

The metallurgical analysis of copper beads and ore from archaeological sites in central Namibia

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Eight copper beads from three central Namibian sites and one possible ore specimen were subjected to metallographic and chemical analysis. The cylindrical beads were found to consist of indigenously produced copper with characteristic cuprite inclusions. The method of fabrication was reconstructed from description of the microstructure, with initial hot working and annealing followed by final cold work to hammer the joins closed without solder. There was significant variation in the inclusion chemistry, probably indicating regional trade, although detailed sourcing studies would be necessary to confirm this.

Introduction

Copper beads are relatively common finds on archaeological sites in central Namibia and furnaces dating to within the last four centuries have been found at several ore deposits in the ortho-amphibolite Matchless Member. Eighteenth century reports of indigenous copper working (Kinahan, 1980) describe the use of simple forced draught furnace technology and state that the copper beads were exchanged for livestock. Exca-

vations have confirmed both the technique of copper smelting (Kinahan and Vogel, 1982) and the association of copper beads with livestock, often on sites located several hundred kilometres away (Kinahan, 1991). The metallurgy of the beads has not been investigated before and the evidence of bead manufacture presented here sheds further light on indigenous copper production in precolonial Namibia.

Figure 1 shows the distribution of copper bead finds in central Namibia and identifies the three main site

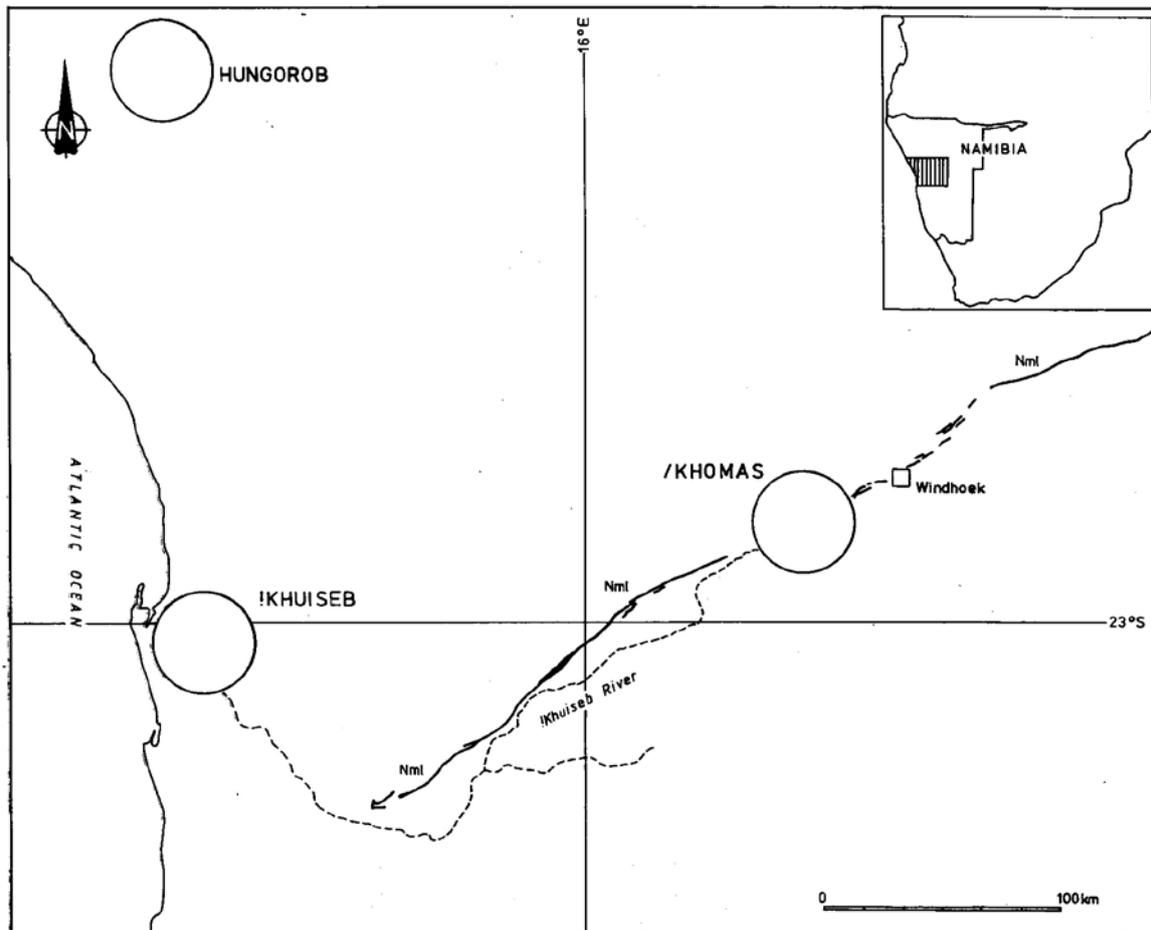


Figure 1: Map showing location of sample areas in central Namibia. Nml designates the Matchless Member

OBJECT	APPEARANCE	CONSTITUENTS	GRAIN SIZE & HARDNESS
KIN 1 Large copper bead from !Khuseb Delta site B 3091	barrel-shaped 9,77 g 15,5 - 16 mm diameter thick green corrosion	recrystallised grains, annealing twins	grain size c. ASTM 8 HV 81 (<i>n</i> = 5). cold-worked region HV 114 (<i>n</i> = 5).
KIN 2a Small copper bead from !Khuseb Delta site B 2740	cylindrical 0,46 g 6,4 mm diameter corroded, greenish	recrystallised grains, annealing twins,	grain size c. ASTM 8 HV 90 (<i>n</i> = 5). cold-worked region HV 108 (<i>n</i> = 5).
KIN 2b Small copper bead from !Khuseb Delta site B 2740	cylindrical 0,44 g 5,8 - 6 mm diameter severely corroded, green	recrystallised grains annealing twins	grain size c. ASTM 10 HV 98 (<i>n</i> = 5).
KIN 2c Small copper bead from !Khuseb Delta site B 2740	cylindrical 0,41 g 5,4 - 6 mm diameter severely corroded, green	recrystallised grains annealing twins	grain size ASTM 6 - 7 HV 83 (<i>n</i> = 5).
KIN 3 Large copper bead from Hungorob Ravine site B 2631	barrel-shaped 8,85 g 14,1 - 15,1 mm diameter not corroded, black	recrystallised grains annealing twins	grain size c. ASTM 10 HV 64 (<i>n</i> = 5).
KIN 4 Small copper bead from Hungorob Ravine site B 2631	barrel-shaped 0,76 g 6,2 - 6,5 mm diameter slight corrosion, green spots	recrystallised grains annealing twins	grain size ASTM 4 - 7 HV 94 (<i>n</i> = 5). cold-worked regions HV 128 (<i>n</i> = 5).
KIN 5 Small copper bead from /Khomas site B 3587	barrel-shaped 0,44 g 5,3 - 5,5 mm diameter uncorroded, dark brown	recrystallised grains annealing twins	grain size c. ASTM 8 HV 69 (<i>n</i> = 5).
KIN 6 Small copper bead from /Khomas site B 1541	cylindrical 0,45 g 3,5 - 3,8 mm uncorroded, green spots	recrystallised grains annealing twins	grain size c. ASTM 9 HV 60 (<i>n</i> = 5).

