Iron-smelting furnaces and metallurgical traditions of the South African Iron Age

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SYNOPSIS

A short survey is given of the Iron Age smelting sites and smelting furnaces that have been found in South Africa.

An attempt is made to classify South African smelting furnaces by the inclusion of functional characteristics such as the numbers and positions of tuyères. An affinity is suggested between the Venda (eastern Transvaal) type of furnace and an East African type.

The principles of the smelting process in South African Iron Age furnaces and the characteristics of the smelting products are discussed. Results of metallographic and chemical analyses of 19 iron specimens found at South African sites are given and compared with those from sites in Zimbabwe-Rhodesia, Mocambique, and Nigeria.

The carburization and steeling of iron during primitive smelting and forging are discussed.

SAMEVATTING

Daar word 'n kort oorsig gegee oor die smeltplekke en smeltoonde uit die Ystertyd wat in Suid-Afrika gevind is.

Daar word 'n poging aangewend om die Suid-Afrikaanse smeltoonde te klassifiseer deur die insluiting van funksionele eienskappe soos die getal blaaspype en hul posisie, en 'n ooreenkoms tussen die oond van die Vendas (Oos-Transvaal) en die Oos-Afrikaanse tipe aan die hand gedoen.

Die beginsels van die smeltproses in Suid-Afrikaanse smeltoonde uit die Ystertyd en die eienskappe van die smeltprodukte word bespreek. Die resultate van metallografiese en chemiese ontledings van 19 ystermonsters wat by Suid-Afrikaanse smeltplekke gevind is, word aangegee en met dié vir monsters afkomstig van smeltplekke in Zimbabwe-Rhodesië, Mosambiek en Nigerië vergelyk.

Die karburisering en verstaling van yster tydens die primitiewe smelting en smeding word bespreek.

Introduction

The term *South African Iron Age* was first deliberately used by R. Mason[1] in 1952 to indicate 'the period subsequent to the introduction of iron-working but prior to the appearance of European metal artefacts within the area defined'. The study of the cultures and the technology of this period has led to many fruitful archaeological and archaeo-metallurgical investigations, especially over the past ten years, when the existence of an Early Iron Age industrial complex in South Africa was recognized and studied.

Early Iron Age Smelting Sites

The production and the use of iron formed an important characteristic of the African Iron Age[2]. Unfortunately, not many iron artefacts and only a few iron-smelting sites from the Early Iron Age, lasting from the 4th century A.D. to the 11th century A.D., have been found in South Africa.

The Early Iron Age smelting sites discovered are generally characterized by the presence of smelting slag and sometimes also of tuyère remains and pieces of iron ore. The only place in South Africa where large slag floors and furnace debris from the Early Iron Age have been excavated is the Broederstroom archaeological site, near Hartebeespoort Dam (district Brits), which has been dated to the middle of the 5th century A.D.[3]. Besides many small pieces of iron ore and corroded iron, a large block of crude iron and some fairly well-preserved iron artefacts were found at this site. A detailed description of these finds will be given in a forthcoming publication by R. Mason[4]. The results of chemical and metallographic analyses of some of the metallurgical material from Broederstroom were reported previously[5]. Additional analyses of iron objects are given here in Tables I and II.

There are indications that more Early Iron Age sites are to be found in the Broederstroom–Magaliesberg area, and it is hoped that more-substantial remains will be found there that will allow some conclusions on the structure of furnaces in the Southern African Early Iron Age — a subject on which the information up to now has been meagre.

Furnaces from the Middle and Later Iron Age

By the 11th century A.D. iron production appears to have spread over wide areas of South Africa — from the Natal coast to the western Transvaal, and from the Limpopo River to the Vaal River. Many fairly well-preserved iron-smelting furnaces of this period have been found there. They are all low-shaft furnaces, being bellows-blown and non-slag tapping, but they vary considerably in structure, size, and functional detail. Two main types can be recognized: one type widely spread in the Transvaal resembles in many respects the beehive- or oval-shaped furnaces found in Rhodesia; a second type, called *Venda furnace*, is found at many places in the eastern and north-eastern Transvaal, but does not show clearly recognizable affinities with furnaces in the neighbouring regions. The characteristics of the Venda furnace are three equally spaced, radially arranged tuyère slits and straight or slightly outwards sloping walls[6]. At one time it was thought that the Venda furnaces showed some affinity with a Madagascar/Eastern furnace type, but it seems more likely that the special features of the Venda type point to a relationship with the Central/East African *intengwe* (*ichingtengwa*) furnace type, 'small blast furnaces shaped like a church bell put upside down'. These *intengwe* had three slits for

