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IRON WORKING AT MEROE, SUDAN

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Indroduction

The site at Meroë in the Sudan lies about 200 km north-east of Khartoum on the banks of the Nile and was for a time the capital of the Kingdom of Kush. During the 25th Egyptian Dynasty (751 — 656 BC) the Kushites ruled Egypt and adopted Egyptian ways. They were forced to retire during the 6th century BC when Egypt was attacked by the Assyrians. The 26th Dynasty under the Saites and Persians sent expeditions into the Sudan, and attacked the north. Gradually, either because of these attacks or the advance of the desert, the Kushites moved their capital from Mapata in the north to Meroë. Here they established a flourishing city, with a Royal Palace, and they buried their kings and queens and some of their nobles under pyramids in the low hills which border the valley of the Nile in this area. These hills contain iron ore and it is possible that the smelting technique was learnt from Greek or Carian (Anatolian) mercenaries who accompanied the invaders on their attacks on the north.

While there is earlier evidence of the use of iron, traces of iron smelting do not turn up a Meroë until about 200 BC. However, the site is renowned for its large iron-slag heaps, one of which was cut through by the railway line from Khartoum to Wadi Halfa which was laid in 1897. It is clear that at one time this was the principal iron-making area of the Sudan, no doubt encouraged by the Royal House. A terminus post quem for the demise of part of the site at least is given by the building of the Lion Temple on one of the slag heaps to the east of the railway line. This temple was built between AD 246 and 266; soon after AD 300 Meroe was sacked by the king of Axum (part of modern Ethiopia), and iron working on a large scale was brought to an end. It is quite possible, however, that it continued spasmodically and on a much reduced level well into the Islamic period (14th cent. AD[1]).

The site of Meroë is at present being excavated by P. L. Shinnie formerly Professor of Archaeology in the University of Khartoum, and it was through his kindness that I was able to examine the site and assist in the excavation.

Iron Ores

The sandstone hills of the northern Sudan are capped by an ironstone formation, and the pyramids of the northern cemetery at Meroe are built on and in this deposit of iron ore; this is a sedimentary deposit of varying ferrugious content interbedded with layers of more richly ferruginous and nodular material. On the site itself can be found large pieces of ore with a crenellated lamellar structure, and dark concretions and ironstone balls. Samples of both the lamellar and nodular types were taken for examination.

A good deal of low-grade ore of a tabular type was used for building purposes. There were various examples in the Royal City, and also in the small settlement mound to the west of the Lion Temple slag heap.

