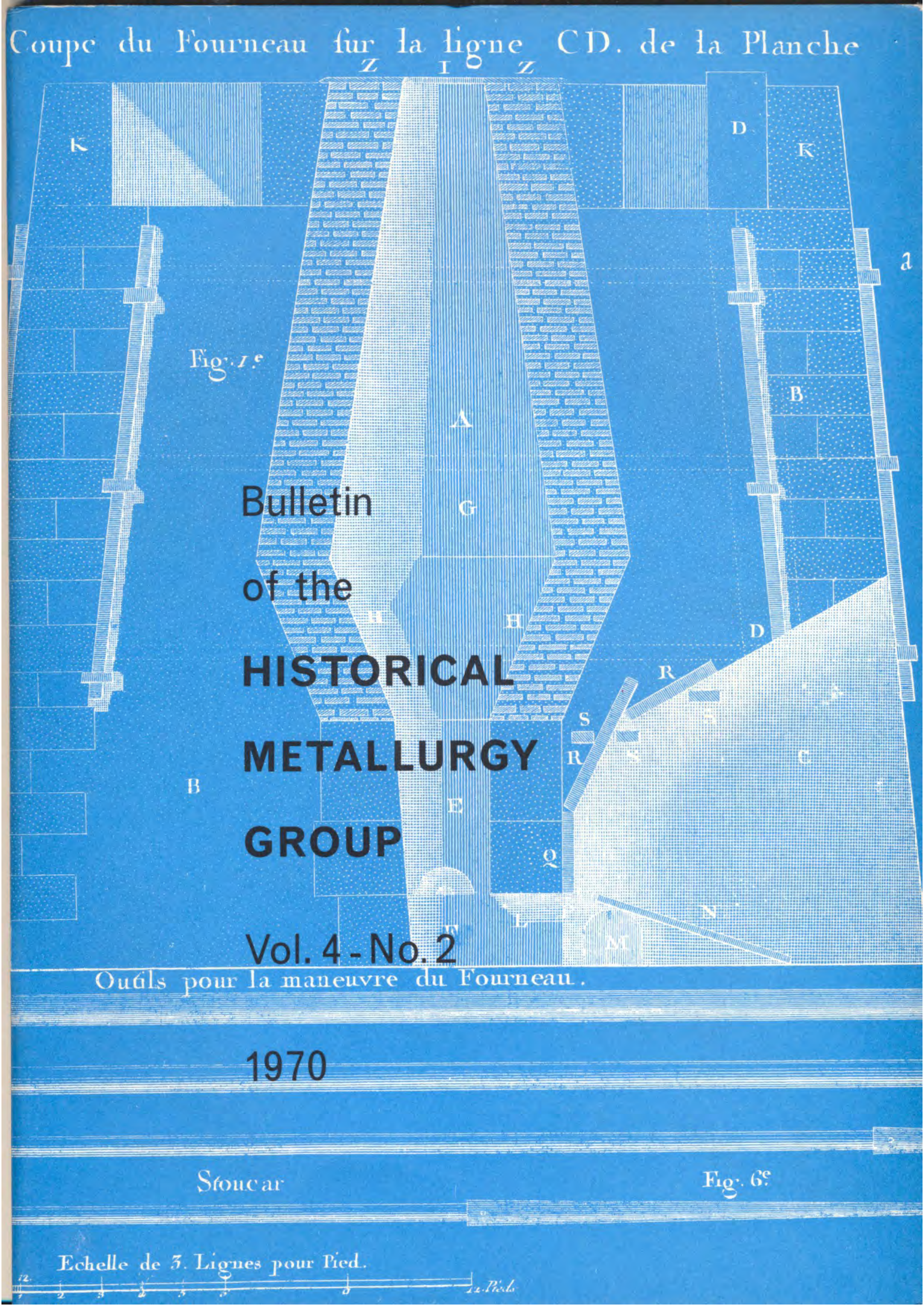

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Iron working at Meroë, Sudan

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INTRODUCTION

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 Napata 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 at 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 Meroë 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).