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TABLE I

METALLOGRAPHIC ANALYSES OF IRON ARTEFACTS FROM SOUTHERN AFRICAN IRON AGE SITES

No.	Catalogue no.	Specimen type	Site	Age of specimen	Carbon content, %	Microstructure	Analyst	Reference
1	A.R.U. 24/73 L162	Iron bit	Broederstroom District Brits	5-6 cent. AD	Outer bands 0,7 Inner band 0,4	Ferrite and fine pearlite. Three distinct bands of metal separated in places by stringers of slag. See Fig. 5.	Mavrocordatos	Rep. 295/76*
2	A.R.U. 24/73 L163	Iron block	Broederstroom District Brits	5-6 cent. AD	Overall 2-2,5 (individual nuggets 0,05-0,35)	Block consisting of insufficiently consolidated nuggets. One nugget consisted of ferrite and duplex slag, others of pearlite, massive 'grain boundary' carbides. Pearlite contained lathes of primary cementite. See Fig. 6.	Mavrocordatos	Rep. 295/76*
3	A.R.U. 24/73 LB1	Iron piece	Broederstroom District Brits	5-6 cent. AD		Patch of hyper-eutectoid structure. Widmanstätten cementite associated with ferrite.	Mavrocordatos	Rep. 303/78*
4	A.R.U. 24/73 LB2	Iron piece	Broederstroom District Brits	5-6 cent. AD	A one end v. low C (0,05) at other end incr. to 0,8	Nugget of iron encrusted by slag. Contains oxide inclusions. Widmanstätten structures in pearlite Matrix. No martensite.	Mavrocordatos	Rep. 303/78/a*
5	A.R.U. 24/73 LB3	Tang fragment	Broederstroom District Brits	5-6 cent. AD		Spheroidized and divorcing pearlite.	Mavrocordatos	Rep. 303/78*
6	A.R.U. 29/72 L135	Adze	Olifantspoort Dist. Rustenburg	13-16 cent. AD	Tip 0,75	Laminated structure. Ferrite–pearlite. Widmanstätten structure in one area.	Mavrocordatos	Rep. 303/78/a*
7	A.R.U. 29/72 L139	Knife blade	Olifantspoort Dist. Rustenburg	13-16 cent. AD		Tip of blade: fine pearlite. Shaft: divorcing pearlite.	Mavrocordatos	Rep. 303/78*
8	A.R.U. 20/71 L124	Adze	Olifantspoort Dist. Rustenburg	16-18 cent. AD		Laminated structure. Ferrite–pearlite.	Mavrocordatos	Rep. 303/78/a*
9	A.R.U. 20/71 L2	Adze	Olifantspoort Dist. Rustenburg	16-18 cent. AD		Spheroidized and divorcing pearlite.	Mavrocordatos	Rep. 303/78*
10	A.R.U. 20/71 L118	Pin	Olifantspoort Dist. Rustenburg	16-18 cent. AD	Head 0,2-0,5, tip 0,25-0,3	Laminated structure. Ferrite–pearlite.	Mavrocordatos	Rep. 303/78/a*
11	A.R.U. 62/71 L86	Bangle fragment	Olifantspoort Dist. Rustenburg	16-18 cent. AD		Spheroidized and divorcing pearlite.	Mavrocordatos	Rep. 303/78*
12	A.R.U. 31/71 L101	Adze	Platberg Dist. Klerksdorp		0,1-0,25	Ferrite and pearlite. Iron nitride needles might suggest heating to over 1200°C.	Mavrocordatos	Rep. 295/76*
13	A.R.U. 37/73 L151	Iron bit	Platberg Dist. Klerksdorp		0,3-0,7	Ferrite and divorcing pearlite.	Mavrocordatos	Rep. 295/76*
14	Rooiberg B	Gad	Rooiberg Mines Dist. Waterberg	c. 15th cent AD (?)	0,35		Schoch	13
15	Rooiberg I	Chisel			Dark zone 0,8 Light zone low C	Dark coarse-grained carbon-rich areas distributed in light-coloured low-carbon mass. Grey strings of slag inclusions.	Schulz	24, 25
16	Rooiberg II	Chisel	Rooiberg Mines Dist. Waterberg	c. 15th cent. AD (?)	Low-carbon zone 0,1 High-carbon zone 0,8 Average 0,5	Zonal structure. Broad dark carbon-rich zones (hardness Br. 335-450) alternating with lighter low-carbon zones (hardness Br. 130-190) in dark zone needle structure (martensite) with troostite spots.	Schulz	24, 25
17	A.R.U. 51/52	Metal piece	Elandsdrif Dist. Rustenburg		0,6-0,9	Sorbite and pearlite. Irregular carbon distribution.	Schneider	26
18		Hoe	Malelane dist.		0,45-0,75	Ferrite–pearlite.	Davidson	27
19	001	Hoe	Makgwareng, O.F.S.	17-19 cent. AD	Surface layer 0,17 Second layer 0,11 Inner layer v. low C	Complex structure of six welds and a lap joint, where thin sheets of strips of metal were joined together.	Cronin	28
20		Iron pieces	Zimbabwe	13-16 cent. AD	6 specimens carbon free to 0,9	Heterogeneous structure. Mostly steely iron (ferrite–pearlite with entangled slag). Sometimes medium-carbon steel in centre of specimen surrounded by low-carbon metal.	Stanley	14
21	Niamara 2	Chisel	Niamara Mocambique	c. 18 cent. AD	Hard centre 0,6	Wide dark zone through centre of piece. Hardness Br. 200. Light outer zone nearly carbon-free. Hardness Br. 115.	Schulz	24, 25
22			Manyikene S. Mocambique	13-17 cent. AD	Surface A: 0,35-0,6 Surface B: 0,1-0,35	Surface A: considerable quantities of pearlite. Hardness Br. 200. Surface B: intermediate pearlite areas. Hardness Br. 136.	Wield	29
23		Axe, blade, knife, etc.	Taruga Nigeria	5-3 cent. BC	12 specimens 0,1-0,8 Spec. F (fragm.) 0,8	Spec. F: spheroidized carbide in the pearlite. Hardness Br. 265.	Tylecote	18
24				5-3 cent. BC	Spec. G (axe) 0,3	Spec. G: carbon-steel with a Widmanstätten structure. Pearlite partly spheroidal. Hardness Br. 180.	Riley	18
25				5-3 cent. BC	Spec. J (blade): 1st layer 0,3 3rd layer 0,1	Spec. J: appears to be made from three separate pieces of metal welded together First layer: ferrite–pearlite with a Widmanstätten structure. Second layer: ferrite with marked nitride precipitation. Third layer: ferrite–pearlite.		18