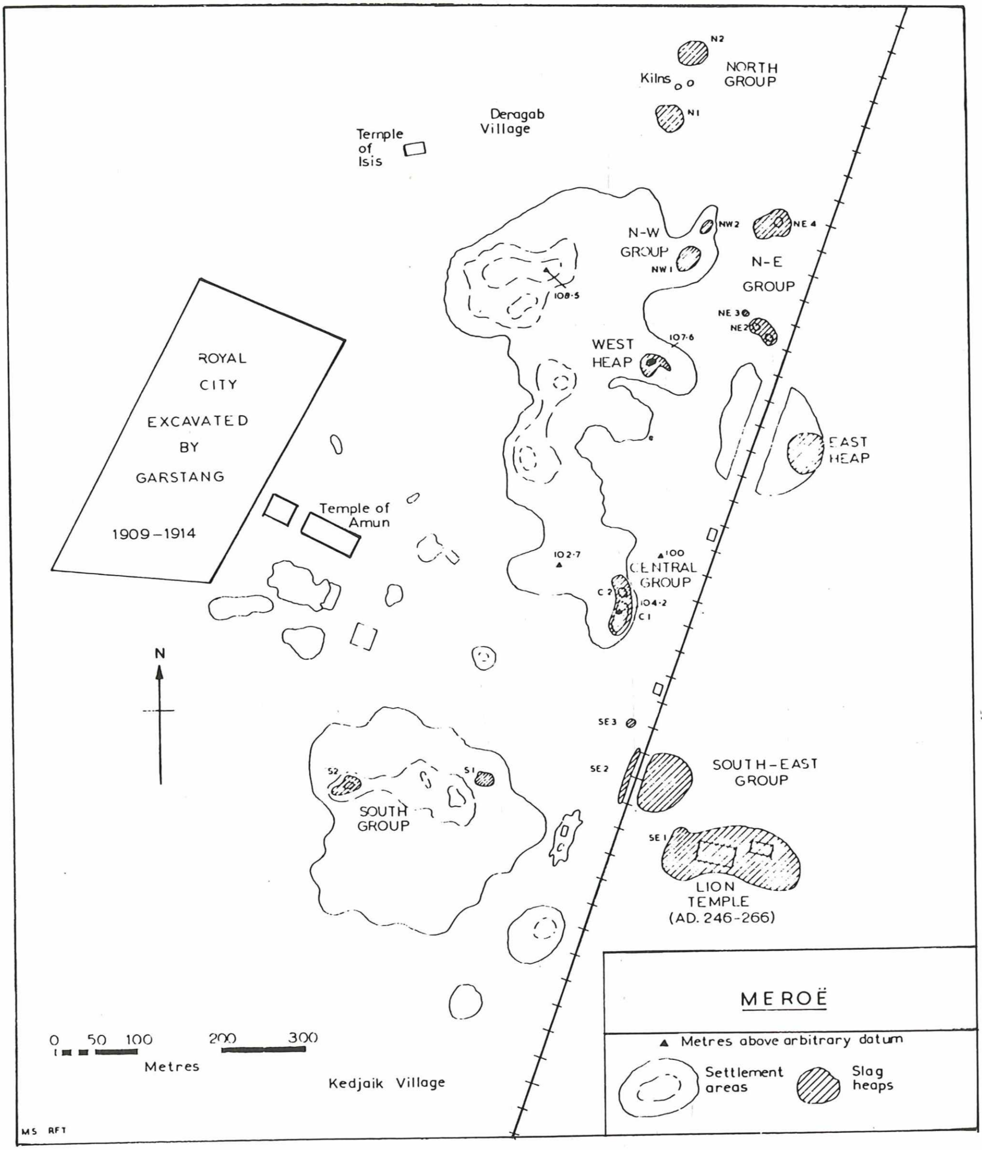

Fig. 1 — General plan of the site of Meroë

General Examination of the Site 1969 — 1970

A plan of the site is shown in Fig. 1. The Nile lies about 200 m to the west, and the most westerly group of buildings that can now be seen are those of the Royal City excavated by Garstang between 1909 and 1914. Between the Royal City and the railway line are a series of settlement sites, and some of those on the east side are topped with slag heaps of unknown depth. In some cases it would seem that the heaps were at first isolated, but later the settlement areas gradually extended towards them; in others the slag heaps gradually extended towards them; in others the slag heaps have actually been built over earlier settlement areas. In the case of the central group, the settlement area was carried over the toe of the slag heap, while on the southern edge of NW 1 in the north-west group excavation revealed a furnace built into the remains of earlier buildings and overlain by later buildings. The East Heap clearly lies on top of a settlement mound, while SE 2 is almost all slag, as shown by the railway cutting.

Evidence from the Slag Heaps

All the large slag heaps seem to contain the same type of material on the surface, which presumably relates to one of the later phases of iron working on the site. The main items found were as follows:

(1) Large pieces of furnace lining with an internal diameter of about 0,5 m, vitrified and slagged on the inside but with red-burnt Nile mud on the outside. The thickness rarely exceeded 4 cm. One piece, excavated from the edge of slag heap C2, had two holes spaced 15 cm apart and of 12 mm bore. A small fragment had one hole 10 mm diameter on the vitrified side and 20 mm diameter on the other. These are the only pieces so far found on the site with small holes.

(2) Fired pottery tuyeres. There were many varieties of these (Fig. 2). The most frequent one was 60 — 70 mm o. d. and 22 mm bore (Type B); the bore was always parallel through-out its length, while the o. d. tapered at one end to give a wall thickness of only a few mm. The longest had a length of 40 cm. There were no indications of an enlarged bore to take the bellows nozzle, and it is therefore probable that this managed to fit into the 22 mm diameter hole; it is even possible that the back end tapered externally like the front end. The next most frequent type had the same o. d. but was 30 mm bore (Type C). One piece was square externally with rounded corners (Type D), 5,5 cm on the extant side and 23 mm bore. Many of the first type of tuyere (A, B and C) were filled with slag for as much as 10 cm. This is very unusual (most tuyeres only show evidence of slag accretion at the ends) and means that the tuyeres could not be used after the slag and entered them.

The tuyeres had been made from the clay used for the rough pottery. Some showed signs of finger marks, and it was clear that they had been made by being pressed round a wooden rod that had been withdrawn before firing. Others had been smoothed before drying but still showed evidence of the use of wooden rods as formers which had been withdrawn from the wet clay.

