# Notes on Iron Age copper-smelting technology in the Transvaal

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**SYNOPSIS**

Earlier reports on Iron Age copper metallurgy and copper-smelting techniques in the Transvaal are surveyed, and a description and tentative classification of the copper furnaces are given. The analyses of furnace slags and sherds of glazed crucibles from archaeological sites of the Transvaal and the neighbouring Orange Free State provide evidence of copper smelting there in Iron Age times.

An investigation conducted by the Department of Archaeology of the University of the Witwatersrand provided information on the details of furnace construction and smelting processes, on the composition of the materials used and produced, and on the making and handling of tools and accessories, such as bellows and tongs, needed by Iron Age smelters.

Three models (the Kaonde/Venda furnace, the Rooiberg crucible furnace, and the Uitkomst furnace) were constructed and operated as a demonstration of Iron Age copper smelting as it was practised in the Transvaal.

**SAMEVATTING**

Daar word 'n oorsig gegee oor vroeëre verslae oor die kopermetallurgie en kopersmelttegnieke van die Ystertydperk in Transvaal, asook 'n beskrywing en tentatiewe klassifikasie van die koperoonde. Die ontleding van oondslakke en skerwe van geglasuurde kroese afkomstig van argeologiese terreine in Transvaal en die aangrensende Oranje-Vrystaat lewer bewys van kopersmeltery daar gedurende die Ystertydperk.

'n Ondersoek wat die Departement Argeologie van die Universiteit van die Witwatersrand ingestel het, het inligting verskaf oor besonderhede van die oondkonstruksie en smeltprosesse, die samestelling van die materiale wat gebruik en gelewer is, en oor die maak en hantering van gereedskap en bybehore soos blaasbalke en tange wat die smelters van die Ystertydperk nodig gehad het.

Daar is drie modelle (die Kaonde/Venda-oond, die Rooiberg-kroesoond en die Uitkomst-oond) gebou en bedryf as 'n demonstrasie van hoe koper gedurende die Ystertydperk in Transvaal gesmelt is.


## INTRODUCTION

It is not known with any certainty when and how the knowledge of mining and metal extraction found its way into Southern Africa. Many archaeologists think that migrating Negro people, probably Bantu-speaking, crossed the Zambesi River in the early centuries of the first millenium A.D. These invaders brought with them a rich cultural heritage: the practice of subsistence farming and domestication of animals, the art of making pottery, and the techniques of iron and copper metallurgy. The possession of iron weapons and implements was probably a decisive factor for the fast and apparently easy penetration of the 'new' people into Southern Africa, where only Stone Age hunters and gatherers or pastoralists had previously lived. It is fitting, therefore, that the culture brought and developed by the invaders from the north, lasting for nearly 2000 years up to the present, is called 'The African Iron Age'[1].

## IRON AGE METALLURGY IN SOUTHERN AFRICA

One of the earliest sites south of the Zambesi where relics of Iron Age people have been found is Mabveni (approximately 50 km west of Zimbabwe). A number of copper and iron beads have been excavated there. Charcoal associated with these finds has been dated[2] to the end of the second century A.D.

Recently, several Early Iron Age sites were found in the Transvaal, among them Silver Leaves Farm[3] (near Tzaneen) and Broederstroom[3] (near Hartbeespoort Dam). The Broederstroom site, dated to the mid-fifth century A.D. could have been a centre of metal production because large accumulations of iron slag, tuyère fragments, and furnace debris were found there by Mason, together with a beautiful little copper chain, which may be the earliest proof of copper production in South Africa[3].

As opposed to the large number of Iron Age iron-smelting sites in the Transvaal, remains of copper smelting and copper working are less frequently found. One reason for this may be that the clay-built copper furnaces had to be broken down once the smelting process had been completed, because the copper extracted could not be removed in any other way. Most of the Iron Age copper artefacts preserved come from the two larger copper centres of South Africa: the Messina–Limpopo Valley area in the northern Transvaal, and the Phalaborwa–Gravelotte area in the Eastern Transvaal[4–6].

Less well known is the pre-European copper industry of the Central and Western Transvaal. James Chapman, who travelled in the Transvaal in 1852, marked a mountain range on one of his maps 'Copper Mountain', and remarked that the copper found in this area is 'converted with great ingenuity into a very fine wire which is worked up into armlets'[7]. This Copper Mountain of Chapman is situated near the Dwarsberg, which, according to A. Boshier[8], was also a great copper centre in the Iron Age. Rooiberg, better known for its tin mines, may also have been a place where copper was produced[9–11].

## IRON AGE COPPER FURNACES IN THE TRANSVAAL

The published archaeological literature gives detailed information on no more than a dozen Iron Age copper-smelting furnaces, most of them from the Eastern Transvaal[4–6], one or two from the Rooiberg area[9–11], and two from Uitkomst Cave[12] (about 20 km north of Krugersdorp).

It appears that two, or possibly

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three, types of copper furnaces can be recognized in the Transvaal.

One type, resembling a beehive or a low dome, is found mainly in the Eastern Transvaal and is represented by four smelting furnaces in the Phalaborwa region, which have been described by Van der Merwe and Scully[13]. These furnaces are 600 to 900 mm in height and in diameter at the base, tapering to a chimney hole at the top of about 300 to 450 mm in diameter. A single arched opening in the front allows the entrance of a tuyère.

The furnaces found by Evers at Harmony (Letaba) also belong to this type, their measurements (590 by 720 mm and 480 by 420 mm) giving them a ground plan that could be described as 'near-circular'[4].

The second type has an oval or elliptical ground plan. The dimensions vary. For example, the base of a Rooiberg furnace measured[11] 450 mm (major axis) to 300 mm (minor axis), and the Uitkomst Bed 3 furnace measured[14] 330 to 250 mm. Such furnaces have either one or two blow holes[12, 13].

It appears that the copper-smelting furnaces were often smaller versions of iron-smelting furnaces, or were used for iron smelting as well as for copper smelting. The 'circular beehive' type corresponds to the 'Loole type' of Küsel's classification, and the 'oval' type possibly to his 'Buispoort type'[6].

