Tin mining and smelting in the Transvaal during the Iron Age

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SYNOPSIS

This paper reviews the historical, archaeological, and metallurgical evidence on Iron Age tin mining and tin smelting in Southern Africa.

The results of the analysis of twenty samples of tin ore, tin slag, and tin ingots found associated with Iron Age materials in the Transvaal (mostly in the Rooiberg area) are reported and discussed. The types of ingots preserved in local collections are described.

A small experimental tin-smelting furnace was constructed and worked according to traditional African Iron Age technology. Qualitative and quantitative results of this experiment are reported.

SAMEVATTING

Hierdie verhandeling gee 'n oorsig oor die historiese, argeologiese en metallurgiese bewyse van die ontginning en smelting van tin in Suidelike Afrika gedurende die Ystertydperk.

Die resultate van die ontleding van twintig monsters van tinerts, tinslak en tingietblokke wat saam met materiale uit die Ystertydperk in Transvaal (hoofsaaklik in die Rooiberggebied) gevind is, word aangegee en bespreek. Die tipe gietblokke wat in plaaslike versamelings bewaar is, word beskryf.

Daar is 'n klein eksperimentele tinsmeltoond volgens die tradisionele tegnologie van die Afrikaanse Ystertydperk gebou en bedryf. Die kwalitatiewe en kwantitatiewe resultate van hierdie eksperiment word aangegee.

HISTORY OF TIN MINING AND WORKING

Almost all our knowledge of tin mining and tin working in Iron Age Southern Africa is derived from the reports on the Rooiberg tin mines published in the early part of this century by Baumann[1], Trevor[2, 3], Wagner[4], and Stanley[5, 6]. More recently a few notes have been published (e.g., by Thompson[7, 8], White and Oxley Oxland[9, 10], and Küsel[11]).

It is interesting to note that a large number of tin mines have been opened up in Southern Africa since the beginning of this century, but Rooiberg (in the Waterberg District of the Transvaal, approximately 60 km from Warmbaths) is still the only place where indisputable remains of Iron Age ('ancient') tin workings have been found.

There are many vague references to tin mining and tin smelting in the reports of the missionaries, traders, hunters, and prospectors who travelled in Southern Africa in the early nineteenth century.

Moffat[12] mentioned that tin was found in the Bakone country, and Livingstone[13] that this metal was mined by the Bagalaka people[13]. Both these localities could refer to the Rooiberg area. An interesting reference is found in an article by Ellenberger[14], who records that Chief Mokgosi of the Malete tribe (Botswana) once stated that his ancestors dug for white iron in the quarries of Ditshiping, which is in the Transvaal. (White iron — 'tshipi e tshweu' — is considered to be the name for tin, whereas 'tshipi e ntsho' refers to black iron[15].)

It has been stated that ancient workings have been found near the Brandberg in South West Africa[16], at Rusapi[17] and Umniati Railway Bridge Mine[18] in Rhodesia, and near Longwe in Malawi[19], but no definite evidence of Iron Age tin production has been found at these places.

A short note in the *Bronkhorstverslag*, a report on the 1836 Voortrekker Commissie Trek, says that '[at Rhenosterpoort on the Randberg] we also found good tin which [the people there] extract from the Randberg and make rings of, calling it "white iron" '[20]. It has been suggested that this Randberg may be the area — or an area nearby — where the rich mines of the Potgietersrus tin fields are now situated. No remains of ancient workings have been found in this area, but it could have happened that all the old tin workings there have been carefully filled in according to the strange habit of the Iron Age tin miners, or that the tin mentioned was a trade product brought from Rooiberg, which is situated a few days' walking to the southwest.

More detailed information on tin comes from a report that Jan van de Capelle, an official of the Dutch East India Company at the Delagoa Bay trading station, sent to the Governor of the Cape of Good Hope in 1723[21]. Van de Capelle wrote:

> [In the later part of the year 1722,] there were black people at La Goa who came from the lands of Paraotte and Machicosje, who brought with them, not only copper, but also tin, to barter at that place . . . . This tin is beautiful in colour but a bit soft and light as can be seen from two pieces of bars [which I had the honour to submit to the Honourable Governor]. One [of these pieces] is much harder in substance than the other, as can be found out by smelting . . . . [The black people] say that they had found the tin in the land Machicosje along the riverbeds and that they had collected it in baskets and had the sand washed out and then . . . had it made into bars for barter. All the inland people use this tin, also what they buy from us, to smelt it with their copper for necklaces and bracelets . . . . [They also] cast ingots from the tin for barter. (Free translation from Van de Capelle's report.)

This description appears to be factual in many respects, but the report on the provenance of the tin ore is probably hearsay evidence. It has been suggested that the country Machicosje mentioned by Van de Capelle is the land of a tribe living on both sides of the Lebombo Mountains[22]. However, before accepting this suggestion, one should remember a warning that was included in the Journal of the Dutch East India Company on the 21st August, 1726, when a ship from Rio de la Goa arrived at the Cape:

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'The reports of the blacks are so confused and doubtful that it is evident that they do not wish us to know much about their country'[23]. So, Van de Capelle's report could just as well refer to a tin field somewhere in the central Transvaal, or even to the rich alluvial deposits of Swaziland, which are much nearer Delagoa Bay.