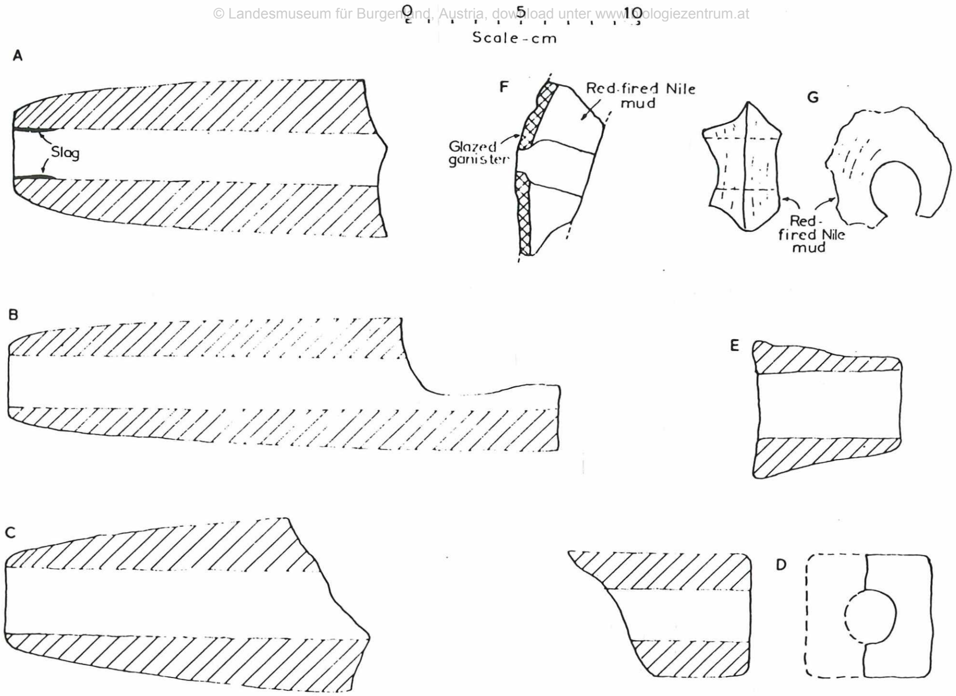

Fig. 2 — Types of tuyere found on the site.

(3) Pieces of dense tap slag that had solidified in a »bowl« about 30 cm diameter. It was clear that the centre of these lumps had been more porous than the surface.

(4) Slag runners about the size of a wrist.

(5) Large masses of tap slag weighing 5 — 10 kg had clearly been attached to the runners and had been formed by running downhill; some had run over a slope and others had fallen vertically, showing that the side of the slag pit was in some cases undercut. Both had solidified on the more or less level bottom of a pit.

Most of the slag found on the slag heaps was typical high density tap slag, undoubtedly from the latest phase. One piece was examined and found to consist of fayalite laths and glass. The surface had oxidized on tapping and showed the presence of magnetite as fine dendrites and angular crystals. Naturally the surface was magnetic; the centre was almost nonmagnetic.

(6) Large pieces of black ganister-like material that had probably resulted form the fritting of a mixture of coarse spherical sand grains with a small amount of clay. This could have been derived form the local sand by a winnowing process. This material had been using for lining the bowl and the lower parts of the shaft. Many pieces showed considerable slag wash, some were slightly glazed, and others were

rough. The nature of the frit was such that the slag lumps that formed the bowl could be easily broken away from it, leaving a thin layer of frit on the slag. Some of the pieces were angular, showing the nature of the junction between the bowl and the shaft.

As it appeared that the local Nile sand could have been used, a partial sieve analysis was carried out on a sample of sand taken from the original natural surface of the site about 10 m down form the top of the occupied levels. This gave the results shown in Table I, which show that it is a coarse sand with over 45 % greater than 0,4 mm diameter. A portion of the whole sample was heated at 1200°C but did not sinter. A second portion of the sample was then mixed with a small amount of clay and finely ground slag and sintered at 1200°C for 4 h. This gave a black material just like that found on the site. It was clear that the small-size fraction had dissolved in the clay and slag which had fritted the coarse sand grains together. This showed that the original ganister could have been made from Nile sand to which a little clay had been added. Most of the black coloration would be due to the penetration of ferruginous slag through the pores of the sintered ganister.

Table I. Partial sieve analysis of Nile sand
(100 g sample; 20 min)

Size of sieve, mm	Weight retained, %
1.400	0.4
0.853	17.8
0.699	11.1
0.500	8.7
0.422	5.4
Less than 0.422	56.2

(7) Pieces of cinder (i. e. thin films of slag surrounding pieces of acacia charcoal). The charcoal was quite large, about 3 × 3 cm on average. The slag was non-magnetic, showing clearly that it came from the lower levels of the furnace and was not a partially reduced charge from the higher levels.

Smithing

The fact that smithing was carried out in the main period is attested by the finding of a nearly complete smithing furnace lining with an integral tuyere on the West Heap (Fig. 3) and the finding of several tuyeres of the same type in stratified levels of NW 1, and these would fit into the smithing fornace lining from WH. The smithing furnace lining is only 20 cm dia. and thus is very small, which suggests that only small artifacts were made in it. However, it is no smaller than the holes in the sand which are used for forging scrap iron in Kabushiya market to-day. The remains of two smithing hearts were found in situ in the trench in NW 1.

