A Technology of Multiple Smelting Furnaces per Termite Mound: Iron Production in Chongwe, Lusaka, Zambia

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Abstract

With exception of Maluma (1979) and Musambachime (2016, 2017), there have been no archaeometallurgical publications on the technology and culture of iron production in Zambia. This paper presents archaeological and archaeometallurgical evidence of a technology of iron production in Chongwe in terms of spatial organization, the process of metal production (either a three-stage process involving smelting in relatively tall furnaces, refining in miniature (*vintengwe*) furnaces, and smithing on a hearth or a two-stage process involving smelting and smithing), furnace air supply mechanisms, liquid slag handling techniques, variation in the geochemistry of ore and clay, and the nature of the final smelting products. Archaeological field data collection techniques included ethnoarchaeological interviews, (furnace) excavation, surface collections, and surface walkover surveys, while laboratory analytical techniques included optical microscopy (OM), scanning electron microscopy (SEM), and x-ray fluorescence (XRF). New field evidence indicates that iron production in Chongwe in the previous two centuries was secluded from respective pre-modern settlements for socio-cultural and technical reasons. There are no settlement remains in and around Chongwe smelting sites. Also, most of the archaeological data in Chongwe are supportive of the two-stage process that did not involve iron refining in *vintengwe* furnaces. There were no iron refining sites in Chongwe. Archaeological evidence also strongly points to the use of natural air supply mechanism for the smelting furnaces because proximal ends of tuyères *inter alia* were not trumpeted. All smelting sites were systematically located on termite mounds. There were three to four smelting furnaces located on the western side of a termite mound. The presence of tuyére mould slags and thin and elongated slag microstructures strongly indicates that liquid slag was tapped outside the furnace apparently through tuyéres and was left to cool quickly. Presence of primary wüstite and iron particles in the slags strongly suggests the production of iron as the final smelting product in Chongwe. The results are compared with the archaeology, chemistry, and mineralogy of iron production from other parts of sub-Saharan Africa, particularly in the Lake Tanganyika-Nyasa Corridor. The presence of three to four smelting furnaces per termite mound makes iron production in Chongwe a unique technology in the Corridor.

Keywords

iron production – slags, tuyéres – multiple furnaces – termite mounds – Chongwe

Introductory Background

Sub-Saharan Africans have used metals for over 2.5 thousand years (see Schmidt 1997; Holl 2000, 2009; Killick 2004, 2009; Mapunda 2010). It is generally accepted that the production and use of iron and steel revolutionized many aspects of human culture; economically, socially, culturally and politically (van der Merwe & Avery 1987; Collett 1993; Reid & McLean 1995; de Barros 2000; Haaland et al. 2002; Haaland et al. 2004; Mapunda 2010; Iles & Lyaya 2015). Because of the importance of iron and steel to human societies, it was difficult for colonial administrators to suppress the technology of metal production in Africa. As Mapunda (2003) puts it, imperialistic attempts to suppress African iron smelting faced massive local resistance, but the technology finally came to an end due to external factors, particularly the importation of industrial ready-made iron products and the use of force to discourage and punish smelters and smiths (Kapinga 1990; Mapunda 2010). What remains of African pre-industrial metal production today is the heritage of metallurgical remains – furnace remnants (walls, bricks or rolls), tuyéres, crucibles, slags, potsherds and charcoal. There are also descendants of the smelters such as great granddaughters and sons. This entire metallurgical heritage is being conserved and studied for the purpose of understanding our past, in particular to grasp how metals were produced and processed in the past by examining the metallurgical relics left behind.

Most professional archaeological studies pertaining to African archaeometallurgy particularly south of Sahara started relatively late compared to African Stone Age studies. According to Mapunda (1995, 2010), the late start of archaeometallurgical studies is attributable to factors that include biases in professional research interests, funding opportunities, the influence of the *first* Stone Age including paleoanthropological discoveries and geographical factors (see also Lyaya & Mapunda 2014, and references therein). Chirikure and Bandama (2014) add shortage of research facilities and expertise to the list of factors for late start of archaeometallurgical studies. Because of this situation, there are few African archaeometallurgists compared to other archaeological specializations. Most of the early archaeometallurgists, particularly at the beginning of the last quarter of the 20th century, were foreigners. Only a few indigenous scholars have specialized in metallurgy in eastern and central Africa for various reasons. The geography of Africa and the variable research interests influenced the coverage of early metallurgical research in Africa South of the Sahara. Thus, some countries have been subject to more archaeometallurgical research than others. Zambia is one country that has not so far had a local archaeometallurgist.

Studies on iron archaeometallurgy began with foreign archaeologists, travelers, missionaries and traders who authored most of the 20th century publications on iron smelting and refining in Zambia (Cline 1937; Chaplin 1961; Fagan 1962; Phillipson 1968). Cline (1937) brings together published works on metal production based on observations of actual smelting activities and observations of some iron smelting furnaces. Other scholars conducted sporadic excavations of iron smelting furnaces in different parts of Zambia (e.g. Phillipson 1964; Inskeep 1978; Maluma 1979). Daniels (1967) noted some iron tools, copper currency bars and iron slag from Kamusongolwa Kopje (Daniels 1967). Clark (1974) reported archaeometallurgical remains including iron slag cast from EIA contexts of Kalambo falls. Derricourt wrote on Early Iron Age (EIA) iron smelting and reported on over 250 Later Iron Age (LIA) iron-smelting furnaces from Luapula Province (Derricourt 1980: 15). He also reported on a few metallurgical remains from Samfya Forest as well as three-meterhigh iron smelting furnaces from several villages of the Southern Lake Tanganyika and Kalambo (Derricourt 1980: 58, 98, 105). Robertson (2000) reported a few pieces of iron slag, iron tools, ornaments, and other iron pieces from M'teteshi, Chalaka, Mondake, and Fibobe from EIA contexts, but – as Killick (1990) puts it – most of these materials have never been studied by professional archaeometallurgists to reconstruct the technology that made them. More recently, Musambachime (2016) has written extensively on mining and metal smelting technology and culture in pre-industrial Zambia, using oral and written historical evidence.

Apart from the publications on iron smelting, it is important to note that there are a few publications on iron refining processes in the region. Colonial travellers, missionaries, administrators and amateur archaeologists reported the presence of this tradition in Ufipa (Sumbawanga) and Unyiha (Mbozi) in south western Tanzania (e.g. Wychaert 1914; Greig 1937; Wise 1958; Brock & Brock 1965; Brock 1968; Willis 1966, 1968; Wembah-Rashid 1969) and it has also been well documented in central Africa (Chaplin 1961; Davison & Mosley 1988; Mapunda 1995). In Zambia as in Tanzania, the iron refining miniature furnaces are called *vintengwe* (Chaplin 1961; Mapunda 2010). According to Maluma (1979), there was also an iron refining process among the Soli of southern Zambia. The Phoka and Chewa of northern Malawi have been reported to practice a similar tradition of iron refining (Phillipson 1968: 102; Davison & Mosley 1988: 77). In Malawi, the refining furnaces are called *chiramba* as opposed to the ore smelting furnace *ng'anjo* (Phillipson 1968; Killick 1990). Further south, there are characteristic indications of the presence of this tradition, particularly in Zimbabwe (cf. Mapunda 2010, 159; Mtetwa 2017) and elsewhere in southern Africa (cf. Stayt 1931, 1968). In support of this tradition, Greig (1937: 79) writes, "at the end of another day the kiln (the tall furnace) has burnt out, and after it has cooled the iron is sorted out from among the ashes. This iron still contains a great deal of impurities and has to be treated further in a miniature blast furnace". This iron refining stage is thought to improve the quality of the smelted bloom prior to smithing, and possibly also to enhance the overall iron yield (Davison & Mosley 1988). As smelting and smithing processes, this second refining stage in the ironworking *chaîne opératoire* – [smelting → refining → (not primary smithing) → smithing] – (Barndon 2004: 92) produced its own slag (Lyaya 2009; Lyaya et al. 2012). Musambachime (2016) gives detailed ethnographic and historical evidence on iron refining. According to him, iron refining in Zambia was vital as the final iron smelting product would not yet be ready to be worked since it contained impurities such as slag, charcoal and ash. Sometimes the smelting product was found in form of small pieces or as dispersed chunks of bloom. The iron refining process was technically and functionally different from a smithing process (Lyaya 2019a, b). It was done in miniature refining furnaces and the iron produced in this fashion was very high-quality steel, with perhaps 1.3 wt% carbon (Chaplin 1961; Maluma 1979; Musambachime 2016: 278-9; for similar information elsewhere, cf. Greig 1937; Wise 1958).

