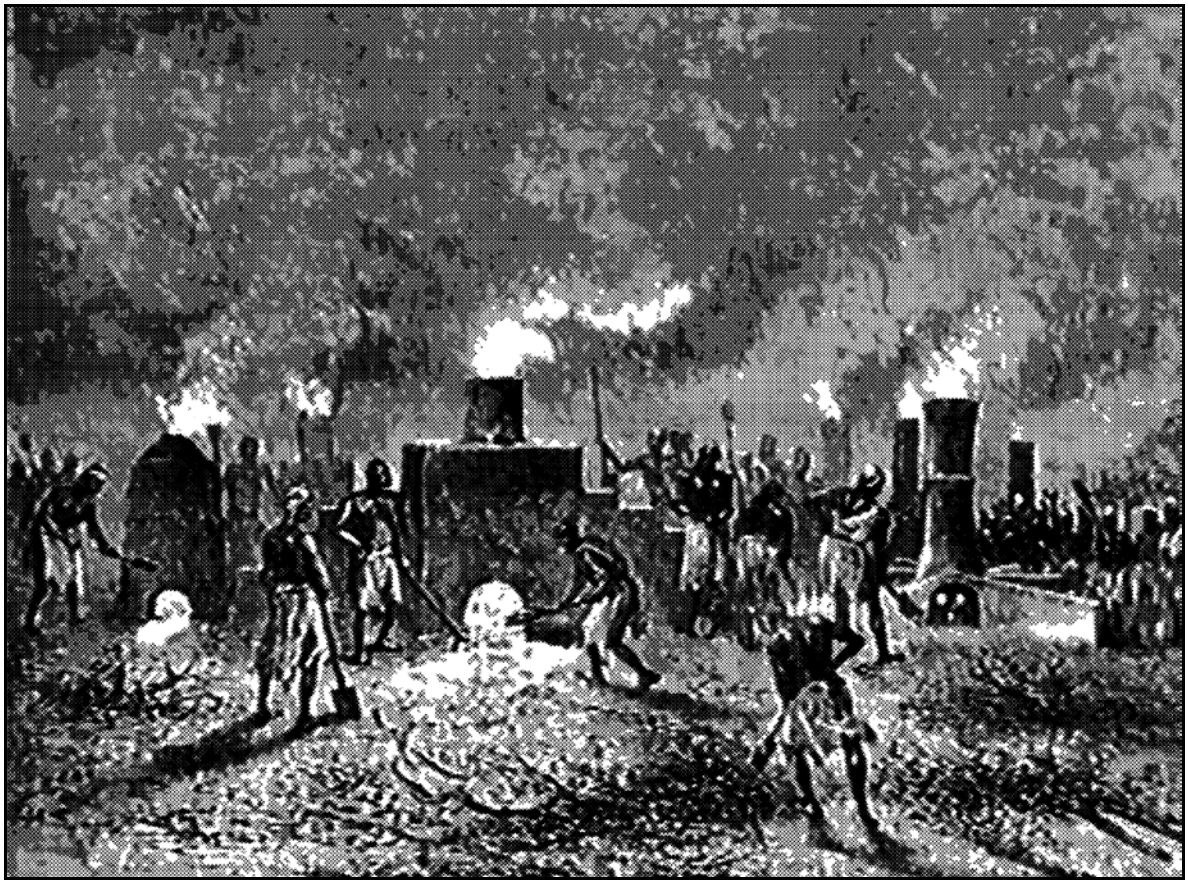
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Métallurgie du fer et Sociétés africaines

Bilans et nouveaux paradigmes dans la recherche anthropologique et archéologique

Édité par

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The Bloom Refining Technology in Ufipa, Tanzania (1850-1950)

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La variabilité des processus sidérurgiques en Afrique a occasionné une classification de ses vestiges peu claire. Le but de cet article est de découvrir si l'on peut rapprocher ou différencier macroscopiquement, chimiquement et microscopiquement le processus de raffinage de celui de la réduction de fonte. Macroscopiquement, les sites de raffinage sur le terrain peuvent être différencié de ceux de réduction sur la base de la taille du secteur, la morphologie des scories, la quantité et la composition des déchets. Chimiquement, il est difficile de distinguer les deux processus, toutefois il y a une différence significative lorsqu'on analyse leurs microstructures respectives. La scorie de raffinage contient principalement des prill de fer de forme arrondie indiquant un important processus de réduction, alors que celle de réduction comprend des particules de fer ferrique de forme plus angulaire. Ces résultats indiquent que le processus de raffinage a dû agglomérer des fragments de scories et de fer à l'intérieur d'une masse de métal riche en carbone.

Analyses métallographiques et chimiques, loupe de réduction et de raffinage, prill de fer arrondi, scorie, Tanzanie.

The classification of African metalliferous relics generally lacks clarity, because African ironworking involved variable processes. The purpose of this paper was to find out how the refining process was related to or different from the smelting process, macroscopically, chemically, and microscopically. Macroscopically, refining sites or clusters in the field can be differentiated from smelting clusters based on attributes such as area size, slag morphology, quantity and composition of the remains. Chemically, it has been difficult to draw a line between the two processes, but there is a significant difference between the two based on microstructural analyses. Refining slag principally contain roundish iron prills indicative of a highly reducing process if compared to the smelting process, which results in more angular ferritic iron particles. These results indicate that the refining process was meant to consolidate incoherent and slag-rich bloom fragments into larger, denser and possibly more carbon-rich metal ready to be forged into high-quality implements.

Metallography and chemical analysis, smelting and refining bloom, roundish iron prills, metalliferous, slag, Tanzania.

Introduction

Bloomery ironworking is generally assumed to have involved two processes, namely smelting and smithing. This two-stage technology has been documented in most parts of the Old World, including southern Africa (e.g. Miller and Killick 2004; Chirikure 2006, 147; Chirikure and Rehren 2006), west Africa (e.g. Filipowiak 1985, 36), eastern Africa (e.g. Sutton 1985; Larick 1986; Childs 1996; Barndon 2004, 76; Craddock *et al.*, 2007), and central Africa (e.g. Van Noten and Raymaekers 1988, 106). These scholars have generally established that the bloom resulting from the smelting process was re-worked during the smithing stage in order to forge tools. Although this assumption is widely accepted, it ought to be rethought for some regions, because it does not give due weight to an intermediate process which involves bloom refining in a special furnace prior to smithing.