It appears that the tin trade from the interior to Delagoa Bay was only on a small scale. The records of the Dutch East India Company contain only a single detailed entry for the tin trade at Delagoa Bay: Van de Capelle reported[21] on the 14th December, 1731, that

> Heeden quamen de machicossers weeder aan boord met haar Eliphands tanden, en een partij tin, w' kogten van haar: . . .
> 56 staven thin, als
> 20 p^{s} groote plat ronde en
> 36 p^{s} kleene lange ronde
> 56 p^{s} staven thin kosten te samen Coral: lb 103.

It is interesting to note that two different types of tin ingot are mentioned in these reports: large flattened rounds and small long rounds (sometimes called 'staafjes'). The cast ingots found in the Transvaal also belong to two main types: heavy rounded bars and long light rods.

Unfortunately, the dimensions and masses of the ingots traded at Delagoa Bay are not stated, but an entry in the books of the Company at the Cape (16th February, 1732) mentions that the ship *De Snuffelaar* coming from Rio de la Goa brought 213 lb of tin to the Cape[23]. This consignment apparently refers to the ingots mentioned by Van de Capelle in his record of 14th December, 1731.

The available archaeological and historical evidence gives no indication of the presence of larger tin mines and tin workings in Southern Africa, with the exception of the Rooiberg tin-mining centre. In a larger frame, the verdict of Cline, who made a critical survey in 1937, appears to be still valid: 'Only two tin mining centres have been found in Negro Africa: the Transvaal and Bauchi Province in Northern Nigeria'[24].

DESCRIPTION AND ANALYSIS OF TIN FINDS

Ores

All the tin ores analysed came from the Rooiberg area and were taken at or near the ancient workings there.

'Tin feeds' were found at the excavation of several old smelting furnaces at the sites of Rooiberg and Blaauwbank. Samples of these ores are preserved in the collection of the former Archaeological Survey, now the Archaeological Research Unit, University of the Witwatersrand.

The analysis of these ores (A1, A2, A4 of Table I) shows the tin content to vary from 15,3 to 31 per cent. These values are typical for the selected high-grade cassiterite ore worked by the Iron Age miners, who understood how to find such ores either in rich deposits near the surface or in pipes of almost pure cassiterite. Some of the ore mined may have been of poorer quality and could have been enriched by washing in baskets or by panning. 'The spruit running through the Rooiberg property was probably the principal scene of these washing operations, but in one case [the miners] appear to have used an old working as a slime pit'[1].

The composition of the ores analysed is not uniform since the cassiterite, embedded in the quartzites and sandstones of the Lower Waterberg Series, is generally associated with tourmaline and iron pyrites. Arsenical and copper pyrites and other minerals in smaller amounts may also be present in addition to various gangue minerals[1]. The analysis of the 'tin feed' ores from Rooiberg therefore shows a number of minor and trace elements, as well as considerable variation in their distribution. No single 'indicator' element or combination of such elements that could be considered typical for all the ores of the Rooiberg complex has been found. Boron and tungsten are associated with most of the Rooiberg ores analysed, but these elements are possibly also present in tin ores from India and Europe. For the time being it is not possible to decide from the analysis of a tin ingot or a tin ornament found at an archaeological site whether it was derived from Rooiberg ore.

Slags

Small slag heaps associated with pieces of tuyères and pottery sherds are found at many places in the Rooiberg area. The best known of the old smelting sites is Smelters Kop, a steep, fairly flat-topped hill about 2 km from Rooiberg Mines. On a nearby hill was another smelting place where several furnace bottoms, weighing about 12 lb each, were discovered[3].

Five samples of slag from Rooiberg sites have been analysed. The results of these analyses, together with two others previously published, are given in Table I (B1–B4, B6, I, II). The tin content of the samples varies widely — from 0,14 to 38 per cent. It is possible that the low-value slags are the products of the smelting, not of tin ore, but of iron or copper ores. On the other hand, some slag specimens are very rich in tin; for example, specimen II (Table I), on which P. Wagner reported '[In this specimen tin was present] almost entirely as grains of unreduced cassiterite, from which it is concluded that this particular slag resulted from the frothing over of the furnace into which the tin ore was fed'[4]. Other tin-rich slags enclosed small particles of metallic tin in the shape of granules, pellets, and small buttons. It appears that the average tin content of typical tin slags ranged from 2 to 15 per cent.

The fluctuation of the tin content in smelting slags indicates the vagaries of the primitive tin-smelting process, which could not be controlled properly — much in contrast to the traditional iron-smelting process, where slags of a fairly uniform iron content were produced regularly. However, the metallurgy of tin extraction is in several respects more complicated and difficult than that of iron.

