

# The extractive metallurgy of copper at Iron Age Madikwe

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**SEM/EDX analysis of ores and slag showed that, with the possible exception of the Wonderboom site, copper was probably smelted from Dwarsberg ore at Madikwe, North West province, in the mid-seventeenth century, either with high iron content or with lower iron content plus an added iron oxide flux. Our analytical technique was adequate as a survey technique here, but low instrument sensitivity limited our ability to be more specific about ore sources.**

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## Introduction

Madikwe Game Reserve covers some 75 000 hectares in the northwest portion of the North West province of South Africa. In addition to natural resources, the reserve has a rich historical heritage. It lies within the traditional homeland of Western Sotho–Tswana (including Hurutshe, Kwena and Kgatla), and copper mines date to pre-colonial times in the Dwarsberg to the west. Furthermore, Voortrekkers chased Mzilikazi into Botswana through what is now the reserve, and then hunters and missionaries established a road from the south to Mochudi to join the ‘missionary road’ to Bulawayo. An old Jesuit mission along this road provided provisions for mission work further north, and it is now the headquarters for the reserve.

This rich historical heritage led the reserve’s management team to consider a conservation strategy that embraced cultural resources. To help plan their strategy, the team contracted Archaeology Resources Management (ARM) to search for sites of archaeological and historical interest. ARM teams examined the reserve in 1996, 1997 and 1998. The entire reserve was not covered because of thick bush, dangerous animals and other factors. The teams instead visited all sites known to reserve staff, as well as likely terrain, such as hilltops for stone-walled fortifications and the bottom of hills for typical agropastoral settlements. Most significant for present purposes were the remains of 20 homesteads with pottery assemblages belonging to the Moloko cluster (Fig. 1). Moloko is the archaeological name for the styles of pottery produced by Sotho–Tswana speakers.<sup>1</sup> The specific facies, called Madikwe after the reserve, belongs in the middle phase of the sequence, dating between AD 1500 and 1700.<sup>2</sup>

A few Madikwe settlements yielded debris from copper production, such as ore, slag and tuyères (Table 1). In addition, two Madikwe settlements contained *in situ* furnaces. Generally, pre-colonial people produced copper objects through a series of technological and cultural steps. First, they smelted the ore, often with ironstone,<sup>3</sup> in a primary furnace to produce impure ingots and a dense iron-and-silica-rich slag that usually contained fine copper prills. These prills are diagnostic of copper smelting, while unreacted silica grains in the slag provide useful information about the carbothermic reduction conditions in the furnace.<sup>4</sup> Second, the metalworkers then refined the prills and impure ingots in crucibles in a secondary, or refining, furnace. As a by-product, a light and frothy slag adheres to the crucible wall.

Separate smelting and refining furnaces are supported by a tradition related to Boshier<sup>5</sup> by a Kgatla man, named Moroki, while they were investigating the Dwarsberg mines.

The ore was not smelted near the mines for fear of offending the spirits. Instead it was carried a considerable distance to the first place of smelting. It was then taken to a second site to be refined and wrought.

The refined copper was usually made into another ingot, or wire, which was later forged (‘wrought’ as Moroki says) into various articles, such as earrings, beads and bangles.

With the Madikwe material, we were particularly interested in the smelting technology and the role of SEM/EDX (scanning electron microscopy/energy dispersive X-ray analysis) in elucidating whether the ore came from the nearby Dwarsberg mines. Due to limitations inherent with SEM/EDX (see Analytical method), this is not a classic sourcing study where marker elements are used to source ores. Here we can say only whether or not we believe that results point to a different source from the Dwarsberg ores. We first describe the furnaces and associated finds before moving to the methods of analysis and their results.

## Excavations

Furnace 1 is part of the Wonderboom site (2426 CC 8) located at the base of the Tweedepoort escarpment. The team placed a 2 m × 2 m square (Trench III) over the furnace and four 2 m × 2 m squares (Trench I) in a midden with surface indications of metal production. Other trenches exposed hut remains.

The furnace itself was about 25 cm wide and 45 cm long, with a surviving height of 15 cm (Figs 2 and 3). The dark interior soil contained charcoal (identified as *Acacia* sp.), slag with copper prills, and broken tuyères. There appeared to have been only one tuyère port.

The midden consisted of grey soil varying from 7 cm to 13 cm in thickness and contained diagnostic pottery, tuyère fragments, crucible sherds containing copper slag, and charcoal. The charcoal has been radiocarbon dated to AD 1650 ± 50 (Pta-7534), which calibrates to AD 1640–1670.

Furnace 2 stood inside the Genadendal Dam site (2426 CD 15B) at the base of the Dwarsberg. Because of extensive erosion, it is not clear if CD 15B was part of site CD 15 or a separate homestead. In any case, both areas encompassed several burnt huts and grain bins. The furnace (Figs 4 and 5) was located behind one such hut. It measured 24 cm × 30 cm, with a surviving height of 17 cm and wall some 4–5 cm thick. This furnace also had a single tuyère port. Copper ore and a flat disc of copper slag were found nearby.

An artificial hole about 150 cm behind the furnace contained an unusual cluster of stone flakes described elsewhere.<sup>6</sup> We now turn to the choice of analysis.