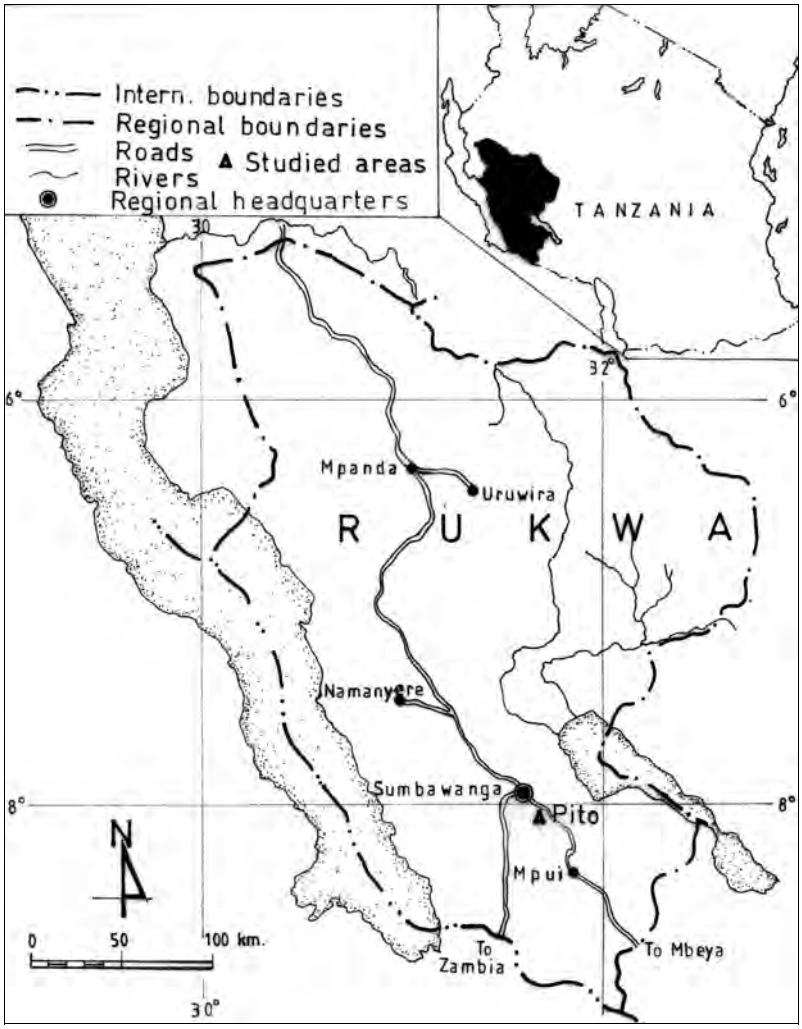


Fig. 1 : Pito Ward, Sumbawanga, in Ufipa, SW Tanzania

A separate refining tradition set between smelting and smithing is well documented in central and eastern Africa (Greig 1937; Chaplin 1961; Brock and Brock 1965; Wembah-Rashid 1969; Davison and Mosley 1988; Mapunda 1995a; Barndon 2004), and is thought to improve the quality of the bloom prior to smithing, and possibly also to enhance the overall iron yield. Just as smelting and smithing processes, this second stage in the ironworking *chaîne opératoire* (Barndon 2004, 92) produced its own slag. The presence and acceptance of refining as a separate technological process calls for a rethinking of the classification of metalliferous relics. For this, we need to investigate what refining slags look like, and how they are different from smelting and smithing slags. Based on theoretical considerations, we expect that refining slag should look different from smelting and smithing slags, because the three ironworking processes were both technologically and functionally different from each other. In particular, based on ethnographic reports and the idea of re-smelting an incompletely consolidated bloom, the refining slag should reflect more reducing conditions and a larger contribution of fuel ash to the slag formation than the smelting slag. A full examination of the refining process is indispensable because it will give the process its due weight, and will enhance clarity on metalliferous slags. This paper presents the results of an initial archaeometallurgical study of Fipa refining slag from the Pito ward in Sumbawanga, Tanzania (Fig. 1), with the view of comparing it to associated smelting slags macroscopically, chemically, and microscopically.

Background Information to Fipa Ironworking Technology

The name Fipa comes from the word 'lyamfipa', meaning plateau people (Wembah-Rashid 1969, 65; Mapunda 2004, 75). The Fipa are famous ironworkers. Traditionally they lived in upland (plateau) regions, often where water, iron ore and termite mounds were plentiful, as these were essential for their basic needs, especially iron working (Mapunda 2010). The Fipa practised a three-stage ironworking tradition, involving smelting, refining, and smithing. Despite the fact that they were banned from smelting iron during the colonial period, they continued producing iron until the second half of the 20th century, due in part to the inaccessibility of Ufipa (the land of the Fipa), which not

only impaired checks by the colonial authorities but also hindered the influx of imported metalware. Noteworthy that because Fipa ironworking medicines, which were important to help the smelt turn out successfully, were controlled by the master smelter, the Fipa are well-known for traditional healing in modern day Tanzania, which is a reflection of the socio-cultural impact of ironworking (Mapunda 2004). Because of these reasons, there is substantial information that has been published on Fipa ironworking technology.

The Fipa ironworking historiography began with amateur ethnographers and anthropologists in the 1910s, followed by professional ethnographers and anthropologists in the 1960s. These early writers, including Wychaert (1914), Greig (1937), Wise (1958), and Wembah-Rashid (1969), focused on documenting and producing descriptive reports of Fipa ironworking, which were based on interviews with retired smelters and observations of smelting processes, especially when the retired smelters were commissioned to demonstrate the process. After the amateur and professional ethnographers and anthropologists, the period between the 1970s and 2000s was marked by the work of ethnoarchaeologists and historical archaeologists. These later researchers had a different approach to the investigation of the Fipa iron technology, and have systematically studied different themes of Fipa ironworking, including the social history, culture and socio-cultural implications of ironworking. This group includes Sutton (1985), Barndon (1992; 1996; 2004), and Mapunda (1995a; 1995b; 2003; 2004).

According to archaeological research conducted so far in Ufipa and neighbouring areas, between 400 and 1000 AD ironworking was already being practised there (Clark 1974). This understanding is based on metallurgical relics found in association with the Kalambo pottery tradition, which is related to Urewe ware in the interlacustrine region, and the Mwabulambo and Gokomere traditions in Malawi and Zambia to the south (Mapunda 2003, 78). Although the evidence is fragmentary and patchy, slag and tuyère analyses indicate that the ironworking technology practised during this period was different from the technologies of later groups, such as the *Katukutu* and *Malungu* (Mapunda 2004, 76). By 1000 AD, the triangular incised ware (TIW) pottery tradition emerged in Ufipa. Because TIW is traditionally a coastal tradition, Mapunda (2003; 2009) argues that it may have spread to Ufipa possibly through trade interaction between the coast and the interior (see also Haaland 1993; 2005).