In specifying various types of smelting furnaces (iron furnaces as well as copper furnaces), one has, of course, always to bear in mind that the observed differences in structural characteristics may be more apparent than real. They could well just be variations and modifications of a single basic design. No fundamental differences in functional characteristics, as displayed, for example, in the 'natural draft furnaces' of Central Africa[15] or in the 'tapping furnaces' of the Sinai Peninsula[16] have so far been observed among the smelting furnaces of South Africa.

However, a technical problem is posed by the final smelting stage necessary for copper refining, which requires fire-resistant crucibles, a sustained high temperature above the melting point of copper (about 1100°C) combined with efficient reducing conditions in the furnace, and some special devices for fast and safe discharge of the liquefied copper into moulds. The common method was apparently a quick breaking down of part of the furnace walls at the end of the melting process to give access to the very hot crucible at the furnace bottom, but this was a very cumbersome and wasteful method. It is possible that the Rooiberg 'stone-circle crucible furnace'[10] was a more efficient melting furnace. This interesting problem of crucibles and crucible furnaces will be discussed later.

It is unfortunate that not a single well-preserved copper furnace has yet been discovered in the Messina–Limpopo Valley area, where so much evidence of copper smelting (slag, crucibles, artefacts) has been found, especially at the Mapungubwe excavation sites. Information on the features of the furnaces used there would permit valuable conclusions to be drawn on the relationships between the ancient copper technology of the Transvaal and that of countries to the north.

## ANALYSIS OF SLAGS AND CRUCIBLE GLAZES

A number of copper ores[17], slag pieces, glazed sherds, and copper ornaments[18] found in the Transvaal were analysed to give an analytical background to the investigation of Iron Age copper-smelting technology.

The main evidence of copper smelting on a prehistoric site is, of course, the presence of copper in various objects found inside or next to furnace remains (slags,

TABLE I

ANALYSIS OF IRON AGE COPPER SLAGS

| **Site:** | | Uitkomst 5/67 I | Uitkomst 5/67 II | Uitkomst | Uitkomst 5/67 | Uitkomst 5/67 | Harmony E. Tvl 4/73 | Messina N. Tvl | Kolwezi, Congo |
|---|---|---|---|---|---|---|---|---|---|
| **Position:** | | Cave Bed 3, slag adhering to tuyères | Cave Bed 3, surface slag scraped from tuyère | Cave Bed 3 | Cave Bed 3, base 1 | Cave Bed 2 | C.VI furnace | | 1955 PAC collected by R. Mason |
| **Constituents:** | Expressed as % | | | | | | | | |
| Silicon | $SiO_2$ | 70,24 | 70,06 | 63,1 | 5,10 | 64,66 | 66,35 | 41,95 | 32,10 |
| Aluminium | $Al_2O_3$ | 9,86 | 10,70 | | 0,15 | 15,24 | 12,98 | 10,10 | 7,58 |
| Ferric iron | $Fe_2O_3$ | 2,56 | 2,56 | | 0,81 | 0,13 | 1,21 | | 0,87 |
| Ferrous iron | FeO | 8,48 | 7,11 | 7,0 | 7,18 | 9,62 | 6,30 | 18,61 | 4,73 |
| Magnesium | MgO | 1,63 | 1,18 | | 5,97 | 1,68 | 1,39 | 1,02 | 5,16 |
| Calcium | CaO | 1,92 | 2,59 | | 27,65 | 1,20 | 6,14 | 21,08 | 1,15 |
| Sodium | $Na_2O$ | 0,18 | 0,53 | | 0,00 | 0,52 | 2,01 | 0,9 | 0,10 |
| Potassium | $K_2O$ | 2,17 | 2,79 | | 0,71 | 3,84 | 1,79 | 1,2 | 1,78 |
| Titanium | $TiO_2$ | 0,49 | 0,43 | | 0,10 | 0,80 | 0,90 | | 0,51 |
| Phosphorus | $P_2O_5$ | 0,39 | 0,45 | 0,38 | 0,22 | 0,27 | 0,12 | | 1,41 |
| Chromium | $Cr_2O_3$ | 0,01 | 0,01 | | 0,10 | 0,05 | 0,01 | | 0,00 |
| Manganese | $Mn_3O_4$ | 0,62 | 0,70 | MnO 0,72 | 0,73 | 0,96 | 0,12 | Combined $H_2O$ | 0,09 |
| Ignition loss | | 0,12 | 0,05 | | 33,20 | | 0,10 | 0,56 | 0,34 |
| Total iron | Fe | 8,38 | 7,32 | 5,44 | 6,15 | 8,38 | 5,74 | 14,47 | 4,28 |
| Total copper | Cu | 4,1 | 2,8 | 0,69 | 13,2 | 1,38 | 0,64 | 2,29 | 35,61 |
| Nickel | | | | | 111 p.p.m. | 149 p.p.m. | | | |
| **Analyst:** | | NIM AA972/4 | NIM AA972/5 | Schneider[12] | NIM AB89/5 | NIM AB89/3 | NIM AA972/3 | Stanley[19] | NIM AA972/10 |

tuyères, crucibles). Unfortunately, not much evidence of this type has so far become available from Transvaal sites. Stanley[19] published the analysis of a slag sample from the Iron Age workings at Messina (Table I). Copper slag has been found at Phalaborwa[13] and at Rooiberg[10], but, as far as is known, no analysis of such slags has been published in the literature. An analysis of a slag specimen excavated at Uitkomst Cave has been given by Mason[12]. Since enough slag material from Uitkomst is available in the collections of the Archaeology Department of the University of the Witwatersrand, some additional specimens of slag were submitted for analysis.

Table I gives the values for three samples of furnace slags and two slag pieces from tuyères. All these samples, which come from Bed 2 and Bed 3 of Uitkomst Cave, show a relatively high copper content, indicating that the slag was produced by a process intended to extract copper from ore.

Four of the Uitkomst samples show a reasonable agreement in composition (iron content 5,4 to 8,4 per cent, copper content 0,7 to 4,1 per cent, lime content 1,2 to 2,6 per cent), whereas a fifth sample shows different values (for copper 13,2 per cent, and for lime 27,6 per cent). It may be possible that this odd sample was enriched by inclusions of ore concentrate.