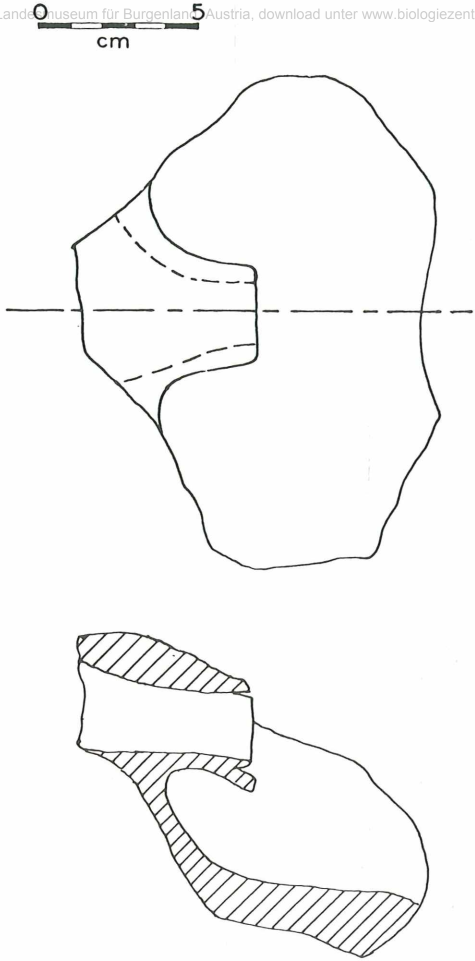

Fig. 3 — Lining of smithing furnace from West Heap

Evidence from Excavation

Earliest Phase

Material from levels 6 and 7 in the trench to the west of Heap C 2 shows a more primitive character in the form of small furnace bottoms about 8 to 12 cm dia. and 3 to 6 cm deep. In this trench, level 9 has a C 14 date of 514 ± 73 BC; whilst producing metal, it did not produce any smithing or smelting refuse. However, level 8 has a C 14 date of 280 ± 120 BC. The furnace bottoms in levels 6 und 7 above could be either smithing or smelting debris, but for the fact that ore was found with those in level 7. This would seem to indicate that some of the bottoms originate from smelting. Very little tap slag was found in this deposit.

The smelting hypothesis was confirmed by the finding of a number of »nodules« of rusted iron. These are now mainly magnetite, but have a core of residual iron and slag. The iron is mostly ferrite with nitride needles, and the slag is a typical smelting slag containing wüstite in a glass matrix.

Some larger furnace bottoms measuring about 19 × 17 cm across and 8 cm deep were found in the upper levels of the trench in the area of Heap C 2. A furnace bottom of similar size was also found on the surface of the West Heap. These relate to the earlier phase of iron working on the site and are typical products of bowl furnaces.

From the technological point of view these bottoms are typical of the earliest phases of the Iron Age in Europe, and one would be inclined to date them about 200 years earlier than the sophisticated technique found over most of the site. They represent the slag accumulation in the bottom of bowl hearths 20 cm in diameter.

Towards the east end of this trench, the toe of a later slag heap comes into the section just on the natural subsoil level. This contains the usual furnace lining, tap slag, etc. of the main Meroitic period. It shows that unoccupied ground still existed at the east side of the site; this is probably why the heaps are mainly on this side.

Excavation of a furnace in 1969 — 1970

An annular trench was laid out on the south side of Slag Heap NW 1; when the east end of this trench had been taken down to about 30 cm, buildings began to appear. These for the most part consisted of re-used material with a considerable

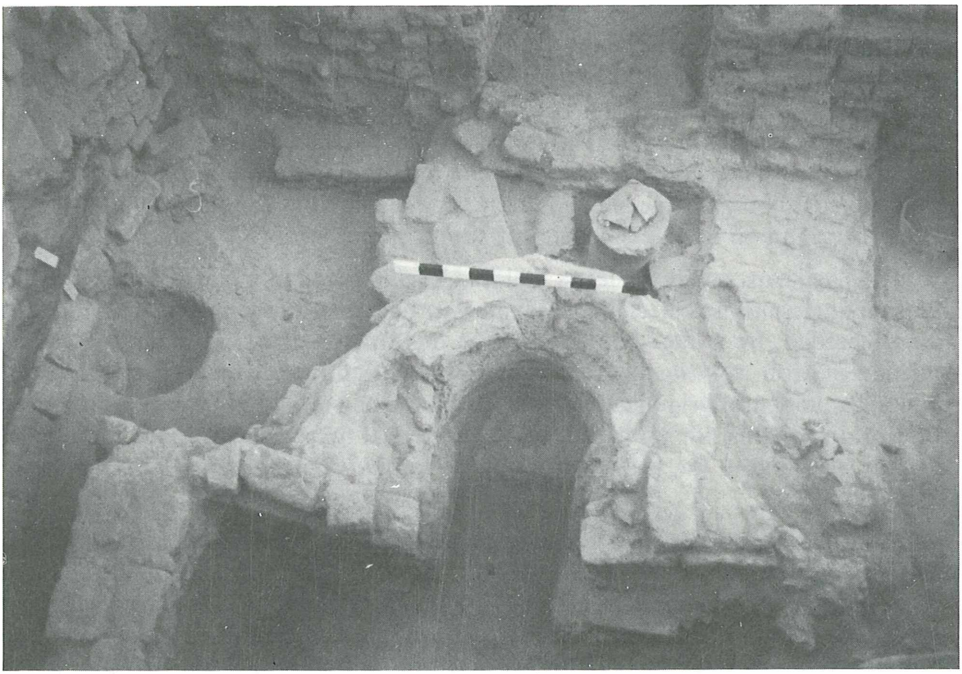

Abb. 4 Smelting Furnace 1. (Scale, 1 m.)

amount of fired brick and stone. At a level of about 2 m, in the middle of a room, the horse-shoe shaped outline of the remains of a smelting furnace became evident (Fig. 4). Between this and the west wall of the room was a considerable amount of red roasted iron ore with very little charcoal, indicating that it was a deposit and not a roasting area. Inside the outline of the furnace wall a piece of vitrified lining could be seen. The inside of the furnace was cleaned out first, involving the removal of a very hard cemented sand deposit. After about 50 cm, the lining, which was only intact on the north wall, came to an end and it became clear that the bottom part of the lining had collapsed and been removed after the last smelt. It was decided to continue the excavation from the outside to see if there were any traces left of the outer ends of the tuyeres.