*These are reports of the Department of Metallurgy, University of the Witwatersrand, Johannesburg.

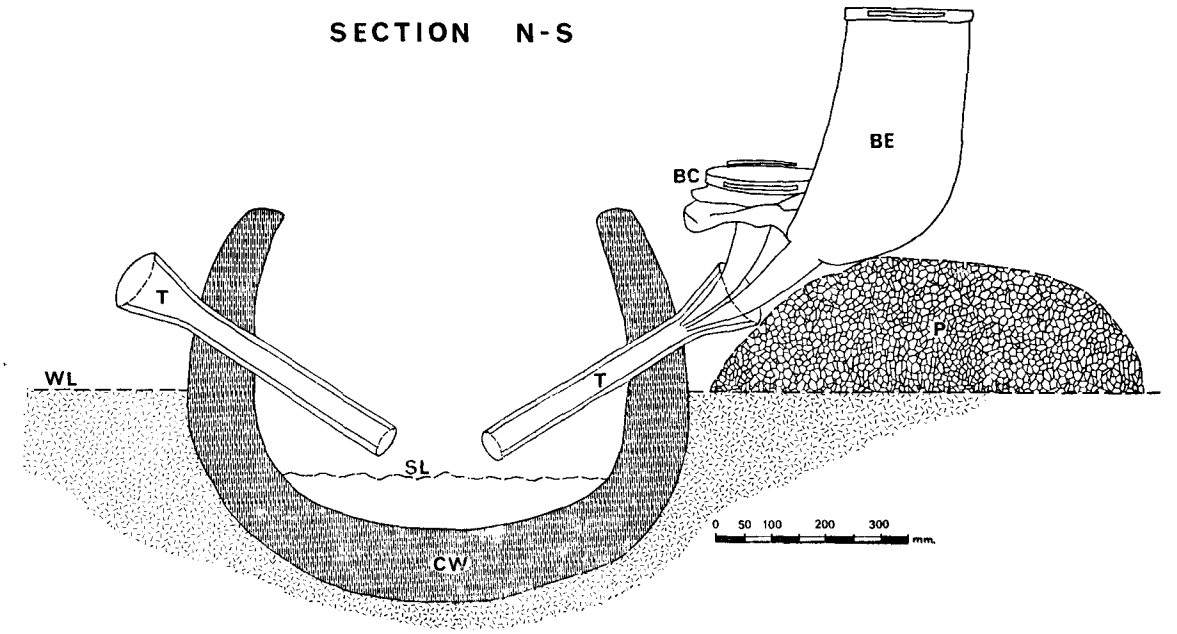

Fig. 1—Reconstruction of iron-smelting furnace 7/63 from Melville Koppies Nature Reserve, Johannesburg

WL Excavated working level BC Bellows compressed BE Bellows extended P Platform
SL Slag level CW Clay walls

Fig. 2—Iron-smelting furnace 7/63 from Melville Koppies Nature Reserve, Johannesburg

tuyères, which were adjusted to slant inwards after the furnace floor had been raised with ash. Such furnaces[7] were used by the Vipas, a tribe living between Lakes Tanganyika and Rukwa (Tanzania).

A possible third type is the *Melville Koppies* type (Figs. 1 and 2). Only one example of this type is known: it was excavated on a hill in the Johannesburg City area[8]. This furnace, the lower part of which is sunk into the ground, could be a developed bowl type, which is a primitive type of smelting furnace. However, being dated to the 11th century A.D., the Melville Koppies furnace could belong to an intermediate type that combines the features of the other types found in the Transvaal, or it could merely be a local variety of one of these types.

A typology based only on structural features may not be the most suitable for smelting furnaces, and the classification could perhaps be functional so that it would also show technological development. The main classes of induced-draught furnaces and forced-draught furnaces are, of course, based on functional features. Similarly, the Southern African forced-draught (bloomery) furnaces could be subdivided according to the position and the numbers of their tuyères. A characteristic of many Rhodesian and some South African furnaces is the position of the tuyères in the furnace wall opposite a large front hole that serves for firing and discharge. In these furnaces, the hottest zone of the furnace would be near the back wall, the heat falling off towards the front portion.

If the ends of the tuyères in a two-tuyère furnace were placed to face one another with a gap between them, the efficient heat and combustion zone would be round the centre of the furnace and spreading upwards in a cylindrical or conical zone. Should the tuyères at the same time be directed slightly downwards and set off at a slight angle towards the wall instead of towards the furnace centre, then a turbulent circular flow of hot air could be created round the furnace interior with obvious advantages in the air and heat regime[9] (Figs. 1 and 2).

