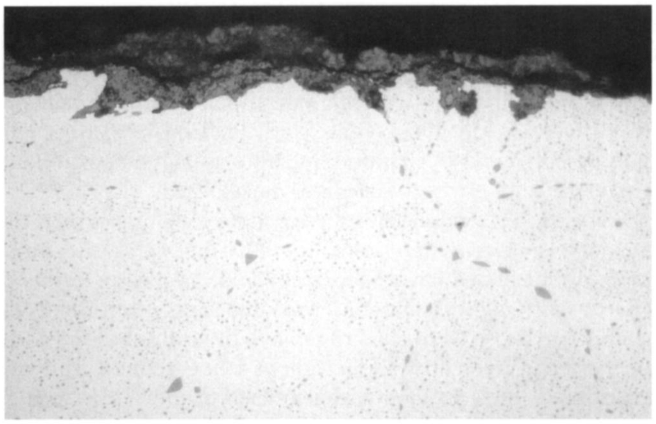

FIG. 28. *A polished section through the end of a stud on the Soutpansberg musuku, showing undeformed casting grains indicating that the stud was not truncated. The studs are deliberate ornamentations and not the residues of casting long rods (width of field of view 0.4 mm).*

sometime after this date, which represents the age of the wood used in making the charcoal. The *musuku* stud consisted of porous copper with a central casting void and numerous spherical gas bubbles. There were quartz grains embedded in the margins, owing to its having been cast in sand. The inclusions formed a grain boundary network of copper sulphides which also occurred in patches of eutectic intergrowth within some copper grains (Fig. 28). These were blue, and isotropic, without any internal reflections. There was no primary cuprite. The *musuku* flange sample contained portions of two casting layers. The one casting had a network of sulphide inclusions, less dense than in the stud, but likewise blue, isotropic and without internal reflections. The other casting layer was very porous, with some primary sulphide droplets, and plentiful secondary cuprite forming the corrosion product within the elongated open porosity originally created by escaping gas bubbles.

The Lekhona *musuku* was found in 1994 by Dr Nils Bergman on a hill (21°32′20′S, 28°56′23′E) in southern Zimbabwe. It consisted of very pure copper, with only cuprite inclusions. Evidently the metal was made from a very pure malachite source, with no residual sulphides. The density was measured by Dr Bergman as 4.8 hence this *musuku* too must be hollow or filled with some substance lighter than copper (density 8.96).

DISCUSSION

In order to assess the archaeological record of metal casting technology in southern Africa, we need first to summarize its nature. There is no archaeological evidence for the deliberate production of cast iron, i.e. molten iron, in the southern African archaeological record. All the iron artefacts studied metallographically are the product of smelting by the bloomery process, which results in a solid product, subsequently shaped by hot forging by a blacksmith (Miller 2002). The smelting of copper ores results in a melt, which in southern Africa appears not to have been tapped but allowed to solidify in the bottom of the furnace to produce primary metal 'dishes'. These were archived, traded, and broken up for the pieces to be reworked either by hot forging or remelting and casting into moulds. The forms of copper castings were very limited; bars of variable dimensions for reworking into rings or bangles, so-called 'nail head' ingots for trade, and the characteristically shaped *marale* and *metsuku*. The use of ordinary domestic ceramics as containers for melting copper meant that very limited volumes of melt could be produced, and castings were correspondingly limited in size. Pouring successive layers of metal, as in the larger *metsuku*, was the only means of making larger objects, which then were prone to fracture long the casting joins. Gold processing necessarily meant that it had to be melted into button-shaped nodules for subsequent working into jewellery or other high status items. The lack of highly refractory ceramics limited the size of individual buttons that could be produced, which in turn limited the size of the final artefacts. Gold was not joined with solder, but individual gold sheets were joined with gold tacks. Molten gold was not poured into pre-prepared moulds. Bronze was worked using techniques derived from copper and gold working, and bronze too was not cast into moulds. Tin was cast into a variety of moulds to produce ingots; buns, rods and bars of various dimensions. The only extant evidence for the use of anything but low-fired domestic pottery for the secondary melting of metal is in the case of the relatively recent carved sandstone crucibles used in the 19th century in KwaZulu-Natal to melt and cast imported brass.

What can we infer about technology transfer from the history of casting technology in southern Africa? As pointed out by Killick (2009a) it cannot be a coincidence that the first appearance of bronze, gold working, and imported metals is at Mapungubwe, where this accompanied radical changes in social structure and intensified contact with the Muslim east coast trade. This is evidence of a new value system in which the yellow of bronze and gold signified elevated status and usurped the former role of copper (Killick 2009a). Indirect contact with the Middle East, India and the Far East may have stimulated the local production of gold and tin, but it does not appear to have introduced any significantly novel metal fabrication technology. Even the most delicate gold items were made using a set of extremely simple techniques derived from copper working (Miller & Desai 2004), without any casting of finished objects. Throughout the second millennium AD, southern African metals were exported, without the adoption of any significant innovation in fabrication technology derived from external trading partners.