## Analytical method

Analytical choices are sometimes controversial, so it is important to explain our decisions. Limited resources restrict the choices. Either one collects bulk compositional data on a small number of samples using an exhaustive suite of techniques, or one employs a simpler, less demanding, surface technique that returns limited compositional data on a large number of artefacts. For the first, neutron activation analysis, inductively coupled plasma/mass spectrometry (ICP/MS), or micro-X-ray fluorescence yield accurate quantification of matrix, minor and trace elements. In the second case, light microscopy and scanning electron microscopy (SEM) are useful for phase examination. Furthermore, SEM has the ability to obtain compositional data on phases using energy dispersive X-ray analysis (EDX). The combined SEM/EDX

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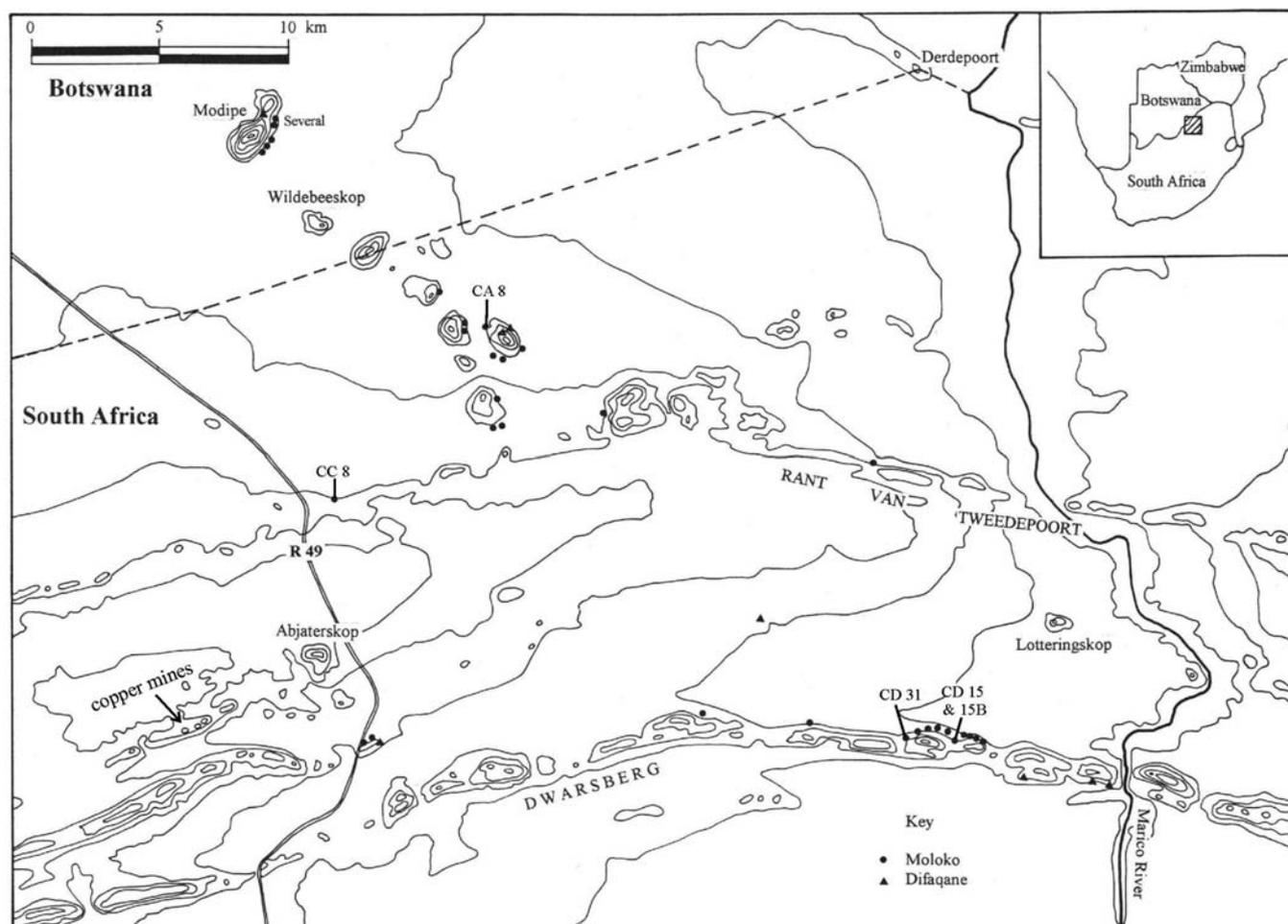


Fig. 1. Map of archaeological sites on record in the Madikwe reserve.

method provides more compositional information than light microscopy alone, and adds but little complexity to the analysis. The main drawbacks of SEM/EDX are well known. It is less sensitive for minor elements and not at all for trace elements, and, because it is a surface technique, one must infer the results in terms of bulk composition. If trace element concentrations or bulk composition are required, SEM/EDX is not the technique of choice. In either case the analytical technique should be capable of examining both geological specimens and archaeological artefacts.

Table 1. Summary of the ores, slags and copper analysed or mentioned in the text.

Site	Samples	Description
(See Fig. 1)	a–e	3 Dwarsberg copper ores (Mason)
CD 31	f, g	Primary furnace lining
	h, i	Copper prill embedded in furnace lining
CD 15	j–m	Iron/copper precipitate, probably delafossite
	n	Copper prill embedded in precipitate
	–	Almost pure ironstone, mentioned in text, EDX spectrum not retained
CD 15B	o, p	Copper ore
	q, r	Crucible slag
	–	Probably nantokite plus iron oxide, EDX spectrum not retained
CA 8	s	Crucible slag
	t	Copper prill in crucible slag
CC 8	u–w	Primary slag, found in a secondary furnace
	x	Copper prill from primary slag
	y	Slag from crucible found in midden
	z	Copper prill from midden crucible slag

We chose SEM/EDX mainly because of the availability of a suitable instrument, but also because it is simple and versatile, and sample preparation is minimal. For these reasons a person with a scientific background can learn to operate the machine with a few hours of instruction. Thus, one person rather than a team of specialists can complete the entire procedure.\* This is an obvious advantage when results from various techniques are in disagreement, or where analytical error is suspected in one of the techniques. Contamination is not a problem, and composition normally does not change during storage. Issues such as change of solubility or residual radioactivity therefore do not complicate re-analyses. Furthermore, analytical precision on inhomogeneous samples is reportedly better than LA/ICP/MS,<sup>7</sup> and the per-sample cost is low compared to NAA.