Another efficient arrangement is the three-tuyère system of the Venda furnace (Fig. 3), in which each tuyère blows against the interstice between the other two tuyères. Here there would be an enlarged central combustion zone and, through internal preheating of the tuyères, the heat economy would be better.

It would be interesting to make both a theoretical and an experimental study of the influence of the various tuyère arrangements, and also of the various furnace shapes and sizes and so obtain a better understanding of the efficiency of the smelting procedures practised during the South African Iron Age.

Smelting Slags

Slag floors and slag heaps are the most common remains found on old smelting sites, since the iron silicates of slag are fairly resistant to weathering and to chemical attack by soil acids. The analysis of slags can give an indication of the ore sources used in iron smelting, and also some information on the smelting process itself. However, such analyses must be interpreted with caution since they are influenced by sampling procedures, variations in ore and fuel material, use of scrap iron and flux, and similar factors. In a previous paper[5], the author reported the analyses of 31 slag samples from smelting sites in Southern Africa. The majority of the samples showed a high iron content (40 to 50 per cent Fe), but in 11 samples the iron content was low (4 to 8 per cent). The slags of high iron content, which are typical of well-conducted bloomery-furnace smelts, consist prob-

Fig. 3—Venda furnace near Iron Mountain, Low Country, northern Transvaal. Photo taken by H. Cros in 1888. Reproduction by courtesy of Africana Museum, Public Library, Johannesburg

ably mainly of the compound fayalite (containing 57 per cent Fe). One of the likely reasons for the production of low-iron slag is the use of a siliceous low-grade iron ore, as it is sometimes found in banded iron ores (for example, in the Magaliesberg area).

Slag deposits can also give an indication of the iron output of smelting furnaces. Slag heaps containing 30 to 50 tons of slag have been found near smelting furnaces in the Phalaborwa area[10, 11]. Impressively large slag heaps have also been reported from a Botswana smelting site near Tautswe[12]. It appears that iron smelting was a sizable industry in the Later Iron Age.

Carburized (Steeled) Iron

Much information on the traditions and the development of iron smelting and working can be obtained from chemical analyses and metallographic examinations of iron artefacts found at archaeological sites. Such methods were already used some fifty years ago by M. Baumann[13] (1919) and G. H. Stanley[14] (1931). The results of this early, as well as of more recent, research work are reported in Tables I and II.

The 'steely' character of Iron Age iron objects is evident from the analyses of these 25 samples. (The term *steel* should be reserved for modern homogeneous high-purity carbon steels and should not be used for the carburized iron of the African Iron Age.) Two hypotheses of the procedures to obtain steely (high-carbon) iron in African Iron Age smelting furnaces can be presented.

Hypothesis: Intentional Carburization

The first hypothesis involves a high-temperature process producing high-carbon iron by intentional carburization in a smelting furnace. This process requires sustained high temperatures (above 1300 °C). This could be achieved either in high furnaces of natural draught as were used in West and Central Africa, or in furnaces with many tuyères like the forced-draught 'blast' furnaces of East Africa[2, 7, 11, 15, 16]. There are indications that natural-draught furnaces were used in Rhodesia[17], but no remains of such furnaces have yet been found in South Africa. High-carbon iron (of the cast-iron type) could probably have been produced in small quantities in bloomery furnaces under favourable conditions (high temperature, suitable ratios of ore to fuel, prolonged firing times, efficient bellows, careful arrangement of tuyères, good insulation of the furnace, etc.). Under such conditions, temperatures of more than 1300 °C could have been obtained — notes on 'white heat' in bloomery furnaces are found in the reports of early travellers. Maximum temperatures of 1300 °C have also been recorded in smelting experiments recently conducted at the Archaeological Research Unit of the University of the Witwatersrand, but it appears to be practically impossible to control the reduction process in small bloomery furnaces at such high temperatures. Also, the tuyères and furnace walls will not stand up to high temperatures. In any case, high-carbon iron (of the cast-iron type) would be too brittle for the making of implements and weapons. It would also be very difficult to reduce the high carbon content to a satisfactory level by oxidation–decarburization and long hammering.

Hypothesis: Unintentional Carburization

The sponge-iron (bloom) produced in bellows-blown low-shaft (bloomery) furnaces is generally a mixture of small solid-iron particles, slag, and unburnt charcoal, with occasional pieces of unreduced ore. Depending on the conditions of the smelting process, either the iron produced could have had a low carbon content (bloomery or wrought iron), or it could have contained some high-carbon iron resulting from accidental carburization. Occasional local overheating in the presence of unburnt charcoal and consequent absorption of the carbon by reduced iron probably happened fairly