The values for elements other than tin also vary considerably in the analysed samples. This is to be

TABLE I

ORE AND SLAG SAMPLES

		A1	A2	A4	A6	B1	B2	B3	B4	B6	I	II	B5
Provenance of sample		Tinfeed from Excav. Furnace, Rooiberg	Tinfeed from Ancient Furnace, Blaauw-bank	Tinfeed from Broken Pot Furnace, Rooiberg	Ore from A3 Area Enriched, Rooiberg	Slag from Central Group, Rooiberg	Slag from Old Smelter, Blaauw-bank	Slag from Smelters Kop, Rooiberg	Slag from Smelters Kop, Rooiberg	Slag from Northern Section, Rooiberg	Slag from Blaauwbank		Slag from exp. batch No. 9
											Reported by Wagner and Gordon[4]		
Accession No. D.A.-U.W.		21.39.11	21.39.12	21.39.14	—	21.39.21	21.39.22	48.75	49.73	21.39.26			—
Constituent	Expressed as	%	%	%	%	%	%	%	%	%	%	%	%
Silicon	SiO_2	27,35	32,82	15,69	36,74	33,70	53,89	37,04	56,65	25,75	33,72	32,51	31,73
Aluminium	Al_2O_3	14,52	10,53	11,76	11,12	7,53	2,32	32,27	15,61	14,16	17,34	7,87	14,75
Total iron	Fe_2O_3	15,68	19,13	30,04	3,67	38,17	28,86	11,11	8,68	34,64	(FeO)35,23	(FeO) 9,26	8,21
Magnesium	MgO	5,28	5,45	3,57	2,36	1,45	0,53	1,29	1,44	2,97	2,67	0,65	3,52
Calcium	CaO	4,13	3,24	3,53	<1	0,61	1,32	11,13	2,27	3,39	2,12	0,80	<1
Sodium	Na_2O	0,46	0,20	0,39	3,43	—	—	—	0,50	0,50	3,32	0,22	1,56
Potassium	K_2O	0,27	0,78	0,14	1,48	0,95	0,35	0,34	1,49	2,51	—	—	1,60
Titanium	TiO_2	0,45	0,23	0,30	0,20	0,10	<0,10	1,58	0,57	0,76	—	—	0,86
Phosphorus	P_2O_5	0,50	0,14	0,27	<0,1	1,02	0,30	2,41	2,29	0,33	—	—	0,13
Chromium	Cr_2O_3	0,11	0,13	0,15	<0,05	<0,10	<0,10	<0,10	0,10	0,12	—	—	<0,05
Manganese	MnO	<0,10	0,15	0,39	0,05	0,18	<0,10	<0,10	<0,10	0,72	0,12	—	<0,05
Zirconium	ZrO_2	0,25	0,25	0,21	—	<0,10	<0,10	0,16	0,23	0,27	—	—	—
Tin	Sn	30,88	15,26	24,92	26,31	1,98	0,14	0,13	10,01	12,96	4,06	38,29	28,83
Other elements present		B,W	B,W	B,W	B,Cu,Ga, V,Pb	As,Cu, W	Cu,Pb, W,As	Sr,Pb	B,W	B,W	Cu traces	No Cu	B,Cu,Pb, W,V
Analyst		NIM	NIM	NIM	NIM	NIM	NIM	NIM	NIM	NIM	A. R. Powell	A. R. Powell	NIM

TABLE II

TIN INGOTS AND TIN METAL

No.	Collection and access no.	Place of origin	Type	Dimensions mm	Mass g	Analysis, % Sn	Cu	Pb	Fe	Ni	Zn	Co	Bi	Sb	Other elements present	Analyst	Reference
1	Univ. Wits. 21-39-3	Camp-Workings Rooiberg	plano-convex bun	major axis 150 minor axis 95 height 58	2100	99,4	0,008	<5 p.p.m.	0,16	(+)	—	—	<5 p.p.m.	+		NIM	
2	Univ. Wits. 21-39-1	Camp-Workings Rooiberg	plano-convex bun	major axis 95 minor axis 75 height 35	800	balance (99,16)	0,41	0,01	0,40	<0,01	<0,01	Tr.	0,005	0,002		McKechnie Brothers S.A.	
3	Rooiberg Minerals Development Co	Smelters Kop Rooiberg	plano-convex bun	major axis 156 minor axis 100 height 51	approx. 2000	95,4	—	—	—	—	—	—	—	—		Analysis on label of Specimen	
4	Univ. Wits. 14-47-1	Malabog Location near Pietersburg, Tvl	rod triangular in section	length 510 equilateral sides of section 8–9	114	balance (99,66)	0,28	0,01	0,03	<0,01	<0,01	+	0,004	0,001		McKechnie Brothers S.A.	
5	A. Dieperink Museum Potgietersrus	Sterkrivier Waterberg Mt, Tvl	rod, triangular in section	length 450 equilateral sides of section approx. 7	—	balance (99,61)	0,3	0,01	0,06	<0,01	<0,01	+	0,004	<0,001		McKechnie Brothers S.A.	
6	Univ. Wits. 14-47-3	Potgietersrus district	horned bar	length 395 width 25 height 28	approx. 1850	balance (99,90)	0,06	0,01	<0,01	<0,01	<0,01	Tr.	<0,001	0,002		McKechnie Brothers S.A.	
7	Univ. Wits. 52-51	Levubu Sibasa district, N. Tvl	Section of original ingot horned bar on circular rod	(original) length 305 width 31 height at ends 57	(estimated) 2300	98,41	0,06	0,12	1,40	<0,01	<0,01	Tr.	<0,001	<0,015		McKechnie Brothers S.A.	L. Thompson Ref. No. 8
8	(lost) Lepehne collection old Library Potgietersrus	Malabog Location near Pietersburg, Tvl	horned bar ornamented	length 406 width 45 height 70	(estimated) 5400	98,5 by balance 99,25	0,3	0,03	0,20	—	—	—	—	0,2	As 0,015	G. H. Stanley	L. Thompson Ref. No. 7
9	Dept. Archaeol. Univ. Wits. Smelting Exp. Batch 10 (Tin)	Smelted from ore found near ancient furnaces Rooiberg	refined tin (bar)	—	—	balance (98,8)	1,03	0,027	0,064	0,037	0,002	+	0,007	0,047	Ag, Al, As Mg, Si	NIM	
10	Dept. Archaeol. Univ. Wits. Smelting Exp. Batch 8 (Tin)	Smelted from enriched ore from A3 area Rooiberg	crude tin (pellets)	—	—	balance (98,3)	1,4	0,073	0,09	0,05	0,002	+	0,02	0,052	Ag, Al, As Mg, Si	NIM	
11	Dept. Archaeol. Univ. Wits. Smelting Exp. Batch 8 (Tin)	Extracted from enriched ore from A3 area Rooiberg	refined tin resmelted from crude tin (bar)	—	—	balance (99,15)	0,56	0,11	0,08	0,032	0,002	+	0,04	0,04	Ag, Al, As Mg, Si	NIM	