Against the above background, it is clear that there has been a dearth of professional archaeometallurgical research to understand pre-industrial metal production in Zambia (for a similar view, see Musonda 2012). This paper specifically presents archaeological and technological aspects of iron production in Chongwe, Lusaka Province, Zambia (Fig. 1). The focus is on spatial organization, the process of iron production in terms of whether it was a three-stage process (smelting → refining → smithing) or two-stage process (smelting → smithing); furnace air supply mechanisms, liquid slag handling techniques, variation in the geochemistry of ore and clay, and the nature of the final smelting products. Chongwe smelting sites have not been radio-carbon dated due to a scarcity of reliable charcoal samples from primary contexts, but still standing furnaces are more likely to be remnants of the last iron smelting practices in Chongwe. According to oral historical evidence, iron smelting was halted in Chongwe when two of our informants were teenagers in 1930s. This suggests a 20th century date for the demise of iron smelting in Chongwe, but it must still have been practiced in 19th century by the fathers (and mothers) of the three informants. Most iron smelting practices in this region were halted in the 20th century, but they were still witnessed in the 19th century (e.g. Davison & Mosley 1988; Killick 1990; Phillipson 1966, 1968; Mapunda 2010). There is a need to keep searching for reliable charcoal samples for radiocarbon dating as some natural induced furnaces elsewhere on the continent have older dates than this (e.g. Phillipson 1964; Prendergast 1974; Killick 1990, 1991; Mapunda 2010).

Methods

Field Techniques

The selection of Chongwe district as a research area was based on an earlier publication by Maluma (1979). Because Chongwe is divided into traditional land and non-traditional (government) schemes land, it was necessary to select archaeometallurgical sites from both lands – traditional and government. Chieftainships own the former and the government owns the latter. The identification and selection of the villages for this study was based on information gathered from meetings with headmen and headwomen. For practical reasons including proximity and accessibility of the villages, this study examined four villages in detail: Chimbali, Mukubulo, Mukwamba and Ndango from Nkomesha Mukamambo II Chieftainship and one Kanakantapa Scheme from the government land (for GPS locations, see Fig. 1).

Ethnoarchaeological interviews were employed to discover new archaeological sites. To this end, the headman or woman was requested to gather elders of the respective villages for discussion or interviews about iron production in the area, with a particular focus on identifying who was related to past smelters and where in the village there might be some remaining iron smelting furnaces (a list of the informants interviewed is attached as an appendix sheet). The informants were aware of the remains of iron production and in many cases remains were located on their own farms. Most of the informants, be it villagers or headmen/headwomen, were related to historical smelters, and indeed two of the informants were sons of a chief smelter, while one informant was the daughter of another chief smelter in Chimbali village. After the interviews, we proceeded to verify potential iron production sites identified during the ethnoarchaeological interviews. This method was very helpful in discovering iron production sites in Chongwe. In addition, we conducted archaeological walkover surveys to identify other archaeometallurgical sites in the respective villages. Because of the nature of vegetation cover, visibility in the areas, and the fact that initial iron production sites were all located on termite mounds, our sampling strategies for the archaeological surface walkover surveys were random. We were biased and concentrated on surveying areas with termite mounds. For security reasons, a team of surveyors was accompanied by at least two local workmen. Through the ethnoarchaeological interviews and archaeological surface walkover surveys, it was possible to discover eighteen iron production sites: six iron-smelting clusters in Chimbali village, four in Mukubulo village, three in Mukwamba village and four from Ndango village. In Kanakantapa Scheme, there was one iron production site (Kanakantapa #1). In addition to smelting debris heaps, each of these iron production sites had remnants of iron smelting furnaces. Surface collections of archaeometallurgical remains for further archaeometallurgical analysis were made from each of the eighteen iron production sites. Depending on the material composition of the sites, at least ten archaeometallurgical remains were collected from north, south, centre, east, and west parts of each of the iron production sites.

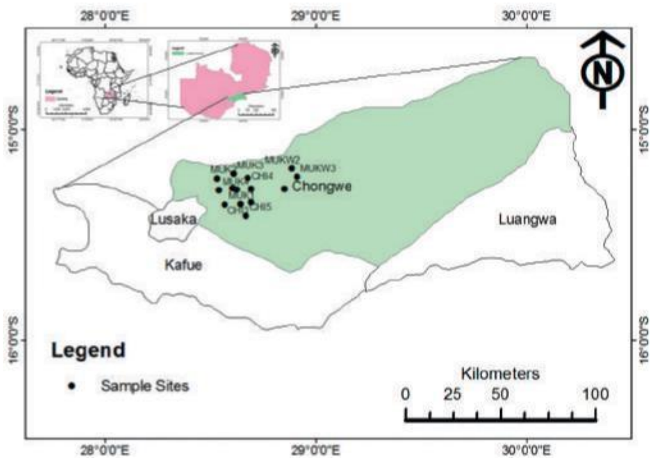


FIGURE 1 Map of Zambia showing location of Chongwe and study iron smelting sites.

Archaeological excavation was conducted inside the remnants of iron smelting furnaces. This limitation of the excavation to the inside had three aims – to verify the presence or absence of slag-pit provision, to recover charcoal samples for radiocarbon dating, and to identify any remnants of ritualistic and techno-medicinal materials beneath the floor such as pottery or wooden materials (for a similar approach, see Mapunda 2010). Excavations proceeded by levels of 10 cm – from the surface through the furnace floor to the sterile level using a spirit level and a cotton thread. All excavated soil was subjected to sieving using a 5 mm mesh. The furnace floor was documented before proceeding with the excavation of the floor and the underlying deposits. Excavation was halted when sterile soil was reached. The reader should note that during excavation, the smelting furnace remnants were not demolished but rather left intact. Photographs of the excavation, materials, and features were taken before backfilling the furnaces. Excavated materials included smelting slags, pieces of tuyères, furnace walls, and charcoal. The surface conditions of some of smelting slags were smooth, while others were rough and broken pieces of slag. The former were greyish with less oxidized surfaces, while the latter were either brownish or reddish grey with more oxidized surfaces. In terms of magnetism, the smooth smelting slags did not attract a pencil magnet, while the rough smelting slags somewhat attracted a pencil magnet. The excavated tuyères provided diagnostic evidence for the air supply mechanism used, as some tuyères were fused together by slag as multiple tuyères, others had slag solidified inside, and others yet had unflared proximal ends (for a detailed discussion, see Lyaya 2016). Some furnace walls were lined, while others were not. Out of the excavated materials and surface collections, a selection of archaeometallurgical samples for further laboratory analysis was made. Sampling criteria for the selection aimed at including each village in the sample for cross-comparison purposes. The selection was also based on context, nature, and concentration of these materials per iron production site. The selected samples were cleaned, bagged and catalogued before being shipped to South Africa (University of Cape Town) via Tanzania.

Laboratory Analytical Techniques

Metallurgical data were generated using three analytical techniques: optical microscopy (OM), scanning electron microscopy (SEM) employing energy dispersive spectrometry (EDS) and X-ray fluorescence (XRF) employing wavelength-dispersive spectrometry (WDS). The OM technique analyzed thirty-six polished slag samples. We started the analysis by adjusting camera zoom of the microscope for accuracy of field of view and crystal sizes. This analysis was carried on a reflected light trinocular Nikon microscope linked to an Olympus camera that captured images using an Analysis GetIt software. The microscope was set at *x*100 and most of the images were photographed at this magnification for cross-sample comparison. This analytical technique focused on the observation and identification of slag microstructures as based on shape, color, distribution and concentration of crystals. The proficiency in identifying the crystals was based on the experience of having looked at many samples (Nesse 2004: 125). Some of the identified crystals were subsequently confirmed by SEM analysis.

Thirty-six polished slag mounts were also subjected to SEM examination, while twenty-four fused slag disks and seven fused ceramic (furnace and tuyére pieces) disks were analyzed by X-ray fluorescence at the University of Cape Town. Samples to be analyzed by SEM were cut using a diamond saw. Each specimen was labelled and mounted in resin and left to harden overnight. The mounts thus produced were polished using grit sizes down to one micron. The polishing was aided by the use of an optical microscope (OM) to make sure that there were no conspicuous scratches on the surface. After polishing, each specimen was examined by optical microscopy to identify the major and minor phases that dominated the specimens. After that, they were cleaned with alcohol and allowed to dry. In the Electron Microscope Unit of the University of Cape Town, the samples were gold-coated prior to analysis to avoid charging, then analyzed using the Nova NanoSEM 230 which is a high-resolution field emission SEM, with an Oxford X-Max EDS detector. It combines low kV imaging and analytical capabilities with unique low vacuum performance. The working conditions were set at acceleration voltage 20 kV, working distance (distance between the sample and detector) 5 mm, probe current *circa* 0.5-1 nA for back-scattered electrons (BSE) image generation and bulk chemical area analysis and deadtime 30-40%.

Sample preparation for XRF involved first cutting a large piece from the collected sample, then this was further cut into small pieces using a diamond saw. The small pieces were then split using a hydraulic splitter and crushed into fragments smaller than 10 mm using a jaw crusher. The fragments thus produced were carefully selected to avoid inclusions before they were placed in a SeibTechnik carbon steel swing mill and ground to a fine powder. This powder was used in all subsequent chemical analyses.

Samples were dried at 110° overnight (to drive off any adsorbed moisture) and "ignited" at 850°C for four hours (to oxidise all FeO to Fe_2O_3 and to drive off any structural volatiles) and the weight changes during these heating steps were recorded. Samples to be analyzed for major elements by XRF were prepared as fused disks. Mixtures were made of 0.7 g of sample powder with 6.0 g of flux, containing 57% Li tetraborate-43% Li metaborate with a small amount of LiBr as a releasing agent. These mixtures were melted and homogenized in Pt crucibles using a Claisse M4 fluxer and poured into Pt molds where the melted mixtures slowly cooled into glass disks. These fused disks were analyzed for major elements using a Panalytical Axios wavelength dispersive XRF spectrometer in the Department of Geological Sciences, University of Cape Town. A series of roughly twenty natural rock standards spanning a wide range in composition and prepared exactly as were the unknowns was measured and used for calibration of the measured X-ray intensities.