TABLE II

CHEMICAL ANALYSES OF IRON SPECIMENS

Site	Catalogue no.	Silicon %	Total iron %	Metallic iron %	Manganese %	Aluminium %	Phosphorus %	Sulphur %	Analyst	Notes
Broederstroom	24/73 KA	0,61	83,7	±20	—	0,19	0,016	—	Iscor Research Laboratory	Fragment, semi-quantitative analysis
Broederstroom	24/73 Azc	3,8	58,2	±10	—	0,44	0,067	—	Iscor Research Laboratory	Fragment, semi-quantitative analysis
Broederstroom	24/73 Aj L163	—	92,6	88,1	—	—	—	—	National Institute for Metallurgy	Iron block
Rooiberg	B	0,17	—	—	Nil	—	Traces	0,01	Schoch	See Table I, no. 14
Rooiberg	I	—	—	—	—	—	0,01	0,014	Schulz	See Table I, no. 15
Rooiberg	II	—	—	—	0,01	—	0,03	0,01	Schulz	See Table I, no. 16
Niamara	I	—	—	—	0,01	—	0,32	0,01	Schulz	Ref. 24
Niamara	II	—	—	—	Traces	—	0,2	—	Schulz	See Table I, no. 21

frequently in bloomery furnaces. As a result of this reaction, areas of high-carbon content (above 0,8 per cent) can be found in many iron specimens from Iron Age smelting sites. The heterogeneous structure of the steely iron appears to be — as G. H. Stanley[14] had pointed out in 1931 — characteristic of the products of Southern African Iron Age bloomery furnaces. This is also evident from the results of the metallographic analyses reported in Table I. (See also A3, A4, B of the Addendum.)

The influence of the forging (smithying) procedures on the carburization of crude iron is discussed later in this paper.

Examination of Iron Artefacts

Of the materials listed in Table I, specimens 1 to 13 are from three Central/Western Transvaal sites: Broederstroom, Olifantspoort, and Platberg, and specimens 14 to 19 are from other parts of the Transvaal and the Orange Free State as recorded by previous authors in this field. Included for purposes of comparison is relevant material from the literature on the Zimbabwe cultures: Zimbabwe, Niamara, and Manyikene (specimens 20 to 22) and the Nok culture (specimens 23 to 25).

The Nok culture of Nigeria (Taruga) belongs to a geographic and ethnographic area having no direct connections with the Southern African Iron Age complex. However, apart from the Broederstroom site, it is the only African Early Iron Age area from which detailed information on the furnace structure and the metallurgical character of the iron products is available[18, 19]. In both respects, there are remarkable similarities between the Western African and the Southern African technologies. Whether such similarities point to any affinities beyond that of a common source for the African Iron Age metal technology can be decided only when much more cultural, archaeological, and metallurgical information becomes available.

A number of iron artefacts found by R. Mason at the Iron Age sites of Broederstroom, Olifantspoort, and Platberg (see Table I, nos. 1 to 13) were submitted to Professor C. E. Mavrocordatos (Department of Metal-