By 1400 AD, the *Katukutu* ironworking technology emerged in Ufipa, as evident in the Nkansi district (Mapunda 1995a; 2003; 2004; 2010). This technology is characterised by short furnaces, 80-120cm high, globular in shape, decorated with holes punched with a stick or a finger, and natural-draft air supply. Mapunda (1995a; 1995b) concludes that this smelting technology utilised high quality magnetite iron ores. The *Katukutu* technology was followed by the *Malungu* technology, which emerged around 1680 AD south of Ufipa (Mapunda 2004), and reached south-western Tanzania around the mid-nineteenth century AD (Mapunda 2010, 159). Characteristic features of *Malungu* include the use of limonite iron ores, and truncated natural-draft furnaces ranging from 2.3m to 4m in height. *Malungu* furnaces are always located on the western side of a termite mound, for various technical and cultural reasons (Barndon 1992; Mapunda 2010) and had about ten tuyère ports, with multiple tuyères placed in each port (Mapunda 1995a, 50). The *Malungu* technology was associated with a separate bloom refining technology in small forced-draft furnaces, called the *vintengwe* technology or the small furnaces technology (e.g. Mapunda 1995b, 50; 2003, 76; Barndon 1992; 1996; 2004). The *Malungu* technology was in turn followed by the Barongo-type forced-draft technology that emerged in the 19th century AD (Mapunda 2003; 2004). This technology is characterised by furnace slabs 60-90cm high that were made from termite mounds, five tuyère ports, and flared tuyère ends (Mapunda 1995b, 53).

The culture and rituals of Fipa ironworking have also been documented. For example, Barndon (1992; 1996, 65-71; 2004) discusses the cultural aspects of the *Malungu* technology by saying that the Fipa ironworking medicines, which were important to help the smelt turn out successfully, were controlled by the master smelter. Symbolically, the furnace was likened to a bride, and the songs, ritual ceremony, and decorations resembled a wedding ceremony. The use of magic, sexual taboos and secrecy probably controlled the transmission of metalworking knowledge (Barndon 1996, 69).

Lastly, the socio-cultural significance of Fipa ironworking is well known. For example, Mapunda (2004, 78-83) interprets its socio-cultural context in terms of iron hoe symbolism, communal labour, political rank, protecting society, stratified economic well-being, and ironworking taboos promoting socio-cultural moral values. Mapunda writes that (1) customarily an iron hoe was used to symbolise the passage to manhood and by extension a legal right to marry, (2) iron smelting stimulated communal labour and concentrated/nucleated settlements, because settlements of this type were necessitated by the demand for communal labour for iron production,

farming, and defence, and (3) ironworking was an indicator of political rank, because smelting was an inherited skill and only members of designated clans could smelt and had the right to become leaders (Mapunda 2004, 79; 2010).

The decline of traditional ironworking in the 1930s or thereafter was due to suppression by the colonial government, with the view to stimulate the use of imported metals (Mapunda 2004, 78), and marked the end of a long social history of the Fipa ironworking technology. The decline of traditional ironworking translated into more importation of manufactured goods from Europe.

Vintengwe: Bloom Refining Technology

It is known that refining furnaces in Ufipa were bellows-operated using three draught holes (Greig 1937; Phillipson 1968; Barndon 1996; 2004), almost cylindrical in shape, and with a height ranging from 30 to 45cm (Greig 1937). They were always built on a sloping area to allow the slag to flow down via a small funnel-shaped channel dug in front of the furnaces following the slope (Wise 1958). The technological function of this process was to refine the smelted bloom from the tall, *Malungu* furnaces. This meant that ore smelting was the first stage and bloom refining was the second stage in the *chaîne opératoire* of traditional ironworking in Ufipa (Barndon 2004, 92). Greig (1937, 79) writes that "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 impurity and has to be treated further in a miniature blast furnace". In addition to Greig (1937), Wembah-Rashid (1969, 66) confirms "exactly there are three stages: the kiln stage [or smelting stage, own interpretation], the blast furnace [or refining stage, own interpretation] and the smithing stage". This three-stage process was not only practised by the Fipa, but also many others, such as the Nyiha south of Ufipa (Brock and Brock 1965), the Tabwa of eastern Democratic Republic of Congo (DRC) (Mapunda 1995a), the Lungu and Kaonde of northern Zambia (Chaplin 1961, 54, 58), and the Phoka and Chewa of northern Malawi (Phillipson 1968, 102; Davison and Mosley 1988, 77). So far, it appears from a geographical perspective that this technology is a central and eastern African phenomenon. Because tall smelting furnaces in this part of Africa are generally called *malungu*, and refining furnaces are called *vintengwe*, we refer to the latter as the *Vintengwe* technology or *kintengwe*, in singular. The 'Tanganyika-Nyasa Corridor tradition'

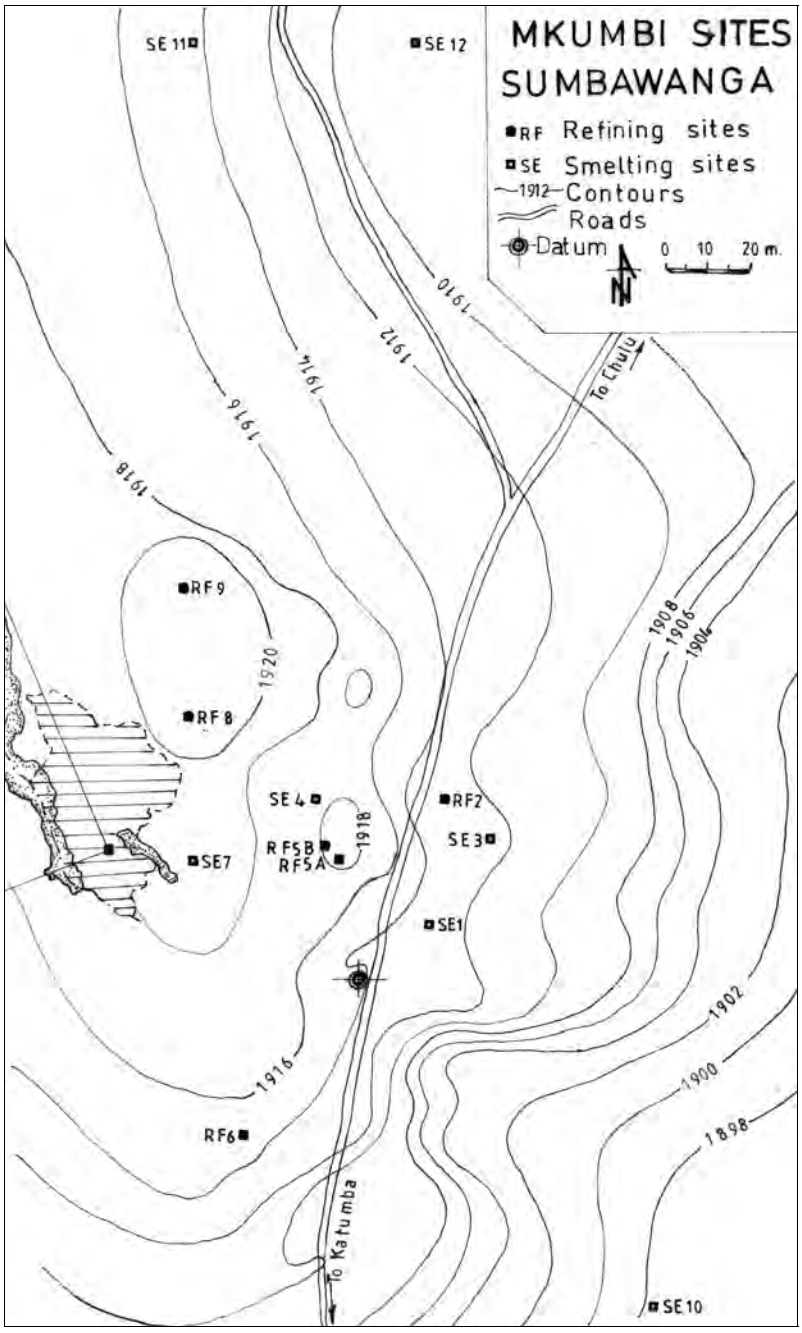


Fig. 2 : Spatial Distribution of Mkumbi Smelting and Refining Sites in Sumbawanga (Note: samples were taken from RF9 and SE6)