Table 1: Summary of metallographic descriptions of copper beads from Namibian sites

Notes for Table 1

1. OBJECT - sample name; identification; provenance
2. APPEARANCE - form; mass; colour
3. CONSTITUENTS - metal phases and textures
4. GRAIN SIZE and HARDNESS - visual estimation from ASTM grain size charts; "HV" - Vickers microhardness 200 g load for 10 s dwell time; "n" - number of replicate determinations of microhardness

localities discussed in this paper: the !Khuseb Delta, Hungorob Ravine and /Khomas Highlands. The /Khomas was a centre of copper production in the eighteenth century and the small beads from this area are similar in age and appearance to beads from the other two lo-

calities. No copper was produced in the !Khuseb or the Hungorob, although both were important centres of livestock production and beads from these sites could therefore include examples from ores other than the /Khomas. Analysis of the beads aimed to compare fab-

INCLUSIONS	DEFORMATION	FABRICATION
strings of spherical blue cuprite globules in concentric bands, except near join	grain compression on inner surface and one side of join	1. hot-worked into thick strip 2. annealed 3. ends cut with chisel 4. bent and closed cold
relatively few, spherical cuprite globules in concentric bands	grain compression on inner surface, with preferential grain boundary corrosion, and grain compression at join.	1. hot-worked into strip 2. annealed 3. ends cut with chisel 4. bent and closed cold
dense, concentric bands of spherical cuprite globules	no visible grain deformation	1. hot-worked into strip 2. ends cut with chisel 3. bent and closed 4. annealed
very few spherical cuprite globules in concentric bands	no visible grain deformation but relict grain orientation in the oxide near the join	1. hot-worked into strip 2. ends cut with chisel 3. bent and closed 4. annealed
spherical cuprite globules visible in polished end surface	no visible grain deformation	1. hot-worked into thick strip 2. severe cold work 3. annealed
large concentric oxide band with dense scatter of small spherical cuprite globules	inner grain compression, outer layer severely cold-worked and grains flattened parallel to outer margin	1. hot-worked into strip 2. ends cut with chisel 3. bent and closed cold 4. outside hammered
sparse spherical cuprite globules in concentric stringers, with elongated ragged brown tails	no visible grain deformation, inclusion stringers taper towards cut ends	1. hot-worked into strip 2. ends cut with chisel 3. bent and join closed 4. annealed
large concentric void, sparse spherical cuprite globules in stringers concentric with inner margin especially near join	no visible grain deformation	1. hot-worked into flat strip 2. ends cut with chisel 3. bent and join hammered closed 4. annealed

Table 1 (continued)

6. DEFORMATION - microstructural evidence of hot or cold work
7. FABRICATION - identifiable steps in fabrication technology
8. This table occupies a pair of consecutive pages which should be read in conjunction horizontally for the description of each artefact

rication technology and identify systematic differences between beads. Comparison with the ore sample was intended to assay their major element composition and assess the prospects of distinguishing ore sources without resorting to more expensive fully quantitative trace element determinations.

Analytical methods

All the specimens were photographed (Figs 2-7), weighed, sketched, and measured. The large bead from the !Khuseb Delta site B 3091 was sectioned with a watercooled rotary diamond saw. This sample and all

the small beads were cold-mounted in acrylic resin under vacuum to remove air bubbles. The large uncorroded bead from the Hungorob Ravine site B 2631 was not sectioned, but a small flat surface at one end was prepared for metallographic inspection. All the bead specimens were ground and polished on rotary laps, with a final micron diamond polish, and etched with $\text{NH}_4\text{OH}:\text{H}_2\text{O}_2$ solution.

All the sections were studied with a Reichert-lung Polyvar-Pol dual metallographic/petrographic microscope using plane polarised light, and differential interference contrast where appropriate. Microhardness measurements were carried out with a Shimadzu microhardness tester, with a load of 200 grams and a 10 second dwell time. Grain size was established by visual comparison with standard charts (ASTM, 1981). A Cambridge S200 scanning electron microscope with a Tracor Northern energy dispersive X-ray fluorescence micro-analysis system (EDS) was used for the chemical analysis of the beads. Analyses were done in spot mode with an analytical volume approximately 1 micron in diameter. This limited the analysis of the inclusions to the larger features. Software ZAP corrections were applied to the analytical results to produce semi-quantitative analyses expressed as atomic percent normalised automatically to 100 percent. As the EDS system used could not detect oxygen the normalisation did not include possible oxide composition. The EDS system has a precision of about 1 percent for the detectable elements, in this case those with atomic weights heavier than sodium. The lower limit of detection is about 0.1 percent under optimal conditions.

The possible ore specimen was analysed by Mrs Chandra Harris in the Department of Geology, UCT. The sample was crushed in its entirety using a rotary Sieb mill. A subsample of the resulting light yellow powder was ashed to determine the loss on ignition (LOI). Another subsample was subjected to duplicate X-ray fluorescence analysis (XRF) to determine the percentage of major elements, and to determine the concentration of selected elements in parts per million.

Descriptions and analytical results

The metallographic descriptions are summarised in Table 1 and the results of the EDS analyses of the beads are listed in Table 2. The results of the XRF analysis of the ore sample are presented in Table 3.

The accuracy of the EDS results was compromised by the significant overlap of the X-ray fluorescence peaks of some of the elements identified. In particular it was difficult to distinguish between silver (Ag) and cadmium (Cd), and between tin (Sn) and antimony (Sb). The analyte peak overlaps between sulphur (S), arsenic (As), and lead (Pb) made accurate measurement of the concentrations of these elements impossible. The X-ray results are best interpreted in terms of the presence or absence in major or minor amounts, with values under

0.1 percent in Table 2 indicating only the detectable presence in minor amounts. The analyses of all the copper grains and of the cuprite inclusions that produced a pure copper spectrum with no detectable additional elements are not included in Table 2.

KIN I Large copper bead from !Khuseb Delta site B 3091

This was a large copper bead (Figs 2 and 3) made from broad, rounded strip, bent around with the ends opposed. The join line was visible. The bead was severely corroded, with layers of oxide, green on the outside and reddish-brown on the inside. It was 15.5-16 mm in diameter, 11 mm broad, with an inner diameter of about 6 mm, and made of strip originally about 5 mm thick. The mass was; 9.77 g and it was not magnetic.

In transverse section the structure was homogeneous with no segregation banding, but fingers of oxide had intruded along the direction of elongation (Fig. 8). The copper consisted of angular, recrystallised grains with annealing twins (Fig. 9), indicating heating to above about 300°C (Maddin, Wheeler and Muhly, 1980). The grain size was relatively fine, about ASTM 8, due to substantial cold work before the final anneal. The annealed copper had a Vickers micro hardness HV 81 (range 80-83, $n = 5$). In places along the inner margin of the bead the copper grains were compressed and they were deformed near the join, particularly on one side. This resulted from cold working, to cut and bend the strip, and in hammering the join closed. The work-hardened regions had a Vickers microhardness of HV114 (range 110-118, $n = 5$). (Compare HV112 reported by Smithells (1967:801) for hard cold-rolled deoxidized copper with 30 percent reduction.) The outer surface was lost to corrosion so any evidence of possible cold work here had vanished. The copper itself was very pure, with no detectable additional elements in significant concentration except a small amount of nickel and zinc (Table 2: analysis 1a).

The inclusions consisted mostly of minute spherical globules of cuprite (Cu_2O), identified on the basis of its blue colour and red internal reflections (Craig and Vaughan, 1981) and lack of any detectable major elements other than copper. These inclusions were arranged in subparallel strings (Figs 10 and 11), mostly concentric to the margins, except near the join where they had been distorted by hammering the join closed. In places there were traces of the cellular structure of former grain boundary copper oxide inclusions typical of a cast structure (Fig. 10). This indicated that the bead was worked directly from cast material and not from recycled scrap. There were also a few elongated inclusions containing iron and copper as major elements, with variable minor amounts of nickel, zinc, tin, and antimony (Table 2: analyses 1 b-d). These inclusions lacked sulphur and were mixed copper/iron oxides.