Data Accuracy and Precision

SEM data quality was checked through the analysis of Jadeite reference material. Data precision expressed as coefficient of variation (CoV) for the SEM-EDS data was almost perfect, 2 wt% for all oxides, with the exception of CaO possibly because of its low concentration of *circa* 0.5 wt% being very close to the detection limit of the instrument (Table 1). Data accuracy expressed as a relative error (Rel. δ) was also very good for all oxides, well below 11 wt%. The accuracy of CaO was poor (see Table 1).

TABLE 1 SEM data quality assessment for Jadeite. Note that MV = measured value, CV = coefficient of variation, and SD = standard deviation

Jadeite	**Na_2O**	**Al2O3**	**SiO_2**	**CaO**
Measurements	**%**	**%**	**%**	**%**

Area 1	13.8	22.9	60.9	1.3
Area 2	13.7	22.3	60.4	1.9
Area 3	14.5	23.6	60.6	0.8
Area 4	14.0	23.1	61.1	1.2
Area 5	14.2	23.4	60.7	1.0
Area 6	14.2	22.6	60.8	1.2
Area 7	14.2	22.4	60.5	1.5
Area 8	14.4	22.4	61.2	1.1
Area 9	14.7	24.1	59.1	1.1
MV	14.2	23.0	60.6	1.2
CV	15.1	25.8	58.6	0.5
SD	0.3	0.6	0.6	0.3
CoV	**2**	**2**	**1**	**59**
Abs. %	−0.9	−2.8	2.0	0.7
***Rel*. %**	***−6***	***−11***	***3***	***132***

The quality of the XRF data was checked through the calibration XRF major element measurements using a series of well-characterized standard reference materials issued by organisations such as MINTEK, the United States Geological Survey and the Geological Survey of Japan, prepared identically as the samples for analysis. The calibration curves of known concentration versus measured analyte peak intensities corrected for the background were used to obtain elemental concentrations in unknowns. Absorption and enhancement effects were corrected through iterative correction routines employing mass attenuation coefficients.

Results

Archaeology of Iron Production in Chongwe Pre-modern settlements in Chongwe were not located in and around iron production sites, which points to the possibility that iron production over last 200 years in Chongwe was secluded from pre-modern settlements, perhaps for socio-cultural and technical reasons, as has been historically documented (Mumford 1934; Sutton 1985; Schmidt 1996; Mapunda 2010; Lyaya 2011). Almost all the iron production sites were situated in bushes, forests, and farms relatively far from the pre-modern settlements. This has been verified through surface walkover surveys around iron production sites that did not encounter any pre-modern settlement remains. If people lived in or nearby iron production sites, we should also expect to encounter such remains in the same area with iron production sites. It is noteworthy that due to ever-increasing human population, the areas with iron production sites are being invaded and made into farms. It was observed that the iron smelting sites in the bushes and forests are better preserved than those on people's farms. There are a few modern isolated settlements nearby the historical iron production sites. Some of these houses have been built on top of historical iron production sites for socio-cultural reasons. We have found three modern (family) houses built close to the sites, of which one was built on the iron production site itself (Fig. 2). According to oral evidence, iron smelting remains are used as charms against mishaps and witchcraft in some villages of Chongwe. The owner of the house built on scatters of Ndango iron smelting site 4 believes that his house and family are strongly protected against mishaps and witches as smelting technomedicines were very powerful and eternal (for a similar cultural belief, see Mapunda 2002, 2010). The owners of the three modern settlements shifted from the past settlements where the rest of the population has been living and built houses after 1985. The descendants of iron smelters in Chongwe were explicit in stating that iron smelting activities were secluded from past settlements.

The iron smelting sites of Chongwe are composed of either broken furnaces or collapsed furnace walls, tuyéres, slags, ore remnants, potsherds, charcoal, and bones. There were no complete furnaces found in the area. There are a few cases where the iron smelting furnaces were completely collapsed and had been reduced to mere rubble. The height of the broken furnaces was 80-90 cm, while furnace wall thickness measured 10-25 cm. The external diameter at the base of the smelting furnace was 110-160 cm, while the internal diameter was 90-140 cm. Based on the large base diameters of the smelting furnaces one can infer that these were tall smelting furnaces, with a height above two meters (see Chaplin 1961; Derricourt 1980). Interestingly, there were three – in most cases – or four smelting furnaces on termite mounds or anthills (Fig. 3), which was also observed by Maluma (1979). The furnaces were built using lumps of clay. It was noted that the distance from one furnace to another was 0.8-1.7 m, with an average of 1.3 m. The furnaces are always located on the western side of the anthills (see Fig. 3) for socio-cultural and technical reasons discussed below.

It was possible to locate and count the tuyére ports of the smelting furnaces. They had six to ten ports, which is indicative of a natural air supply mechanism (Lyaya 2016). The size of the ports was 20-30 cm high and 20-40 wide. Because the tuyéres had 5-6 cm external diameters, the width of the tuyére ports should have allowed insertion of at least three tuyéres arranged horizontally one beside the other. Similarly, the height of the tuyére ports should have allowed insertion of at least three tuyéres arranged vertically one on top of the other (Mapunda 2010). The insertion of multiple tuyéres in a single port has been verified by the recovery of frequent multiple tuyéres fused together in Chongwe (Fig. 4). The presence of frequent tuyére mould slags (Fig. 4) at the smelting sites strongly supports

FIGURE 2 Three remnants of iron smelting furnaces at Ndango site 3 (left) and informant’s house built on Ndango site 4 (right) in Chongwe.

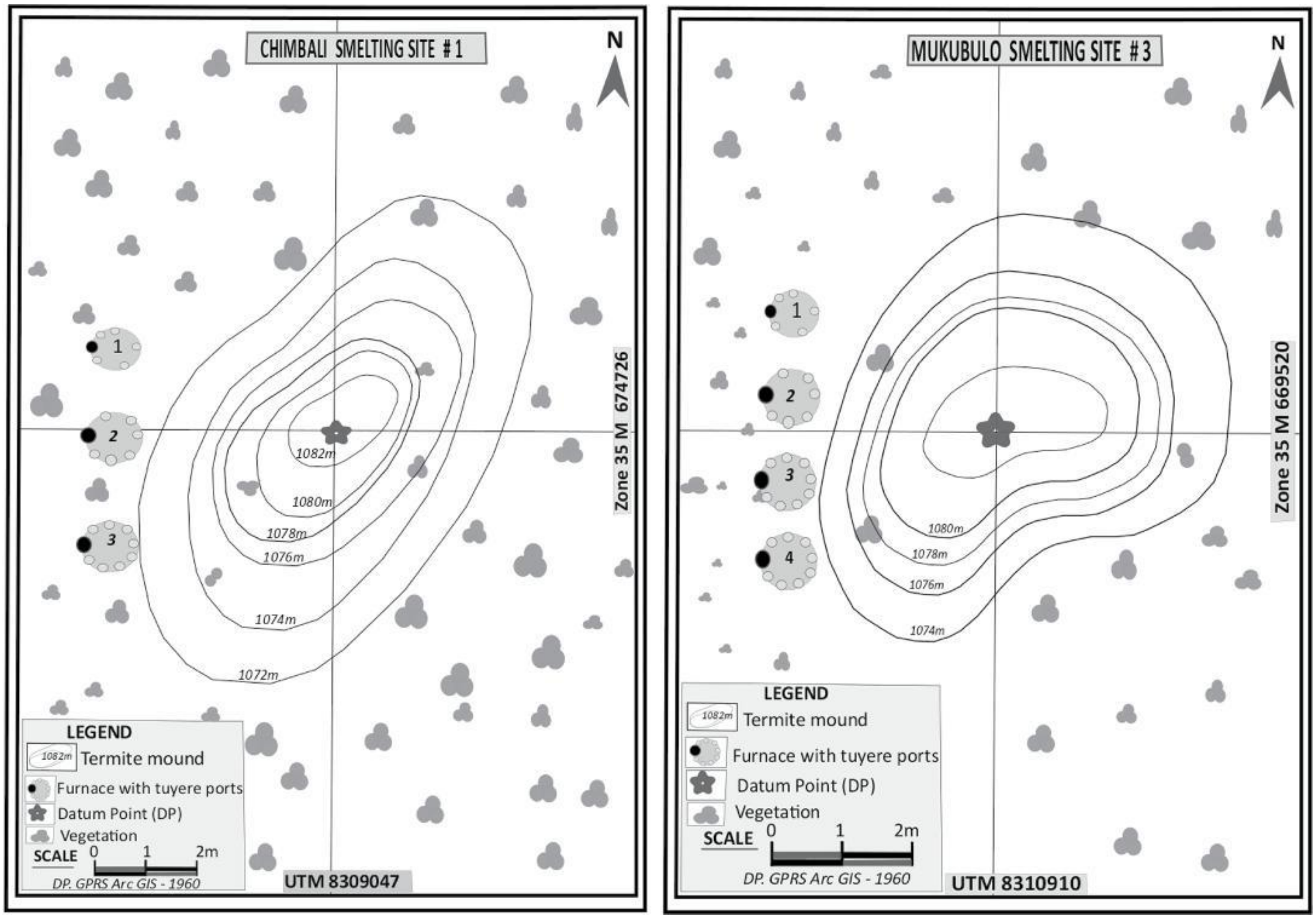


FIGURE 3 Site plans of Chimbali smelting site #1 (left) and Mukubulo smelting site #3 (right) showing location of smelting furnaces in relation to anthills. Note that black circle on the furnaces is a mother door.