The site of Meroë is at present being excavated by P. L. Shinnie, 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 Meroë are built on and in this deposit of iron ore; this is a sedimentary deposit of varying ferruginous 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 large piece of lamellar ore weighing 2.23 kg and having a specific gravity of 3.27 was cut in two; a slice was removed from the centre and chemically analysed. The result is given in Table I. This shows an unexpectedly high silica and low iron content. As the loss on ignition is small it is neither a hydrate nor a carbonate and must be classed as a low-grade hematite. This piece must have been discarded as useless since the iron content of the slags on the slag heaps cannot be much less than this. Clearly, the silica must be in a very finely divided state as the grains cannot be seen with a hand-lens (x10).

A piece of the nodular ore which showed coarse silica grains underwent a loss of 12.5% upon ignition, and most of this was water. This is therefore in a much more hydrated condition (i.e. limonitic) and would make a more reducible ore if the silica content was low enough. It is not unusual to find that the ore on a smelting site is thus discarded, for obvious reasons. It is certain that some part of the deposit on which the northern cemetery lies is of sufficiently high grade for the direct reduction process which produces high-iron slags.

TABLE I Analysis of Sudanese Iron Ore %

Fe_2O_3	43.20
FeO	0.86
SiO_2	42.20
Al_2O_3	5.28
MnO	0.20
CaO	0.32
MgO	0.45
S	0.05
P	0.28
H_2O	0.48
Combined H_2O	1.18
	94.60

Hematite: Low grade.

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.

GENERAL EXAMINATION OF THE SITE

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 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 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 and 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 C2. A furnace bottom of similar size was also found on the surface of the West Heap. These