This bead was fabricated from cast starting material,

TARGET	ELEMENTS														
	Si	S	Ca	Fe	Ni	Cu	Zn	As	Se	Sr	Ag	Cd	Sn	Sb	Pb
1a metal	-	-	0.01	0.07	0.18	99.13	0.58	-	-	-	-	-	-	0.04	-
1b inclusion	-	-	0.01	42.71	0.24	57.03	-	-	-	-	-	-	0.01	-	-
1c inclusion	-	-	0.20	16.62	2.15	77.32	0.64	-	-	-	-	-	2.84	0.23	-
1d inclusion	-	-	0.06	45.44	5.95	47.86	0.64	-	-	-	-	0.03	-	0.03	-
2Ba inclusion	0.42	10.12	0.05	0.12	0.12	27.49	0.02	11.31	-	2.17	0.12	0.36	-	0.02	47.69
2Bb inclusion	0.51	6.80	0.06	0.04	0.02	43.68	-	8.61	0.22	2.05	0.53	0.44	0.13	0.17	36.73
2Bc inclusion	0.66	10.28	0.07	-	-	21.88	-	11.90	0.21	2.95	0.53	0.69	-	0.16	50.67
2Bd inclusion	0.71	9.34	0.13	-	-	27.13	-	10.81	0.53	2.97	0.61	0.73	0.17	0.43	46.45
2Ca inclusion	0.24	0.61	0.03	0.07	0.08	96.32	0.71	-	0.61	0.67	0.17	0.16	0.21	0.13	-
2Cb inclusion	0.26	0.52	0.03	0.02	0.07	96.93	0.61	-	0.68	0.57	0.09	0.06	0.06	0.10	-
2Cc inclusion	0.32	0.63	0.02	0.05	-	96.55	0.59	-	0.86	0.66	0.14	-	0.14	0.05	-
3a metal	0.21	0.18	0.03	0.05	0.08	96.77	0.60	-	1.09	0.45	0.14	0.14	0.07	0.06	0.14
3b inclusion	0.36	0.42	0.04	0.07	0.10	95.45	0.50	-	1.51	0.84	0.29	0.12	0.23	0.08	-
3c inclusion	0.49	8.39	0.11	-	0.02	12.63	-	13.33	3.23	2.54	0.37	0.71	0.20	0.42	57.56
3d inclusion	0.54	9.44	0.23	-	0.79	11.10	-	13.18	3.25	2.70	0.36	0.73	0.14	1.09	56.46
3e inclusion	0.54	9.95	0.67	0.27	0.12	7.82	-	12.74	2.51	2.79	0.36	0.89	4.10	2.59	54.65
3f inclusion	0.49	8.52	0.08	-	0.08	12.64	-	13.51	3.10	2.54	0.25	0.65	0.05	0.24	57.86
3g inclusion	0.49	8.69	0.25	-	0.44	11.79	-	13.23	3.21	2.58	0.23	0.82	0.81	0.98	56.49
4a inclusion	0.23	9.78	9.25	0.70	0.09	68.46	0.55	-	0.41	0.95	0.01	0.14	-	9.44	-
5a inclusion	0.22	0.37	0.27	-	-	69.78	0.48	-	26.36	0.57	1.24	0.41	0.15	0.15	-
5b inclusion	0.37	0.47	0.06	0.01	-	88.12	1.00	-	8.28	0.97	0.30	0.18	0.10	0.12	-
5c inclusion	0.32	5.83	0.05	-	-	55.06	0.27	6.72	0.77	1.55	0.31	0.41	0.09	0.12	28.51
5d inclusion	-	0.85	0.06	0.01	0.02	94.66	1.09	-	4.08	-	-	-	-	0.03	-
5e inclusion	0.05	0.26	0.07	0.08	0.04	92.33	1.10	-	6.00	-	0.01	-	0.02	0.04	-
5f inclusion	0.49	10.99	-	-	-	36.35	-	-	4.93	-	0.30	-	-	-	46.93
5g inclusion	0.17	6.30	-	-	-	52.95	-	-	1.48	-	0.13	-	-	-	38.96
6a inclusion	0.28	0.72	0.10	-	0.02	94.46	0.91	0.29	1.02	0.58	0.09	0.08	0.06	0.18	1.21
6b inclusion	0.32	7.78	0.10	0.06	-	7.08	-	15.32	1.99	1.77	0.18	0.42	-	0.48	64.49
6c inclusion	0.34	7.33	0.04	-	-	8.10	-	15.23	2.08	1.83	0.26	0.39	0.01	0.18	64.20
6d inclusion	0.53	0.64	4.83	0.44	0.04	7.44	-	12.25	0.73	1.10	2.17	1.95	70.63	9.51	52.59
6e inclusion	0.26	6.63	0.50	0.30	0.63	21.11	0.13	14.83	1.12	1.47	-	0.30	0.13	2.58	52.59
6f inclusion	0.33	6.54	0.06	-	-	11.24	-	14.83	2.01	1.72	0.24	0.41	0.07	0.24	62.32

Table 2: EDS analyses of copper beads from Namibian sites

Notes for Table 2

1. TARGET - specimen number and analysis identifiers (a,b,c etc.)
2. ELEMENTS - elemental composition as atomic percent normalised to 100 percent on the assumption of no oxygen

hammered into a thick flat strip, and annealed, possibly more than once. In the cold state the strip was cut from one side with a chisel, bent around, and the join hammered closed and smoothed off without solder.

KIN 2A Small copper bead from !Khuseb Delta site B 2740

This was a small copper bead made from thin flat-strip, bent around and the ends opposed (Figs 2 and 4). The join line was visible. The bead was corroded (Fig. 12), with splits in the greenish oxide coating. The outer diameter was 6.4 mm, the inner diameter about 2.7 mm, and the length about 4 mm. The original thickness of the strip was about 1.8 mm. The mass was 0.46 g and it was not magnetic.

In transverse section the metal was homogeneous, with angular recrystallised grains and annealing twins resulting from heating to above about 300°C (Maddin *et al.*, 1980). The grain size was about ASTM 8, indicating considerable cold work prior to the final anneal. The annealed copper had a Vickers microhardness of HV 90 (range 85-97, $n = 5$). There was grain compression on the inner margin and preferential corrosion attack here along the radial grain boundaries (Figs 13 and 14). There was also grain distortion at the join where the metal was cut with a chisel. Here the Vickers microhardness had been elevated through coldwork to HV 108 (range 103-111, $n = 5$). This indicated that the bead was worked into its final shape cold. Any possible sign of cold work in hammering the ends closed had been lost to corrosion. The copper itself was very pure, with no detectable additional elements.

The inclusions consisted of sparse disconnected spherical globules of cuprite (Cu_2O) arranged in concentric strings. At the join these lines followed the direction of grain elongation. The EDS analysis of several of these inclusions revealed no detectable elements other than copper.

This bead was fabricated from heavily worked flat strip which was annealed. The ends were cut with a chisel while cold, and the strip was then bent around with ends opposed to form the solderless join.

KIN 2B Small copper bead from !Khuseb Delta site B 2740

This was a copper bead, now barrel-shaped but possibly originally cylindrical. It was very severely corroded (Figs 2 and 4) and covered with a heavily fissured green oxide layer (Figs 15 and 16). The outer diameter was 5.8-6 mm, and the length about 4 mm. The central hole was filled with corrosion product. The mass was 0.44 g and it was not magnetic.

In transverse section the copper was homogeneous with the original outline of the bead still visible in the corrosion rind (Fig. 17). The copper grains were angular, recrystallised, and contained annealing twins indi-

cating heating to above about 300°C (Maddin *et al.*, 1980). The grain size was very fine and about ASTM 10 due to severe prior cold work. There was no visible preferred grain orientation (Fig. 17) and no sign of cold work after the final anneal, although this may have been lost to corrosion. The Vickers microhardness of this annealed material was HV 98 (range 95-99, $n = 5$). The metal itself was very pure, with no detectable elements other than copper.

The inclusions consisted mostly of concentric strings of spherical cuprite (Cu_2O) globules (Fig. 16). Many of these had elongated tails containing high concentrations of copper and lead, with sulphur, arsenic, and strontium present as major elements (Table 2: analyses 2Ba-d). Silicon, selenium, silver, cadmium, tin, and antimony were present in minor amounts. These inclusions represented ductile envelopes around the cuprite globules drawn out into comet like tails during working. The cuprite inclusions were also visible in the corrosion product replacing the outer portion of the copper. Small clots of corrosion product were present in the copper itself.