FIGURE 4
Multiple tuyéres fused together (left) and tuyére mould slags (right) from Chongwe.

FIGURE 5 Iron smelting tuyéres with unflared proximal ends from Chongwe.

double function of multiple tuyéres – to supply air into the furnaces in the first place – and to tap slag toward the end of the smelt (Mapunda 2010; Lyaya 2016).

Additionally, the presence of tuyéres with unflared proximal ends (Fig. 5) further supports use of natural draft smelting furnaces in Chongwe as the tuyéres have no bellow receptacles (Mapunda 2010; Lyaya 2016). The inside wall of the furnace was beautifully lined and the floor sloped westwards following the ‘mother door’ (bloom rake-out hole) direction, possibly for slag tapping purposes. The lined floor depression was 15-20 cm deep, which can be considered relatively shallow as a slag-pit provision for such a large smelting furnace. Unfortunately, there were neither ritualistic nor techno-medicinal materials below the furnace floor.

Chemistry of Iron Production in Chongwe

Table 2 presents slag chemical data from Chimbali 1, Mukwamba 3, Mukubulo 1, and Ndango 4 sites on one side, and chemical data of technical ceramics (furnace walls and tuyères) from Mukwamba 1 and Mukubulo 1 sites on the other. In order of concentration, the slags of Chimbali 1 site comprise 50-70 wt% of iron oxide, 21-33 wt% silica, 3.8-6 wt% alumina, 1.5-6 wt% lime, and 0.7-2.4 wt% potash. Phosphorous oxide, titania, magnesia, manganese oxide, soda, sulphide trioxide, chromium oxide, and nickel oxide have a concentration less than 1 wt%. It should be noted that slag samples from Mukwamba 3, Mukubulo 1, and Ndango 4 sites also have a concentration less than 1 wt% of the latter oxides. It is also vital to note that chromium oxide was present in most of the slags below the detection limit of the machine.

Mukwamba 3 slags comprise 48-59 wt% iron oxide, 31-40.5 wt% silica, 4.5-7 wt% alumina, 0.6-2.8 wt% lime, and 0.4-1 wt% potash. Slags from Mukubulo 1 site contained 58-79 wt% of iron oxide, 12-25.5 wt% silica, 2.5-6 wt% alumina, 1.8-5.5 wt% lime, and 0.6-1.8 wt% potash. Final but not least, the slags from Ndango 4 site contained 53-72 wt% of iron oxide, 21-34 wt% silica, 3-6 wt% alumina, 0.3-4 wt% lime, and 0.7-1.5 wt% potash. Based on the chemical data, it is noticeable that the slags from Mukubulo 1 comprise the highest concentration of iron oxide of 67 wt% on average. In support of this, wüstite crystals were observed in all the slags from this site. Next in the order of concentration are the slags from Ndango 4, with 61 wt%; and the slags from Chimbali 1, with 57 wt% of iron oxide. This middle position can be explained as almost half of the slags from both Ndango 4 and Chimbali 1 exhibited wüstite while the other half did not exhibit such microstructures.

Mukwamba 3 slags have the lowest concentration of iron oxide of *circa* 54 wt%. This low concentration is consistent with the absence of wüstite crystals and other high iron oxides (hematite and magnetite) in all slags from this site. Other factors kept constant, iron production here can on the whole be interpreted as technically efficient on the basis of iron oxide concentration in the slags. It is important to consider variation in ore richness when discussing reduction or rather technical efficiency – the ability to reduce iron from ore – because smelting of laterites can produce lean slags. Nevertheless, it is vital to note that smelters did not produce such lean smelting slags effortlessly. According to Rehren et al. (2007), slags with the range of 54-67 wt% FeO cluster into the Optimum 1 efficiency (fayalite) zone (Fig. 6), with approximate temperature of 1088-1200 degrees Celsius. To achieve this, the smelters of Chongwe would need to have been skilled enough to control the parameters of reducing conditions in the furnaces efficiently (cf. Morton & Wingrove 1969; Tylecote et al. 1971). Control of the reducing conditions helped the smelters of Chongwe to eventually produce the intended final product, which appears to have been *soft* iron.

Silica concentration is relatively higher in the slags from Mukwamba 3 than in the slags from Chimbali 1, Mukubulo 1 and Ndango 4 sites. One possible interpretation is that silica was accidentally picked up in the system, which is attested by the glimpses of unreacted quartz in the slag (e.g. ZaMUKW31). The increase of silica concentration has systematically affected the concentration of other major oxides including major ore and fuel ash indicators. The major ore indicator systematically affected

TABLE 2 Slag and Ceramics Chemical Data obtained using X-ray fluorescence spectrometry. Note that H_2O represents the sample weight lost upon heating the sample powder at 110° overnight. LOI is "loss on ignition", and; represents the weight change (positive if weight lost) upon heating the sample to 800°C for 4 hours. Samples can gain weight during ignition if they have little water and abundant ferrous iron (as FeO, which oxidizes to ferric iron oxide, Fe_2O_3), thus up taking of oxygen. Sulphur reported as wt% SO_3 is measured on fused disks. The lower limit of detection for major oxides is 0.01 wt.%, and "b.d." is an abbreviation of "below detection" meaning that the concentration of the element was too low to quantify (generally <0.01 wt.% for major elements

Sample name	**FeO wt.**	**SiO2 wt.%**	**Al2O3 wt.%**	**CaO wt.**	**K2O wt.**	**P_2O_5 wt.**	**TiO_2 wt.**	**MgO wt.**	**MnO**	**Na_2O**	**SO3 wt.**	**Cr2O3 wt.%**	**NiO wt.**	**H_2O- wt.%**	**LOI wt.%**	**Total wt.%**
ZACHI1-1	58.46	30.55	5.48	1.63	0.87	0.31	0.53	0.27	0.14	0.24	0.06	b.d.	0.01	0.01	−4.38	100.68
ZACHI1-2	69.66	21.09	3.89	1.55	0.73	0.29	0.78	0.31	0.19	0.26	0.04	0.01	0.01	0.01	−6.19	100.39
ZACHI1-3	53.33	32.75	4.66	4.01	1.76	0.43	0.41	0.47	0.11	0.25	0.07	b.d.	0.01	0.00	−4.29	99.91
ZACHI1-4	50.48	31.49	5.59	5.94	2.36	0.77	0.54	0.61	0.16	0.24	0.10	b.d.	0.01	0.12	−4.46	99.56
ZACHI1-5	59.89	26.76	3.81	4.55	1.46	0.73	0.38	0.72	0.16	0.28	0.08	b.d.	0.00	0.13	−5.82	99.81
ZACHI1-6	53.92	30.39	6.07	3.86	1.79	0.57	0.52	0.67	0.24	0.27	0.07	b.d.	0.01	0.09	−5.30	99.16
ZAMUKW3-1	51.75	35.63	6.16	2.71	0.81	0.44	0.40	0.38	0.21	0.22	0.03	b.d.	0.01	−0.03	−5.00	99.49
ZAMUKW3-2	51.52	36.27	5.96	2.37	0.99	0.48	0.41	0.41	0.24	0.22	0.04	0.01	0.01	0.03	−5.10	99.59
ZAMUKW3-3	58.30	31.82	5.46	1.00	0.55	0.34	0.35	0.17	0.53	0.23	0.03	b.d.	0.01	0.02	−5.86	99.45
ZAMUKW3-4	58.57	33.19	4.66	0.64	0.47	0.26	0.35	0.15	0.20	0.23	0.02	b.d.	0.01	0.03	−5.24	100.05
ZAMUKW3-5	56.82	34.24	4.72	0.97	0.60	0.32	0.35	0.24	0.21	0.24	0.03	b.d.	0.01	0.02	−5.33	99.76
ZAMUKW3-6	48.26	40.28	6.99	0.96	0.63	0.24	0.45	0.20	0.27	0.21	0.04	0.01	0.01	0.02	−4.32	99.61
ZAMUKU1-1	64.47	20.80	5.89	3.64	1.51	0.80	0.45	0.52	0.29	0.27	0.08	0.01	0.01	0.03	−6.37	99.57
ZAMUKU1-2	58.36	25.09	4.85	5.37	1.73	0.86	0.38	0.86	0.58	0.24	0.08	b.d.	0.01	0.06	−5.46	99.51
ZAMUKU1-3	60.31	25.27	5.09	3.40	1.55	0.56	0.34	0.59	1.02	0.25	0.08	b.d.	0.01	0.07	−5.79	99.46
ZAMUKU1-4	78.87	12.59	2.69	1.84	0.61	0.45	0.22	0.38	0.53	0.26	0.05	b.d.	0.01	0.07	−6.84	100.51
ZAMUKU1-5	65.41	20.91	4.03	4.63	1.21	0.73	0.28	0.60	0.70	0.24	0.06	b.d.	0.01	0.03	−6.07	100.06
ZAMUKU1-6	72.35	16.95	3.66	2.88	1.06	0.64	0.23	0.45	0.58	0.25	0.06	b.d.	0.01	0.03	−6.90	100.30
ZANDA4-1	53.10	33.93	6.07	2.78	1.20	0.45	0.49	0.28	0.15	0.22	0.03	0.01	0.01	0.03	−5.40	99.26