The SEM/EDX spot analyses on material collected by ARM<sup>8</sup> and by Mason<sup>9</sup> used a DS-130S SEM and Link AN10000 EDX, with a beam energy of 20 or 30 keV, stage WD 26 mm and a tilt angle of 45°. Spot analyses indicate the relative presence of the listed elements at that spot only. They should not be combined and averaged. We used a different system—JSH-840 SEM and Link AN10000 EDX, with beam energy of 20 keV, stage WD 39 mm and tilt of 0° (the detector is inclined) to produce scan analyses. Scans may well be more representative of the whole sample composition, as long as each sample phase has been analysed in the correct proportion.

\*It seems justifiable to accept analyses done by a non-specialist as long as they are internally consistent and not contradicted by other data. There seems to be more opportunity for the non-specialist to mishandle the statistical, rather than the elemental, analysis.



Fig. 2. Excavated furnace at site 2426 CC 8 (Wonderboom).

**Results**

The results are presented in Table 2. Three ores collected by Mason from the worked Dwarsberg mines are characterized [a–e]. Ore samples from Genadendal CD 15B [o, p] generally match the Dwarsberg signature except for the higher iron content. We believe that ore high in both copper and iron would probably have been preferred, and that this may have resulted in the deposit being worked-out during the Iron Age. As the relict Dwarsberg ores Mason collected are low in iron, the metal would need to be added to form slag. Ironstone was surface collected at CD 15. It proved to be virtually pure iron oxide; no marker elements were observed. Thus, none would be added if this material were used as a smelting flux. Similarly, the material from CA 8, CD 15 and CD 31 is also consistent with the use of Dwarsberg ore (copper oxides/carbonates and aluminosilicate gangue), plus added ironstone flux. Given these results, one is then faced with the choice of expending further resources, on

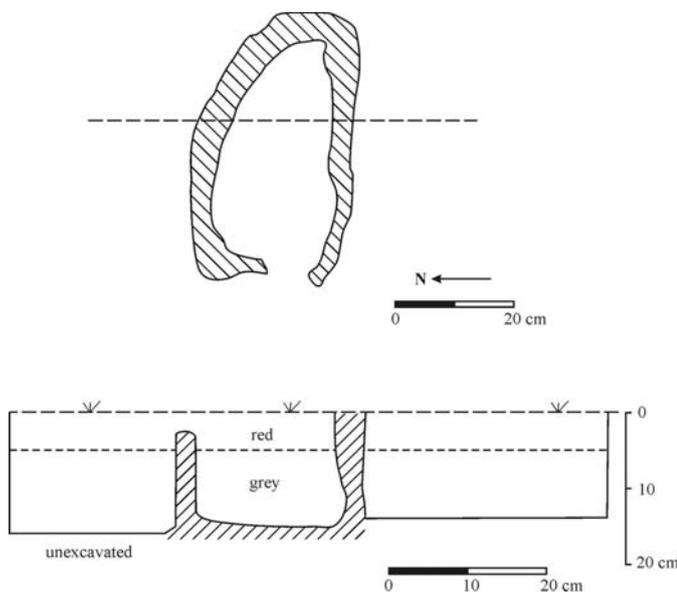


Fig. 3. Plan and section of Wonderboom furnace.

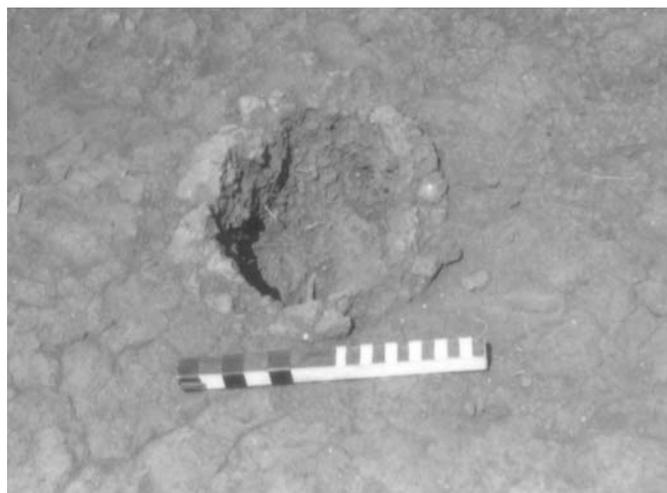


Fig. 4. Excavated furnace at site 2426 CD 15B (Genadendal dam).

X-ray diffraction or Mössbauer spectroscopy for example, to recover more information. We do not consider that this expenditure is worthwhile here.