This bead was fabricated from heavily cold-worked flat strip. This was presumably cut with a chisel and bent around to form the solderless join, but any traces of this step of working have been obliterated by the final anneal.

KIN 2C Small copper bead from !Khuseb Delta site B 2740

This was a copper bead, barrel-shaped but very severely corroded (Figs 2 and 4) with several deep fissures in the green oxide integument (Fig. 18). The outer diameter was 5.4-6 mm, the inner diameter about 2.2 mm, and the length about 4 mm. The mass was 0.41 g and it was not magnetic.

In transverse section the relict metal was homogeneous (Fig. 19). The copper grains were angular, recrystallised, and contained annealing twins (Fig. 20) indicative of heating above about 300°C (Maddin *et al.*, 1980). The grain size was about ASTM 6 to ASTM 7. The Vickers microhardness was HV 83 (range 77 - 88, $n = 5$). There was no visible grain orientation except local relict distortion preserved in the oxide at the join. This indicated that the ends were cut cold after the anneal. The copper itself was very pure, with no additional detectable elements.

The sparse inclusions consisted of rounded globules of cuprite (Cu_2O) in fine concentric strings. These contained minor amounts of a wide variety of elements including sulphur, zinc, selenium, and strontium, but none in major amounts (Table 2: analyses 2Ca-c). There were angular clots of oxide corrosion product scattered throughout the metal.

This bead was fabricated from annealed copper strip. It was cut cold with a chisel and bent around to oppose the ends at the join without solder.

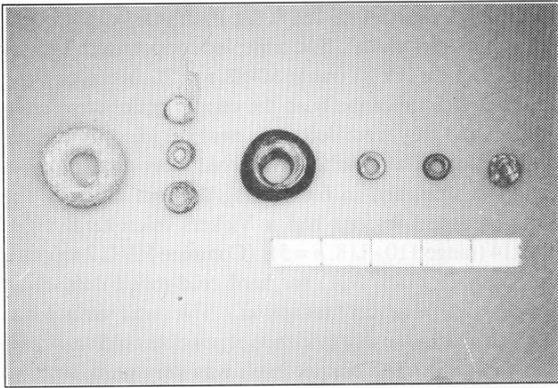


Figure 2: Photograph of the Namibian copper beads KIN 1-6 (scale in cm)

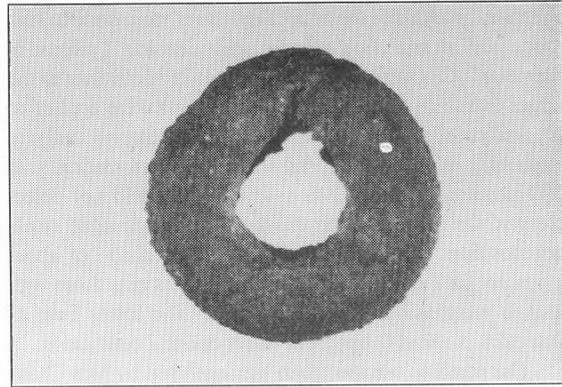


Figure 3: Photograph of bead KIN 1

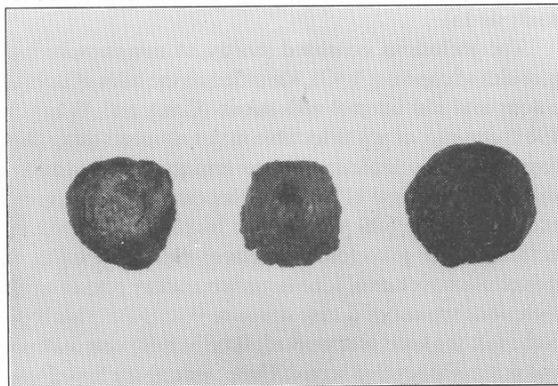


Figure 4: Photograph of beads KIN 2A,B,C (left to right)

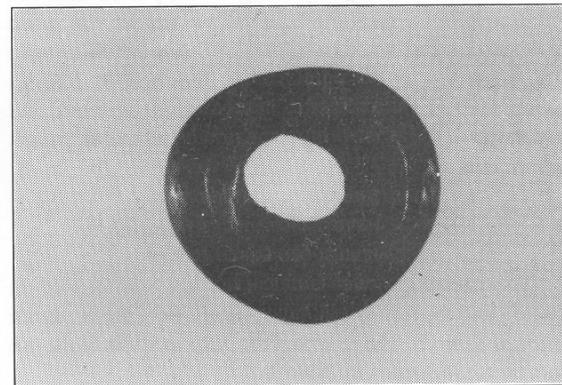


Figure 5: Photograph of bead KIN 3

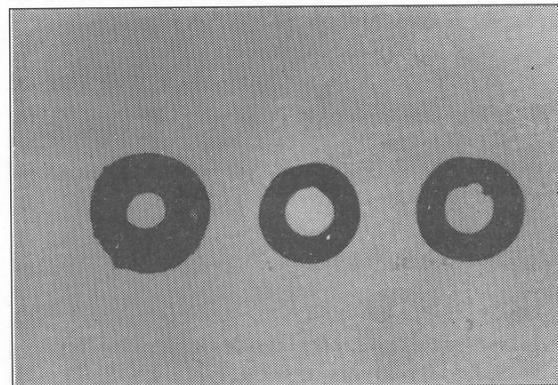


Figure 6: Photograph of beads KIN 4,5,6 (left to right)

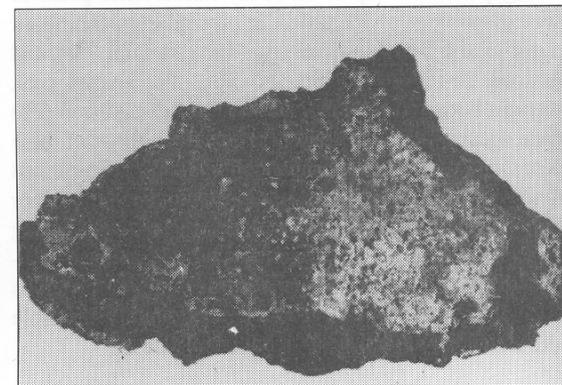


Figure 7: Photograph of ore sample KIN 7



Figure 8: Polished section of bead KIN 1 showing join area (20 X)



Figure 9: Etched section of bead KIN 1 showing recrystallised copper grains with annealing twins (124 X)

*KIN 3 Large copper bead from Hungorob Ravine site
B 2631*

This was a large barrel-shaped copper bead with a markedly wedge-shaped section (Fig. 5). The join line was visible and the outline somewhat irregular with a stepped entrance to the hole on each side. One end was worn into a small flat. The bead was not corroded, but had a dark copper colour with a black oxide patina in places. The outer diameter was 14.1-15.1 mm, the inner diameter was 5.0-5.5 mm, and the length was 9.3 mm. The mass was 8.85 g and it was not magnetic.

To preserve the display quality of this elegant bead only the small flat at one end was polished for metallography. The copper was homogeneous, with a very fine grain size of ASTM 10 indicating heavy cold work before annealing. The grains were angular and recrystallised (Fig. 21), with annealing twins indicating heating to above about 300°C (Maddin *et al.*, 1980). The Vickers microhardness of this fully annealed material was low; HV 64 (range 60-66, $n=5$). The copper contained about 1 percent selenium, and minor amounts of a wide variety of elements (Table 2: analysis 3a).

The sparse inclusions were dispersed spherical cuprite (Cu_2O) globules and even more rare elongated vermiform stringers. The cuprite also contained about 1 percent selenium and a similar suite of minor elements to those in the copper. The stringers consisted predominantly of lead, with copper, arsenic, sulphur, strontium, and selenium in major amounts. (Table 2: analyses 3c-g). Silicon, calcium, nickel, silver, cadmium, tin, and antimony were present in variable minor amounts.