ZANDA4-2	54.84	30.80	5.33	4.01	1.49	0.54	0.45	0.54	0.15	0.23	0.08	0.01	0.01	0.04	−5.44	99.17
ZANDA4-3	71.73	21.38	3.18	0.30	0.77	0.10	0.30	0.19	0.12	0.26	0.01	b.d.	0.01	0.06	−6.33	100.08
ZANDA4-4	63.53	26.34	4.55	2.18	0.95	0.45	0.36	0.28	0.13	0.26	0.03	b.d.	0.01	0.05	−6.14	100.04
ZANDA4-5	66.09	21.46	3.88	3.95	1.29	0.71	0.31	0.62	0.21	0.22	0.09	b.d.	0.01	0.03	−6.49	99.73
ZANDA4-6	57.18	29.24	5.83	2.74	1.51	0.62	0.44	0.84	0.14	0.26	0.05	b.d.	0.01	0.02	−5.57	99.69
ZAMUKU1F-1	7.14	65.84	12.56	2.95	1.65	0.08	1.52	0.92	0.16	0.52	0.02	b.d.	0.01	1.41	4.00	99.58
ZAMUKU1TYR	5.58	69.89	16.90	0.81	1.75	0.06	1.15	0.41	0.09	0.29	0.01	b.d.	0.01	0.47	1.25	99.29
ZAMUKU1TYR	5.89	68.64	17.45	0.74	1.68	0.08	1.21	0.44	0.10	0.29	b.d.	0.01	0.01	0.77	1.27	99.24
ZAMUKW1F-2	7.53	64.53	15.23	4.32	1.39	0.10	1.36	1.21	0.22	0.37	0.03	0.01	0.01	0.23	2.00	99.37
ZAMUKW1TY	2.60	77.68	13.89	0.27	0.39	0.06	1.45	0.24	0.04	0.23	b.d.	0.01	0.01	0.76	1.43	99.35
ZAMUKW1TY	2.59	79.37	12.94	0.78	0.51	0.06	1.43	0.38	0.10	0.23	b.d.	0.01	0.01	0.15	0.45	99.31
ZAMUKW1TY	2.72	78.08	13.93	0.21	0.43	0.07	1.43	0.24	0.04	0.23	b.d.	0.01	0.01	0.29	1.06	99.07

was phosphorous oxide, as there is less concentration of this oxide in Mukwamba 3 compared to the other slags of Chimbali 1, Mukubulo 1, and Ndango 4 sites. It appears that the concentration of alumina was not affected, as its concentration is similar throughout the slags of the four sites. Titania and manganese oxide were also not affected directly, as there is relatively high titania in the Chimbali 1 slags and high manganese oxide in the slags from Mukubulo 1 site. Slag chemistry is sometimes difficult to predict (e.g. Miller & Killick 2004). On the side of fuel ash oxides, there is systematically less concentration of the fuel ash oxides including lime, potash, and magnesia. Note that this did not affect soda concentration, as its concentration is similar to the slags of the other three smelting sites.

On average, the furnace wall from Mukubulo 1 site comprises 66 wt% silica, 13 wt% alumina, 7 wt% FeO, 3 wt% lime, 2 wt% potash, 2 wt% titania, and 1 wt% magnesia, while its tuyéres comprise 69 wt% silica, 17 wt% alumina, 6 wt% FeO, 1 wt% lime, 2 wt% potash, and 1 wt% titania. The furnace wall from Mukwamba 1 site comprises 65 wt% silica, 15 wt% alumina, 8 wt% FeO, 4 wt% lime, 1.4 wt% potash, 1.4 wt% titania, and 1.2 wt% magnesia, while its tuyères comprise 78 wt% silica, 14 wt% alumina, 3 wt% FeO, and 1.4 wt% titania. It is noteworthy that other oxides of phosphorous, manganese, sodium, and sulphur – for furnace and tuyère samples from both Mukubulo 1 and Mukwamba 1 – have concentrations well less than 1 wt%. Note that magnesia concentration in the tuyéres from Mukubulo 1 and Mukwamba 1 was also less than 1 wt%. It is also noted that the concentrations of lime and potash from tuyéres of Mukwamba 1 were less than 1 wt%. The concentrations of chromium and nickel oxides were sporadically below detection limits. Based on the close similarity in concentrations of silica, alumina, and iron oxide in the furnace walls from both sites, it can be argued that a similar source of clay was used, although it may also have been different sources with a similar geology. Oral evidence has suggested the use of termite mound clay for furnace construction. This suggestion is strengthened by the location of all furnaces at termite mounds. The question of whether the termite mound clay was used to make tuyéres cannot be supported with our current chemical data, as there is a systematic difference between furnace walls and tuyéres in terms of silica, alumina, and iron oxide. It can be speculated also that smelters sought another source of clay for tuyére making *per se* that they tempered with the termite mound clay to ensure workability of the clay for this purpose.

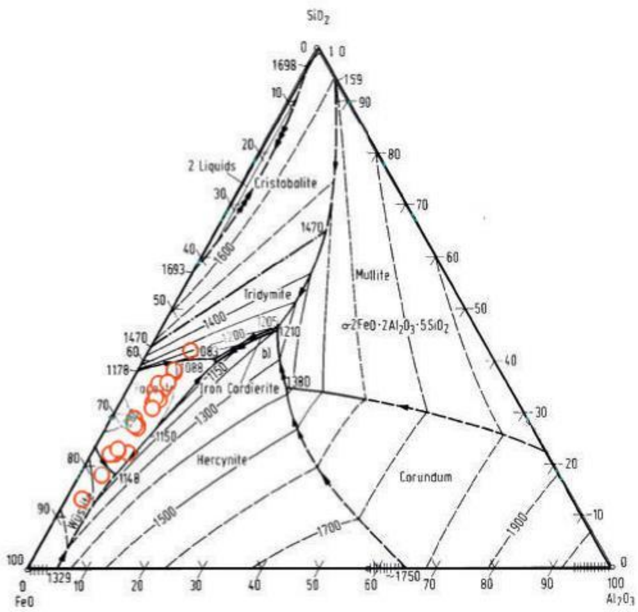


FIGURE 6 Al_2O_3-SiO_2-FeO ternary phase diagram for smelting slags (red open circles) from five sites (Chimbali 1, Mukwamba 3, Mukubulo 1, and Ndango 4) in Chongwe district (After Rehren et al. 2007).

Mineralogy of Iron Production in Chongwe

Table 3 presents phases of the 36 polished slag mounts including fayalite, wüstite, glass, iron particles, magnetite

TABLE 3 List of phases of the smelting slags from Chongwe

ZaCHI11	□ □	Tap
ZaCHI12	□ □ □ □ □	Furnace
ZaCHI13	□ □ □	Tap
ZaCHI14	□ □	Tap
ZaCHI15	□ □ □ □	Tap
ZaCHI16	□ □ □	Tap
ZaCHI31	□ □ □ □ □	Tap
ZaCHI32	□ □ □ □	Furnace
ZaCHI33	□ □ □ □ □	Furnace
ZaCHI34	□ □ □ □ □	Furnace
ZaCHI35	□ □ □ □ □	Furnace
ZaCHI36	□ □ □ □ □	Furnace
ZaMUKW11	□ □ □	Tap
ZaMUKW12	□ □ □ □ □	Tap
ZaMUKW13	□ □ □	Tap
ZaMUKW14	□ □ □ □ □	Furnace
ZaMUKW15	□ □ □	Tap
ZaMUKW16	□ □ □	Tap
ZaMUKW31	□ □ □	Tap
ZaMUKW32	□ □	Tap
ZaMUKW33	□ □ □	Tap
ZaMUKW34	□ □ □ □	Tap
ZaMUKW35	□ □ □	Tap
ZaMUKW36	□ □ □	Tap
ZaMUKU11	□ □ □ □	Tap

ZaMUKU12 ✓ ✓ ✓ ✓ Tap
ZaMUKU13 ✓ ✓ ✓ ✓ ✓ Tap
ZaMUKU14 ✓ ✓ ✓ ✓ Furnace
ZaMUKU15 ✓ ✓ ✓ ✓ Tap
ZaMUKU16 ✓ ✓ ✓ ✓ Furnace
ZaNDA41 ✓ ✓ ✓ ✓ Tap
ZaNDA42 ✓ ✓ Furnace
ZaNDA43 ✓ ✓ ✓ Furnace
ZaNDA44 ✓ ✓ ✓ Furnace
ZaNDA45 ✓ ✓ ✓ ✓ Furnace
ZaNDA46 ✓ ✓ Tap

tap lines, leucite, quartz, droplets and hercynite. All of the slags analyzed contained pure fayalite crystals in the ratio of 2 molecules of FeO and 1 molecule of SiO_2 ($2FeO.SiO_2$) (cf. Bachmann 1982). With the exception of a few samples, namely, ZaCHI31, ZaMUKW15, ZaMUKU11 & 12, which