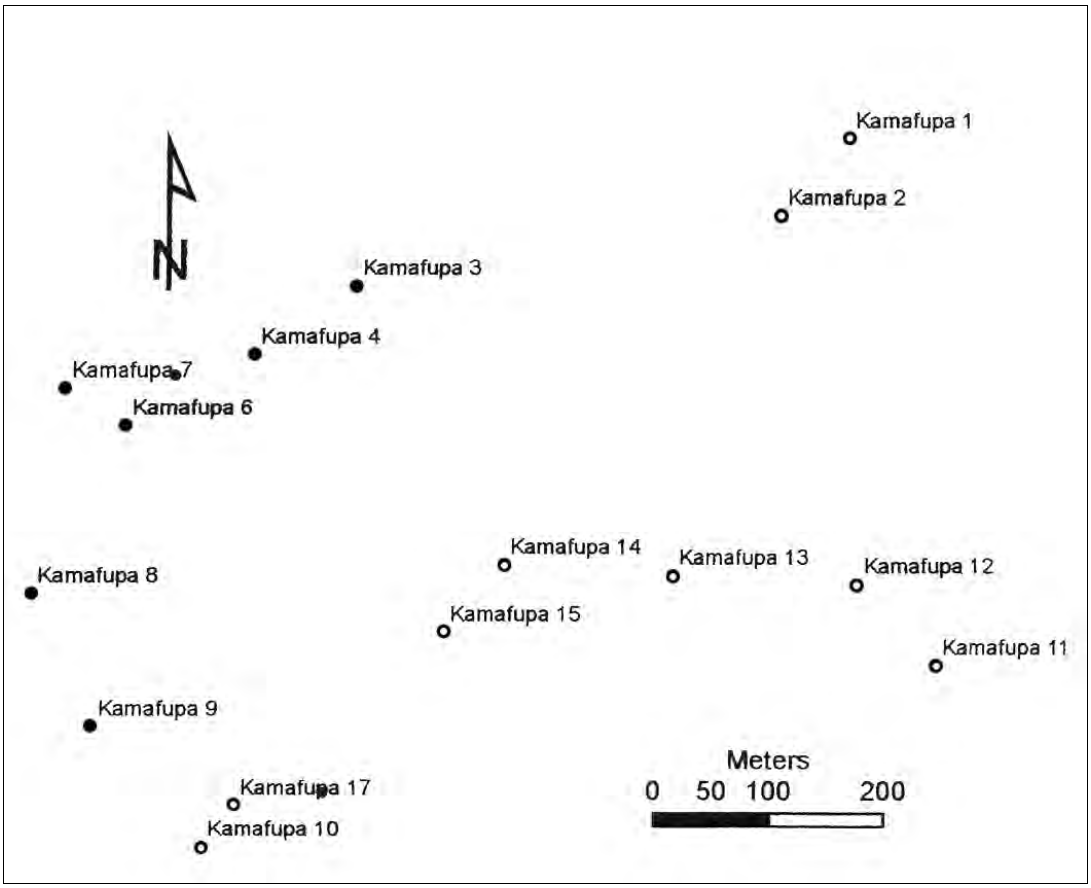


Fig. 3 : Spatial Distribution of Kamafupa Sites in Sumbawanga (Note: Empty circles are smelting and black dots are refining sites, and samples were taken from Kamafupa 9 and 11)

nomenclature (e.g. Davison and Mosley 1988; Barndon 1992; 1996) refers to both traditions, and did not stimulate the search for this technology in other parts of Africa, including southern Africa, where Mapunda (2010, 159) argues it is very likely that the technology expanded as far as Zimbabwe. His argument is based on evidence that the technology practised at Chigarambo Hill near Great Zimbabwe has much in common with *ilungu* furnaces, including the fact that the date range falls close to that of the *malungu* furnaces. However, before we search for this technology in other regions, we need to devise appropriate means of identifying this tradition.

A refining furnace was usually situated next to a smelting furnace for convenience, since the materials to be refined in the small furnaces would be the bloom from the smelting furnace (Mapunda 1995b). Recent fieldwork in Sumbawanga in SW Tanzania has found that Mkumbi refining sites are located at a distance of between 15 and 37m away from neighbouring smelting sites (Fig. 2). Barndon (1996; 2004) claims that all these activities were secluded from settlements in Ufipa contexts; in contrast, early travellers, missionaries, and ethnographers in Tanzania had suggested that small furnaces were built near or in a village (Greig 1937, 79). This claim was recently verified by a field survey conducted in Ufipa, in the context of which we found one refining site (Malimbo 1) and a smithing site (Malimbo 2) close to each other, as well as very close to the village, but far away from Chulu smelting sites, which were secluded from settlements (Lyaya 2009). Moreover, refining activities took place away from both smelting and settlement areas, in a separate refining industrial area (Lyaya 2009; Mapunda 2010). This observation is based on archaeological surveys conducted at Kamafupa sites, which yielded many refining sites confined in one area located between at least 167 and 413m away from smelting sites (Fig. 2 et 3). To sum up, the location of the sites associated with the refining process appears spatially unconstrained, as the process has been recorded to occur in secluded areas, or conducted in close proximity to the sites associated with the smelting process, as well as in or near villages. Regardless of the location, refining was conducted by the smelters (Wise 1958), who used a different technological process from smelting.

There is not much written about the cultures or rituals associated with this tradition, but Davison and



Fig. 4 : Selected samples of smelting slags from Ufipa



Fig. 5 : Examples of refining slags from Ufipa showing characteristic tap flow morphologies

Mosley (1988) note that no taboos were attached to the secondary refining process. However, Barndon (1996) indicates that Fipa refining furnaces did have the anthropomorphic attributes of a woman, and that medicinal barks from different tree species and animal bones, as well as a 'white juice', were used as part of the rituals. Furthermore, taboos surrounding the refining process may have been in place together with those related to smelting during the construction of the furnaces, and the Nyiha of Tanzania did exactly this. Brock and Brock (1965, 100) write: "As he (the master smelter) prayed to *mulungu* (Nyiha divinity) cocks were killed and their blood spread on the large (*ilungu*) and small (*ishitengwi*) furnaces".