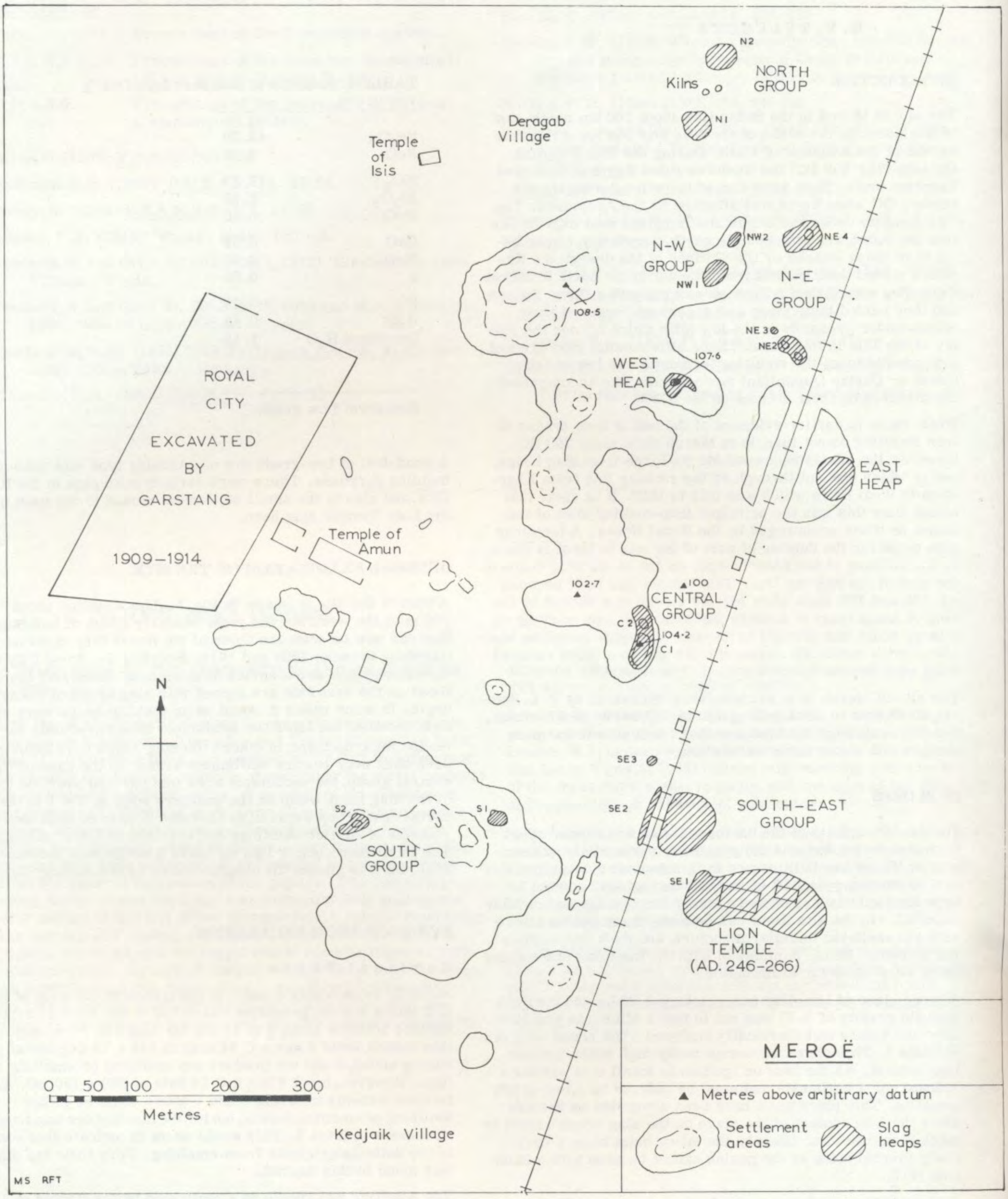

Fig. 1 — General plan of the site of Meroë

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.

Evidence from the Slag Heaps

All the large slag heaps seem to contain the same type of material on the surface, which presumable 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 throughout 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 of a different type was found on slag heap SE2; this 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 had 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.

(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.