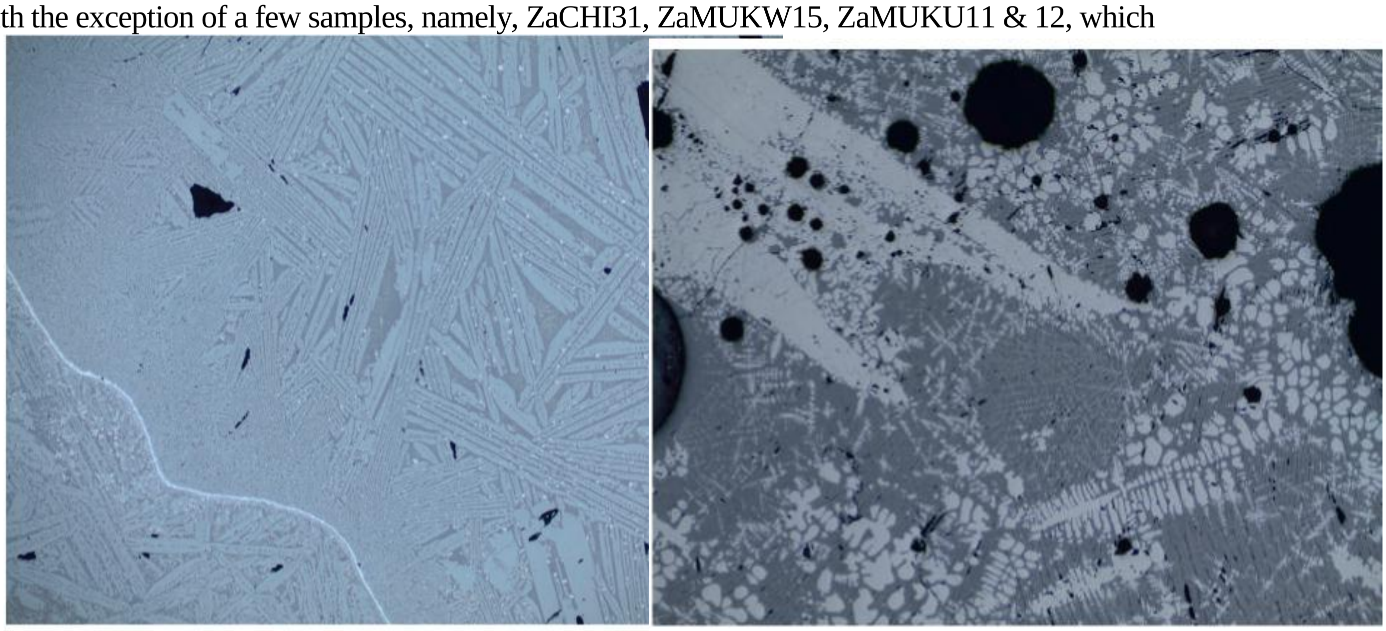


FIGURE 7 OM image at *x*100 of a tap slag from Mukwamba 3 in Chongwe. Note blocky (first generation) and thin (secondary generation) fayalite crystals (grey), with a magnetite tap line (whitish), glass matrix (dark grey), angular hercynite crystals (brownish), and porosity (black).

exhibited the second generation of the fayalite; the remaining fayalites were all first-generation crystals (Fig. 7). Based on the size and shape of the fayalite (and other) crystals, it was possible to distinguish tap slags from furnace slags. There were 23 tap slags and 13 furnace slags. The tap slags comprised of thin, elongated and in most cases feathery fayalite crystals indicative of possible rapid cooling, while the furnace slags comprised of blocky and angular fayalite crystals pointing to a slow cooling process of the slags perhaps in the furnace. Note that sample ZaMUKW12 neither cooled rapidly nor did it cool very slowly. It is possible that this sample trickled into a hole perhaps outside the furnace where it cooled this way (e.g. Schmidt 2006).

Out of the 36 specimens, 19 slag samples equivalent to *circa* 53% comprised primary wüstite crystals. Of the 19 specimens, three, namely, ZaCHI31, ZaMUKW12, and ZaCHI16 exhibited only secondary wüstite crystals (Fig. 8). Note also that out of the 19 specimens, ten were furnace slags, while nine were tap slags. All the slags from Mukubulo 1 site exhibited primary wüstite crystals. Out of 17 slag samples without wüstite crystals, it is observed that 15 were tap slags, while only two were furnace slags. No wüstite was seen in any of the slags from Mukwamba 3 site, while only one slag from Chimbali 3 site exhibited wüstite crystals. Based on the observation above, it is correct to posit that most of the tap slags had no wüstite crystals. Other factors kept constant, it can be argued the slag in the furnace was still undergoing the reduction process where wüstite could reduce to iron while the tap slag indicates that the reduction was almost finished and so one should not expect more wüstite in the tap slag if the technology was efficient (e.g. Killick & Gordon 1989).

All of the slags analyzed contained glass groundmass. One thing very clear from the microscopic analysis is that all the furnace slags have a relatively little volume of glass (Fig. 9), while the tap slags have a relatively larger volume of glass groundmass (Fig. 9). The former cooled so slowly that fayalite and other crystals in the slag had enough time to grow thicker, while the latter cooled so rapidly that the crystals in the slag did not develop thicker as there was not enough for this formation. In no particular order, the glass oxides include silica, iron oxide, alumina, potash, lime, phosphate, titania, manganese, and soda.

Out of 36 slag samples, there were angular iron particles in 24 specimens, which is equivalent to 67%. Other factors kept constant, the presence of angular iron particles in slags is suggestive of low reducing conditions, which at maximum can produce soft impure iron (cf. Gordon & Killick 1993: 261). None of the slags from Mukwamba 3 and Ndango 4 sites exhibited angular iron particles. This is significant because the absence of iron particles in slags is indicative of highly reducing conditions in the furnace, among other things. Out of 36 samples, only six slags equivalent to 17% contained leucite microstructures. The leucite crystals were particularly seen in two slag samples of Chimbali 1 site and in four slag samples of Chimbali 3 site. On the basis of SEM chemical composition ratio, with 1 molecule of potash and alumina and 2 molecules of silica ($K_2O.Al_2O_3.2SiO_2$), the crystals of leucite were essentially pure (see Anthony et al. 1995). Given the proximity of the two sites, it is possible that the smelters used similar iron ores which produced this phase similarity. Another phase present in the slags was roundish metal droplets. This phase was seen in three slag samples (8%), namely, ZaMUKW11, ZaMUKW36, and ZaNDA41. The presence of this phase is indicative of highly reducing conditions in the furnaces that produced them (for a similar argument, see Tholander & Blomgren 1985: 423). This indication is further strengthened by the absence of wüstite and iron particles in these slags.

Hercynite spinels were confirmed present with SEM analysis in four slag samples (11%), namely, ZaMUKW14, 15 & 16 and ZaMUKW34. Based on the SEM molecule ratio of 1:1 for iron oxide and alumina ($FeO.\ Al_2O_3$), the spinels are pure crystals (Anthony et al. 1997). They are indicative of the geochemistry of the Al-rich lateritic ore (for a similar argument, see Lyaya et al. 2012). It may also have been derived from Al-rich ceramics. Other factors kept constant, it is possible that the smelters of Mukwamba 1 and 3 sites used a similar ore. Seven specimens (19%) out of 36 polished slag mounts comprised tap lines indicative of successive slag taping episodes in a smelt (Humphris et al. 2009). Tap lines were formed when iron on the surface of the slag oxidized when met with the ambient air while trickling down from the furnaces. Interestingly, it was noted that at least one slag from each of the study sites exhibited clear magnetite tap lines. This means all the iron smelting furnaces in Chongwe were tapping slag.

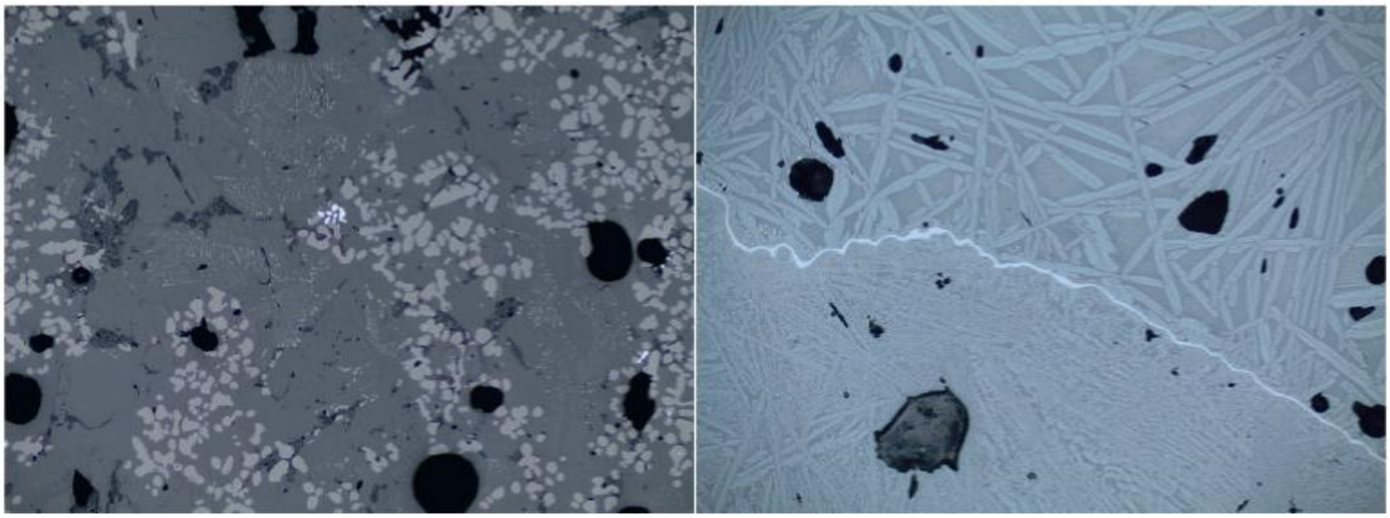
Discussion

The present paper has sought to explain spatial organization, the process of metal production which followed three-stage versus two-stage, furnace air supply mechanisms, liquid slag handling techniques, variation in geochemistry of ore and clay, and nature of the final products. This section discusses those aims in relation to oral evidence, archaeological, chemical, and mineralogical data presented above. Reference is also made to (un) published data from elsewhere for comparative purposes.