Refining Slag in the Field

This section presents the physical properties of refining slag in order to show what refinery slag look like in the field. We know that archaeological materials without known contexts are less useful, so interpretations of refining slag in the laboratory without prior knowledge of refining sites may also easily cause confusion (Miller and Killick 2004, 27; Chirikure 2006, 147). Thus, correct field identification is the first step towards an accurate interpretation of archaeometallurgical materials; meaning that the role of matrix and provenience should be given due weight in the classification of metalliferous slags (Lyaya 2007). Following the same line of thought, a field survey was carried out at the Pito ward in southern Ufipa (Fig. 1), because the eastern Ufipa or the area along the shore of Lake Tanganyika and northern Ufipa have received relatively due weight (Mapunda 1995a; 1995b; 2010). The fieldwork was carried out principally in the Mkumbi, Chulu, Nangesu, Kamafupa, Malonje, Nantula, and Tupa villages, and the field results have been published elsewhere (Lyaya 2009). More specifically, the samples for this work were surface collections from the Mkumbi, Kamafupa, and Tupa sites. They were chosen because (1) they were within reach of several still standing smelting furnaces, and (2) in these villages, there are still smelters and sons of smelters who actually participated in the traditional ironworking technology.

In the field, refining sites are always situated on small ant-hills, whether in the bush or in settlements. The fact that the refining process was separated from the smelting and smithing processes shows that they were both functionally and technologically different, and also provides a good opportunity to examine the respective remains separately and determine reliable information. If these processes had taken place in the same area, the remains would probably have been mixed; and therefore it could be difficult to distinguish these metalliferous slags from each other, since they can have a very similar appearance.

Unlike smelting slag (Fig. 4), two basic types can morphologically be distinguished among refining slag, namely flow or tap slag and cake-like slag. The first type flowed and cooled outside the furnace (Fig. 5); in contrast, the second type did not flow outside the furnace, but melted and cooled inside the furnace. The flow of slag was functionally and technologically necessary, and enabled the removal of impurities from the crude bloom. Physical attribute analysis of the refining sites at Mkumbi (Fig. 2) showed that flow slag dominated refining site materials at about 98%, the remaining 2% being cake-like slag, including furnace wall and tuyère pieces. Although the 98% figure of flow slag may not be exactly replicable everywhere in the field, we are confident, based on field observations from the other study sites, that refining slag is basically flow slag. It appears in many geometric forms, which are

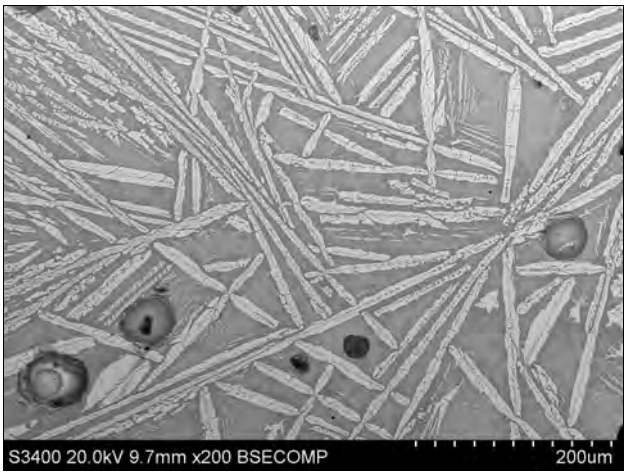


Fig. 6 : Photomicrograph of tap smelting slag from Mkumbi sites

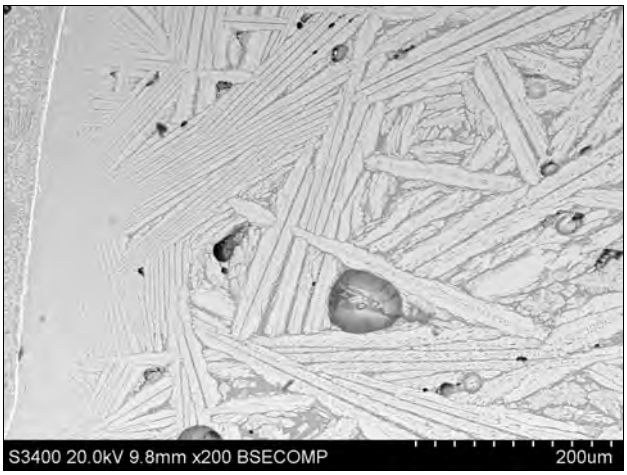


Fig. 7 : Photomicrograph of tap refining slag from Mkumbi sites

essentially not significant as they are products of chance, and not resulting from functional and technological factors. The minority cake-like slag appears as a hemi-spherical cake or cup-shaped, and is not considered further.

In terms of colour, almost all refining slags are basically grey, ranging from pure grey to green colour, while refinery cake slag appears greyish brown. Normally the difference in colour is the function of the slag's chemical composition and oxidation. The greyish colour of the refinery slag is an indication of little, if any, free iron oxides.

In addition to shape, texture, and colour, refining slag is generally smooth and slippery, except for the cake type, which tends to be rough. The smoothness or roughness of the surface is the function of slag viscosity, so their smoothness indicates a low viscosity or high fluidity.

Furthermore, refinery slag tends to have very low ferro-magnetic properties when tested on a bar magnet. While this can give us a rough idea of magnetic properties of slags in the field, it remains a qualitative field method. Refining slag also tends to have sand or quartz inclusions that are picked up on the way while flowing outside the furnace. For that reason, the inclusions are found on the bottom surfaces of the flowed slags. Lastly, refining slag has a high tendency of appearing in smaller fragments than smelting slags, which is the function of the little materials, the little bloom and charcoal charged in the *vintengwe* as compared to the large quantities of ore and charcoal charged in the *malungu*. The above are the physical characteristics of refinery slag as visible in the field; the following section deals with the chemical properties of refinery slag.

Refining Slags in the Laboratory

In this section we present the results of the chemical and microscopic analyses of three sets of smelting and refining slags from the sites of Kamafupa, Mkumbi and Tupa, respectively, all three located in Ufipa, SW Tanzania. These samples were selected randomly, and, for the purpose of comparison, each of the sets includes three refining slags and two smelting slags from each of the sites. Metallography was first carried out by means of optical microscopy, followed by scanning electron microscopy, and the chemical analysis was performed by X-ray fluorescence. The comparative analysis of smelting and refining slags from different sites in the Ufipa region is ongoing. Preliminary results based on optical microscopy suggest that the macroscopic similarities noted in the field, with subtle but systematic differences in attributes such as colour, size, and surface condition, are also found in the analytical studies, while the chemical analysis by X-ray fluorescence analysis proved less diagnostic so far.

Both slag types show the typical textures of tap slag (Fig. 6 and 7), with magnetite skins or tap lines outlining the lightly oxidised surfaces of the hot slag in contact with ambient air, and the very elongated fayalite morphology characteristic of rapid cooling.