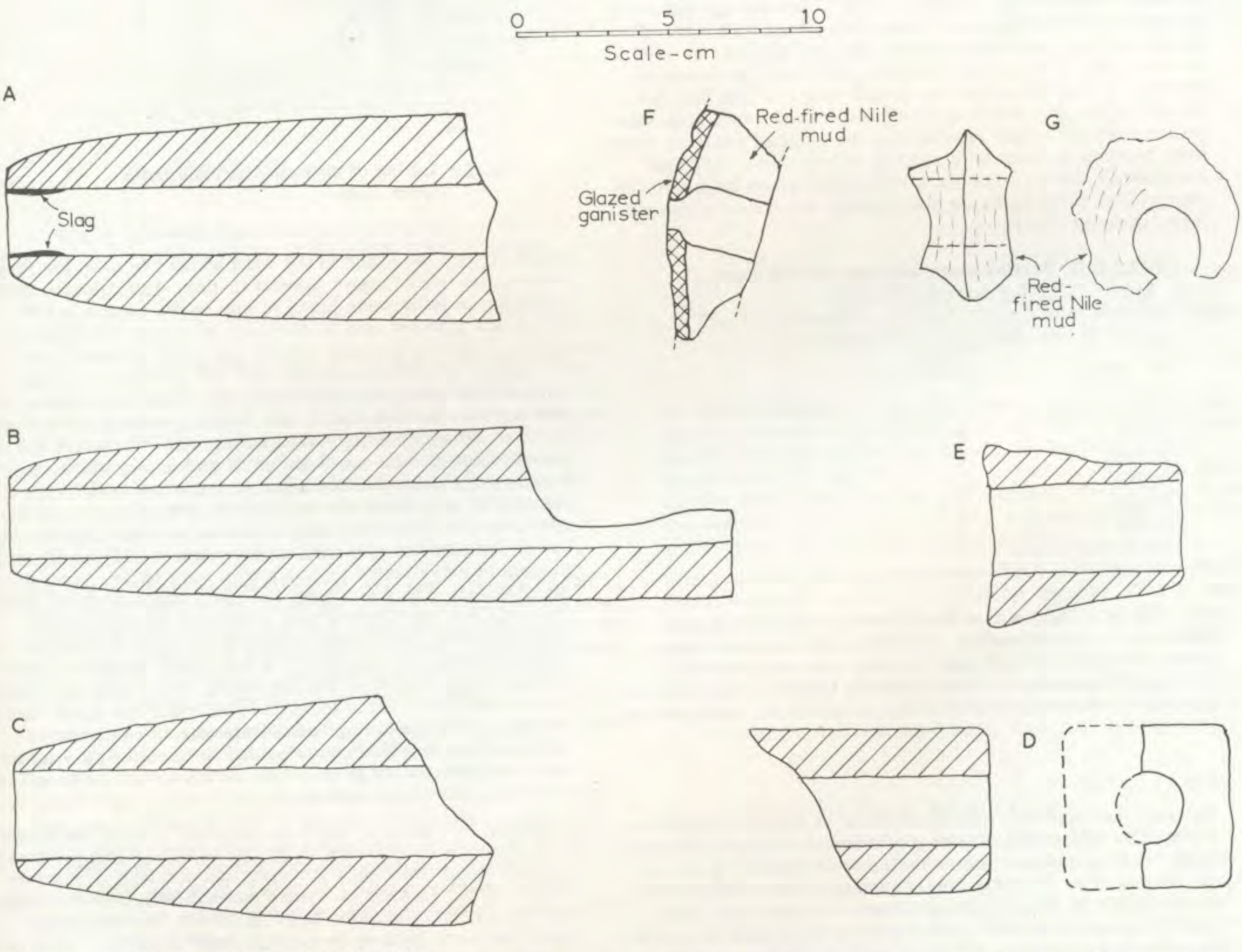

Fig. 2 – Types of tuyere found on the site.
Types A, B, C and E are all smelting furnace tuyeres. Type D, is probably from a smelting furnace. F, is an upper-level tuyere from a smelting furnace. G, is an unused tuyere from a smithing furnace.

(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 non-magnetic.

(6) Large pieces of black ganister-like material that had probably resulted from the fritting of a mixture of coarse spherical sand grains with a small amount of clay. This could have been derived from the local sand by a winnowing process in which only the fraction above 0.5 mm had been retained. This material had been used 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 from the top of the occupied levels. This gave the results shown in Table II, 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 II 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. Two smithing furnace bottoms were also found in a trench in NW 1, and these would fit into the smithing furnace 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 hearths were found in situ in the trench in NW 1.

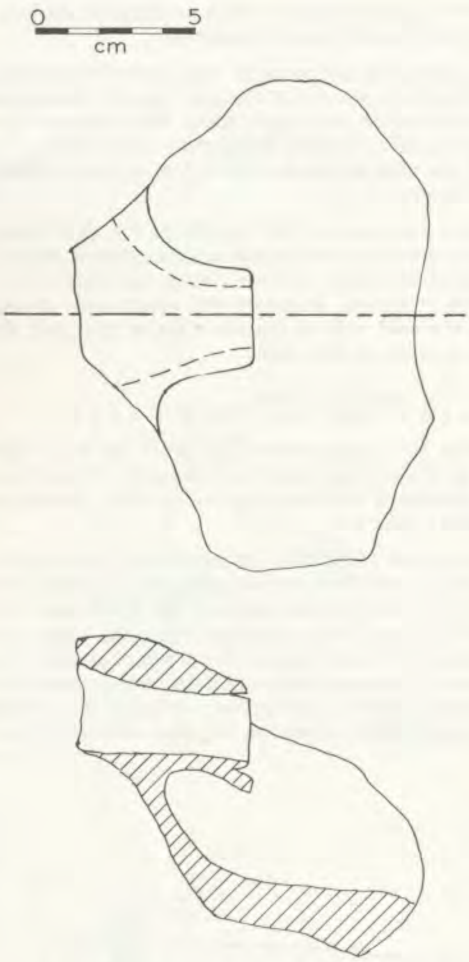

Fig. 3 — Lining of smithing furnace from West Heap

Excavation of a furnace

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 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.