How can this lack of technology transfer be explained? All technological developments are historically contingent in the sense that they depend in part on pre-existing material and social circumstances (Miller 2001b), and the barriers to technology transfer can be both internal and external. Austen & Headrick (1983) have emphasized the need to consider 'technological systems' to explain African selectivity towards foreign technologies, not only in the realm of metallurgy: '…even when Africans were exposed to the technologies of supposedly more advanced societies, they had material and cultural reasons for not adopting most of them' (Austen & Headrick 1983: 175). We can only speculate about the cultural reasons that might have obtained a thousand years ago to inhibit the uptake of a more sophisticated casting technology, but one material explanation may be connected to the nature of indigenous ceramic technology. Low-fired domestic pottery was commandeered to act as crucibles, allowing the production of only small volumes of molten metal barely above its melting point. As the production of such pottery was the role of women, men may have been inhibited from experimenting with more refractory formulations to create purpose-made clay-based crucibles. By ethnographic analogy we might speculate that metallurgy was highly ritualized, which also may have inhibited the uptake of novel technologies that were not seen to add anything useful to the indigenous applications of metal. Where there was an external requirement, like the casting of readily portable ingots for trade, just sufficient innovation was adopted to meet this requirement. In addition, pure copper is notoriously difficult to cast because of its high surface tension (Brepohl 2001), which may have inhibited further experimentation with casting into more intricate moulds.

Nevertheless, further north than the area under consideration here, copper was cast into H- and X-shaped moulds to make trade items, found both as presumed currency caches and interred with burials from northern Zimbabwe to the southern Congo. Ceramic and carved soapstone ingot moulds have been found at a number of sites dating from the 9th to the 14th century AD, principally in Zambia but including Great Zimbabwe (Swan 2007). This casting tradition, which has its most recent expression in 20th century Zambian copper smelting reconstructions in which molten copper was tapped from the furnace into external X-shaped moulds (Miller 1994), does not appear to have extended further south than Great Zimbabwe. According to Swan (2007) no H-or X-shaped copper ingots have been found in South Africa or Botswana. Evidently copper casting practice was not uniform throughout the sub-continent during the first half of the second millennium AD, pointing to varied economic and social structures.

Killick (2009b) has explored both the economics and information flow associated with the east coast trade. The evidence from Mapungubwe, and the later Zimbabwe state, points to a centralized authority exercising very close control over the redistribution of imported goods such as exotic metals and glass beads. This implies a corresponding control over the activities of subordinates responsible for the production of goods for export, like metals. Those commanding this flow of goods were not personally involved in their production, and the contact between metallurgical practitioners at both end of the trade must have been minimal, if not non-existent. (Tellingly, at Mapungubwe, the only evidence for actual metal working on the site is in the most basal layers on the hill-top (Layer 11). Thereafter, as the occupants of Mapungubwe acquired elite status, metal production and processing seems to have taken place elsewhere (Miller 2001a).) Thus, there would have been no need for Muslim traders to suppress the flow of information to maintain southern African metal workers in a state of ignorant dependency. Technology transfer may have been frustrated simply by the hierarchical social structure of the Mapungubwe and Zimbabwe states and the wide geographic separation of the primary metal workers at the extremes of the trading network.

CONCLUSION

It is evident from the descriptions and analyses reported here that in southern Africa casting of molten metal was not used to produce utilitarian items, like axes, picks, or vessels. The production of molten metal took place as a matter of course in copper smelting, resulting in characteristic plano-convex 'dishes'. Further deliberate melting in open crucibles was used to refine the raw copper by drossing. This technique may also have been used to refine tin produced at Rooiberg and nearby sites like Rooikrans.

Tin was cast into moulds of various designs. These included stone moulds to produce characteristic bar shaped ingots, bowl moulds to produce bun ingots, and sand moulds to make golf club-shaped *marale,* more commonly associated with copper production. Copper was cast not only into *marale* but also top hat-shaped *metsuku*. Both types of casting were often adorned with ornamental studs, but the significance of these, and of the objects themselves, is unknown. Copper was cast into trade ingots, often as nail headed finger-like bars, and also into small bars for reworking into rings and bangles.

While gold was melted in crucibles to agglomerate gold dust or small prills into workable nodules of metal, there is no evidence for direct casting of gold into beads or any other jewellery components. At both Mapungubwe and Thulamela these were made by hot and cold working strip or small nodules of metal by hammering into usable shapes, or by perforating spherical gold prills to make beads.

The earliest evidence for the secondary melting of metal is at Mapungubwe, where numbers of casting spills of copper and copper alloys have been recovered, as well as ceramic sherds with adhering metal working slag, interpreted as skimmers. These were used to remove dross from the surface of molten copper and copper alloys being refined in open crucibles. This technique was also used at more recent sites such as Marothodi and Rooikrans.

The absence of evidence for closed two-part or three-part moulds, for lost wax casting, or for the production of cast figurines and functional objects like axes or bowls is telling. This points to there being no direct technological influence from the Far East, India, the Middle East, or West Africa where various metal casting techniques were used to create a wider variety of more complex objects. Thus, there is evidence for the export and import of metals, but not for the importation or adoption of any significant exogenous metal working technology.

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