Samples [f] and [g] at site CD 31 appear to be lining from a primary smelting furnace. This forms in the continuous smelting of copper when a new charge is added periodically to the hot furnace. Complete equilibrium is not reached in such smelting, as the furnace is continuously either heating up or cooling down, and areas of oxidation alternate with those of reduction. At times, the added material cools the furnace sufficiently to

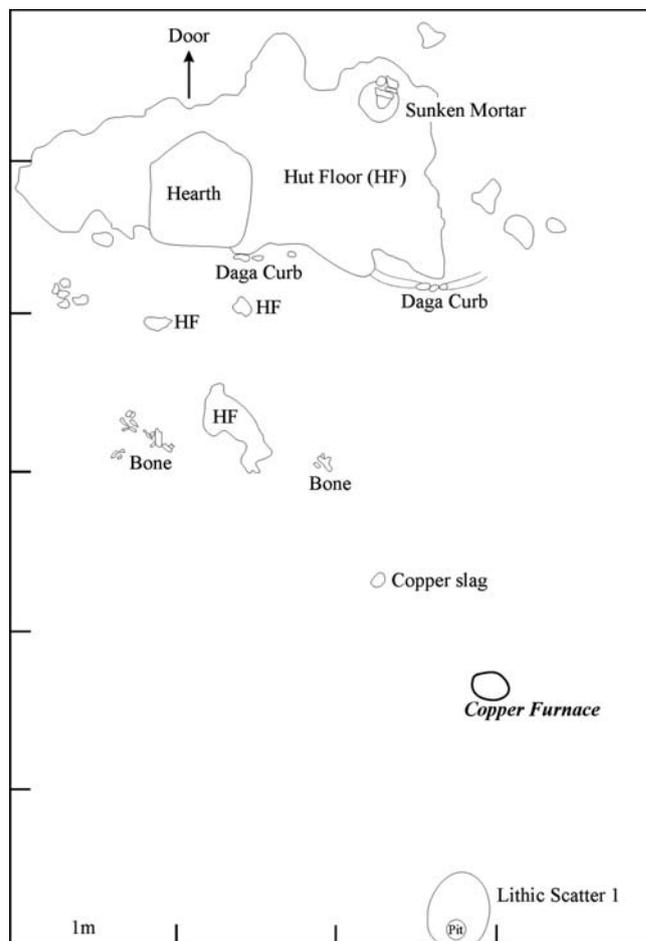


Fig. 5. Plan showing location of Genadendal furnace behind the remains of a house (after Hall<sup>6</sup>).

**Table 2.** Ore, slag and metal analyses; spots are normalized mass % excluding oxygen (1  $\sigma$  mass error from spectral data).

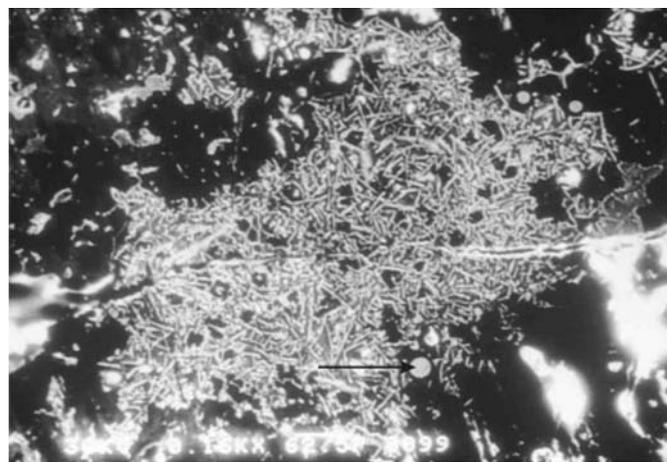
Element	45/81		46/81		47/81	CD 31 furnace lining		CD 31 copper prill		CD15 crucible slag			
	a	b	c	d	e	f	g	h	i	j	k	l	m
Mg	1.9 (0.13)	–	–	0.7 (0.22)	0.4 (0.15)	–	–	–	–	2.4 (0.31)	–	–	–
Al	–	–	–	–	0.9 (0.15)	1.3 (0.21)	1.0 (0.20)	1.2 (0.19)	0.9 (0.18)	1.7 (0.20)	3.6 (0.14)	3.0 (0.14)	6.6 (0.28)
Si	85.4 (0.26)	67.9 (0.23)	43.8 (0.34)	9.1 (0.17)	90.0 (0.33)	13.7 (0.23)	12.3 (0.23)	0.5 (0.13)	0.5 (0.12)	6.0 (0.18)	19.0 (0.16)	13.4 (0.14)	32.1 (0.13)
S	1.2 (0.07)	3.5 (0.09)	0.3 (0.13)	0.3 (0.10)	0.2 (0.10)	–	–	–	–	–	–	–	–
Cl	–	–	0.3 (0.09)	0.2 (0.08)	0.3 (0.09)	–	–	–	–	–	–	–	–
Ti	0.4 (0.06)	–	–	–	0.4 (0.09)	–	–	–	–	–	0.3 (0.05)	0.2 (0.05)	–
K	–	–	–	–	2.0 (0.09)	0.6 (0.11)	–	–	–	0.5 (0.10)	0.9 (0.05)	0.5 (0.05)	1.2 (0.08)
Ca	0.1 (0.06)	–	–	0.4 (0.08)	0.3 (0.08)	2.1 (0.12)	1.6 (0.12)	–	–	0.8 (0.10)	2.5 (0.07)	1.4 (0.06)	2.8 (0.10)
Mn	–	–	–	0.3 (0.09)	–	–	–	–	–	–	0.4 (0.08)	0.3 (0.08)	0.3 (0.11)
P	–	–	–	1.3 (0.12)	–	–	–	–	–	–	0.6 (0.07)	0.5 (0.06)	1.1 (0.15)
As	–	–	–	–	–	–	–	–	–	–	–	–	–
Cu	8.7 (0.21)	27.8 (0.27)	53.6 (0.62)	85.4 (0.62)	4.5 (0.22)	6.4 (0.31)	16.8 (0.42)	97.6 (0.74)	96.3 (0.75)	16.2 (0.39)	44.4 (0.41)	50.3 (0.45)	40.4 (0.61)
Fe	1.9 (0.10)	0.6 (0.07)	1.8 (0.14)	2.4 (0.12)	1.0 (0.13)	76.0 (0.60)	68.3 (0.56)	0.6 (0.12)	2.3 (0.14)	72.3 (0.55)	28.2 (0.25)	30.5 (0.26)	15.5 (0.30)
Ni	–	–	–	–	–	–	–	–	–	–	–	–	–