ED-XRF results (Fig. 8) and microstructural analyses show that both slag types are almost devoid of free iron oxides (wüstite or iron-rich spinels), which is an indication of technical efficiency if other factors, such as labour, nature of ore, and fuel consumption, are kept

Oxides	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	V_2O_5	MnO	FeO	Co_3O_4	CuO	ZnO	Rb_2O	SrO	Y_2O_3	ZrO_2	BaO	La_2O_3	CeO_2	Nd_2O_3	WO_3	Analytical
	wt%	wt%	wt%	wt%	wt%	wt%	wt%	wt%	wt%	wt%	wt%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	Total
Refining Slag: Mkumbi																								
S9 RF1	0.24	0.23	8.80	35.11	0.06	1.50	0.64	0.50	0.04	1.62	50.69	438	37	12	28	69	38	440	3677	170	589	143	23	106.28
S9 RF2	0.07	0.17	9.21	36.48	0.13	1.04	0.68	0.50	0.06	1.35	49.74	482	16	7	9	55	33	566	3274	152	827	259	11	106.89
S9 RF3	0.18	0.18	7.24	31.07	0.10	1.05	0.48	0.43	0.05	1.38	57.32	550	37	13	3	47	35	436	2908	125	580	208	9	105.06
Smelting Slag: Mkumbi																								
S6 SE1	0.21	0.26	10.06	41.15	0.26	1.38	1.15	0.51	0.05	1.36	43.11	367	19	34	38	76	33	465	2918	157	614	242	31	104.80
S6 SE2	0.19	0.10	10.49	50.73	0.34	1.65	1.15	0.50	0.04	0.74	33.55	467	38	35	49	88	38	605	2773	180	632	238	33	107.24
Refining Slag: Kamafupa																								
S 9 RF1	0.12	0.12	10.53	34.18	0.10	1.21	0.59	0.47	0.03	0.84	51.43	671	27	16	10	53	44	458	1699	228	543	75	9	105.75
S 9 RF2	0.14	0.17	11.20	38.06	0.13	1.16	0.57	0.39	0.03	0.85	46.82	671	29	16	16	47	33	755	1635	206	1029	139	28	104.94
S 9 RF3	0.09	0.23	7.01	28.28	0.30	0.90	1.19	0.36	0.04	0.34	60.99	714	63	21	3	80	27	410	821	144	330	86	16	103.99
Smelting Slag: Kamafupa																								
S11 SE1	0.18	0.21	8.29	27.05	0.52	1.44	1.38	0.37	0.02	0.28	60.02	535	50	41	4	103	41	341	549	144	584	71	12	107.93
S11 SE2	0.11	0.10	7.47	28.52	0.43	1.38	0.90	0.39	0.01	0.26	60.15	702	47	30	4	63	47	392	476	200	581	108	7	107.73
Refining Slag: Tupa																								
S8 RF1	0.12	0.10	7.49	36.65	0.09	0.49	0.81	0.39	0.08	0.08	53.49	531	25	13	3	61	24	526	263	159	252	73	16	106.22
S8 RF2	0.10	0.16	8.32	35.50	0.14	0.76	0.97	0.43	0.02	0.50	52.79	740	23	24	3	88	27	438	1133	135	347	73	8	107.84
S8 RF3	0.07	0.07	7.02	27.08	0.16	0.60	0.62	0.35	0.02	0.73	62.90	830	32	11	4	42	25	423	1694	143	359	142	19	102.48
Smelting Slag: Tupa																								
S33 SE1	0.17	0.10	5.96	39.85	0.08	0.80	0.65	0.41	0.04	0.07	51.71	437	23	15	3	61	25	518	312	134	212	61	13	106.15
S34 SE1	0.19	0.10	5.78	38.84	0.17	0.57	0.70	0.33	0.08	0.06	53.00	545	37	32	3	46	31	420	140	167	283	59	21	109.47
Ore																								
Wanzale1	0.07	0.03	9.79	22.77	0.07	0.16	0.06	0.28	0.05	1.05	65.18	904	31	30	4	1	27	637	1920	121	909	117	6	77.73
Tupa1	0.16	0.03	5.71	42.12	0.00	0.24	0.00	0.28	0.05	0.02	51.23	514	38	21	2	1	22	371	95	156	168	66	16	85.45

Fig. 8: ED-XRF compositional data obtained from the 15 slag and 2 ore samples from the Fipa sites. Results have been normalised to 100% and represent the average of three ED-XRF runs. Only trace elements above 10 ppm are shown. Analytical total prior to normalisation is given at the end column

constant (Morton and Wingrove 1969; 1972; Tylecote *et al.,* 1971). Initially, we expected more iron oxide, and possibly even free iron oxide such as wüstite, in smelted slag than in refining slag, because refining was meant to reduce any residual free iron oxides incorporated within the bloom and transform it into iron metal of the desired quality (e.g. Greig 1937; Davison and Mosley 1988; Barndon 1996). Nevertheless, careful metallographic examination of the 15 samples showed that none of the slags had any significant amounts of free iron oxide, and were instead solely composed of fayalite and a glassy matrix (Fig. 6 and 7). Small particles of metallic iron were very rarely found, and occasionally residual quartz grains were encountered. Also, both slag types showed a similar flow and cooling pattern. Thus, in the following section we explore the chemical composition of the slags in order to test our hypothesis that smelting and refining slags show systematic differences related to their technological origin.

Smelting versus Refining Slag: Melting Temperatures and Efficiency

One feature observed in Kamafupa slag, despite the fact that the refining slag sample S9 RF3 overlaps with smelting slag, is that there is generally more iron oxide in smelting slag than in refining slag. Unexpectedly, however, the slag samples from the Mkumbi sites exhibit the opposite pattern to the Kamafupa slag, with higher iron oxide content in the refining slag, and slag from Tupa shows no systematic difference in terms of iron oxide levels between the two types. The very low levels of iron oxide in the Mkumbi slag can be attributed to the mechanical incorporation of quartz within the slag while it was flowing out of the furnace, as shown by optical microscopy and ED-SEM analyses (Fig. 9).

A common method of presenting the composition of iron smelting slags is by plotting them into the ternary diagram FeO – Al_2O_3 – SiO_2, and interpreting their position within this diagram in light of theoretical melting temperatures and technical efficiencies. In the iron-rich region typical for bloomery slag, this diagram offers two broadly linked regions of low melting temperature, labelled Optimum 1 and Optimum 2 (Charlton 2006; Rehren *et al.,* 2007).

Most of the samples analysed in this study fall into or near the Optimum 1, associated with technically highly efficient and relatively fuel-intensive iron smelting (Charlton 2006). Only the two silica-rich samples with incorporated quartz grains are situated

above Optimum 1, with theoretical melting temperatures in excess of 1400°C. This is unlikely to have been the actual smelting temperature for this bloomery process, and we can thus ignore these samples, because the quartz inclusions resulting in the high silica level identified by the chemical analysis were not part of the original smelting process. All other samples from both processes cluster around Optimum 1 (Fig. 10), with the refining slag on average at slightly more iron-rich positions than the smelting slags. This is in contrast to the expectation that the refining process operated under more reducing conditions, removing more iron (as metal) from the system than the preceding smelting process.