expected since, as has been mentioned, the composition of tin ores varies from one deposit to another. Silicon dioxide contents are in the range 26 to 57 per cent, aluminium oxides from 2 to 32 per cent, and iron oxides from 9 to 39 per cent — values corresponding to those in ores based on quartzites and sandstones. The alkali metals contained in tin ores are also found in the slags derived from them. There appears to be no need to interpret the presence of lime or magnesium as resulting from the use of fluxes in the smelting process.

A rather unusual slag analysis is reported by Baumann[1], who states that a slag discovered at Haartebeestfontein (near Rooiberg) contained, in addition to 2,5 per cent tin, not less than 30 per cent oxide of tungsten. Small amounts of tungsten are present in nearly all the slags found in the Rooiberg area.

A great variety of minor and trace elements are found in the slags of the Rooiberg smelting sites — a fact that is not surprising considering the number of associated minerals in the ores: arsenical, iron, and copper pyrites, wolframite, scheelite, galena, annabergite, calcite, and siderite[1]. Therefore, it is to be expected that arsenic, copper, nickel, lead, antimony, tungsten, etc. will find their way from the ores into the slags in larger or smaller amounts.

Ingots

Not many 'ancient' tin ingots have survived in South Africa. Table II (No. 1–7) gives descriptions, measurements, and analyses of seven ingots preserved in collections in Johannesburg, Rooiberg, and Potgietersrus. A previously published analysis of an ingot in the lost Lepehne collection (Potgietersrus) is also included (No. 8).

The tin ingots described in Table II belong to three different types, which can be called 'bun' ingots, 'rod' ingots, and 'bar' ingots.

Bun ingots

All the known bun ingots have been found in the Rooiberg area. The mass of these ingots ranges from 800 to 2100 g, and their tin content from 95 to 99,4 per cent. The hemispherical or plano-convex shape of the bun ingots indicates that they represent furnace bottoms or that liquid tin was run into clay pots direct from the furnace. The lower, convex surface of these ingots is fairly smooth, whereas the upper flat surface shows fissures and cracks formed on cooling (Fig. 1). Stanley[5] reports the analysis of two ingots from Rooiberg that contained 99,5 and 94,9 per cent tin respectively — values similar to those found for the bun ingots mentioned in Table II. It is possible that the lower tin values and the higher iron contents of some ingots indicate 'crude' tin and the higher tin values refined tin, but such differences could, of course, also be the result of variations in the composition of the ores or in smelting conditions. The analyses of three bun ingots are given in Table II (No. 1–3).

In the collection of the Rooiberg Minerals Development Company, there is an odd-shaped tin object (tin content 91 per cent) that was found in the Rooiberg Northern Workings. The shape of this specimen — an irregularly formed cylinder — suggests that it was probably designed as an ornament or that it was a cast from which tin bangles were made.

The analysis of the group of Rooiberg ingots preserved in the collection of the University of the Witwatersrand revealed an unexpected fact. One of the ingots (specimen 21–39–2) resembled the bun tin ingots described in dimensions, mass, and superficial appearance, but in the test for hardness it had a much higher value, a V.P.N. (Vickers Pyramidal Hardness Number) of 114 against a V.P.N. of 12,5 for tin ingot 21–39–3. This unusual ingot (21–39–2) contained little tin (1,18 per cent), but, in addition to some iron (1,51 per cent) and lead (0,07 per cent), it contained high amounts of copper (66 per cent) and arsenic (5,5 per cent) (analysis given by the National Institute for Metallurgy). This ingot must therefore be described as an arsenical bronze. Such arsenical bronzes are known from Early