Element	CD 15 crucible slag	CD15B copper ore		CD15B crucible slag		CA8 slag	CA8 copper prill	CC8 secondary refining surface				CC8 crucible (midden)	
	n	o	p	q	r*	s	t	u	Primary slag v	w	Copper prill x	Slag y	Copper prill z
Mg	1.2 (0.12)	2.8 (0.36)	–	0.6 (0.10)	2.2 (0.14)	12.7 (0.28)	–	–	–	–	4.9 (0.29)	3.1 (0.30)	2.8 (0.29)
Al	–	0.4 (0.18)	–	0.3 (0.10)	10.6 (0.14)	8.0 (0.09)	–	15.8 (0.25)	13.8 (0.14)	7.5 (0.27)	–	8.7 (0.28)	1.4 (0.19)
Si	13.9 (0.13)	3.2 (0.27)	7.2 (0.31)	91.7 (0.34)	65.6 (0.30)	55.2 (0.42)	0.9 (0.22)	69.3 (0.34)	65.2 (0.19)	48.5 (0.27)	–	34.8 (0.30)	4.6 (0.15)
S	–	0.3 (0.13)	0.3 (0.13)	3.5 (0.12)	–	–	–	–	–	–	–	0.3 (0.14)	1.4 (0.13)
Cl	0.7 (0.05)	–	0.2 (0.11)	0.9 (0.07)	–	–	–	–	–	–	–	–	–
Ti	0.3 (0.06)	–	–	–	–	0.3 (0.05)	–	1.2 (0.10)	0.9 (0.09)	0.5 (0.08)	–	–	–
K	0.3 (0.06)	–	–	–	1.2 (0.05)	–	–	3.4 (0.12)	4.7 (0.11)	4.0 (0.13)	–	1.6 (0.11)	–
Ca	0.8 (0.06)	0.2 (0.09)	0.3 (0.08)	0.8 (0.06)	4.1 (0.08)	10.1 (0.09)	–	0.5 (0.09)	4.6 (0.11)	8.2 (0.17)	–	9.9 (0.17)	1.2 (0.10)
Mn	–	–	0.2 (0.10)	–	0.1 (0.05)	0.2 (0.07)	–	–	0.3 (0.11)	0.7 (0.14)	–	0.3 (0.12)	–
P	–	–	–	–	–	–	–	–	–	–	–	–	–
As	–	–	–	–	–	–	–	–	–	–	4.0 (0.50)	–	0.8 (0.33)
Cu	67.0 (0.7)	59.7 (0.51)	42.6 (0.56)	0.9 (0.09)	0.2 (0.06)	0.4 (0.11)	97.3 (0.59)	–	–	1.6 (0.22)	91.1 (0.79)	–	82.8 (0.67)
Fe	15.7 (0.18)	33.5 (0.24)	49.0 (0.33)	1.4 (0.07)	15.9 (0.14)	13.0 (0.17)	1.7 (0.08)	9.7 (0.21)	10.4 (0.24)	29.2 (0.39)	–	40.8 (0.43)	3.8 (0.14)
Ni	–	–	–	–	–	–	–	–	–	–	–	–	1.0 (0.16)

\* (r), chromium = 0.1 (0.05); (s) and (t) are spots; (o) [0.7 × 0.7 mm], (p) [2 × 2 mm], and (q, r) [0.03 × 0.03 mm] are scans.

cause iron (as Fe, Fe<sub>3</sub>O<sub>4</sub> or FeO, depending on the oxidizing conditions) to be exsolved from the molten copper. Some glassy slag forms by reaction with the furnace wall, and over time, a layered, iron-rich lining forms in the furnace.<sup>10</sup> In order to hinder build-up, ashes apparently are sometimes used to line the bottom of the furnace in primary smelting and the crucible in secondary refining.<sup>11,12</sup> The interpretation of this material as furnace lining is disputed, however, and as SEM/EDX does not analyse oxygen, additional slag analysis is indicated.<sup>13</sup> The lining also contains prills of relatively pure copper [h, i].

Crucible sherds, among other evidence, show that the two



**Fig. 6.** Iron-copper precipitate, possibly delafossite, in refining slag from site CD 15. The arrow points to a round copper prill (lower middle-right), which is spot (n) in Table 2. Magnification ×80.

small, excavated furnaces were built for the secondary, or refining, stage of copper smelting. The refining slag in the crucible fragment from site CD 15 appears to contain metallic-looking needles of delafossite, CuFeO<sub>2</sub> ([j–m] and Fig. 6<sup>14,15</sup>). When copper melts in a crucible in an oxidizing atmosphere, iron impurities float to the surface, where they react with the liquid copper to form delafossite and with clay minerals in the crucible wall to form crucible slag.<sup>16</sup> Because delafossite indicates an oxidizing atmosphere, the crucible must have been left uncovered, open to the atmosphere, during at least part of the refining stage. It appears that the smelters were prepared to throw away copper in order to remove impurities such as phosphorus, manganese and iron. Alternatively, the crucible slag may have been re-smelted in a primary furnace.