Iron-smelting activities in Chongwe were located far and secluded from historical settlements. This spatial pattern is similar to many other parts on the continent (Sutton 1985; van der Merwe and Avery 1987; Schmidt 1997; de Barros 2000; Mapunda 2010; Lyaya 2011). As discussed below, it is noteworthy in some other parts of the continent iron smelting took place within villages (Hatton 1969). The seclusion was in many places guided by socio-cultural and technical

reasons. African iron smelting comprised a cultural package that involved techno-medicines, symbols, rituals, and taboos, but there was variation within this (Herbert 1993; Haaland 2004a, b). This package engulfed African iron smelters South of Sahara and largely influenced the seclusion (Schmidt 1996; Mapunda 2010). It was seen as critical for successful smelts (van der Merwe and Avery 1987) and one can argue that the packages were in a way unique and particular to each group

FIGURE 9 OM images at *x*100 of a furnace slag (left) and tap slag (right). Note iron particles (white), wüstite (whitish), tap line (whitish), fayalite (brownish grey (left)), light grey (right), leucite (blackish in glass mass), glass matrix (blackish (left)), dark grey (right), and porosity (black).



of smelters (Mapunda 2010). There was a need to hide practices from viewers and strangers so as to protect the technology that was passed on to the next generation secretly on family or clan inheritance basis (Mapunda 2002). It is also agreed that iron smelting was hidden from witches and other people with bad intentions toward the smelts. In terms of the technical reasons, smelters were frequently located close to raw materials – clay, firewood, charcoal and iron ores (Chaplin 1961; Sutton 1985; Barndon 2004). While the seclusion phenomenon has received more research attention in African archaeometallurgy (Greenfield & van Schalkwyk 2003; Darling 2004; Musa-Mohamed 2004; Whitelaw 2005; Lyaya 2011; Wynne-Jones 2012; Iles & Lyaya 2015), it is vital to note there is variation in this topic depending on the nature and context of the technology. In other words, the spatial organization of iron smelting activities was variable as dictated by multiple factors. There are cases where iron smelting has been found within occupation areas (Haaland 1994; Haaland & Msuya 2000; Hall et al. 2006) or contiguous with living areas (Schmidt 1997). There are cases also where iron smelting activities within villages were consistently obscured from strangers and other viewers through means of a vegetation screen or other physical barrier (Reid & MacLean 1995; Anderson 2009; Iles & Lyaya 2015 and references therein). A further example is where smelters opted to transport iron ores – especially pure magnetite – to residential areas, but they always concealed the smelting activity (Anderson 2009: 214). Tswana people in southern Africa desired to conceal iron smelting activity because to them heat is the source of all problems such as drought, illness, mishaps, and death (Anderson 2009: 223). They strongly believe that women are inherently hot, but men are cool and stable, which means that in order for activities – especially those performed by men such as rainmaking, initiation, ritual offerings to ancestors, or iron smelting – to be successful, women, especially those menstruating, should not be allowed to see or come close (Anderson 2009). Another completely different set of variation on this topic is that there are cases in many parts of the continent where involvement of non-menstruating women in iron smelting has been reported (Hatton 1969; Raum 1973; Chirikure 2005; Mtetwa 2017). The seclusion of smelting activities eventually located metal production sites close to sources of ore, fuel, clay and water (Sutton 1985; Davison & Mosley 1988; Reid 1994; Haaland & Msuya 2000; Robertson 2000; Musa-Mohamed 2004; Barndon 2004). The interplay between the need to locate smelting sites close to raw materials and resources, and potential socio-cultural reasons for physical seclusion from other community members is particularly interesting, and will no doubt continue to be explored in future scholarship (Iles & Lyaya 2015) even though it has been explored since the second half of twentieth century.

According to Lyaya et al. (2012), pre-industrial iron production is assumed to have involved two processes, namely smelting and smithing in southern Africa (Miller & Killick 2004; Chirikure 2006: 147; Chirikure & Rehren 2006), west Africa (e.g. Filipowiak 1985: 36), eastern Africa (Sutton 1985; Larick 1986; Childs 1996; Barndon 2004: 76; Craddock et al. 2007), and central Africa (van Noten and Raymaekers 1988: 106). These scholars have established that the smelting product was worked during the smithing stage to forge tools and ornaments. This is widely accepted, but it does not give due weight to a separate refining tradition set between smelting and smithing documented in central and eastern Africa (Greig 1937; Chaplin 1961; Brock & Brock 1965; Wembah-Rashid 1969; Maluma 1979; Davison & Mosley 1988; Barndon 2004; Mapunda 2010; Lyaya 2019a, b). Iron refining was technologically and functionally different from smelting and smithing and was thought to improve the quality of the smelted product through introduction of carbon in the yield (Lyaya et al. 2012; Lyaya 2019a, b). Because Maluma's (1979) oral evidence alluded to a presence of the iron refining tradition in Chongwe, our purpose was to examine the archaeological and archaeometallurgical data in support of the refining process. Examination of archaeological and archaeometallurgical data would enable authors verify whether Chongwe iron production was a two-stage or three-stage process (see Lyaya 2019a, b). Unfortunately, field archaeological evidence from the five study sites, namely, Chimbali 1, Chimbali 3, Mukwamba 1, Mukubulo 1 and Ndango 4 are typically iron smelting debris including the presence of three large still standing furnaces per termite mounds (see also Maluma 1979), multiple tuyéres fused together by slag, heavy, rough and blocky slags, and frequent tuyére mould slags (see Fig. 4). Large sizes and volumes of the archaeometallurgical debris also indicate typical iron smelting sites (Killick 1990; Mapunda 2010). The arrangement of the multiple furnaces precisely located on the western size of anthills is also characteristic of smelting sites in this region (see Chaplin 1961). According to Lyaya (2010) and Lyaya et al. (2012), virtually over 97% of the refining site debris respectively in Mbozi and Sumbawanga is composed of smooth, relatively small flow slags (Lyaya 2019b). The remaining *circa* three percent would be relatively small cake slags and refining furnace wall remains (Lyaya 2010, 2019b). According to Davison and Mosley (1988), refining sites were situated next to smelting sites. Mukwamba 3 site had no standing furnaces and it was located on a farm with crops. Its small size and flow texture of the slags promised to a refining site, but it was difficult to conclude this with certainty based on the little and fragmentary evidence. Also, the absence of wüstite and presence of droplet microstructures on its polished slag mounts from this site is congruent with its small-sized flow slags, but the first step towards correct identification of archaeometallurgical sites is the field primary context (Miller & Killick 2004; Veldhuijzen & Rehren 2007). Therefore, we do not have significant contextual field data to support Maluma's (1979) oral evidence on the three-stage process of iron production in Chongwe (for extra details on three-stage process, see Lyaya 2019a, b).