This bead was fabricated from a wedge-shaped bar. It was probably bent and worked into its final shape cold before being annealed.

*KIN 4 Small copper bead from Hungorob Ravine site
B 2631*

This was a barrel-shaped copper bead, with very little corrosion (Fig. 6). It was dark brown with bright green corrosion spots. The outer diameter was 6.2-6.5 mm, the inner diameter was 2.0-2.2 mm, and the length was 4 mm. The join line was not visible on the surface. The mass was 0.76 g and it was not magnetic.

In transverse section the metal was very inhomogeneous. There was a large concentric oxide band associated with a high density of inclusions (Figs 22 and 23). The copper consisted of angular, recrystallised grains with annealing twins indicative of heating to above about 300°C (Maddin *et al.*, 1980). The grain size varied from ASTM 4 to ASTM 7. The annealed metal had a Vickers microhardness of HV 94 (range 88-99, $n=5$). There was severe cold work in some areas. The inner margin showed grain compression and a radial grain orientation (Fig. 24). The outer margin had been cold-worked extensively with the grains flattened parallel to the surface (Fig. 25). Strain bands were visible in some of the

larger copper grains, indicating the absence of a final anneal. The Vickers microhardness in these areas was elevated to VH128 (range 120-135, $n=5$). (Compare HV112 reported by Smithells (1967:801) for hard cold-rolled deoxidised copper with 30 percent reduction). The copper in all three zones was very pure with no additional detectable elements in the EDS analysis.

The inclusions consisted of spherical cuprite (Cu_2O) globules arranged mostly in strings. These were fairly sparse near the margins but were densely clustered around the concentric oxide inclusion. This represented a very poorly executed join between two strips of metal to create a thicker section. There was no surviving evidence that this was done by folding over a single strip and cutting sections from it, but this was possible. The cuprite inclusions contained no detectable elements other than copper. Only one inclusion was found that was not cuprite. It contained copper, sulphur, antimony, and calcium as major elements, and silicon, iron, zinc, selenium, strontium, and possibly cadmium, in minor amounts (Table 2: analysis 4a).

This bead was fabricated from two poorly joined strips, trapping surface oxides between them. Hot working dispersed and spheroidised some of these oxides to create the dense inclusion swarms in and around the junction. Subsequent cold work resulted from cutting the ends, bending the strip around to form the solderless end join, and hammering the outside to shape without a final anneal.

KIN 5 Small copper bead from /Khomas site B 3587

This was a small barrel-shaped copper bead made from flat strip with the ends hammered over each other, and the edges bevelled by hammering (Fig. 6). The join was just visible, and the edges have a stepped appearance around the hole. It was uncorroded and dark brown. The outer diameter was 5.3-5.5 mm, the inner diameter was 2.6 mm and the length 3.5 mm. The mass was 0.44 g and it was not magnetic.

In transverse section the copper was homogeneous except for one concentric oxide stringer (Fig. 26). The grains were angular, recrystallised, and had inclusion twins indicating heating to above about 300°C (Maddin *et al.*, 1980). The grain size was about ASTM 8. The Vickers microhardness was HV69 (range 56-78, $n=5$). There was no evidence of cold work, which implied a final anneal. The copper itself was very pure with no detectable alloying elements.

The inclusions consisted of strings of spherical cuprite (Cu_2O) globules with ragged brown tails elongated parallel to the strings (Figs 27 and 28). The inclusion strings tapered towards the ends (Fig. 29) indicating that the strip was cut from one side with a chisel. The cuprite globules themselves contained no detectable elements other than copper. The ragged tails were areas which etched preferentially in the $\text{NH}_4\text{OH}:\text{H}_2\text{O}_2$ solution. The residues in the holes left behind contained

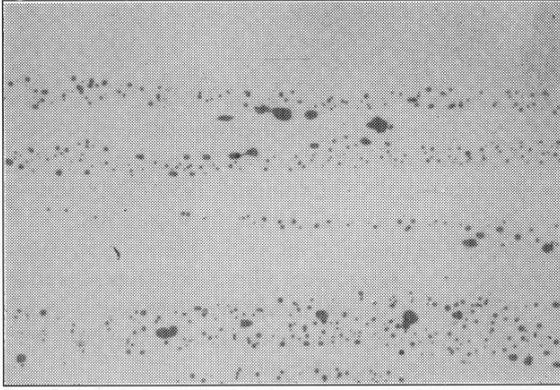


Figure 10: Polished section of bead KIN 1 showing dispersed cuprite eutectic (448 X)

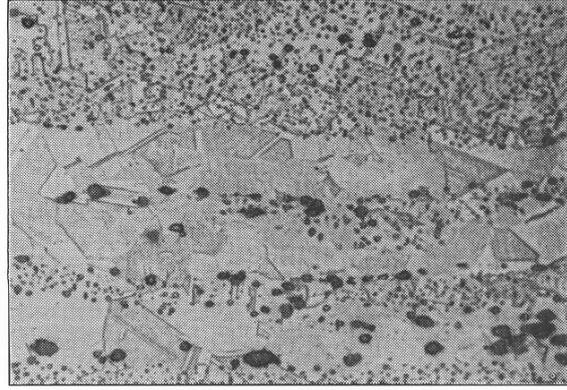


Figure 11: Etched section of bead KIN 1 showing cuprite inclusion bands (252 X)

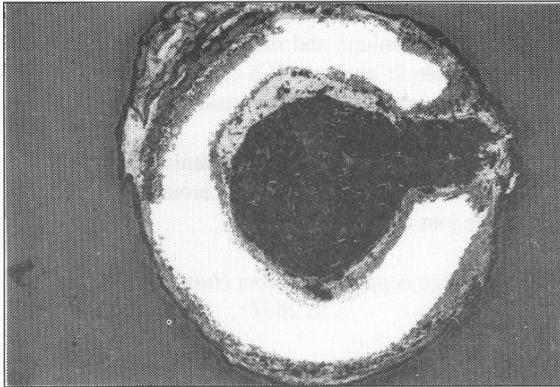


Figure 12: Polished section of bead KIN 2A (8 X)

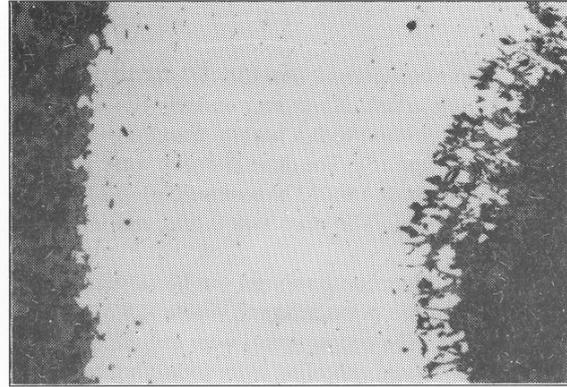


Figure 13: Polished section of bead KIN 2A showing preferential corrosion attack on inner margin (50 X)

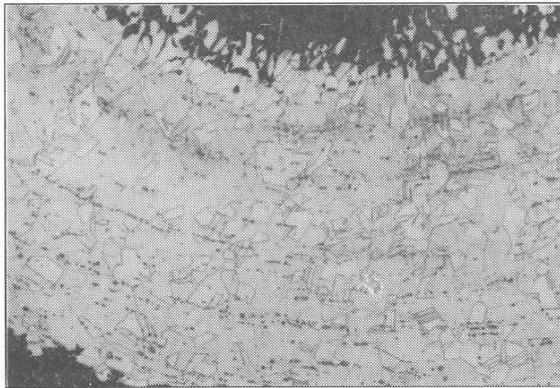


Figure 14: Etched section of bead KIN 2A showing grain deformation and preferential corrosion attack on inner margin (50 X)