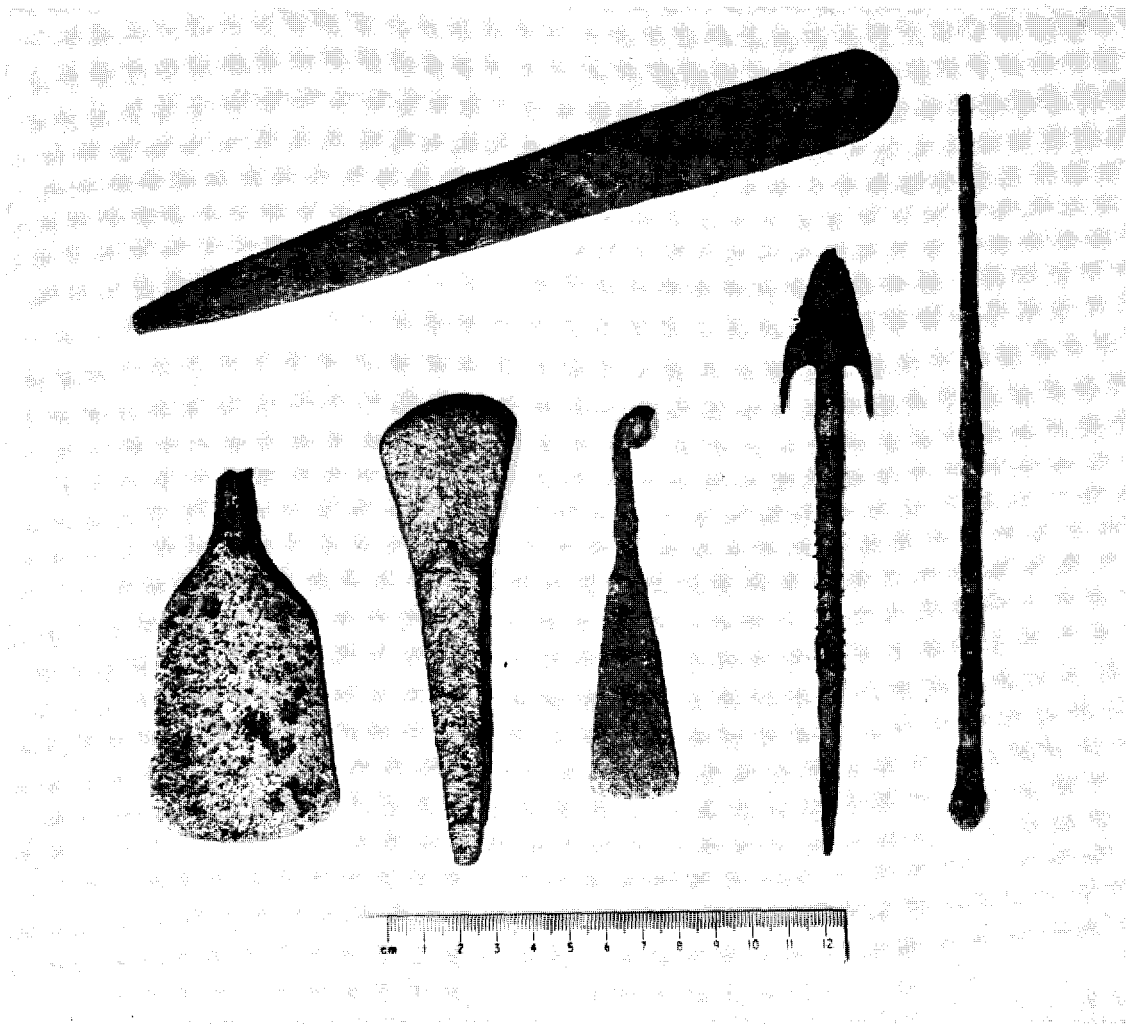

Fig. 4—Iron Age artefacts

Top: Chisel from Rooiberg Mines
Bottom (L. to R.): Blade (Marikana, Rustenburg dist.), adze (Marikana, Rustenburg dist.), scraper (Mapungubwe, Soutpansberg dist.), barbed arrowhead (Mapungubwe, Soutpansberg dist.), pin(Olifantspoort, Rustenburg dist.)

Fig. 5—Photomicrograph of section of iron bit L162 from Broederstroom. Junction of an inner (low carbon) and an outer band (high carbon). Scale X170. By courtesy of C. E. Mavrocordatos

Fig. 6—Cross-section cut from bottom of iron block L163 from Broederstroom site. Black areas are cavities produced by the irregular shapes of insufficiently consolidated nuggets. Scale X2. By courtesy of C. E. Mavrocordatos

lurgy, University of the Witwatersrand) for metallographic examination. A summary of his results is given in the Addendum. (The designations of the specimens correspond to those given in Table I.)

Distribution of Carbon in Iron Specimens

The irregular distribution of low-carbon areas, high-carbon areas, and entrapped slag is a typical feature of African bloomery iron. The carbon-rich areas are the result of natural carburization by occluded charcoal particles in the furnace fire and by carbon trapped in the pores of the bloom when it is hammered out in the forge. Additional carburization takes place when carbon is absorbed and diffused into the reduced iron from the hot charcoal bed of the forge. The resulting heterogeneous structure of the iron is observed in nearly all the specimens analysed (Table I).

Zonal Structure in Iron Age Artefacts

Zonal structures are often found in Iron Age artefacts. A laminated structure is present in a very early blade from Taruga (Nigeria), which is approximately dated to the 4th century B.C. In that specimen (no. 25J), three separate pieces of metal are joined together. Similarly, in an iron piece from Broederstroom (no. 1), an inner low-carbon band is sandwiched between two high-carbon outer bands. In a specimen from Rooiberg (no. 16), carbon-rich zones alternate with low-carbon zones. A report[28] on a hoe found at Magwareng (no. 19) describes it as a 'complex structure of six welds and a lap joint where thin sheets of strips of metal were joined together'.

In the specimens mentioned, the carbon content is higher in the outer layers, but in other specimens the reverse is the case, the carbon content being higher in the centre zone (nos. 15, 20, 21). (See also A1, A2, B in the Addendum.)

One could assume that the laminated structures are the result of deliberate carburization (cementation) of thin iron strips in the hot charcoal bed of the forge. However, doubts have been expressed as to whether bloomery iron could be intentionally carburized to high-carbon steely iron by the African blacksmith in a direct forging process. R. F. Tylecote[16] comments: 'The variable carbon content (of Iron Age artefacts) has led many to talk about intentional carburization. But the fact is that reheating can remove or add carbon according to the carbon level of the area of the bloom heated and the precise position of the metal in the hearth in relation to the tuyère'.

If R. F. Tylecote's objection is accepted, one has to look for a more empirical explanation of the carburization process. It could be that the blacksmiths observed differences in the appearance, hardness, and strength in iron pieces forged at different places in the hearth and recognized the influence of varying temperatures and heating times. The pronounced effect of these factors has been shown in a recent study by Maddin[20], who found that, after nine hours' firing at 1150 °C, the concentration of carbon at 1,5 mm below the surface of an iron piece can reach 2 per cent. The corresponding figures at 920 °C are 0,02 per cent and 0,48 per cent carbon after one hour's firing and after nine hours' firing respectively. So both low-carbon and high-carbon iron could be obtained.

Much more analytical, metallographic, and experi-

mental work is required before the problems of carburization in the metal produced by the early African blacksmiths are completely understood.