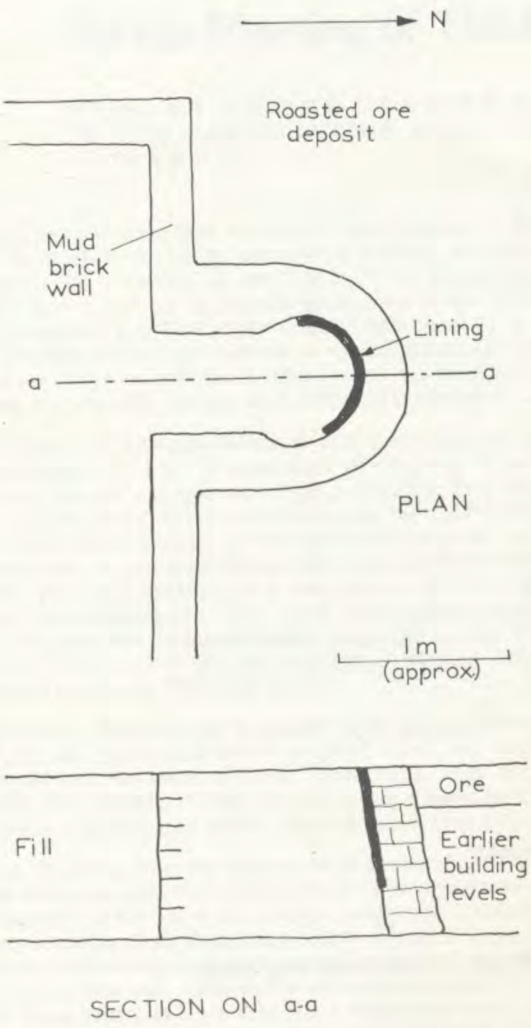

Fig. 4 — Sketch plan of furnace excavated on the southern side of Heap NW 1 (not to scale)