For comparison, analytical values for slag samples from three other copper-smelting sites (Harmony in the Eastern Transvaal, Messina in the Northern Transvaal, and Kolwezi in the Congo) are included in Table I. The two Transvaal samples show copper values falling into the majority range of the Uitkomst slags, whereas the Congo sample shows a very much higher copper content (35,6 per cent). This is probably the result of the use of a richer type of ore, or of different extraction methods.

The relative uniformity of the values for titanium, manganese, and phosphorus in the slag samples from Uitkomst may point to a fairly constant ore supply. The low values for nickel (149 p.p.m. and 111 p.p.m.) in two samples appear to exclude the use of ore of the nickel—copper type, which would yield a slag of a much higher nickel content.

The presence of substantial amounts of calcium, sodium, and potassium in the slags analysed could be regarded as evidence for the use of flux in the smelting process. However, these elements could find their way into the slag from ores containing alkaline-based compounds such as the calcite found in the malachite ores from Phalaborwa. Such ores can be regarded as self-fluxing, where the addition of flux material would be superfluous.

Evidence of copper smelting or, more accurately, of copper melting in the Northern Orange Free State is given by the analysis of the 'glazing' adhering to crucibles found there. Van Riet Lowe[20] excavated a number of sandstone crucibles at the Vegkop site (district Heilbron), and thought it possible that these crucibles were used for iron smelting. However, X-ray-fluorescence scan analysis of glazed surface particles from two crucibles found in the Orange Free State (now kept in the Department of Archaeology at the University of the Witwatersrand) showed the presence of larger amounts of copper, tin, and zinc in the glaze, pointing to the smelting of copper or copper alloys (Table II). These findings are confirmed by the analysis of chippings from crucible fragments found by Maggs[21] at Makgwareng site (Lindley District, O.F.S.).

## IRON AGE COPPER–SMELTING TECHNIQUES IN SOUTHERN AFRICA

There are not many reports on the construction of copper-smelting furnaces and on the smelting processes used in Iron Age Southern Africa.

The only report to give detailed information on the subject is that published by Chaplin[15] in 1916. Chaplin, an Inspector of Rhodesian Monuments, arranged a demonstration of copper smelting by Kaonde tribesmen at Solwezi, a place west of the main Copper Belt in Zambia. The Kaonde tribe had a tradition of copper smelting that had died out there about 1914, whereas, in the Northern Transvaal, the Bavenda had stopped their metal

TABLE II

X-RAY-FLUORESCENCE ANALYSIS OF CRUCIBLE GLAZE ON STONE CRUCIBLES FROM ORANGE FREE STATE

| **Site:** | | Vechtkop, Dist. Heilbron, O.F.S. | Dist. Harrismith, O.F.S. | Makgwareng, Dist. Lindley |
|---|---|---|---|---|
| **Dimensions of Crucible** | Int. diameter, mm | 40 | 35 | 110 |
| | Int. depth, mm | 51 | 30 | 90 |
| | Thickness/wall, mm | 20—25 | 25—33 | 20 |
| **Elements** | | **Indications** | **Indications** | |
| Copper | | Very strong (2,6 %) | Very strong (1,8 %) | 0,38 % |
| Iron | | Very strong | Very strong | 3,8 % (total as $Fe_2O_3$,) |
| Zinc | | Medium | Very strong | |
| Manganese | | Weak | Medium | MnO 0,1 % |
| Titanium | | Weak | Strong | |
| Calcium | | Very strong | Very strong | CaO 10,1 % |
| Tin | | Not detected | Very strong | $TiO_2$ 0,6 % |
| Sodium | | — | — | $Na_2O$ 1,7 % |
| Potassium | | — | — | $K_2O$ 6,4 % |
| Magnesium | | — | — | MgO 4,1 % |
| Aluminium | | — | — | $Al_2O_3$ 7,0 % |
| **Analyst:** | | M. Milner The Corner House Lab. Johannesburg. | M. Milner The Corner House Lab. Johannesburg. | Dr Verbeek[21] |

working long before. Chaplin found a group of old men who had taken part in smelting with their fathers, and still remembered and could practise the traditional methods. The following is an abstract from Chaplin's report[15].

> The kiln was prepared by digging a hole approximately 20 cm wide. Round the excavated hole a wall about 40 cm high was built from sections of broken-down ant-hills and puddled clay. A small hole at the base of the furnace provided entrance for a tuyère. The bottom of the furnace was filled with ashes, above which a charcoal layer was placed. The charcoal was fired and brought to (red-hot) glow with the help of an airblast from a pair of skin-bellows connected to the tuyère. Then ore was piled on the hot charcoal and covered with more charcoal. After three hours of firing when the copper was smelted down, the furnace walls were broken up with a long pole. The liquid (crude) copper at the furnace bottom solidified rapidly and could be taken out after cooling.
>
> The copper was then refined in a second similar furnace. A clay pot filled with ashes was placed into the furnace which was heated as described, and when the temperature in the furnace was high enough, pieces of the crude copper were placed on the glowing ashes in the pot. After two hours of firing the furnace was quickly broken down, the pot taken out (probably with the help of tongs) and the still liquid copper poured into a mould.

The Kaonde furnace, as described by Chaplin resembles the stone-walled bowl hearth used for copper smelting since time immemorial, e.g., by the Chalcolithic smelters of the Sinai[16] (third millenium B.C.).

There is some evidence that a furnace similar to the Kaonde furnace described by Chaplin was used in the Messina–Limpopo Valley copper centre. Unfortunately, Van Warmelo, whose book[22] is otherwise one of the best reports on early mining and metal working in the Transvaal, gives little information on the smelting process, but Stayt[23] had the good luck to meet an old tribesman in Vendaland who had been a copper worker in his youth. His description of building a kiln, smelting the ore in it, resmelting the extracted crude copper in a potsherd-crucible, and pouring it into a mould closely resembles many details in Chaplin's report.

## INVESTIGATION OF IRON AGE COPPER SMELTING

Since the information on Iron Age copper smelting in Southern Africa is rather scanty, it was decided to investigate the subject by some experimental work that could give information on the following points.