Welding Methods

There are indications that, at the beginning of the African Iron Age, a rather sophisticated method of welding was already known. A pile of crude-iron pieces was wrapped up in a fireclay envelope and heated to a high temperature in a forge fire. The clay envelope containing the iron was then taken out of the fire and was broken up by hammering, the hot iron being welded together. In this way, excessive oxidation of the crude iron during a long heating period in the forge could be avoided[18, 21]. This appears to have been a method by which a very clean iron could be obtained. A cylindrical iron block, 960 g in mass, found at the Early Iron Age site of Broederstroom (5th century A.D.), as well as metal pieces from the even earlier site of Taruga (5th century to 3rd century B.C.), may have been produced in this way[5, 18]. A sample taken from the Broederstroom block had a total iron content of 92,6 per cent and a metallic iron content of 88 per cent (Table II).

Quenching Methods

Another field of Iron Age metallurgy of which we know little is the treatment of hot forged iron by quenching and tempering. Some metallurgists think that such sophisticated procedures were unknown to the African blacksmith. However, at least one report[22] on iron-working by the Nyiha smiths of south-western Tanzania mentions that 'the hot beaten iron was plunged into water . . . to harden it'. The presence of martensite in a specimen from Rooiberg (Table I, no. 16) and of Widmanstätten structures in a number of specimens (Table I, nos. 3, 4, 6, 24, 25) could also point to accelerated cooling after the metals had been heated to elevated temperatures, but relatively low outside air temperatures could be responsible for the effect.

Chemical Analyses

The few iron specimens that were analysed chemically give only limited information (Table II).

Some iron pieces from the Early Iron Age site of Broederstroom contain fairly high amounts of impurities, but this is not necessarily a characteristic of iron produced during the African Iron Age, since metal from Taruga (Nigeria) dated to between the 5th and the 3rd century B.C. shows an extraordinary degree of purity[16]. Products from the Later Iron Age, e.g. from Rooiberg, also contain very little impurities. In the samples from Niamara the phosphorus content is high. Such differences can be explained as being the result of the varying compositions of the iron ores used for smelting.

Some implements made in the later phases of the South African Iron Age appear to have been high-quality products. M. Baumann[13] remarks that iron chisels found in the ancient Rooiberg tin mines were of 'exceptional purity — equal in quality to the best Swedish iron'. Similarly, Sir Theophilus Shepstone[23], an administrator of Natal, wrote in a report of 1853 that iron produced by African blacksmiths was 'very good and possibly superior to Swedish iron'.

Conclusions

(1) Furnaces of the South African Iron Age can be classified into two or three structural (possibly also functional) types belonging to one functional main class, the forced-draught, low-shaft bloomery furnace.

(2) There is no firm evidence that iron ore was smelted in South African bloomery furnaces at sustained high temperatures (over 1250 °C) for the deliberate production of high-carbon (steeled) iron. Unintentional accidental carburization of reduced iron in smelting furnace and forge, and irregular distribution of high- and low-carbon iron in bloom, crude, and forged iron, are inherent characteristics of the South African bloomery process.

(3) Steeled iron could also be made by the heating, beating, and pile-welding of selected iron strips of dissimilar carbon contents.

(4) From archaeological investigations and from metallographic and chemical analyses of iron pieces and artefacts found at the 5th century A.D. Broederstroom site, it can be concluded that all the basic elements of Iron Age metal-working technology (blowing and firing procedures, forging and piling techniques) were known to the earliest iron workers of South Africa. Our present knowledge is insufficient to indicate whether the techniques of iron production in South Africa changed relatively little during the Iron Age, or whether improvements in furnace construction and production methods (influenced by contact with East African and European cultures) led to a real technological progress in the later stages of the Iron Age. This is a field for further investigation.

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Addendum: Metallographic Examination

by C. E. MAVROCORDATOS*

Several items found at excavations in Olifantspoort, Broederstroom, and other sites were submitted to metallographic examination. The results of this investigation are summarized below.

A. *General Features*

1. All the specimens were laminated, generally in a longitudinal direction. Occasionally signs of 'upsetting' of previously laminated blocks were observed.
2. The laminations, as a rule, were separated by oxide or slag layers. The carbon content varied, usually abruptly, from lamination to lamination. On several occasions where no oxide or slag springer separated the laminations, diffusion of carbon from the high-carbon to the low-carbon lamination had taken place.
3. Several implements showed signs of 'carburization' or decarburization on the surface, and that not necessarily on both sides of the examined cross-section. This rather suggests that such apparent carburization was accidental rather than deliberate.
4. All the specimens examined, both on this occasion and on another (see report 295/76), were in some form of annealed state. No bainitic and, certainly, no martensitic structures were observed.
   This strongly suggests that neither a deliberate nor an accidental attempt at hardening was made, which in turn suggests that the ability of carbon steels to harden was not known or appreciated by the native artisans. This again would tend to discredit the claim that steel was produced deliberately. That the items can be described as 'steels' does not necessarily suggest the deliberate production of steel. This statement implies that, in the opinion of the writer, no conscious and/or deliberate control of the carbon content of the finished articles was exercised.
5. On the other hand, no article (except for the 'ingot' L163, which was discussed elsewhere) showed any 'cast-iron' structure, and no implement was found consisting of almost 'pure iron' in its entirety. Only occasionally, some laminates — or a single nugget in the ingot L163 — consisted of ferrite alone.
6. All the specimens consisted of pearlitic structures. These varied from very large grains of coarse to fine pearlite, to small grains of fine pearlite.
7. Spheroidized and divorcing pearlite was observed in at least 5 implements (LB3, L139, L151, L86, and L2). This structure is produced by the reheating to about 700 °C of a previously fully annealed article, so as to consist of pearlite with or without proeutectoid ferrite or proeutectoid cementite (depending on the carbon content of the laminates); the temperature of reheating would normally not have been below 650 °C (very long times of heating are necessary at that temperature) but would certainly not have been above 723 °C. Steel articles with such a structure are, of course, in their softest condition.
   In the opinion of the writer such reheatings were entirely fortuitous since very accurate temperature control could not have been employed. If the full effect of temperature on the properties of steel had been appreciated, attempts at quenching, rather than at fully tempering, would have been made.
   On the other hand, there is no evidence of articles having been reheated to temperatures between 723 °C and 900 °C. But this, of course, is due to the fact that no article (except one) was examined all along its length. For instance, on the fully finished knife blade (item L139), from which two specimens were cut, the shaft consisted of 'divorcing' pearlite, a structure characteristic of a steel heated to a temperature below 723 °C, while the tip of the blade showed a structure of fine pearlite, indicating a heating temperature of about 900 °C. If further specimens were cut at intermediate positions, it is certain that structures of undissolved ferrite and pearlite would have been found, proving that the article had been heated differentially.