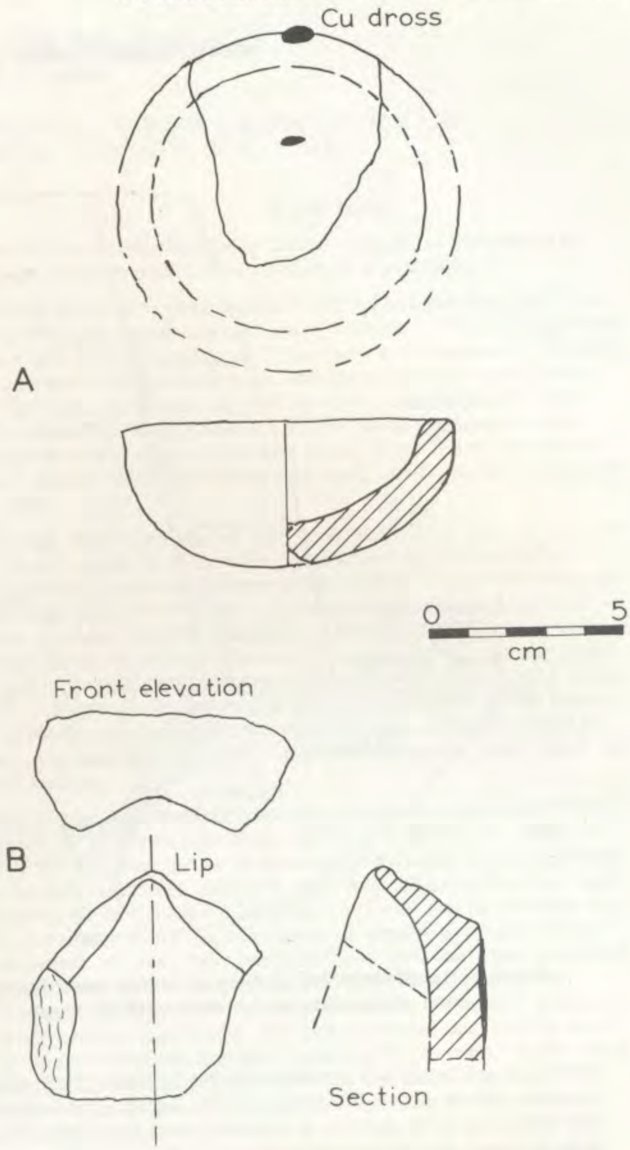

Fig. 5 — Crucibles: A, unstratified from Heap NE 4; B, stratified; from the south side of NW 1

Unfortunately the furnace bottom was missing and no tuyeres were found in situ. Apart from 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. It would seem very difficult to place tuyeres in the back or sides of such a furnace, which leaves us with two possibilities: (1) all the tuyeres were placed in the front wall, or (2) there were at least two types of furnace.

The furnace found seems to have been very similar to the 2nd century AD furnace from Ashwicken, Norfolk, which had a single opening in the front wall about 30 cm high and 30 cm wide. At Meroë there would also have been other free-standing furnaces with tuyeres distributed round the circumference, possibly at two levels as shown in Fig. 6.

The layers of roasted red ore to the west of the furnace 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 on 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 may 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.

Reconstruction of Furnace

The typical free-standing furnace (probably of the period 50 BC to 200 AD) was a shaft furnace with a bowl for the receipt of the slag before tapping (Fig. 6). The pottery tuyeres entered the bowl at a slight angle to the ground and must have been at least 40 cm long. The bowl was about 45 cm dia. and 10 cm deep. The higher-level tuyeres, made by making holes in the inside surface of the lining and perhaps joining these to pieces of the standard 20 mm bore tuyere, were at