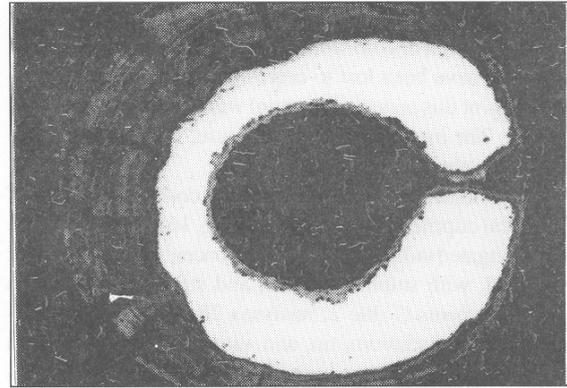


Figure 15: Polished section of bead KIN 2B showing severe corrosion (8 X)

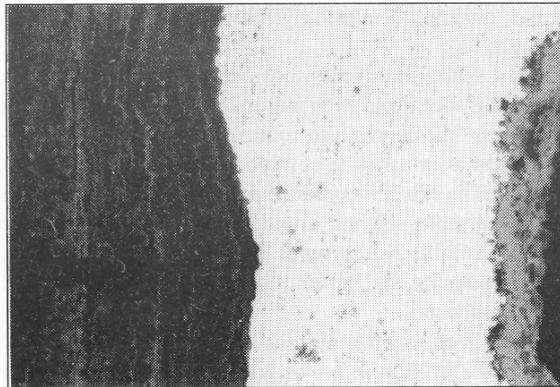


Figure 16: Polished section of bead KIN 2B showing strings of cuprite inclusions (50 X)

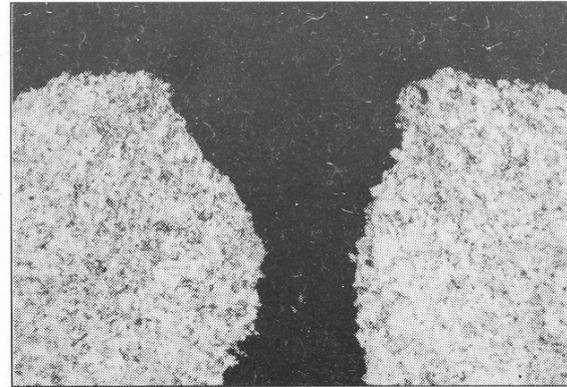


Figure 17: Etched section of bead KIN 2B showing relict surface near the joint (40 X)

predominantly copper and selenium, with variable minor amounts of silicon, sulphur, zinc, strontium, silver, and cadmium (Table 2: analyses 5a,b,d,e). One vermiform inclusion contained principally copper and lead, with sulphur, arsenic, and strontium as major accessory elements, and minor silicon, selenium, silver, and cadmium (Table 2: analysis 5c). The presence of copper, lead, sulphur, selenium, silver and silicon in these inclusions was confirmed by the subsequent EDS analysis of the repolished specimen (Table 2: analyses 5f,g).

This bead was fabricated from a strip cut with a chisel. The ends were bent around and hammered closed to form a join without solder, and the edges bevelled, before a final anneal.

KIN 6 Small copper bead from /Khomas site B 1541

This was a cylindrical copper bead (Fig. 6) made from flat strip bent around and the ends opposed. It was a coppery brown with a few green oxide patches. The outer diameter was 5.6 mm, the inner diameter was 3.5-3.8 mm, and the length was 3.4 mm. The original thickness of the strip was about 1.2 mm. The bead had a mass of 0.45 g and was not magnetic.

In transverse section the metal was very inhomogeneous. There was a large concentric void (Fig. 30). The copper consisted of angular, recrystallised grains with annealing twins, indicating heating to above about 300°C (Maddin *et al.*, 1980). The grain size was fine, about ASTM 9, probably resulting from heavy cold working before the final anneal. The Vickers microhardness was HV 60 (range 54-70, $n = 5$). Apart from the fine grain size there was no additional sign of cold work or grain deformation after the anneal. The copper was pure, with no detectable alloying elements.

The inclusions were predominantly sparse spherical cuprite (Cu_2O) globules arranged in strings parallel to the inner margin and curving outwards near the join where they were truncated by the outer surface (Fig. 31). The cuprite inclusions (Fig. 32) contained no detectable elements other than copper. The non-cuprite inclusions were rare. One etched tail to a cuprite inclusion contained copper with selenium and lead, and minor sulphur, zinc, arsenic and strontium (Table 2: analysis 6a). Two other vermiform inclusions and an irregular blob had a preponderance of lead and subsidiary copper, with major components of sulphur, arsenic, selenium, and strontium (Table 2: analyses 6b,c,e,f). One elongated inclusion contained 70 percent tin, with major amounts of antimony, copper, and calcium, with silver, strontium, and cadmium (Table 2: analysis 6d).

This bead was fabricated from a double thickness of thin flat strip, poorly welded together or perhaps not really joined at all. The ends were cut with a chisel, and then wrapped around and hammered together to form a solderless join before the final anneal.

KIN 7 Fragment of possible copper ore from /Khomas area

This was a flat rock fragment (Fig. 7) consisting of a coating of green malachite ($\text{Cu}_2(\text{OH})_2\text{CO}_3$, $\text{Cu}(\text{OH})_2$) on a piece of gossan, or leached ore. The length was 67 mm, the breadth 42 mm, and the thickness about 15 mm. The total mass was 74.5 g.

The XRF chemical analysis (Table 3) showed a preponderance of iron oxide (29% Fe_2O_3). This would be more than sufficient iron oxide to act as a flux, combining with the silica (7% SiO_2) to form a fayalite ($2\text{FeO} \cdot \text{SiO}_2$) slag and to release the copper during smelting. The copper content was about 11 percent, probably mostly in the form of malachite, in which case the carbonate would make up some of the missing mass in the analysis. (These XRF results are only approximate

OXIDE	ANALYSIS
	%
SiO₂	7,043
TiO₂	0,065
Al₂O₃	0,681
Fe₂O₃	29,081
MnO	0,029
MgO	-
CaO	0,065
Na₂O	0,084
K₂O	0,014
P₂O₅	0,018
Cr₂O₃	-
NiO	-
LOI	6,805
H₂O	1,038
TOTAL	44,924
TRACE ELEMENT	parts/million
Zn	14612,09
Cu	113816,79
Ni	-
Mo	460,55
Nb	28,28
Zr	39,62
Y	-
Sr	3286,00
U	-
Rb	-
Th	-
Pb	4401,42

Table 3: XRF analysis of copper ore from /Khomas area in Namibia

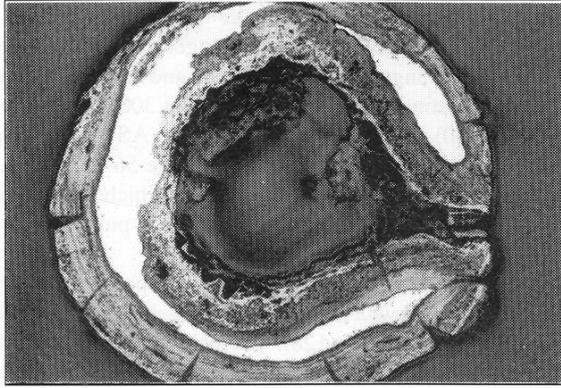


Figure 18: Polished section of bead KIN 2C (8 X)

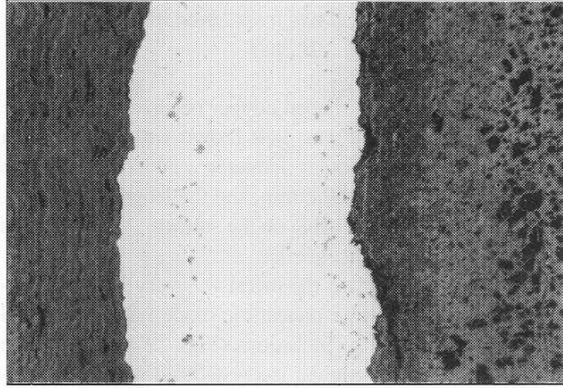


Figure 19: Polished section of bead KIN 2C showing bands of cuprite inclusions, and severe marginal corrosion (50 X)