An example of phase information is shown by the refining slag from site CD 15B (Fig. 7). This material was unique. Some areas seem to comprise only four elements—copper, iron, silicon and chlorine. The total mass returned by SEM/EDX for these elements was only 9%, however, so there was obviously a large error in the matrix correction used for the EDX. The total mass should be close to 100% if the matrix correction is accurate, but nothing like this had been seen in other samples and we were unprepared for it. Thus, the analysis is qualitative only and is not included in Table 2. This material appears to be nantokite, CuCl, mixed with iron oxide, which seems to be dissolving into the surrounding high-silica matrix [q, r]. The sample has possibly suffered weathering and the nantokite is a corrosion product. Lechtman and Klein<sup>17</sup> reported nantokite as ‘the matrix material’ of slag produced in their experimental crucible smelting of arsenical copper. Interestingly, they produced ‘large volumes’ of nantokite by smelting

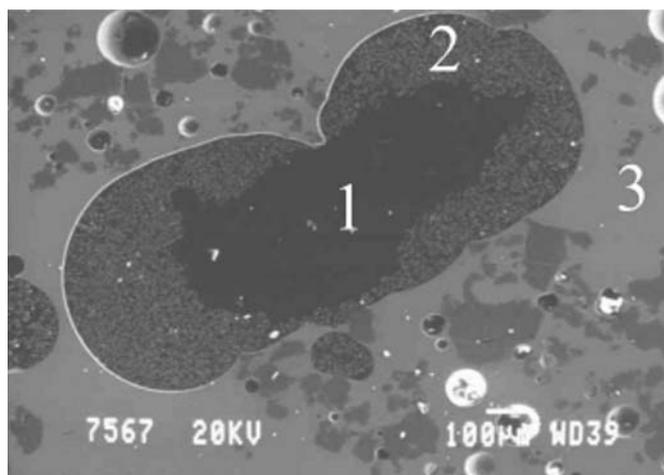


Fig. 7. (1) Possible area of nantokite in refining slag from site CD 15B, (2) area of reaction into surrounding high-silica matrix (3). Magnification  $\times 50$ .

arsenopyrite ( $\text{FeAsS}$ ) together with atacamite [ $\text{Cu}_2\text{Cl}_4(\text{OH})_4 \cdot \text{H}_2\text{O}$ ] or paratacamite [ $\text{Cu}_2\text{Cl}(\text{OH})_3$ ]. The mechanism of its formation here remains obscure.

The sherds in the Wonderboom midden (CC 8) originated from small crucibles. Perhaps only enough copper was refined in one crucible to make one or at most a few small items such as bracelets. The secondary furnace here contained several lumps of very dense slag [u–w] too large to come from the small crucibles. We postulate that this was primary slag, brought to the site in order to be crushed and the copper prills removed for refining. (In this respect, copper prills in the crucible slag from CA8 [t] were not spherical, but elongated, indicating that the slag may have been hammered at some stage in order to remove copper.) Why these pieces were left in the refining furnace is not known.

The Wonderboom slag had higher calcium than in the Dwarsberg ore. This calcium may have come from bones, used to flux the smelt, or calcite, which is found in the Dwarsberg.<sup>18</sup> Of more importance forensically are arsenic and nickel, observed in copper here and at no other site. Sample [x] is a copper prill embedded in the primary slag. If the spot analysis is representative of the prill as a whole, it is a natural arsenical bronze. In this regard, note that marker elements arsenic and nickel occur in another prill [z] in crucible slag from the Wonderboom midden. This is evidence for an ore that does not have a typical Dwarsberg signature [a–e].

## Discussion

Numerous authors<sup>19–22</sup> reported finding bronzes (arsenical and tin) at sites in southern Africa early in the 19th century. Arsenical bronzes fall within the 1–8% range of arsenic that confers advantageous properties on the copper.<sup>23</sup> The origin of the arsenic at Madikwe is unknown. None of the Dwarsberg ores contains arsenic, although it may have been undetected. The olive-green mineral olivenite [ $\text{Cu}_2(\text{AsO}_4)(\text{OH})$ ] sometimes occurs in the oxidized zone of copper ore deposits, associated with other secondary copper minerals.<sup>25</sup> According to the available literature,<sup>18,26</sup> it does not occur in the Dwarsberg. The copper deposits there are spotty and of little or no economic value, however, and so, even if it was present, it may have been overlooked. Nevertheless, it is still unclear why Wonderboom is the only site where arsenic occurs in the copper. Arsenosulphides (enargite, tennantite, arsenopyrite) are another possible source, but they would probably have left a diagnostic sulphur residue. No such residue occurs in the primary slag [k–m] or in the copper prill [n].

There is a third possibility. The arsenic and nickel in prill [p] at

Wonderboom suggests that a hydrated nickel arsenate mineral such as annabergite [ $\text{Ni}_3(\text{AsO}_4)_2 \cdot 8\text{H}_2\text{O}$ ] was added accidentally to the smelt. Annabergite is apple-green in colour and could easily have been confused with copper ore. Annabergite has not been found in the Dwarsberg, but it did occur at Rooiberg and has been suggested as the source of arsenic in the copper smelted there.<sup>23</sup>

Pollard *et al.*<sup>27</sup> demonstrated that arsenic and nickel can be reduced in a furnace charged with secondary copper minerals. The literature is somewhat inconsistent concerning the conditions under which nickel is reduced and a cupro-nickel alloy formed. Tylecote *et al.*,<sup>28</sup> in a series of experiments designed to determine the trace element partitioning in copper smelting, report that the Cu/Ni ratio should be the same for both ore and metal. Srinivasan<sup>29</sup> agrees, stating that: 'studies on partitioning of elements during copper smelting indicate that Ni, Co and Ag are amongst the most chalcophilic.' Meliksetian *et al.*<sup>30</sup> show a good correlation in Ni content between ores and metal for most, but not all, of the artefacts they studied. Hook<sup>31</sup> points out, similarly to Pollard *et al.*, that the nickel content of a copper alloy may be a function of process temperature, and also may be due to the variability in nickel content of ores from various sources. Further experimental work is needed to settle this question conclusively.