1. Details of the furnace structure (structural material, dimensions, furnace building, etc.).
2. Details of the smelting process (temperatures, bellows action, air volume, proportion of charcoal to ore, methods of charging and discharging, time of operation, etc.).
3. Chemical composition of the material used and produced in the smelting process (ore, charcoal, slag, intermediate products, refined copper). Determination of minor and trace elements in these materials.
4. Economic aspect (efficiency of the process).
5. Influence of 'flux' addition on the quality of the copper.
6. Making and handling of the tools and accessories used by the ancient smelters (bellows, tuyères, tongs, crucibles, moulds, wire-drawing equipment).
7. Special problems of crucible furnaces.

Of necessity, the project had to be on a small scale. It was therefore limited to an investigation of copper smelting in only three types of furnaces:

an experimental furnace based on the information given in Chaplin's report on the Kaonde furnace[15] (Model A),

an experimental furnace based on information given in Wagner's report on Rooiberg crucible furnaces[10] (Model B), and

a furnace representing a full-scale replica of the Uitkomst furnace as described by Mason[12] (Model C). This experimental furnace was constructed from a termite mound, following a Rhodesian tradition[24]. (The original Uitkomst furnaces were probably made from clay).

Funds were provided by the Department of Archaeology.

It was necessary, for practical as well as economic reasons, to use modern material and equipment in the experiments, e.g., prefabricated refactory units, asbestos insulating material, an air compressor. The choice of ore used in the experiments was arbitrary, since only two suitable types of ore were available in large quantities. Of course, such modifications diminish the value of the experimental work in some respects, but one can still obtain much comparative information and a better general understanding of Iron Age copper technology.

### Material Used

In all the twenty smelting experiments undertaken, use was made of an enriched malachite ore provided by the Palabora Mining Company. There were some difficulties in the processing of this ore, which, after dressing, had a copper content of 17,5 per cent. The conditions of the smelting procedure were varied in a number of experiments, but in each case only a small quantity of reduced copper, in the form of tiny globules and of thin irregular-shaped copper layers coating the surface of the slag, were obtained. The bulk of the copper was present in the slag as copper oxide (black cupric oxide, as well as red cuprous oxide). To improve the yield, the oxide slag cake was re-smelted at about 1100 °C, with an addition of silica to neutralize the high alkalinity of the slag. This procedure improved the copper yield, but the yield was still low (16,4 per cent).

Fortunately, a small quantity of high-grade (40 per cent) azurite mined at Nchanga Mines (Zambia) was obtained from the South African Copper Development Association. A mixture of equal parts of this azurite and malachite ore from Palabora Mining Company gave more satisfactory results. A fair amount of copper pellets and copper lumps could be recovered from the slag (yield 24,2 per cent).

Ore provided by the Messina (Transvaal) Development Company was also tried, but its copper content was too low for the purpose.

The charcoal used in the experiments was commercial Natal 'braaivleis' charcoal, reportedly made from mimosa wood. The larger pieces of charcoal were broken up to walnut size, and the coaldust was sifted off.