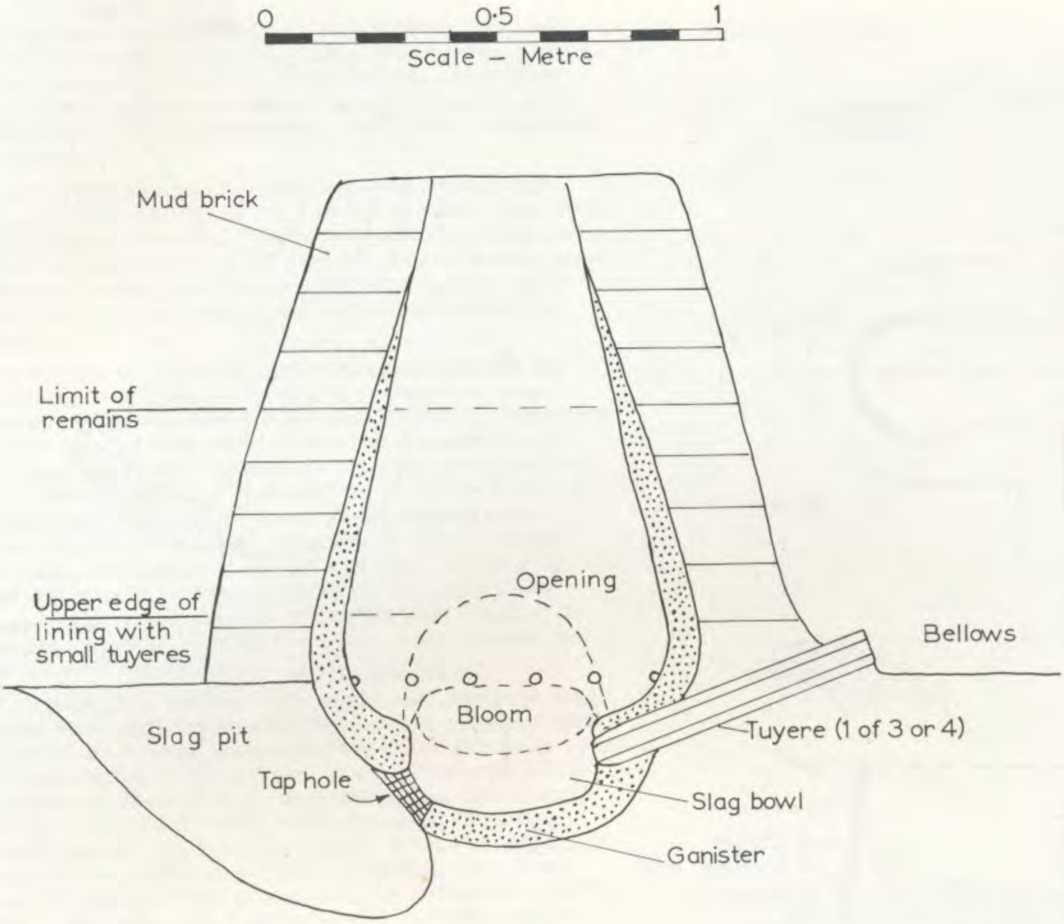

Fig. 6 — Reconstruction of free-standing later Meroitic furnace. Based on finds from slag heaps and excavation of the embanked furnace

about ground level and presumably horizontal. They would be about 20 cm above the bottom of the bowl. The height of the shaft would be about 1 m above ground level and the inside tapered slightly inwards. It would have an internal dia. of 0.7 m at the bottom and 0.3 m at the top. There would be about 12 high-level tuyeres and probably three of four low-level ones. It is most probable that the furnace was bellows-blown, mainly because of the frothy nature of the slag round the end of some of the tuyeres and the very high temperatures obtained.

The working of the furnace would be as follows. The furnace would first be filled with charcoal which would be ignited by putting a small piece of glowing charcoal down one of the tuyeres or through the bloom withdrawal opening in the side. Blowing would start at once and only when the contents of the furnace had reached a good red heat throughout would charging of ore start. Charcoal and ore would be charged alternately in proportions of about 1 to 2 parts of ore to 1 of charcoal by weight. In actual practice, volume measures would be used. After a time the bowl would fill with slag and this stage would be noticed by the tuyeres tending to fill with slag. The slag would then be tapped through the wrist-sized hole in the side into the pit and the bowl would be more or less empty; some of the tuyeres would be stopped up and unusable. Blowing would then be transferred to the higher-level tuyeres; the bloom would begin to form below them and the slag to liquate from the underside of the bloom into the bowl. This could probably be emptied a second time, but since the most of the heat would now be around the higher-level tuyeres this is not very likely; once the bowl was full of slag the process would be finished.

The bloom would then be withdrawn by crowbars or timbers through a side hole at about ground level. It would be stuck to the ledge of the furnace, but its removal could probably be assisted by an upward thrust with a bar through the taphole. The bloom would be about 25 cm dia. and about 20 cm deep. It would consist of porous iron low in carbon with some charcoal and slag, particularly on its outer surface. This would be knocked off, and the rough bloom sent to the smiths for cutting up and for forging into smaller and denser pieces. This would be done in small 15 cm dia. hearths with a single tuyere such as was found on the West Heap.

This reconstruction is based on the evidence cited above and personal experience in working a bloomery furnace with a single tuyere. It could be wrong in some details (for example, the double-level tuyere arrangement is unique) and only excavation of a complete furnace can confirm it.

ACKNOWLEDGEMENTS

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