According to Pollard, smelting below 1000°C results in arsenic-free (and presumably also nickel-free) copper, as the diffusion rate of arsenic into solid copper (pure copper melts at 1083°C) is so low that most of the arsenic volatilizes during smelting. Arsenic lowers the liquidus temperature of copper, making it easier to cast, but the liquidus temperature of 4% arsenical bronze is still over 1000°C. The diffusion rate of arsenic into molten copper is much higher, so that molten copper, produced in a smelt containing olivenite or annabergite, should contain arsenic, in an amount that depends on the smelting temperature, the amount of olivenite or annabergite in the charge, and the  $\text{O}_2$  partial pressure.

The arsenical copper at Wonderboom does not seem to be an intentional product. Rather, there could have been a cosmological reason for removing arsenic that concerns colour. Traditional African societies valued copper most when it was deep red or even purplish.<sup>32</sup> But as Budd and Ottoway<sup>33</sup> state:

Perhaps the most immediate effect of adding arsenic [to copper] is the colour change of the cast metal. Arsenic causes a notable whitening that is certainly detectable at the upper end of the range of compositions reported from Eneolithic contexts (approximately 4% arsenic).

It is thus possible that the smelters removed the arsenic for the colour change alone.

The desire for a red product is part of a traditional cosmology that provides a context for smelting as a whole. Because of its colour and softness, Sotho-Tswana (as well as other Bantu speakers) associate copper with women. Iron, on the other hand, belongs to the domain of men. With this dichotomy in mind, the Madikwe excavations alerted us to a previously unrecognized spatial pattern. In addition to the two 17th-century examples, small copper furnaces in the residential zone are on record at Leopard's Kopje Main Kraal, dating to the 11th century in Zimbabwe,<sup>34</sup> at a 15th-century Khami-period homestead in Botswana,<sup>35</sup> and at the 19th-century Olifantspoort complex near Rustenburg.<sup>36</sup> Other 19th-century examples are under investigation west of the Pilanesberg (S.L. Hall, pers. comm.). All these examples are located in secluded areas of the residential zone. Campbell<sup>37</sup> noted this pattern in 19th-century Hurutshe (Western Sotho-Tswana) settlements. The archaeological data

therefore show that this pattern was widespread and has great time depth.