### Furnace Model A (Kaonde Smelting Furnace)

This furnace, like the Model B

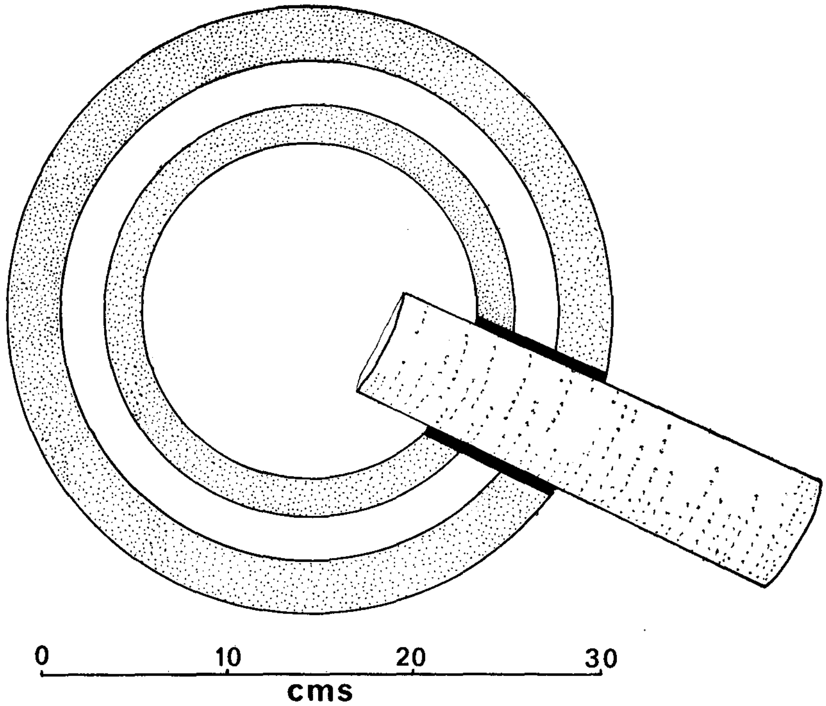


**Fig. 1—Floor plan of smelting furnace, model A**

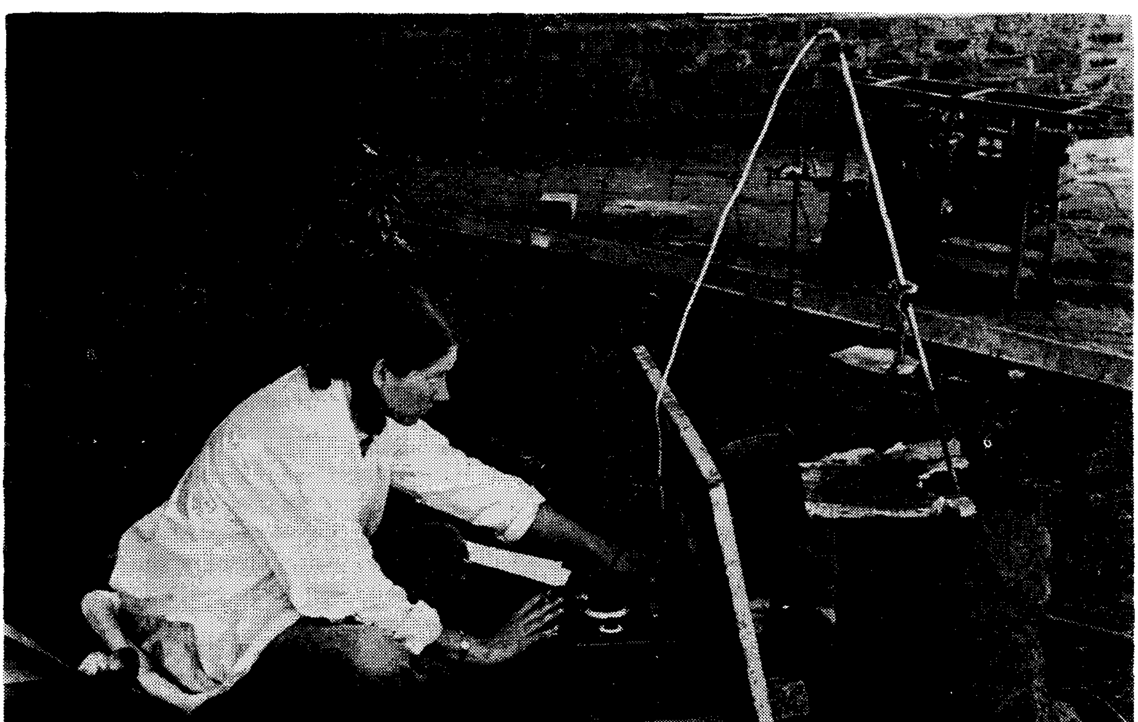

**Plate 1—Experimental furnace A, with potentiometer, thermocouple, and air compressor.**

furnace, was erected on a small piece of open ground on the campus of the University of the Witwatersrand.

*Furnace Construction*

A shallow dished hole (18 cm in inner diameter and 3 cm deep) was dug into the ground and coated with clay. A shaft composed of three ceramic rings (each 13 cm in height, 18 cm in inner diameter, and 22 cm in outer diameter) was erected above the dished hole. The rings were cemented together and to the ground with a sealing compound. A second cylinder composed of two larger rings (each 21 cm in height, 26 cm in inner diameter, and 32 cm in outer diameter) was built round the inner furnace shaft. The annular space between the two ceramic ring cylinders was filled with vermiculite insulating material. The top of the furnace could be covered with an asbestos sheet cut into two sections to allow adjustment of the chimney opening. A rectangular opening (7 cm by 10 cm) was cut into the bottom rings for the insertion of a tuyère, which was sealed in with clay. See Fig. 1 and Plate I.

After each firing, the furnace was rebuilt and any cracks formed were sealed with clay.

*Tuyères*

Various types of tuyères were used, reproducing patterns of tuyères found at Iron Age sites. The tuyères (approximately 30 cm in length, 2,5 to 4 cm in inner diameter, and 4,5 to 7 cm in outer diameter) were made either from alumina clay or fire clay.

*Air Supply by Blow Bellows*

The pair of bellows used in the experiments was patterned on the Zulu bellows kept in the Africana Museum (Johannesburg), the air from the bellows being discharged through cut-off ox horns. The effective air delivery from these bellows as measured by flowmeter was 60 to 90 l/min when the bellows were worked at medium speed (at about 70 double strokes). This appears to be low, since the volume of each of the bellows, found by the mass of water filling it, was 5 litres. One reason for the low efficiency may be the poor craftsmanship of present-day African skin workers, and another reason, the relative inefficiency of the inexperienced men working the bellows. Furthermore, the bellows used were made in the modern way, by the sewing together of skins that had been taken from carcasses by cutting them open ventrally lengthwise, whereas the bellows bag of the ancient metal workers was pulled off in one piece by drawing the skin over the head, body, and hindquarters of the animal (goat or buck). In this way, very little sewing was required to obtain practically airtight bellows.

It is possible that a pair of well-made bellows could supply 100 litres of air per minute, or even more when the skins of large bucks (e.g., sable antelopes[25]) are used.

*Air Supply by Compressor*

The petrol-driven compressor used delivered approximately 120 litres of air per minute. Two control valves were built into the delivery line leading from the air compressor to the tuyère and, by regulation of these valves, fairly constant air volumes could be obtained from a minimum of 60 l/min to a maximum of 120 l/min — roughly comparable with the blowing capacity of one and two pairs of blow bellows respectively. From the values obtained, it was calculated that an air volume of 0,42 $l/cm^2/min$ is required to operate a smelting furnace of 18 cm diameter at 1100 °C. The corresponding air volume required for larger furnaces may be relatively lower.

*Measurement of Furnace Temperatures*

The temperatures in the furnace were measured at regular intervals by a potentiometer registering the voltage potential of a thermocouple (Ni/Cr v Ni/Al) dipped into the furnace centre at the level of the tuyère mouth. The corresponding temperatures were read from a table. However, after comparison of a number of instrument readings with the observed glow of the furnace charge, the appearance of the flames above the firebed, and the 'feel' of the heat developed, it was not difficult to control the smelting process sufficiently well by sensory observation, as done by the Iron Age metal workers.

*Details of Smelting Progess*

After the furnace bottom had been covered with wood ash, wood sticks, and dry leaves, the fire was lighted. A pile of charcoal broken up to a size of 10 to 20 mm was heaped up opposite the tuyère and the airblast was started. When the pile showed a dark-red glow, layers of ore pieces and charcoal were placed on the firebed and the airblast increased until the fire glowed cherry red (800 to 900 °C). The charcoal was replaced as it burnt off.

At the end of the firing (approximately three hours after starting), the airblast was increased again until the charge showed a dull orange colour (950 to 1000 °C). Then the blast was stopped, the furnace allowed to cool down, the top section of the furnace broken off, and the mixture of charcoal, ash, and copper slag at the furnace bottom taken out.

The copper–slag cake contained the smelted-out copper in the shape of pellets of various sizes, ranging from tiny globules to nuggets of approximately 5 mm in diameter. Sometimes fairly large chunks of copper could be picked out, but in a number of experiments the smelted-out copper showed up only in 'specks' or as a thin coat sticking to the slag and the charcoal cinder.