Lyaya (2016) presents and discusses the archaeological evidence for air supply mechanism into smelting furnaces in the Great Lakes region. According to Lyaya (2016: 12-4), the size and height of the smelting furnace, frequent multiple tuyéres fused together, the frequency of tuyére mould slags, and shape of the proximal ends of a tuyére can indicate the way air was supplied into pre-industrial iron smelting furnaces. All these factors have earlier been verified from Chongwe in the archaeology section. First, the large external diameter of *circa* 1-1.5 m of the still standing smelting furnace remnants of Chongwe is indicative of the tall smelting furnaces in the region. Derricourt (1980) has recorded hundreds of 3 meters high smelting furnaces in Zambia. It is thus more likely that the recorded external diameter of the Chongwe smelting furnaces supports a height of around 3 meters. The tall smelting furnaces of Mbozi, southwestern Tanzania with similar external base diameter, 1.5 m on average; were 3 m high (Lyaya 2013: 207). This size and the speculated height of the Chongwe furnaces corresponds well with natural draft smelting furnaces. The range of six to nine tuyére ports per furnace in Chongwe further strengthens the idea of a natural draft mechanism (Sutton 1985; Chirikure 2005; Mapunda 2010; Lyaya 2013; Mtetwa 2017). Second is the evidence of the high frequency of tuyére mould slags, which is suggestive of slag tapping apparently through tuyéres. It is difficult to establish if smelters could place bellows on tuyéres that were eventually expected to function for slag tapping. It is indeed impossible for tuyéres neatly tied with bellows to tap (hot liquid) slag, of course; the smelt would be halted. Thirdly, there is also evidence of numerous multiple tuyéres fused together at the Chongwe archaeometallurgical sites. Based on the width and height of the tuyére ports, it seems the multiple tuyéres (four to eight) were also placed horizontally one on top of the other. This arrangement of tuyéres in a port where one tuyére was placed on top of the other was a technical design and not a mistake, because when slag started trickling down it was tapped out of the furnace through the tuyéres placed at the bottom, while those tuyéres placed on top of others continued performing the function of supplying air into the smelting furnace following the principle of buoyancy air (cf. Mapunda 2010; Lyaya 2016). Finally, Lyaya (2016) argues that the absence of flared proximal ends of tuyéres and presence of uniform diameter tuyére ends is indicative of a natural draft mechanism at any smelting furnace. This work has found evidence for uniform diameter tuyére proximal ends. Additional evidence for modes of air supply mechanism is multiple furnaces per termite mound in Chongwe. With the exception of one termite mound, with four furnaces, the remaining had three smelting furnaces which were all located on the western side. The furnaces are spaced around one meter apart. This space in between the furnaces has two tuyére ports on each furnace, but it is almost impossible for four adults who would be bellowing the two adjacent furnaces to squeeze into such a small space. To operate the three furnaces at a time with bellows would also mean employing at least 18 adults per furnace. The best explanation is that the multiple furnaces operated through a natural draft mechanism. It is possible that the smelters of Chongwe used natural draft furnaces because they were labour efficient.

There are archaeological and microscopic data in support of smelting slag tapping techniques in Chongwe, where slag was allowed to flow outside the furnace. The location of the multiple furnaces on sloping ground is critical evidence for slag tapping. Excavation of the floor of the furnaces revealed an intact lined floor, which was shallow at 15 to 20 cm. The lined floor was designed to slightly incline downward in the direction of the mother door or rake door. In the smelting debris clusters, there were tuyére mould slags indicative of slag tapping using tuyéres. The frequent occurrence of multiple tuyéres fused together is a phenomenon suggestive of slag tapping through tuyéres. The multiple tuyéres were formed or rather fused together by liquid slag that was trying to find its way out through the tuyéres but did not make it. The slag that was tapped through the tuyéres was eventually exposed to relatively rapid cooling conditions outside the furnace due to ambient air. This can be verified through
microscopic data. The presence of thin and elongated microstructures in the smelting slag is indicative of rapid cooling conditions. All tap slags have shown thin phases of fayalite and hercynite, perhaps because there was not enough time for the crystals to grow thicker as they cooled rapidly. This explanation is further supported by the presence of highly spaced glass groundmass in the slags. The presence of noticeable magnetite tap lines in the slags of Chongwe strongly indicates slag-tapping episodes outside the furnace. The smelters of Chongwe selected this technique for technical

and socio-cultural reasons that have not been established from the data for the current work and so this will be an avenue for future research.

We have also aimed at examining variation in the geochemistry of the slag and clay for manufacturing of tuyéres and construction of smelting furnaces. Given the similarity in geochemistry of the slags in terms of major ore oxide indicators including alumina, phosphorous oxide, titania, and manganese; it is possible that a similar iron ore was smelted in Chongwe. It is possible to point to a lateritic ore on the basis of the silica and alumina geochemistry of the slags. Most of the tall ore smelting furnaces in the Great Lakes region utilized low- grade ores, particularly lateritic ones (e.g. Killick 1991; Mapunda 2010; Lyaya 2013). Although currently we do not have confirmed data on whether smelters had a choice of many iron ores, laterites are abundantly available in the region due to its geology. Based on experience, smelters may also have liked this ore because it is a self-fluxing ore. The significant difference in silica, alumina, and iron oxide between furnace wall and tuyére geochemistry indicates that clay for manufacturing of tuyéres may have been procured from a different source. On the basis of this difference, it can be suggested that the smelters were clay-selective, which is similar elsewhere in East Africa (Childs 1989, 1990). It is also possible that the smelters mixed furnace clay with another type of clay to enhance the workability properties for tuyére making. Note that the selection of refractory clays was critical to the success of smelts as they had to withstand smelting temperatures. Although we have no chemical data of the termite mound clay, it can be suggested that smelting furnaces were built using termite mounds clay. There are three reasons: (i) the smelting furnaces in Chongwe are always located on termite mounds, (ii) clays from termite mounds have been verified as refractory for this purpose (Lyaya 2013), and (iii) it is unreasonable to dig and transport huge amounts of clay from distant sources other than available refractory termite mound clay for the construction of massive smelting furnaces.

Generally, iron production aimed at producing either iron, steel, or a mixture of iron and steel, and cast iron. How systematically the intended final product was produced can be used as a measure of the experience and efficiency of the smelters. Based on slag phase analysis, we can argue that most of the smelters in Chongwe aimed at producing soft iron metal as opposed to carbon-rich steel or cast iron. With the exception of furnace and tap slags from Mukwamba 3 smelting site, which had no any wüstite whatsover; the remaining smelting sites: Chimbali 1, Chimbali 3, Mukwamba 1, and Ndango 4 comprised of wüstite crystals. In order to produce iron metal, one needs strongly reducing conditions to reduce wüstite into iron or steel. One of evidence for reducing conditions is wüstite and iron crystals. The presence of wüstite coupled with angular iron particles suggests that the smelting conditions were perhaps lower reducing conditions (cf. Tholander & Blomgren 1985). Other factors kept constant, it is only soft iron that could have been produced in Chongwe furnaces (for a similar interpretation, see Tholander 1989). On contrary, the absence of wüstite in all Mukwamba 3 sites is indicative of highly reducing conditions capable of producing steel. The presence of iron prills in the slags from Mukwamba 3 site strongly signals that carbon-rich steels were perhaps produced (see also Tholander & Blomgren 1985; Tholander 1987). The fieldwork for this paper has found no explicit evidence of smelting at Mukwamba 3 site, but as noted earlier the evidence of small and flow slags is essentially fragmentary. So even if carbon-rich was produced at this site, we cannot confirm that this was a refining site and we cannot attribute it to a smelting site. We shall need to do more field and laboratory work to verify the presence of refining tradition in this country as suggested by Chaplin (1961), Maluma (1979) and Musambachime (2016).

Conclusion

This paper presented the technology of iron production in the last two centuries of the second millennium AD in Chongwe. Based on the data and discussion presented in this paper, it is possible to conclude that the technology of iron production in Chongwe is unique in the Corridor due to the presence of multiple iron smelting furnaces per termite mound. Iron smelting technology in Chongwe was secluded from historical settlements. It was possibly a two-stage process that employed multiple smelting furnaces per termite mound. Iron smelting was consistently located on the western side of the termite mound. The smelting furnaces operated through a natural draft mechanism and liquid slag was tapped out of the furnaces through tuyéres. Iron smelting in Chongweutilized low-iron grade lateritic ore for technical reasons. The people of Chongwe largely produced iron, with a possible exception of one site, Mukwamba 3. Further research is needed to confirm the historical presence of a possible refining tradition in Chongwe. The expansion of farming and settlements are the major factors threatening the preservation of archaeometallurgical sites in Chongwe.

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Appendix: List of Informants Interviewed for This Study

Interviewed	Name	Workplace	Position
14/2/2017	Stephen E. Nkausu	Kanchubwi, Zone 8	Senior headman
14/2/2017	Kennedy Mapulanga	Kanchubwi, Zone 8	Assistant senior headman
14/2/2017	Janiya Mushipi (84)	Chimbali, Zone 7	Villager
14/2/2017	Rafael Mwalusha (84)	Chimbali, Zone 7	Villager
14/2/2017	Solomon Mayungo (64)	Chimbali, Zone 7	Villager
14/2/2017	William Ngandalo	Kanakantapa	Villager
15/2/2017	Watson Banda	Mukubulo	Headman
15/2/2017	Kazimili Maluman	Chitete	Headman
17/2/2017	Robert L. Champanga	Chimbali	Headman
17/2/2017	Moreen Movita Mwale	Kanakantapa	Secretary
17/2/2017	Misalo Mwenda	Kanakantapa	Scheme manager
18/2/2017	Gasela Sandasi Nyoni	Mukwamba	Owner

18/2/2017	James Mukwamba	Mukwamba	Headman
18/2/2017	Isaac Ntaimo	Mukwamba	Villager
18/2/2017	Iredi Chiota	Chiota	Senior headman, Zone 12-19
18/2/2017	Jija Njovu	Chimbali	Owner
20/2/2017	McMillan Mudenda	Commission for Cultural Heritage	Heritage expert
20/2/2017	Muyumbwa Ndioyi	Commission for Cultural Heritage	Heritage expert
20/2/2017	Kagosi Mwamulowe	Commission for Cultural Heritage	Heritage expert
20/2/2017	Lameck Mwanza	Mukubulo	Villager
25/2/2017	Elizabeth Mulenje	Soli Chieftainship	Senior Chieftainess Nkomesha Mukamambo II