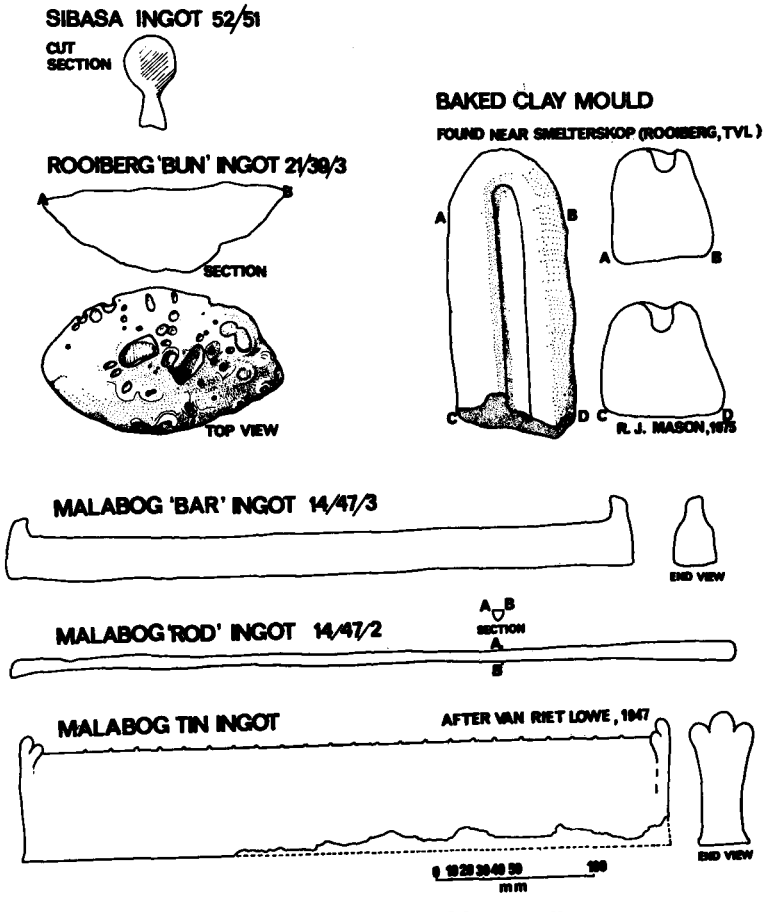

Fig. 1—Tin ingots from South African collections

Bronze Age sites (e.g., from Israel[25] and Central Europe[26]) and were possibly the first alloys known to man. A number of prills and pellets from Blaauwbank–Rooiberg[4] and the well-known Blaauwbank bronze slug[27] also belong to this type. It is not likely that these South African arsenical bronzes were alloyed intentionally. They were probably the results of the unintentional addition of copper- and arsenic-containing ores to the furnace charge. The problem of these arsenical bronzes needs more detailed metallurgical investigation.

Rod ingots

The rod ingots found in South Africa are slender tin sticks, 400 to 500 mm in length, roughly triangular in section, each side measuring 8 to 9 mm (Fig. 1). Such ingots, which can easily be cut into pieces, would have been quite suitable for the making of rings and bangles. The analyses of two rod ingots are given in Table II (Nos. 4 and 5).

Bar ingots

These ingots are much more massive than the rod ingots. Of the two extant specimens, one, which was obtained in the Malabog location near Pietersburg, is now in the collection of the University of the Witwatersrand; the other, found 6 ft below the surface of a cave near Thabazimbi, is in the National Cultural History Museum, Pretoria. Both these bar ingots show the horns at both ends of the bar, a peculiar feature of this type of ingot (Fig. 1).

There were two more such ingots in the Lepehne collection, which before 1949 was kept in the old Potgietersrus Library. Unfortunately, this collection, which also contained nine rod ingots, has since disappeared. However, Thompson[7] has given a good description of the lost ingots. One bar ingot closely resembled the University of the Witwatersrand specimen, whereas the second showed a most interesting feature: on the top of the bar a number of small but distinctive studs could be seen sticking out — fairly similar to the stud or nipple pattern typical of the Mu-Tsuku copper ingots of the Messina area (Fig. 1). The purpose of such 'studs' is unknown. They may have been marks to indicate the value of a metal ingot, or they were perhaps an ornamental pattern of a forgotten tradition.

The analyses of three bar ingots are given in Table II (No. 6 to 8).

A variant of the bar ingot is the so-called 'Sibasa' ingot, which has a rather peculiar history. This ingot was found buried 2 ft below the surface by an African who uprooted a tree in the Levubu settlement (Sibasa district, northern Transvaal). The original mass of the ingot was almost 2,5 kg, but for some unknown reason the ingot was cut up into several pieces. Thompson, who wrote a report on this ingot[8], mentions that 'the ingot has the appearance of having been cast in sand at two castings. A circular bar . . . was cast; on top of this a second casting was added . . . . When found, at the bottom of each end of the ingot was a circular stud decoration'. (See reproduction of drawing in Fig. 1.) The mutilated ingot was seen in 1951 by C. van Riet Lowe, who retained a narrow section of it (analysis of this section is given in Table II as No. 7). What happened to this ingot afterwards is unknown.