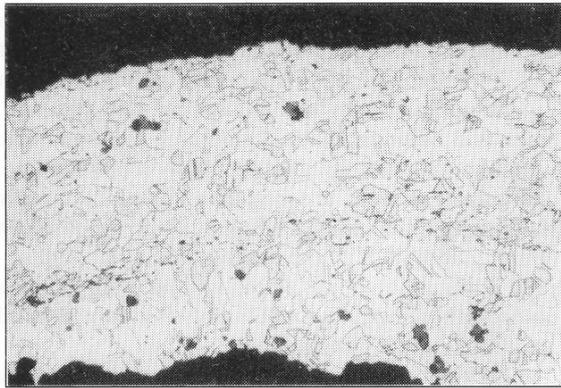


Figure 20: Etched section of bead KIN 2C showing recrystallised copper grains with annealing twins (50 X)

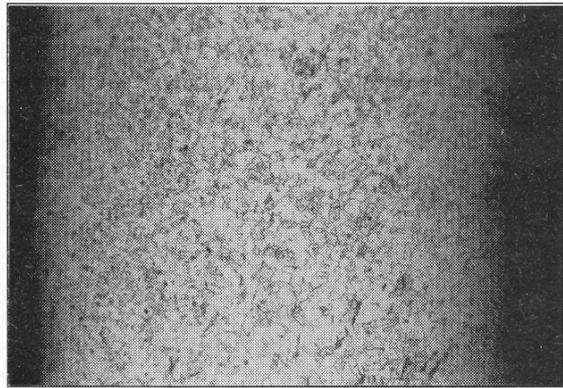


Figure 21: Etched edge of bead KIN 3 showing recrystallised copper grains (63 X)

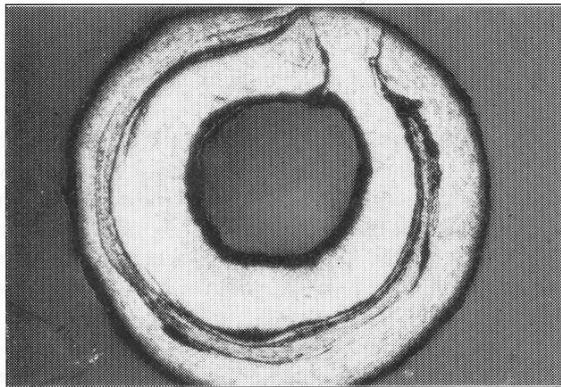


Figure 22: Etched section of bead KIN 4 showing concentric oxide band (8 X)

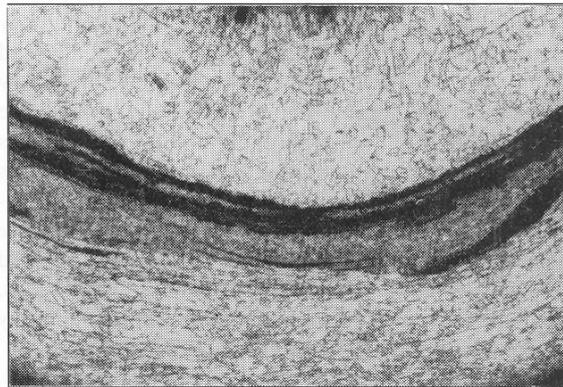


Figure 23: Etched section of bead KIN 4 showing dense inclusion scatter associated with oxide band (25 X)

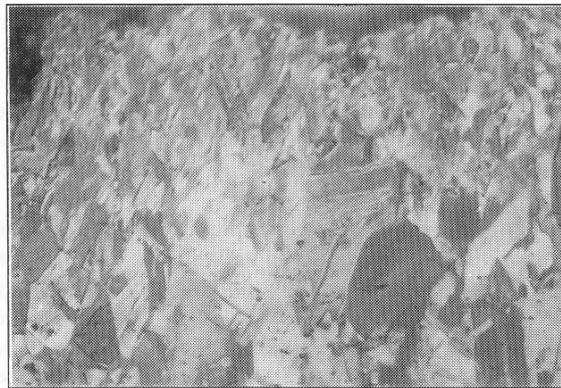


Figure 24: Etched section of bead KIN 4 showing compressed grains on the inner margin (100 X)

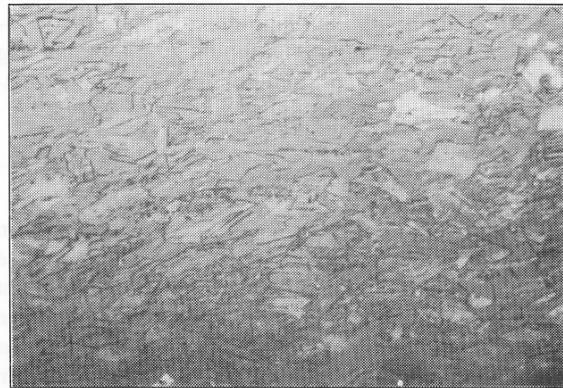


Figure 25: Etched section of bead KIN 4 showing flattened grains at outer margin (100 X)

because this system is not standardised for such high values for copper). The other elements present in significant concentration in these determinations were zinc (ca. 1.46 percent), strontium (ca. 0.33 percent), and lead (ca. 0.44 percent). A full XRF trace element analysis was precluded by the expense, and only the elements listed in Table 3 were sought.

Discussion and concluding remarks

The four copper beads from the coastal !Khuseb Delta site were all more severely corroded, which was not the case with those from the interior (Fig. 2). This was due probably to the saline sea mists of the coastal area. In general appearance most of the beads were cylindrical or slightly barrel-shaped. The two beads from the Hungorob Ravine were more markedly barrel-shaped and appeared to have been shaped more carefully than the others (Figs 4 and 5). This is possibly a significant distinction but it cannot be asserted on the basis of such a small sample.

The copper beads were all fabricated from indigenously produced copper with characteristic bands and stringers of cuprite inclusions (Figs 10, 11, 13, 14, 16, 19, 20, 23, 26-32). These were cuprite precipitated out in a Cu-Cu₂O eutectic network in the original smelted and unrefined copper and redistributed throughout the metal by hot working (cf. Brooks 1982:279, Figs 8-3 and 8-4). The metal itself was generally very pure, without any detectable iron in solution. This indicated that a low smelting temperature was maintained, probably a temperature just in excess of the melting temperature of copper at 1083°C, which precluded the reduction of metals requiring a higher smelting temperature (Cradock and Meeks, 1987).

Native copper does occur in central Namibia and must be considered as a potential source. The presence of the deformed Cu-Cu₂O eutectic network indicates that these beads were not made from hot- or cold-worked native copper. The possibility exists that the native metal may have been melted (as opposed to the smelting of ore), and oxygen allowed to dissolve in the molten metal. Unless the original fragments of native copper were very small and needed to be fused nothing would have been gained by this process.

Although there was no supporting evidence in the form of coppersmithing tools, all the beads showed signs of having been worked hot. This dispersed the initial Cu-Cu₂O eutectic network, allowed the cuprite inclusions to maintain their rounded shapes, and facilitated the initial forming of the strip. They also all consisted of angular recrystallised grains with annealing twins (Figs 9, 11, 14, 20, 21, 24, 25, 27, 32), evidence of prior cold work followed by annealing at temperatures in excess of about 300°C (Maddin *et al.*, 1980:217). In some cases the final anneal may have been accidental and taken place in a cooking hearth after loss. The fabrication of all the beads which were investigated in sec-

tion involved shaping a bar or flat strip, cutting both the ends from one side with a chisel and annealing the strip to soften it. It was then bent over cold to oppose or overlap the ends. The gap was hammered closed and joined without solder (Figs 8, 12, 15, 17, 18, 22, 26, 29-31). In only one case, the small bead from the Hungorob Ravine, was there evidence for extensive cold work after the final anneal (Figs 23-25). This involved hammering the outside into a barrel shape. The large bead from the Hungorob had suffered a final anneal, obliterating any possible traces of final cold work to shape the outside.