A section through the trench on the north side of the furnace went through the remains of earlier buildings and produced various small finds such as beads and amulets. It became clear that the furnace structure had not been free-standing but was cut into the older building levels, the remains of which had been held up by a rough mud-brick wall about one brick thick to provide a backing for the furnace and the working area in front. This wall had been built to a height of at least 1 m.

Unfortunately the furnace bottom was missing, and no tuyeres were found *in situ*. Appart form the fact that the furnace was not free-standing, the only additional piece of evidence obtained in this area was the finding of a large section of vitrified lining *in situ*, which shows that the internal diameter of the furnace at a height of about 0,9 m above the bottom was about 0,5 m and that the shaft had a considerable inward slope.

The layers of roasted red ore to the west of the fornace went down into the building levels, showing that there had been smelting in the area prior to the erection of the furnace found. The roasted ore which alternated with grey layers of clay-sand varied in size from about 8 — 20 mm, and was soft and friable. As is usual an early sites, it was still magnetic, showing that the roasting had not gone to completion. But it was highly permeable and would be very satisfactory for smelting after some further breaking up to give a consistent size of about 8 mm.

The slag heaps overly the latest building level in the smelting area, thus showing that smelting continued after the excavated furnace had fallen into disuse and had been succeeded. by a later building. While this furnace is by no means the latest evidence of iron-working on the site, it was certainly not the earliest both on typological and stratigraphical grounds. We do not yet know the latest period of iron working on this site: it my well go into medieval times. This furnace can almost certainly be dated to the principal period of iron working, i. e. the first two centuries AD.

Two crucible sherds were found which show that non-ferrous metal working was also practised on the site. The first (A in Fig. 5), came from Heap NE 4; it is a typical shallow hemispherical crucible of Nubian or Roman type. It contained some copper-base alloy dross. The second (B) is from a flattish-bottomed crucible with a pronounced lip. Apart from the lip, this crucible would have been circular. There was no internal deposit, but the bottom was vitrified with wood ash.

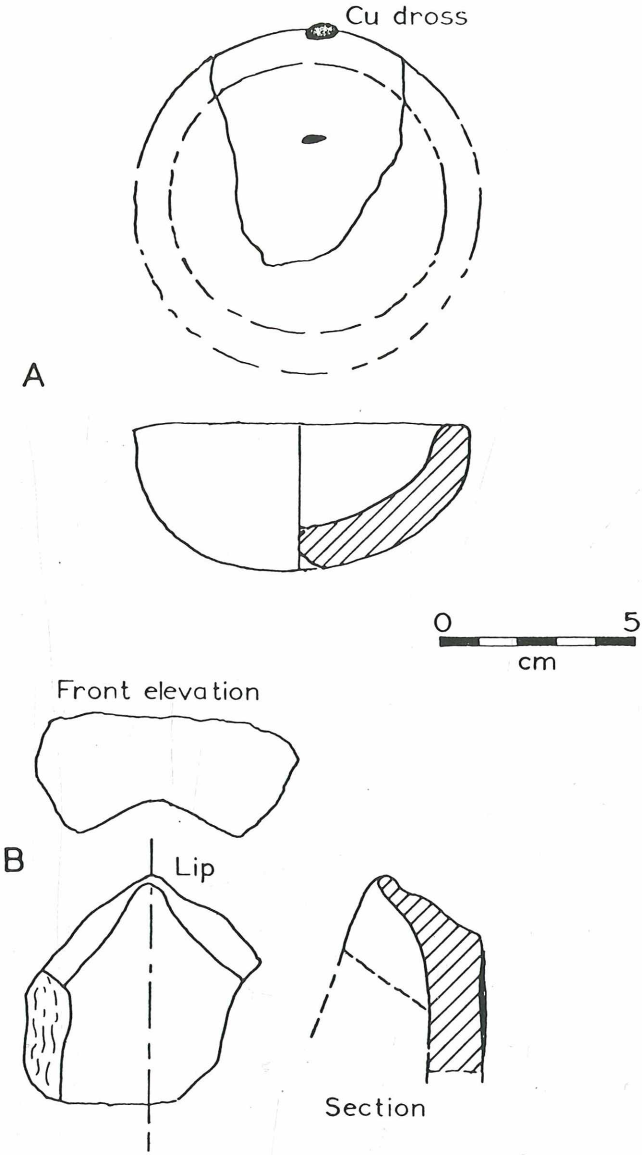

Fig. 5 — Crucibles: A, unstratified from Heap NE 4; B, stratified; from the south side of NW 1

In the season of 1973 — 74 further furnaces were found adjacent to the one reported above. Up to the time of writing six furnaces have been found at Meroe.