Ingot moulds

Ingot moulds, either made from clay or carved into stone, have been found at various places, e.g. at Marico[28] (Transvaal), at Smelters Kop, Rooiberg (Fig. 1), and at Potgietersrus[29].

Provenance of ingots

One can be reasonably certain that the tin smelted at Rooiberg and the tin ingots found there were produced from locally mined ore. The pieces of high-grade tin ore and the heaps of tin-containing slags lying next to smelting furnaces, as well as prills of tin sticking to furnace bottoms, are ample evidence for this belief.

It is less easy to state whether the rod and bar ingots found at other places in the Transvaal — near the present Potgietersrus, on the Blaauwberg, and in Vendaland — or the crude tin used for the casting of these ingots also came from Rooiberg. It cannot be excluded that tin imported from India or Europe was also used at South African smelting sites. Some evidence of imports of tin to the East Coast is found in trade reports. The factor of Sofala, De Brito, noted in 1519: 'A ship from Cambaya discharged at Kilwane tin from Cambaya'[30], and Jan van de Capelle, an official of the Dutch East India Company at Delagoa Bay, records in 1723: 'Ook het [de negers] thin van ons inkoopen'[21].

There is little doubt about the considerable antiquity and the large extent of the Rooiberg tin-mining activities. Tin mining in this area goes back at least to the mid-fifteenth century. This dating is based on a (corrected) radiocarbon determination on a piece of mining timber (*Burkea africana*, or wilde sering) found in an ancient shaft[31].

The quantity of ores removed from the ancient Rooiberg tin mines may have been very high. Some estimates give figures up to 18 000 tons[1], from which at least 500 tons of tin metal should have been extracted. One of the puzzles of South African prehistory is what could have happened to such large quantities of tin. It is possible that much tin was exported to Rhodesia and the East coast along an old trade route, which, according to Punt[29], led from Rooiberg to the Nylvlei and the Sandriver and then to the Zoutspanberg and the Limpopo.

MODEL OF A TIN-SMELTING FURNACE

The evidence for Iron Age tin smelting in Southern Africa is meagre. As far as is known, no well-preserved tin-smelting furnace has ever been found in Southern Africa. However, foundations of saucer-shaped hearth furnaces were discovered on the Blaauwbank smelting sites (near Rooiberg) by Wagner and Gordon[4], who report: 'Only the bottoms of these [furnaces] remain, so that it is not possible accurately to reconstruct them . . . . There is definite evidence that tin was smelted in these furnaces, as one had slag containing prills of tin stuck in the bottom'.

Since no reliable knowledge of tin smelting in Iron Age Southern Africa is available, it was thought that some relevant information could be obtained from the construction