If the reduction conditions (carbon monoxide atmosphere in the furnace chamber) were unsatisfactory, much copper oxide was formed and the smelting had to be repeated. If the smelt was successful, the crude copper pieces could be picked out easily and hammered free from slag, cinder, and other impurities.

## Furnace Model B (Crucible Furnace)

*Use of Crucibles*

The use of crucibles for the smelting of metals is nearly as old as the art of metal production itself. Egyptian tomb reliefs and tomb paintings of the twenty-fifth and fifteenth centuries B.C. show clearly how molten copper or bronze was poured from crucibles into moulds[26].

Evidence of Iron Age crucible smelting in Southern Africa is given by a number of crucibles and crucible fragments found at archaeological sites such as Zimbabwe[27], Inyanga[28], Mapungubwe[29], Rooiberg[10], and several places in the Orange Free State[20, 21].

Bryant[30] notes that, for the smelting down of metal, 'a sandstone basin, five or six inches wide, shaped like the half of an egg' was used in Zululand. Some well-preserved sandstone crucibles found in the Orange Free State are kept in the collection of the Archaeology Department of the University of the Witwatersrand. The effective pouring volume of four of these crucibles ranges from 10 to 40 ml. This appears to be a low value, but only a small volume was sufficient to melt copper ingots weighing up to 300 g, enough to make a number of bangles, earrings, and other small ornaments valued by the Bantu.

*Use of Crucible Furnaces*

There are only a few reports on how crucibles were heated to the high temperatures (1110 to 1200 °C) at which copper will liquefy so that it can be poured into moulds.

Chaplin[15] describes how the smelting furnaces of the Kaonde were adapted to melt copper. A rather vague description of the methods used by the Bavenda for making copper rods is given by Stayt[23]: 'the crude copper [produced in the smelting kiln] was hammered into small cobbles and re-smelted in a potsherd about 7 inches in diameter, which was put over the impression in the ground so that the molten copper could be manipulated easily and poured out into the moulds prepared for it'.

In their report, Wagner and Gordon[10] give some details on crucible furnaces used at Blaauwbank–Rooiberg:

> [The furnaces] are built of stones set in a rough circle which had apparently been excavated out of the ground. Big stones were used, each separated from the next by smaller stones . . . a gap of four inches was left in the circle, possibly for inserting the tuyère. The most perfect furnace measured approximately 22 inches across . . . the stones forming the sides were about 8 inches deep, of which about half was above ground and half below. On one side of this furnace there was found in place, what is evidently a worked stone of a peculiarly tapered shape. This stone had been shaped . . . to act as a support for a smelting pot or crucible. Similarly tapered stones may have originally formed a complete circle.

In the Waterberg Mountains (Central Transvaal), one of the present authors found the remains of a furnace that had features similar to those of the Rooiberg furnace described above.

*Construction of Model B Furnace*

The construction of the crucible furnace was based on the observations mentioned above. A ring of large stones was built round a dished hole of 20 cm diameter, the spaces between the stones being filled with smaller stones and sealed with casting clay. The dished base and the furnace walls were coated with fire clay. Two openings at opposite sides of the furnace walls allowed the insertion of tuyères. Four tapering stones were placed round the centre, leaving the space facing the tuyères open. The top of the furnace was left open, but could be covered with stone slabs or asbestos sheets. See Fig. 2 and Plate II.

*Operation of Model B Furnace*

The crucible was filled with small pieces of crude copper until it was about three-quarters full. A thin layer of dry leaves was placed above the copper. The fire was started as described for the operation of smelting furnace A. When the charcoal in the furnace began to glow, the prepared crucible was placed on the support stones set round the centre of the furnace. The crucible was covered with a potsherd and more charcoal was heaped round the crucible up to the crucible rim. Air was blown in from the bellows or the compressor until the glow in the furnace showed a yellow–orange colour (about 1100 to 1200 °C). Burnt-off charcoal was replaced continuously to keep up the reducing atmosphere in the furnace.

The crucible was kept at top temperature for about half an hour until all the copper was molten. Then the potsherd lid was removed and the liquid copper in the crucible stirred for a short time with a stick of green wood. (This procedure, still employed in modern copper refineries for the removal of the oxygen absorbed by the copper, was used by the Iron Age smelters of

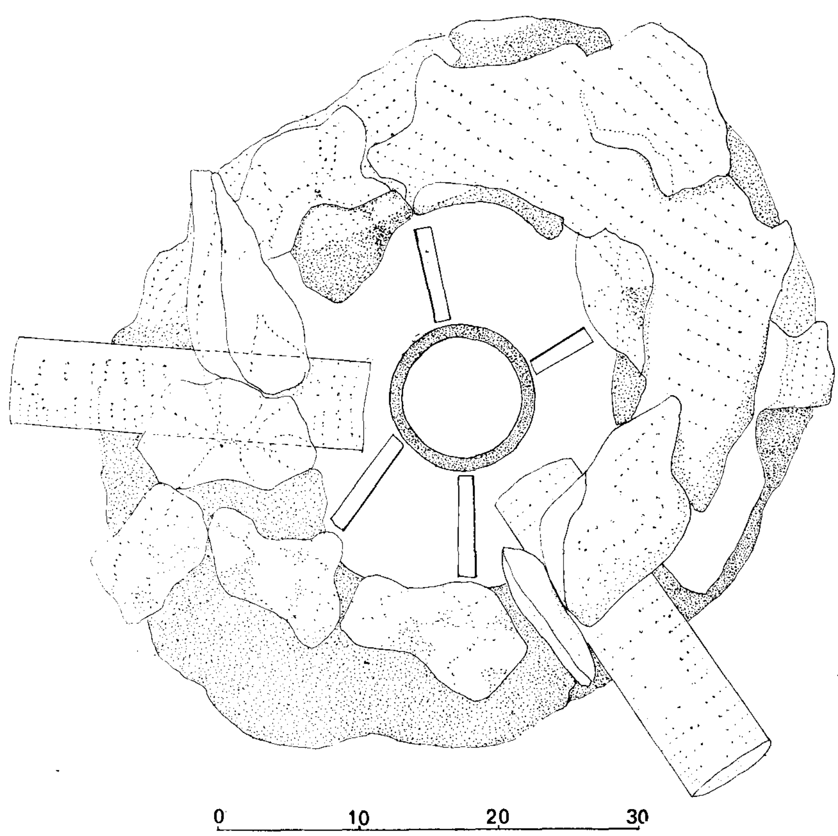


**Fig. 2—Floor plan of crucible furnace, model B**

**Plate II—Experimental furnace B (crucible furnace). The two gemsbok horns on the left lead from the blow bellows to the tuyère. The crucible in the centre is set on four supporting stones.**

Africa 'to bring the copper together'[31].)