Furnaces 2,3 and 4 are shown in Figs. 5 — 7. These show plans and sectional elevations through the slag-tapping pit. Furnaces 2 and 3 formed one production unit enclosed by a wall to keep the tapping area of the two furnaces free of sand complete with a water bosh between them. It is quite certain that the top of the wall was level with the normal ground level at the time of use shown by steps leading down to the working area (Fig. 8). The bellows would be placed at this level both behind and at the sides of the furnaces. These would be about 70 cm above the tapping floor.

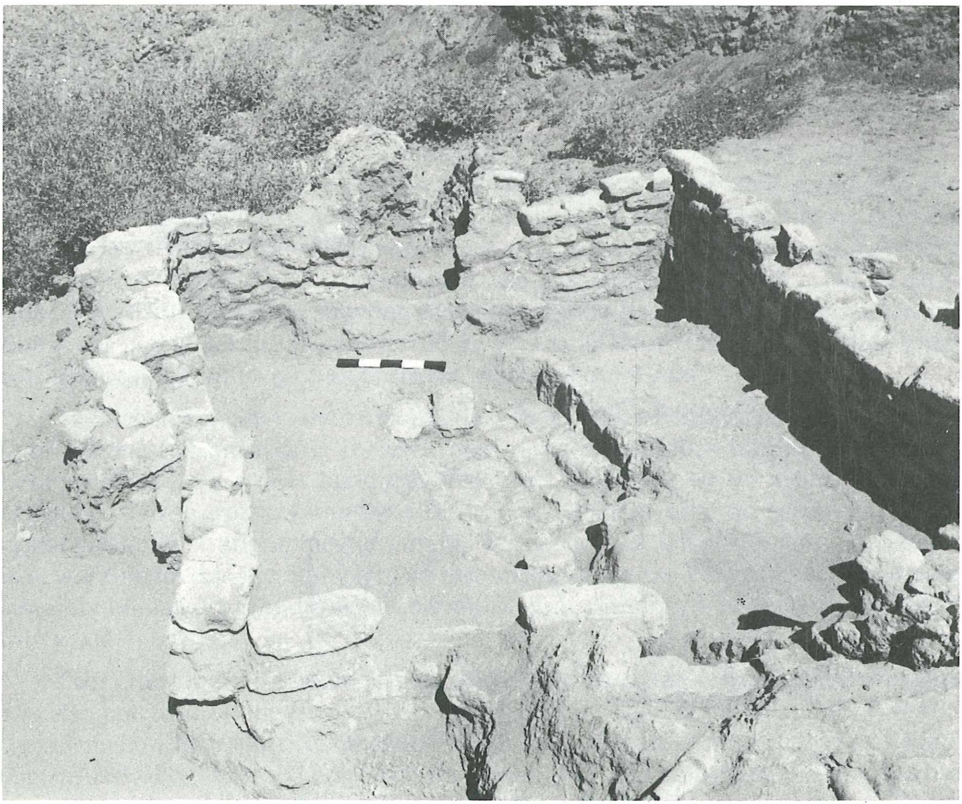

Abb. 6 Enclosure containing furnaces 2 and 3; (Scale, 1 m) steps down on left-hand side.

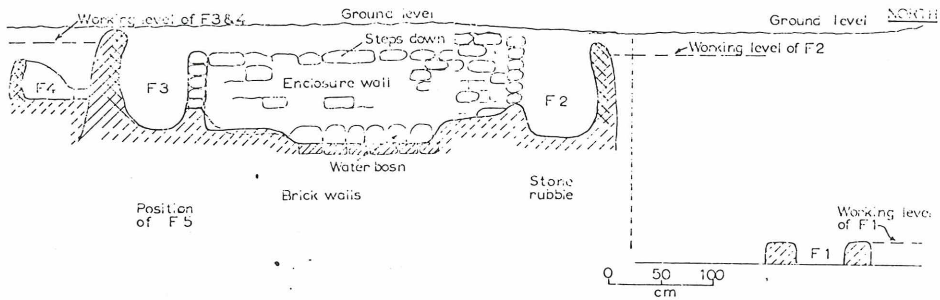

Abb. 7 Section through furnace area.