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B. *High Carbon Content*

It is perhaps very significant that, with the exception of one implement in which only a patch of a hypereutectoid structure was observed (LB1), the only specimen with a structure close to that of cast iron was the section of the 'ingot' (L163). In both these specimens, the grain boundary cementite (L163) and the Widmanstätten cementite (L163 and LB1) were associated with ferrite, suggesting 'abnormality' (see below). The coexistence of grain-boundary and Widmanstätten cementite reflects a comparatively fast rate of cooling coupled with the absence of alloying elements. Both these objects were rather massive, resulting in an appropriate rate of cooling to produce such structures by merely cooling in air.

The fact that the only really high-carbon (1,5 to 2 per cent) materials were the 'nuggets' from which the 'ingots' were made, and the fact that no more very high-carbon structures were observed on the laminates of the implements (with the exception of the *unfinished* article labelled LB1), indicate that the reduction of the iron ore in low-shaft blast furnaces produced sufficient carburization for the nugget to perhaps reach cast-iron consistency when it came into contact with solid carbon in the 'hearth'. When the nugget was subsequently reheated for the production of the laminated article, the carbon became oxidized, leaving the various articles with greatly varying carbon contents, ranging from almost pure iron to a eutectoid composition (0,8 per cent carbon). The fact that an almost pure iron nugget was found in the section of the ingot examined, and that it was entirely surrounded by nuggets of almost cast-iron composition, suggests that the degree of carburization in the low-shaft blast furnace employed for the reduction was not the same on every occasion.

C. *Abnormality*

Both specimens showing primary cementite (L163 and LB1) are typical of an 'abnormal' steel. This fact is mentioned here as a 'curiosity'. It would be interesting to hear from others who have investigated such specimens whether they have observed the same phenomenon.

D. *Conclusions*

The examination of specimens of ancient iron implements found in South Africa (some 13 articles) leads to the following conclusions.

1. It would appear that the blacksmiths produced all the implements by consolidating small 'nuggets' of iron reduced from ore.
2. These 'consolidated' nuggets were then reheated and hot-worked until eventually the final article was produced.
3. During this subsequent reheating, any excess carbon was oxidized, leaving lamellae with various amounts of carbon.
4. In the majority of cases, but not always, the outer surfaces were poorer in carbon. In some cases, the reverse was true and then not necessarily on both sides.
5. No evidence of deliberate 'carburization' was found. In one implement in which both outer surfaces were of a eutectoid composition, the transition from a high-carbon surface to a low-carbon core was more or less sharp and in places it was interrupted by elongated oxide and slug stringers, indicating that the surfaces of high-carbon content were merely caused by the accidental joining of two high-carbon 'nuggets' to one or more lower-carbon nuggets, which were placed in the middle.
6. All the articles were in the 'soft' condition, consisting of pearlite or of ferrite and pearlite. Some were in a subcritical annealed condition.
7. No attempt at 'quenching for hardening' was detected.
8. There are indications that the iron produced by the 'blast furnace' is high in carbon, but that it is decarburized to below eutectoid composition during the hot-forming operations.

Welding workshops and exhibition

The Welding Institute is to exhibit at the International Welding, Cutting and Metal Fabrication Exhibition, which is being held in Birmingham from 24th to 28th September, 1979.

During the period of the Exhibition, the Institute will arrange the following programme of six afternoon workshop sessions to study topical aspects of welding technology.

Tuesday, 25th September:

—Thermal sprayed coatings for improved product performance and greater cost-effectiveness in mechanical components

—The application of robots in welding

Wednesday, 26th September:

—Exploiting advanced welding processes

—High-energy density processes

—Safety in welding and the law

Thursday, 27th September:

—Exploiting advanced welding processes

—Friction welding and diffusion bonding

—Automatic operation and control of welding in heavy engineering.

This arrangement will allow the busy visitor an opportunity to tour the exhibition in the morning and attend one of the workshops in the afternoon.

Further details are obtainable from The Welding Institute, Abington Hall, Cambridge CB1 6AL, England