Up to this stage, the melting of the copper is a relatively simple process, but the removal of the very hot crucible is a fairly difficult procedure, since the taking out of the crucible and the pouring out of the liquid copper must be done very quickly.

Paintings and reliefs in Egyptian tombs show Dynastic foundrymen grasping a red-hot crucible with flat stones pressed against it, or gripping the smelting pot with boughs (which were probably soaked in water)[26].

It is likely that the metalworkers of Africa used similar methods to protect their hands—such as wrapping them in 'thick cloths' or wet pieces of skin. The use of 'tongs made from bark' is also mentioned[32]. However, all such methods are rather cumbersome and dangerous. It is likely that iron tongs were used early in the metallurgy of the African smiths, who knew well how to make iron tools. Angas illustrated a pair of 'native forceps' in a picture showing a Zulu blacksmith at work[33]. Holden mentioned that the smiths (of the Kaffirs) 'use tongs of very rude construction (made of iron)'[34]. A photo in Van Warmelo's book *The Copper Miners of Musina*[22] shows an 'old pair of tongs' approximately 50 cm long. Based on this design, a pair of such tongs was made from wrought iron for use in the work described here. No difficulty was experienced in removing the hot crucible from the furnace with these tongs, and then pouring the molten copper into moulds that had been prepared from sand or into holes dug with a stick into the ground, using the often-described techniques of the metal workers of the Northern Transvaal[22, 23].

One of the copper rods cast from the copper smelted and melted in the experimental furnaces was submitted to Messrs McKechnie Brothers S.A. for analysis. The rod contained much iron (4,4 per cent) and some nickel (0,02 per cent), but only small traces of zinc (0,008 per cent) and less than 0,001 per cent of each of the following elements: tin, lead, antimony, bismuth, and arsenic. These values are similar to those of some copper objects found at archaeological sites in the Transvaal[18].

## Furnace Model C (Uitkomst Type)

In some reports from Rhodesia[24] and Zambia[15], the use of termite mounds or of parts of such mounds for the construction of smelting furnaces is mentioned. It seemed interesting to investigate such a method. There were suitable termite mounds at Melville Koppies Nature Reserve (Johannesburg), and permission was obtained from the City Council of Johannesburg to use one of them.

The making of a workable smelting furnace from a termite mound takes only a few hours. A slit was cut 8 cm wide, reaching from the top of the mound, along its major axis, to a depth of 36 cm into the interior of the mound. Then, a