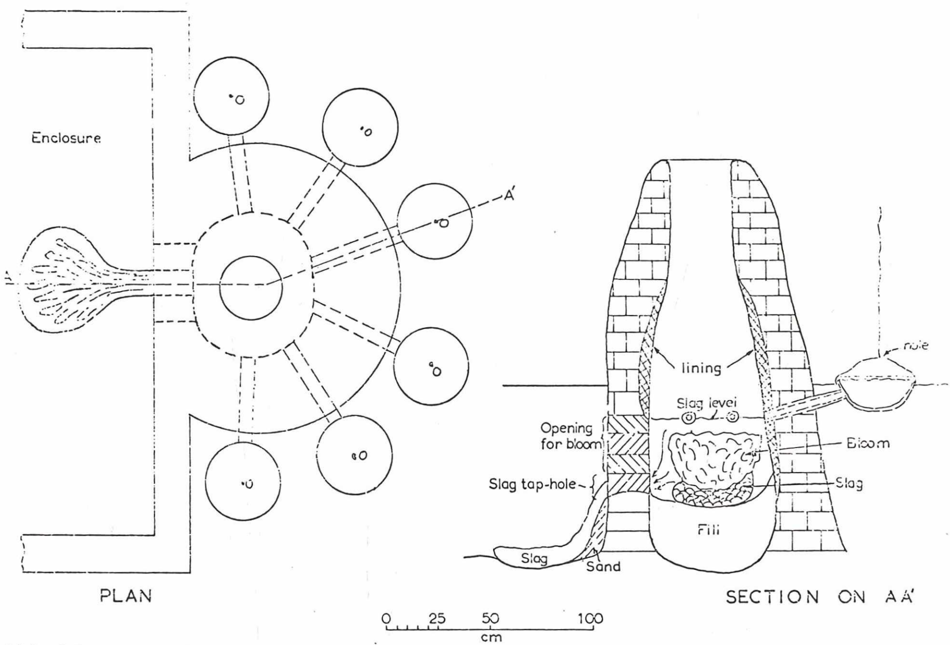

Abb. 8 Reconstruction of Furnaces.

It is not certain whether the central area was covered in any way but the existence of channels leading from both the furnaces suggests that during the rainy season at least the furnaces were protected from rainwash and the water lead into the bosh. There is no doubt that slag did not flow along these channels; there was no evidence of the sort of temperatures — 1200° — that this would entail. Nor could such a long flow be expected from experience.

The position of the lining of the three furnaces shown in section in Figs. 4, 5 and 6, all pointed to one thing — that the effective working bottom of the furnace was more or less level with the top of the still over which the slag was tapped. This means that the tuyeres were 30 — 40 cm above the working bottom of the furnaces. This »bottom« was 30 — 40 cm above the foundation of the furnace which were for the most part of mud-brick; the raising of the bottom was to protect the foundations from the hot zone of the furnace.

Fig 9 shows a section through the furnace complex indicating the various levels. It is clear that F 3 and 4 could not be worked simultaneously. It appears that F 5 is similar in size to F 2 and 3. It would seems that furnaces 1 and 4 were similar, and earlier than the others. F 1, and probably F 4, were built into the same type of enclosure as F's 2 and 3. The latter enclosure was cut into and below levels previously associated with F 4 yet above those associated with F 1 and F 5. Altogether there was a great deal of rebuilding in this area and it would be unwise to say much except that F's and 3 are later than 4 and 5 and probably later than F 1. But generally one gets the impression that all this spans a period very much less than 100 years.

Furnace 3 had 5 tuyeres in position, while F 2 had only three. Neither F 1 nor 4 had any tuyeres in position and it is now clear that this is because the remains were below the tuyere level.

Furnace 5 showed that the tuyeres were connected to pot-bellows like those shown in Egyptian tomb drawings. There was one pot per tuyere in which case the rate of blowing would be halved — only half the number of tuyeres would be operating at any one stroke.

It would seem that the tuyeres were tapered at both ends so as to allow the rear-end to enter a hole fired into the pot; the join would be sealed with clay.

Some of the tuyeres found in situ in the furnaces were filled with slag. Considering their high level this seems surprising but indicates that the slag came up to this level during the operation. If this is so it would terminate the operation as far as that particular tuyere was concerned. No doubt this only occurred towards the end of the smelt. At this stage the space between the tuyere level and the working bottom of the furnace would be filled with a solid mixture of iron and charcoal (the »bloom«) and liquid slag surrounding it. Before removal of the bloom most of the slag would be tapped away through the taphole leaving the bloom sitting on a slag block in the bottom of the furnace (Fig. 10). In Furnace 5, specially constructed shields made of ganister were placed above and to the side of the furnace ends of the tuyeres to prevent slagging.

The manner of working is in some ways very like the Catalan hearth process in which the blooms were immersed in a bath of slag which was more or less completely tapped before the bloom was withdrawn.

The existence of sills in front of the furnaces 2 and 3 make it easier to understand the wristshaped pieces of slag that seem to be cast vertically and which fan out (Fig. 10). These are the runners of slag which ran over the sill onto the ground below. The slag bowls were more rudimentary than those found on Roman sites such as at Ashwicken and it seems that a larger proportion of slag remained behind forming a »bottom« in the furnace itself.

The finding of pot-bellows with Furnace 5, and the remains of Furnaces 2 and 3, would justify a reconstruction of the type shown in Fig. 10.

At Meroë the bloom would be withdrawn just in front of the furnace over the sill and left above the slag tapping pit until cool. No doubt the cooling was assisted by sprinkling with water from the bosh. This may be the true explanation of the channels which appear to lead to the water bosh. Surplus water would drain back into the bosh rather than the furnace. Tools also would be cooled in the bosh.

The bloom would be a heterogeneous mixture of slag, charcoal and iron, and broken up perhaps with an axe and the individual pieces would be re-heated in small smithing hearths like those shown in Fig. 3. Several more of these were found in the season of 1974 — 75; two of them in situ near Furnaces 2 and 3.