The concentrations of alumina and silica were technically expected to rise in the refining process, because any remaining free iron oxide in the smelting slag was expected to be further reduced to iron metal, which should have definitely increased the concentration of all other oxides per unit weight. In our data, this is not the case, and a less clear-cut picture emerges from these figures. Although other factors might be responsible for the mismatch, one possible technical factor is that slags from both sites were collected randomly, not contiguous to each other (Fig. 2 and 3). This idea is further supported by the indication of different ore types being used, not only between the different sites, but also within them, as shown by inconsistent concentrations of typical ore markers such as barium and zirconium. This means we might be comparing two clusters within some of the sites which are technically not directly related. In order to avoid this mismatching of chemical data, we plan in the near future to compare slag samples from the closest clusters, because, based on ethno-historical and archaeological information, refining furnaces were often built immediately next to smelting furnaces for convenience reasons (e.g. Davison and Mosley 1988, 77; Mapunda 1995b, 50). It is worth noting that it was also difficult to differentiate smelting from smithing slags on the basis of chemical analyses in southern Africa (Miller and Killick 2004, 27).

Another prediction was that more fuel ash indicators such as magnesia (MgO), phosphorous oxide (P_2O_5), potash (K_2O), and lime (CaO) would be expected in refining slag than in smelting slag, because of the fact that further fuel ash was added into the refining system in addition to the fuel ash from the initial smelting stage, which would lead to an increase in the concentration of such indicators per unit weight. Unfortunately results have turned out to be either inconclusive, or even opposite to our expectations. Although the results from Kamafupa sites do not show this overturn systematically, slags from Mkumbi sites

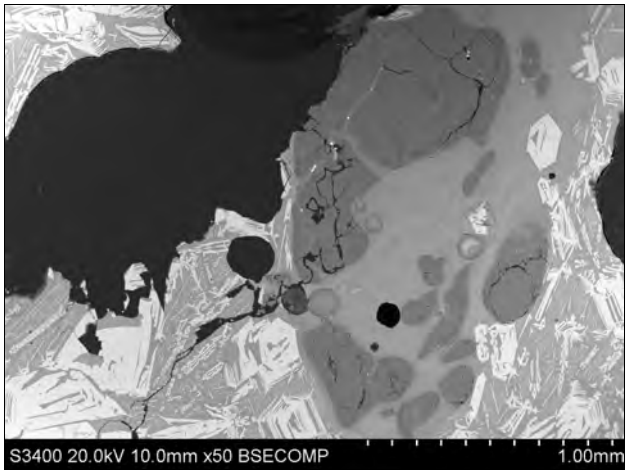


Fig. 9: Photomicrograph of quartz inclusions in smelting sample S6 SE2 from Mkumbi area, SW Tanzania