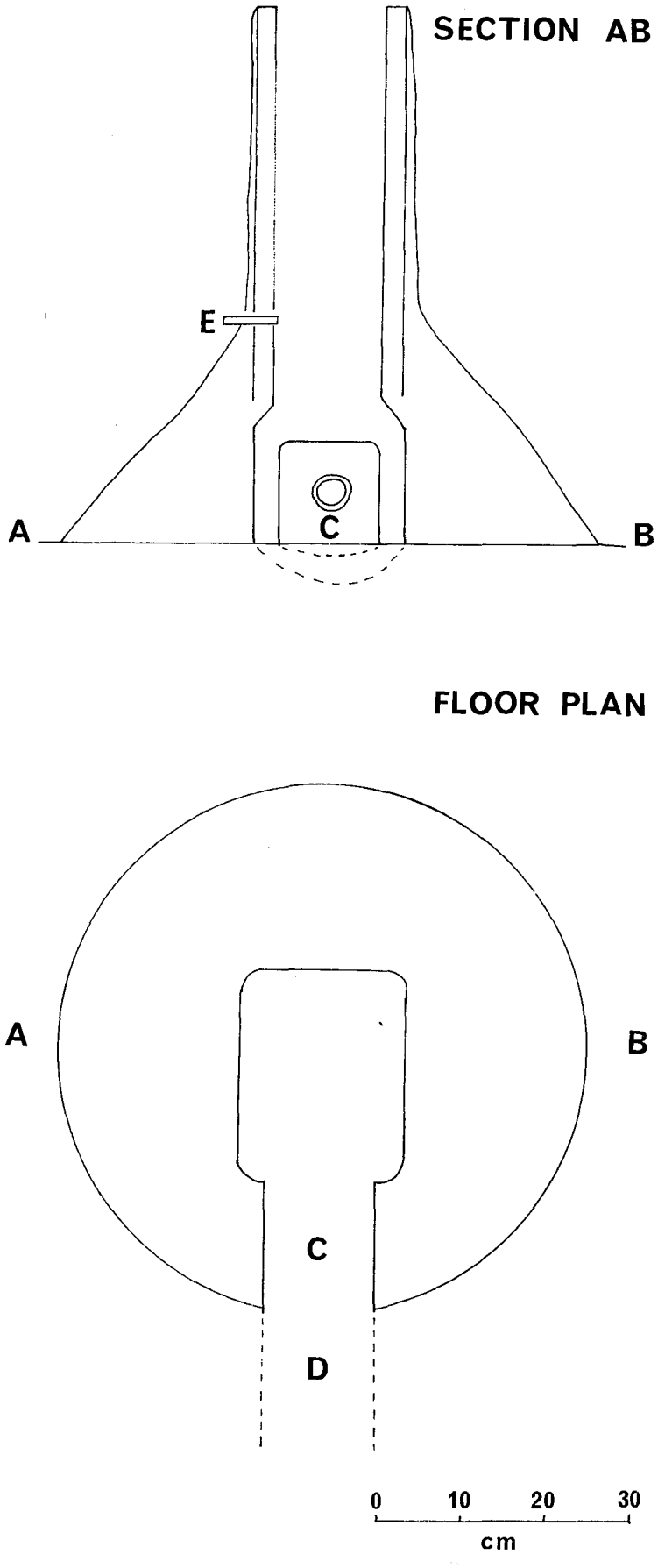

Fig. 2—Floor plan and section of the experimental tin-smelting furnace. A–B diameter of furnace floor, C discharge opening, D discharge trough, E hole for thermometer

and working of an experimental furnace. The model was designed on the general pattern of the metal-smelting furnaces found in Southern Africa, some features being based on descriptions of old Nigerian tin-smelting furnaces[32,33]. Even if it is unlikely that the tin-smelting technology of Southern Africa is directly related to that of far away Nigeria, it is possible that there was a common source for all the smelting technology in Africa.

Construction of the Furnace

The structure and the dimensions of the experimental furnace are shown in Figs. 2 and 3. The furnace, 640 mm high, had the shape of a truncated cone, with the large diameter at the bottom. The furnace chamber was built from fire bricks, a ceramic pipe being used as a chimney shaft. An opening in front of the furnace chamber allowed the discharge of the smelted metal and the slag. An aperture at the back of the furnace served for the insertion of a tuyère, which was directed towards the slightly forward-sloping furnace bottom. The outside of the furnace was covered with insulating layers of puddled clay and daga. The temperature in the furnace could be measured by a thermocouple probe inserted through a hole in the furnace wall.

Details of the air supply (from a compressor blower delivering a volume of air equivalent to that supplied by two traditional skin bellows) were given in a previous article[34]. For the mild blowing action required at the end of the firing period, a small electric blower (drier type) was used.

Use was made of the same type of Natal braaivleis charcoal (made from wattle wood, *Acacia nigra*) as had proved satisfactory in the copper-smelting experiments[34]. However, it is possible that the charcoal used by the Iron Age metal workers, burnt from the wood of selected indigenous trees, was superior to the modern product.

Ore

Through the generosity of the Rooiberg Minerals Development Company, a large quantity of tin ore was obtained from Rooiberg A3 mining area, where old workings still exist. The ore had a tin content of 6,3 per cent. When this ore was used in the original state in the smelting experiments, very little metallic tin was recovered. Nearly all the reduced tin was in the shape of minute granules and globules embedded in the slag, from which the metal could not be separated mechanically. It appeared that the clayey and sandy material, which was present in large amounts in the ore, caked and fused in the fire and coated the tin minerals, inhibiting complete reaction with the charcoal. Any reduced tin was also coated with a clayey layer, which tended to prevent the formation of larger tin particles.

For this reason, the ore was washed in imitation of the stream-washing process that was probably used by the Iron Age miners[1]. The ore was washed under a running tap and was then screened through a 3 mm sieve. In this process, much of the original ore material including the tin-containing sand was lost, but the black and black-and-white speckled particles rich in cassiterite (tin stone) could be easily hand-picked from the residue of stony material. The final concentrate, which had a tin content of 26,3 per cent, was found to be suitable for the experiments (Batches 7, 8, and 9).

A second type of Rooiberg ore used in the experiments was 'tin feed' ore collected at various smelting sites and kept as demonstration samples in the Archaeological Research Unit at the University of the

Fig. 3—The experimental tin-smelting furnace

Witwatersrand. A small amount (445 g) of each of three samples was used, the combined amounts being just sufficient for a single smelting experiment (Batch 10). The analyses of the enriched ore and of the tin feed samples are given in Table I.

OPERATION OF THE EXPERIMENTAL FURNACE

A small fire was started in the furnace with a few dry sticks, followed by charges of charcoal (15 to 25 mm). After the front opening of the furnace had been closed with large stones and clay, air was blown through the tuyère and some more charcoal was added until the furnace was about half full. When the furnace charge was well aglow, a few handfuls of ore (10 to 20 mm) were thrown in from the top and covered with a layer of charcoal. This procedure was repeated at intervals of about ten minutes until the furnace was three-quarters full. (The total charge of ore in the experiments varied from 1 to 1,8 kg.) When the fire in the chimney showed an orange-yellow glow, the compressor air was stopped and replaced with a mild blast from an electric blower. At that stage, a strong upward draught had developed and, when the temperature in the furnace had reached between 1200 and 1250 °C (measured by thermocouple potentiometer), the blower was worked only intermittently. Charcoal was added when necessary, and 2½ to 3 hours after the fire had started, the tuyère hole was blocked and the fire was allowed to burn down. When the furnace had cooled down, the stones blocking the front opening were removed and the furnace contents raked out onto the discharge trough.