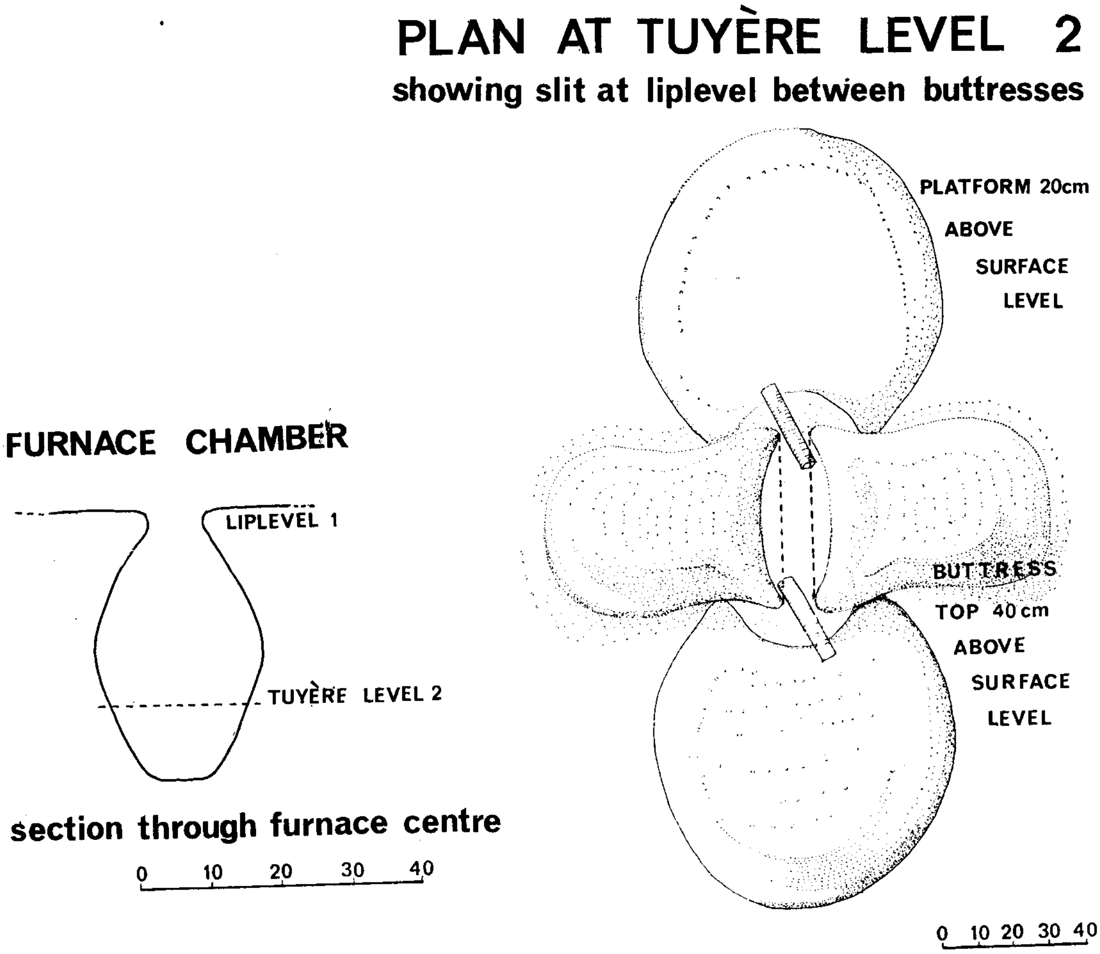


**Fig. 3—Furnace model C**

flask-shaped furnace chamber was excavated by scraping away soil from both exposed sides of the slit. The walls of this chamber were lined with clay, and the openings at both ends of the slit were sealed with termite soil, leaving holes for insertion of the tuyères. Then two earth buttresses were built, one joining each side of the furnace, for strengthening the structure, and finally two platforms were constructed opposite the tuyère holes to accommodate the bellows workers. Details of the furnace structure are evident from Fig. 3.

The design of the furnace is based on that of the Bed 3 furnace excavated at Uitkomst Cave by Mason[12], who kindly provided the measurements of this furnace. However, for structural and material reasons, some dimensions of the furnace model were modified slightly.

A few trial firings were undertaken to prove that copper smelting was practicable in this furnace. The furnace stood up well to firing, reaching yellow-orange heat (about 1200 °C).

An interesting feature of the original Uitkomst furnace was the position of the tuyères, which were placed at a slight angle to the left of the longer axis of the furnace, whereas the tuyères are usually aimed radially direct at the fire in the centre of a smelting furnace. If this off-centre position of the tuyères in the Uitkomst furnace was intentional, it was a sophisticated design indeed, creating a turbulent, circular flow of hot air round the central fire. This tuyère arrangement was reproduced in the model furnace C. It was observed, when the fire in the furnace was lighted and air blown in through the tuyères, that the heat in the firebed was more uniformly distributed and that the furnace temperature rose faster than in the experimental runs in models A and B. It appears also that the cellular structure of the termite mound layer between the furnace lining and the earth buttresses insulates the furnace chamber very well, a feature that contributes to the higher efficiency of this furnace.

It was not difficult in this furnace to reduce copper ore (malachite–azurite) to crude copper. From the slag cake produced, many well-formed copper pellets could be easily separated. The furnace was also used for the refining of crude copper, which was placed in a clay crucible into the centre of the furnace chamber. The copper in the crucible became liquid after firing for one hour. After the clay wall at one of the slit ends had been broken down, the hot crucible was taken out with tongs, and the copper poured out into a mould.

## CONCLUSIONS

(1) The number of analyses of copper slags found at various smelting sites was insufficient

**Plate III—Experimental furnace C (working replica of copper-smelting furnace found in Uitkomst Cave by Mason), showing the platforms for the bellows workers. The smoke rising from the fire in the furnace chamber hides the chimney opening.**

to permit definite conclusions to be drawn on the smelting procedures and on the provenance of the ores used. A further investigation, by neutron-activation analysis, on minor elements and trace elements in copper slags is being conducted at present in a combined project by the Department of Archaeology and the Nuclear Physics Research Unit of the University of the Witwatersrand. This project may give some of the required information.

(2) The investigation on the smelting of copper in model furnaces has facilitated interpretation of many aspects of prehistoric copper production in South Africa, and the quantities involved in prehistoric Transvaal copper production can now be assessed more accurately. The information obtained from these experiments will also assist in the evaluation of the material effects of prehistoric copper production.


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# NIM report

The following report is available free of charge from the National Institute for Metallurgy, Private Bag 7, Auckland Park, 2006.

**Report no. 1742**

*The determination of tin in ores, residues, and concentrates by X-ray-fluorescence spectrometry.*

The method described is suitable for the determination of tin in a concentration range from 0,002 to 60 per cent. The samples for analysis are briquetted at a pressure of 15 t, cellulose powder being used as a binder. Calibration curves are established by the use of chemically analysed samples. The coefficient of variation at the concentration level of 20 per cent is 1 per cent.

# Vacuum metallurgy

The Fifth International Symposium on Vacuum Metallurgy and Electroslag Remelting Processes is to be held in Munich from 11th to 15th October, 1976.

The purpose of this international conference is to continue in the tradition of earlier events held since 1964 in giving experts from all parts of the world the opportunity of acquainting themselves with the state of the art in the field of vacuum metallurgy. Both theoretical and practical themes are to be discussed. The field of electroslag remelting is to be integrated into the conference for the first time because of its close technical relationship with similar processes. Particular attention is to be given to the problems in this field because of the growing interest in the refining of important non-ferrous metals and improvement of their properties.

The lecture themes are as follows:

1. The physical chemistry of vacuum metallurgy.
2. The vacuum treatment of molten steel.
3. The vacuum treatment of molten non-ferrous metals, including vacuum distillation.
4. Melting and remelting processes under vacuum (vacuum induction furnace, VAR, EB, etc.).
5. Metallurgy and use of the plasma beam.
6. The physico-chemcial problems of the ESR process.
7. The properties and special applications for vacuumtreated and remelted materials (incl. ESR).
8. The characteristics of ESR plants and operating experience.
9. Jointing processes under vacuum (brazing, diffusion welding, EB welding).
10. Heat treatment under vacuum.
11. Characteristics of vacuum plants for metallurgical processes.
12. The economy of vacuum metallurgical processes in comparison with conventional techniques.

Further information is available from Dr.-Ing. Gerhard Frey, c/o Leybold-Heraeus, D-8000 Munich 50, Lerchenstr. 5, Fed. Rep. of Germany.

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Each year the South African Institute of Mining and Metallurgy offers a prize (or prizes should the entries warrant it) of up to R100 for the best paper or dissertation on a topic appropriate to the interests of the Institute. The competition is open to all Student Members of the Institute.

A Student Member who is in full-time study at a university may submit the dissertation or thesis he has to write in part fulfilment of his university degree, provided that it is presented in a manner and on a topic suitable for publication in the journal.

Entries for 1975 should reach the Institute by 31st December, 1975.