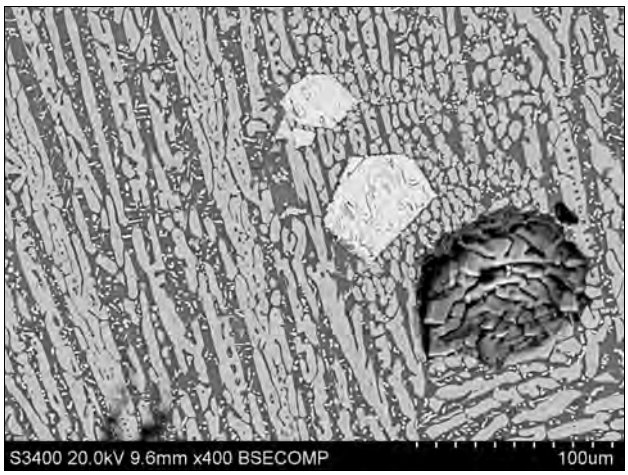


Figure 11: Photomicrograph of angular iron prills in smelting slag

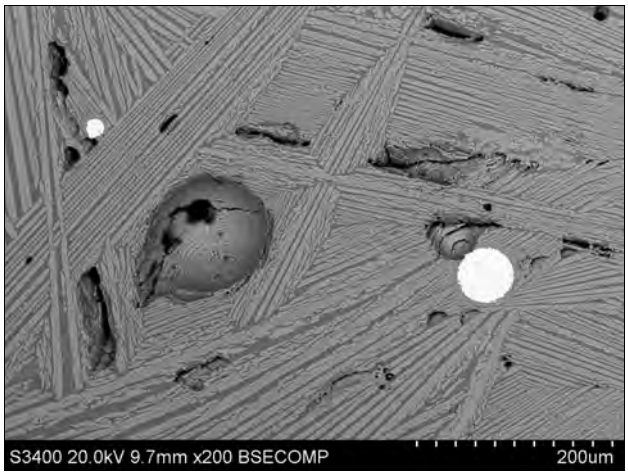


Figure 12: Photomicrograph of roundish iron prills in refining slag

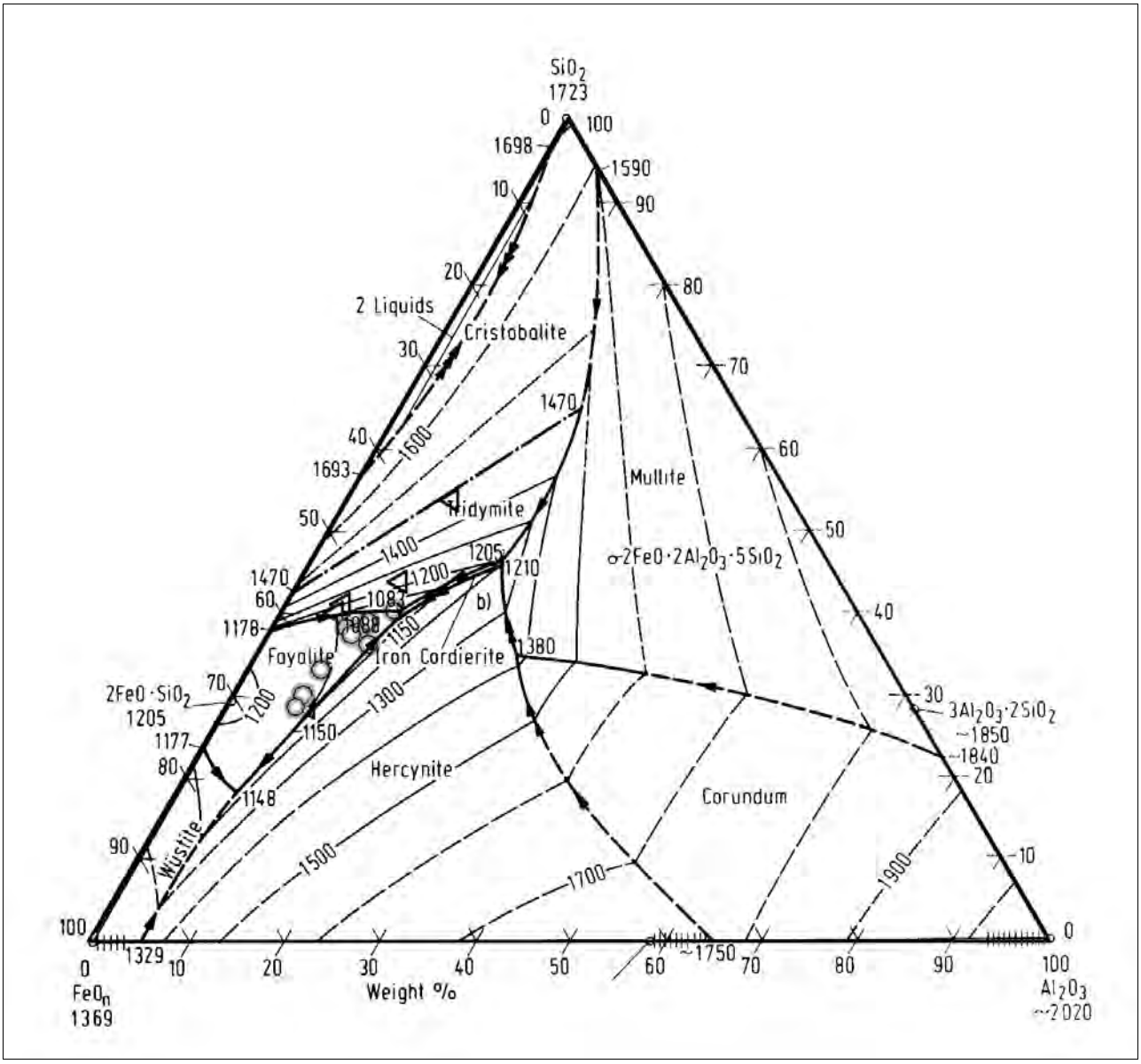


Fig. 10: FeO-SiO2-Al2O3 diagram showing ideal melting temperatures in the system, with refining (circles) and smelting (triangles) samples from Ufipa, SW Tanzania, plotted. Note that none of the slags falls in the wüstite field.

show these unexpected results systematically across their minor and trace oxides related to fuel ash. This finding, and the fact that there is no visible difference between the processes in the slags from Tupa sites, can be explained if we accept that the samples for this study were collected randomly, and not necessarily by selecting slags from directly related smelting and refining episodes. Nevertheless, such a close match is difficult to obtain from archaeological material.

The main difference observed so far between smelting and refining slags is that the former have occasional crystals of iron metal in an angular crystal shape typical of ferritic soft iron (Fig. 11), while refining slags have more frequent inclusions of roundish iron prills rich in carbon (Fig. 12), that is steel or even cast iron prills due to the carbon-rich environment provided by the refining furnace. Some of the refining slags also show regions which solidified as glass rather than fayalitic crystals, consistent with their position near the Optimum 1 (Fig. 10). Thus, the refining slags appear to indicate more strongly reducing conditions than smelting slags, suggesting that the refining process changed the original bloom of soft iron rich in slag inclusions into a carbon-rich and dense steel bloom of much higher metal quality.

Technical Efficiency and Ore Type of the Ufipa Smelting Process

Based on the FeO content in the analysed slag, it appears that the Fipa smelters were relatively successful iron smelters. The FeO content of their slags averages around 55 wt%, whereas the FeO content in iron smelting slag from central Kenya (Iles and Martinon-Torres 2009) and Yoruba in western Nigeria (Ige and Rehren 2003) averages 58 wt% and 59 wt% respectively. Similarly, Fipa smelters were relatively more skilled than the smelters of Baganda in Southern Uganda, and as skilled as the Nyanga smelters of eastern Zimbabwe, because the FeO content in their slag averages 59 wt% and 54 wt% respectively (Humphris *et al.,* 2009; Chirikure and Rehren 2004). Although we need to study more samples and consider other factors as well, it is already possible to propose that the Fipa ironworking technology was one of the best in the region, with relatively little iron lost in the slag.

Both refining and smelting slags have relatively high levels of alumina relative to silica. Refining slag levels of Al_2O_3 range from 7 to 11 wt%, and SiO_2 from 27 to 38 wt%, with a ratio of alumina to silica of approximately 1:4, while alumina levels in smelting slags range from 6 to 10 wt%, and silica from 37 to 51 wt%, which is indicative of an alumina to silica ratio of approximately 1:5. However, the higher silica levels in this group are due to incorporated quartz in the analysed material, and the ratios are therefore nearly identical for both slag types. Significant minor oxides often associated with different ore types, such as titania, manganese, or phosphorous oxide, are all very low in the Ufipa slags. On the basis of the low levels of these oxides and the high alumina, it is possible to suggest that the Ufipa smelters used a lateritic ore. The low level of titania in Fipa slag and potential iron ores as compared to slags associated with the Yoruba of south-western Nigeria (Ige and Rehren 2003, 18) and pastoralist smelters of central Kenya (Iles and Martinon-Torres 2009, 2321) rules out the possibility of the use of a 'black sand' magnetite ore. The raw material could have been a bog ore, but again all samples show very low levels of phosphorous oxides as compared to, say, the Yoruba samples. Also, based on trace oxides carrying more specific geo-chemical signatures, such as the Rare Earth Elements, zirconium, or barium, which show no systematic and significant difference between refining and smelting slags and among the different sites, it seems likely that all the three sites used a similar ore.

Conclusion

Ethnographic and archaeological work from the beginning of the last century has identified a three-step sequence of iron production processes in south-western Tanzania and central Africa, comprising a unique refining stage set between the ubiquitous smelting and smithing stages of the traditional bloomery process. Overall, the smelting and refining processes seem to produce very similar slags, indistinguishable within their own variability. This is understandable when one considers that the original smelting process was already very efficient in reducing all free iron oxide to iron metal, leaving little if any chemical work to be done for the refining process. As a result, the original smelting slag initially trapped in the bloom simply re-melted and flowed from the bloom during the refining process, without any further chemical change and hence appearing indistinguishable from the smelting slag, other than by its lower quantity and flow size. What chemical change may have happened during this process seems to be confined to a carburisation of the bloom, visible in the on average higher carbon content of the metal prills trapped in the slag. The main purpose of the refining process, then, seems to be the consolidation of incoherent and slag-rich bloom fragments into larger, denser and possibly more carbon-rich blooms ready to be worked into high-quality artefacts.

We are aware that this picture is based on preliminary results, and that there is a need to extend this research to other areas in Tanzania and outside it, so as to find out whether the observed features of Fipa refining slag are replicable. A more systematic mapping and collection of refining slag will be critical in order to achieve this end, and to avoid an unnecessary mismatch of sites, as this may have caused the unexpected results discussed above. If we are able to reach this goal, then this could prove that African ironworking, especially in east and central Africa, was different from that practised in other parts of the continent at least from this point of view, and that the refining process was meant to improve the quality of the original bloom from the smelting furnaces.

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