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- Evers T.M. (1983). "Oori" or "Moloko"? The origins of the Sotho-Tswana on the evidence of the Iron Age of the Transvaal, reply to R.J. Mason. *S. Afr. J. Sci.* **79**, 261–264.
- Huffman T.N. (2002). Regionality in the Iron Age: the case of the Sotho-Tswana. *Southern African Humanities* **14**, 1–22.
- Van der Merwe N.J. (1978). *Occ. Pap. Natn. Mus. Rhod.* **A4(3)**, 101–105.
- Eric H., Stirling P., Huffman T. and Grant M.R. (1995). An SEM-EDX study of residues from Iron Age copper furnaces in Botswana. *S. Afr. J. Sci.* **91**, 312–314.
- Boshier A.K. (1969). Mining genesis. *Mining Survey No. 64*, p. 27. Chamber of Mines of South Africa, Johannesburg. Moroki reported that, 'The ore was not smelted near the mines for fear of offending the spirits. Instead it was carried a considerable distance to the first place of smelting. It was then taken to a second site to be refined and wrought.'
- Hall S.L. (2000). Forager lithics and early Moloko homesteads at Madikwe. *Natal Mus. J. Humanities* **12**, 3–50.
- Tykot R.H. (1997). Characterisation of Monte Arci (Sardinia) obsidian sources. *J. Archaeol. Sci.* **24(5)**, 474.
- Huffman T.N., Calabrese J.A. and Grant M.R. (1997). *Archaeological Research in Madikwe Game Reserve, North West Province*. Archaeological Resources Management, University of the Witwatersrand, Johannesburg.
- Mason R. (1982). Prehistoric mining in South Africa, and Iron Age copper mines in the Dwaarsberg, Transvaal. *J. S. Afr. Inst. Min. Metall.* **82(5)**, 134–142.
- Wertime T.A. and Muhley J.D. (eds) (1980). *The Coming of the Age of Iron*. Yale University Press, New Haven.
- Herbert E.W. (1984). In *Red Gold of Africa*, pp. 55–56. University of Wisconsin Press, Madison, WI.
- Friede H.M. and Steel R.H. (1975). Notes on Iron Age copper-smelting in the Transvaal. *J. S. Afr. Inst. Min. Metall.* **76**, 224.
- Miller D. and Killick D. (2004). Slag identification at southern African archaeological sites. *J. Afr. Archaeol.* **2**, 23–47.
- Miller D. (2003). Archaeological bronze processing in Botswana. *Proc. Microsc. Soc. Sth. Afr.* **33**, 18.
- Grant M.R. and Stirling P.A. (1998). Iron Age copper smelting at Madikwe. *Proc. Microsc. Soc. Sth. Afr.* **28**, 25.
- Rovira S. (2003). Early copper metallurgy slags at Kargaly (Orenburg, Russia). In *Proc. Archaeometallurgy in Europe*, Vol. 1, pp. 483, 485. Associazione Italiana di Metallurgia, Milan, Italy.
- Lechtman H. and Klein S. (1999). The production of copper-arsenic alloys (arsenic bronze) by cosmelting: modern experiment, ancient practice. *J. Archaeol. Sci.* **26(5)**, 521.
- Coetzee C.B. (Ed.) (1976). *Mineral Resources of the Republic of South Africa*. Government Printer, Pretoria.
- Stanley G.H. (1929). The composition of some pre-historic South African bronzes with notes on the methods of analysis. *S. Afr. J. Sci.* **26**, 44–49.
- Wagner P.A. and Gordon H.S. (1929). Further notes on ancient bronze smelters. *S. Afr. J. Sci.* **26**, 567, 591.
- Baumann M. (1919). Ancient tin mines of the Transvaal. *J. Chem. Metall. Min. Soc. S. Afr.* 120–132.
- Trevor T.G. (1912). Some observations on ancient mine workings in the Transvaal. *J. Chem. Metall. Min. Soc. S. Afr.* **12**, 272, 372.
- Grant M.R., Huffman T.N. and Watterson J.I.W. (1994). The role of copper smelting in the precolonial exploitation of the Rooiberg tin field. *S. Afr. J. Sci.* **90**, 85–90. They write: 'The principal advantage for an ancient metallurgist of adding arsenic to copper is the increased strength of the alloy. Pure copper can be cold hammered to increase its strength, such as for the cutting edge of a knife, but the addition of as little as 1% arsenic raises the cold hammered strength much above that for pure copper. The maximum solid solubility of arsenic in copper is about 8%, however, and if more arsenic than this is added the resulting alloy is brittle and will crack when it is cold worked. When copper contains more than 8% arsenic it can apparently be hot worked without cracking, but as hot working is carried out above the recrystallization temperature, it does not result in hardening or strengthening of the metal. According to Tylecote,<sup>24</sup> the beneficial effect of 1–8% arsenic addition on the cold-working properties of copper was so pronounced that it would not fail to have been noticed by ancient metalsmiths.'
- Tylecote R.F. (1990). *The Prehistory of Metallurgy in the British Isles*. The Institute of Metals, London.
- Roberts W.L., Campbell T.J. and Rapp G.R. Jr. (eds) (1990). *Encyclopedia of Mineralogy*. Van Nostrand Reinhold, New York.
- Kynaston H. and Humphrey W.A. (1920). The geology of the northern portions of the districts of Marico and Rustenburg. *SA Geological Society Explanation Sheet* **15**.
- Pollard A.M., Thomas R.G., Ware D.P. and Williams P.A. (1991). Experimental smelting of secondary copper minerals: implications for early Bronze Age metallurgy in Britain. In *Archaeometry '90*, eds E. Pernicka and G.A. Wagner. Birkhauser-Verlag, Basel. They write: 'Our experiments indicate that secondary copper minerals are capable of being reduced to the metallic state using charcoal as the reducing agent at any temperature above 700°C. In the temperature range 600 to 900°C, the only metals capable of being reduced along with copper are arsenic, silver and antimony. Nickel oxide was reduced only at furnace temperatures approaching 1000°C.'
- Tylecote R.F., Ghaznavi H.A. and Boydell P.J. (1977). Partitioning of trace elements between ores, fluxes, slags and metal during the smelting of copper. *J. Archaeol. Sci.* **4**, 305–333.
- Srinivasan S. (1999). Lead isotope and trace element analysis in the study of over a hundred South Indian metal coins. *Archaeometry* **41**, 99.
- Meliksetian Kh., Pernicka E., Badalyan R. and Avetissyan P. (2003). Geochemical characterisation of Armenian Early Bronze Age metal artefacts and their relation to copper ores. In *Proc. Archaeometallurgy in Europe*, Vol. 1, p. 602. Associazione Italiana di Metallurgia, Milan.
- Hook D. (2003). The composition and technology of early copper-alloy metal work from Italy. In *Proc. Archaeometallurgy in Europe*, Vol. 2, p. 61. Associazione Italiana di Metallurgia, Milan.
- Herbert E.W. (1984). In *Red Gold of Africa*, pp. 164–165, 277–280. University of Wisconsin Press, Madison, WI.
- Budd P. and Ottoway B.S. (1989). The properties of arsenical copper alloys: implications for the development of Eneolithic metallurgy. Paper presented at *Conference on Archaeological Sciences '89*, Bradford.
- Huffman T.N. (1974). *The Leopard's Kopje Tradition*. (Museum Memoir). National Museums of Rhodesia, Salisbury.
- Huffman T.N. and Kinahan J. (2002–2003). Archaeological mitigation of the Letsibogo Dam: agropastoralism in southeastern Botswana. *S. Afr. Field Archaeol.* **11-12**, 4–63.
- Mason R.J. (1986). Origins of black people of Johannesburg and the southern western central Transvaal AD 350–1880. *Archaeological Research Unit Occasional Paper* 16. University of the Witwatersrand, Johannesburg.
- Campbell J. (1822). *Travels in South Africa*, Vol. 1. Francis Westly for the London Missionary Society, London. He writes: 'The Marootzee are confidently reported by other nations to smelt copper; they profess the same themselves, and they abound in copper articles more than other nations. They asserted also that copper furnaces were behind the houses of some of their captains, but we never could obtain a site of them. They did not flatly refuse, but put it off from time to time'.