No liquified tin was observed in any of the experiments. The metallic tin generally adhered to the slag in the form of semi-solid beads and pellets (2 to 9 mm in diameter), and sometimes larger chunks of tin were found. After the slag had cooled down completely, it was broken up by being hammered, and the loosened tin particles were picked out.

In two experiments, small portions of slag obtained in previous firings were added to the ore charges, but, in spite of the high tin content of the slag (20 to 30 per cent), the tin yield did not increase.

The separated crude tin (which had a tin content of about 98 per cent) was collected in a clay crucible and reheated in a crucible furnace. This type of furnace, based on the pattern of a smelting furnace found at Blaauwbank–Rooiberg[4] had been previously used for the smelting of copper[34]. The temperature of the charcoal fire round the crucible was brought to between 900 and 1000 °C. When the tin in the crucible became liquid, the crucible was quickly removed from the fire and placed on a bed of glowing charcoal. The scum formed by the impurities was skimmed off repeatedly until the surface of the tin stayed clean and shiny. Then the liquid metal was poured into the moulds that had been prepared in sand. The refined tin contained 98,8 to 99,15 per cent tin, 0,5 to 1 per cent copper, and small amounts of other elements (Table II).

The recovery of tin from the ore was low in all the experiments. The yields in three smelting experiments in which washed and sorted ore from the Rooiberg A3 area was used varied from 12,8 to 19,1 per cent, calculated on the tin content of the ore. The corresponding yield in one experiment in which a combined 'tin feed' sample from Rooiberg smelting sites was used was 19 per cent.

The yields recorded are much lower than would be expected from the calculated value, but high losses are probably an inherent feature of the traditional process of Iron Age tin smelting. Some of the following could be reasons for the low yields.

1. The use of too much charcoal, producing an excess of carbon monoxide, may result in the reduction of the metal oxides that are present in the ore in addition to tin oxide[35]. Reduced iron in larger amounts is especially undesirable since, at the higher temperatures, it may form with tin intermetallic compounds that do not separate properly from the liquid tin on cooling.
2. At high temperatures, silica (from the quartzite and sandstone present in the ore) can combine with tin oxide and form tin silicates that remain in the slag[35].
3. Much of the reduced tin is finely divided on and in the slag and can be recovered only by a re-smelting process. (Such a process was a regular feature of Nigerian tin smelting[32].)
4. If, in the presence of air, tin is kept at higher temperatures for extended periods, a considerable amount of already reduced tin may be re-oxidized.

In these experiments, losses also resulted from the small size of the experimental furnace and the short operation time. In furnaces as large as the Nigerian furnaces, if the smelting process is prolonged by continuous charging of ore and charcoal over periods lasting 12 to 18 hours as was traditional in African smelting, the temperature in the smelting chamber would be much higher and more equally distributed. As a result, the reduction rate, as well as the separation and liquefaction of tin, would be better and the yields would be higher. It is also to be expected that the use of higher-quality ore combined with the use of a more suitable charcoal would give better results.

The proper regulation of ore additions, temperatures, and blowing rates as used in a primitive process can be learnt only by long experience. Such empirical knowledge gained over many generations was incorporated in the traditions of the metal workers of the African Iron Age.

It is much to the credit of these people that they could handle the difficult process of tin smelting efficiently, achieving a reasonable output of tin of good quality.

CONCLUSIONS

(1) A survey of the literature on the history of tin mining and tin metallurgy in Southern Africa shows that nearly all the relevant reports refer to the Rooiberg–Waterberg area in the Transvaal.

(2) The available records on the tin trade indicate a small volume of trading at Delagoa Bay.

(3) The analyses of slags and ingots found at Rooiberg give evidence of a relatively efficient local mining and smelting industry. Tin ingots found at other places in the Transvaal have a high purity, but it is not clear whether all the tin used was produced by African Iron Age smelters or whether it was imported.

(4) The problem arising from the presence of high amounts of arsenic in some 'bronze' specimens from the Blaauwbank–Rooiberg area needs closer investigation.

(5) The operation of an experimental tin-smelting furnace showed that the smelting of tin under conditions available to Iron Age people is a complicated and difficult process. The yield of tin in these operations was low, but the tin produced was of high purity.

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Refractory Colloquium

The Nineteenth International Refractory Colloquium, which is to be held in memory of Professor K. Konopicky, will be held in Aachen on 14th and 15th October, 1976.

The colloquium will have no general theme, but invited speakers from many countries that have often been represented at Aachen Colloquia will present papers on topical themes in refractories. The following have agreed to speak: Professor Aleixandre (Spain), Professor Hasselman (U.S.A.), Professor Forssberg (Sweden), Professor Letort (France), Dr Nameishi (Japan), Professor Nekrasov (U.S.S.R.), Dr Piatkowski (Poland), Professor Savioli (Italy), Dr Staron (C.S.S.R.), Professor Trojer (Austria), Professor White (G.B.), and Professor Kienow, Dr Krönert, Professor Majdic (Federal Republic of Germany). The colloquium languages are German, English, and French.

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