Bellows

The finding of F 5, with the remains of pottery bellows surrounding it, early in 1975 has confirmed the supposed Egyptian affinities. It seems that the bellows were solidly attached to the tuyeres and that there was no opening between bellows and tuyere through which air could be draw in to the bellows on the up-stroke.

This means that the bellows had valves which allowed air to enter on the up-stroke and which were closed on the down-stroke like those shown in the drawings from the tomb of Rek-me-re (1500 BC). These drawings do not actually show the valves but they clearly refer to a well-known type fo foot-bellows which have a hole which is closed by the heel of the foot on the down-stroke. The pot-bellows must be well supported in the ground as they are going to take the whole weight of the bellows-man as he transfers his weight from one foot to the other. His toes will be on the rim of the pot while his heel would be closing the hole on the down-stroke. In this way he would be working one of a pair alternately. It would seem that each furnace had 6 bellows pots worked by three men.

The ores used

Following the analysis of the lamellar low grade hematite published in the first report, a second analysis was made on one of the nodules mentioned on p. I. This is shown in column B of Table II and contains even less iron than the lamellar ore (Col. A.).

This is mostly due to the large visible silica grains, and it is doubtful if this ore would be a viable proposition even if beneficiated by grinding and winnowing.

For this reason a closer study was made in 1974 – 75 of the roasted ore found in layers on the slag heaps, particularly heaps NWI. A. This roasted ore was very light and porous and it was clear that quite a lot of water or carbon-dioxide had been expelled during roasting.

A stereoscan (scanning electron microscope) photograph of the fractured surface of a partly magnetic ore particle picked up near the surface of slag heap NW1A showed that this ore is highly porous, as its density would suggest, and contains occasional grains of silica (unchanged in roasting). The porous material is mainly hydrated iron oxide with a little residual siderite left over after roasting. Further roasting removes the water from the hydrate between 150 and 300° C and the CO_2 from the siderite at 500° C. The FeO so formed after heating at 300° C oxidises to Fe_2O_3 with some gain in weight. (TGA results).

Column E, Table II, gives the iron oxide content on the basis that the roasting of the original ore was not complete or that further hydration has taken place in the last two thousand years. By removing the water and carbon-dioxide that might have remained in the original ore we have increased the iron content from the 48.2 % as found in slag heap NWIA to 55.2 %. On this basis, and taking the slag analysis into account, we have arrived at the hypothetical composition of the roasted ore shown in column F.

The difference between the iron in the slag and that of the ore suggests a yield of about 20 % of the iron in the ore, which is about average for the bloomery process.

It is a pity that we have been unable to find some of the original ore on the site. But it is now clear that this is likely to be a weathered siderite from the hills on which the North and South cemeteries are built.

Discussion

The closest known parallels to the type of furnace found are the Noric furnaces. These — some of the largest furnaces know in pre-Roman and Roman Iron Age Europe — were found in Austria[3]. Unfortunately neither were sufficiently complete to be certain about their reconstruction; but that from Feisterwiese in the Austria Erzberg showed evidence of 6 tuyeres at quite a high level (about 20 — 30 cm above the bottom of the furnace). Unfortunately Straube and his colleagues[2] in their reconstruction of this type of furnace discounted this fact and placed their single tuyere near the base of the furnace. Not surprisingly they had trouble with it blocking. Even so, with their single tuyere they showed that with continuous working with a compressor, the furnace needed 320 litres of air/minute. One can deduce that a 6 tuyere Meroitic furnace with intermittent bellows operation would need 3 x 320 = 960 l/min. As the size is something less than the 1100 mm of the Erzberg furnace we can reduce the airflow by one third to give an air consumption of 640 l/min. Using more of Straube's data in the same way we arrive at a charcoal consumption of 26 kg/hr.

The Romans who, in so many cases, were not innovators of a process, diffused the best technique throughout the Roman world. It seems that this is yet another example of Roman-inspired diffusion using Egypt as the intermediary.

Table II.

Meroitic Ores and Slags
Composition — %

	A	B	C	D	E	F
	Ore. Lamellar.	Ore. Nodular.	Slag	Roasted ore from slag heap NW 1 A	Re-roasted ore.	Roasted ore; estimated from cols. C and E.
SiO_2	42,2	58,2	20,7			12,20
CaO	0,32	2,1	2,4			1,50
FeO	0,86	0,07	42,4			—
Fe_2O_3	43,20	32,5	20,8	69,0	79,0	79.00
MgO	0,45	0,45	0,90			0,57
MnO	0,20	0,70	2,35			1,50
Al_2O_3	5,28	1,20	6,70			4,30
P_2O_5	0,65	0,08	1.00			0,64
S	0,05	0,014	0,033			0,02
K_2O	—	—	0,54			0,35
Na_2O	—	—	0,12			0,08
TiO_2	—	0,47	0,77			0,50
V_2O_5	—	0,15	0,14			0,09
Moisture	0,48	0,44	—			0,0
CO_2	—	0,36	—			0,0
Loss on Ignition	1,18	3,25	—	12,5	0,0	0,0
Total	94,87	99,58	98,65			100,75
Fe	30,80	22,60	45,4	48,2	55,2	55,2

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