There was clear variation in the inclusion chemistry (Table 2). The four beads from the !Khuseb Delta site clearly differed from one another. For instance, lead and arsenic were detected only in KIN 2B. Sulphur was absent in KIN 1 and KIN 2A, but present in KIN 2B and KIN 2C, although in minor amounts in the latter. Zinc was present in significant minor amounts only in KIN 1 and KIN 2C. This variation in minor element chemistry indicates that it is likely that these beads all originated from different ore sources, either different ore bodies or, less probably, a single chemically very variable ore body. The two beads from the Hungorob Ravine also differed markedly from each other in inclusion chemistry. KIN 3 contained inclusions high in lead and arsenic, which were altogether absent in KIN 4. Even the two beads from the /Khomas site appeared to differ in both the morphology and composition of most of their inclusions although there was more overlap between these two. The greatest similarities were between KIN 2B, KIN 3, and KIN 6 which all contained lead-rich inclusions with relatively high values for sulphur, arsenic, and strontium.

A comparison of the inclusion analyses for KIN 5 and KIN 6 with the XRF analysis of the potential ore sample KIN 7 showed the presence of copper, lead, and strontium in significant quantities. Zinc was largely absent from the beads, but zinc is very volatile and may have been lost in the smelting operation. Unfortunately XRF analysis for the other elements present in the beads was not financially feasible.

These results agree with the archaeological evidence that livestock-producing areas such as the !Khuseb and Hungorob were involved in extensive trading networks (Kinahan, 1991). This reflected in the greater compositional diversity of copper beads from these areas compared to the /Khomas, a likely source of at least some of the !Khuseb and Hungorob beads.

The semi-quantitative EDS of the bead inclusion chemistry did show a promising variability in inclusion chemistry and demonstrated that it was possible to distinguish significant differences in composition with this analytical method. The small sample sizes precluded any more concrete statements about the possible sources of these beads. A thorough sourcing study would require a detailed knowledge of the geochemistry of the potential source ore bodies, as well as a more detailed understanding of the smelting procedure than

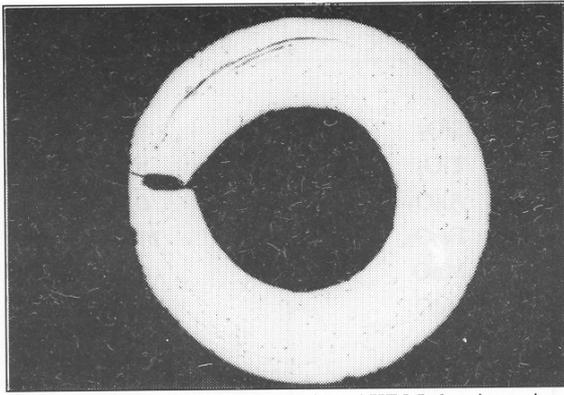


Figure 26: Polished section of bead KIN 5 showing strings of cuprite inclusions (8 X)

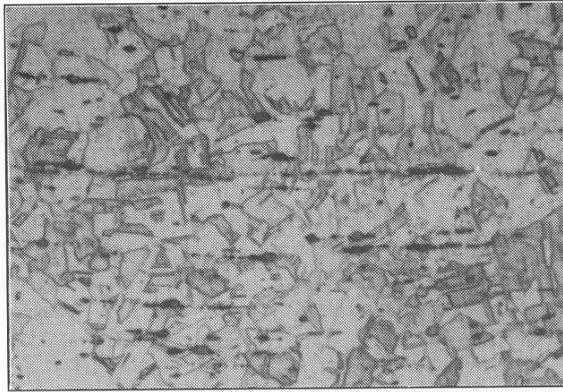


Figure 27: Etched section of bead KIN 5 showing recrystallised copper grains and strings of cuprite inclusions (124 X)

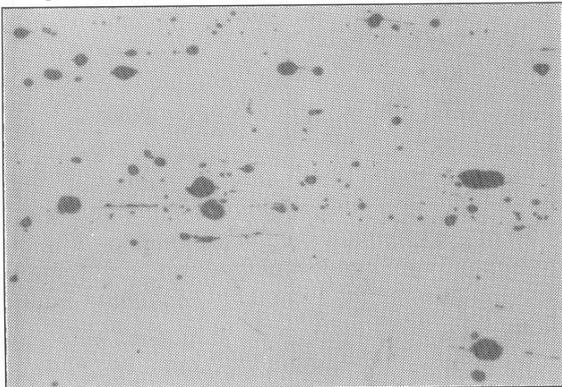


Figure 28: Polished section of bead KIN 5 showing cuprite inclusions with elongated tails (250 X)

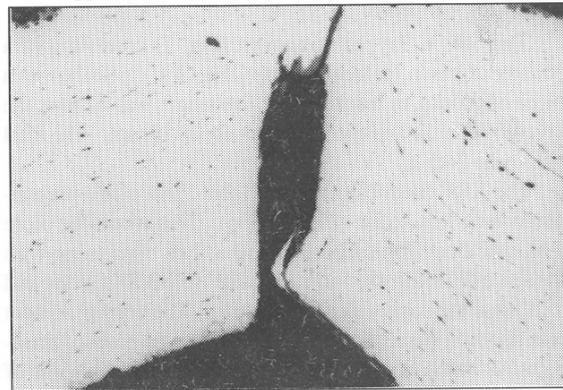


Figure 29: Polished section of bead KIN 5 showing the join area (72 X)

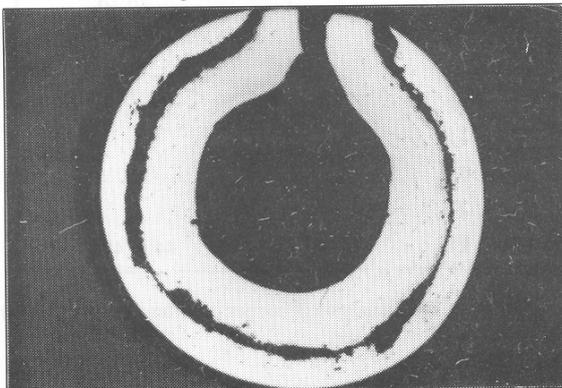


Figure 30: Polished section of bead KIN 6 showing large concentric void (8 X)

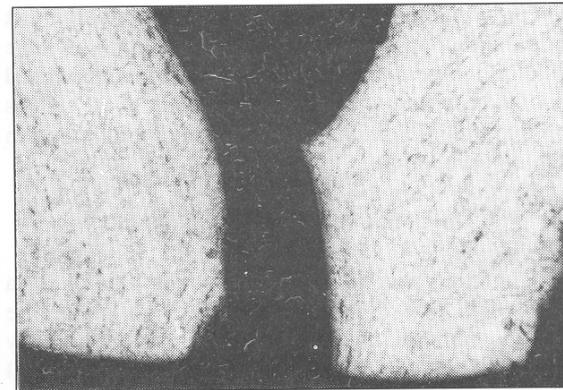


Figure 31: Etched section of bead KIN 6 showing the orientation of the inclusion bands at the join (40 X)

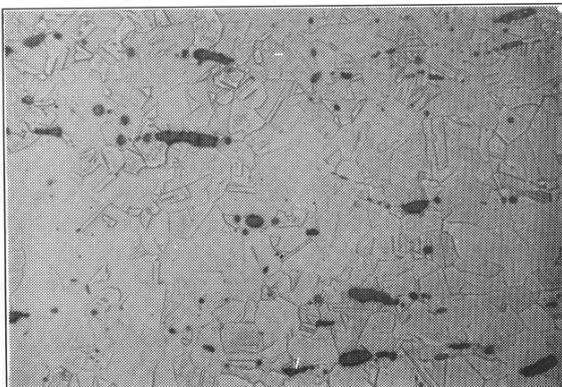


Figure 32: Etched section of bead KIN 6 showing recrystallised copper grains and dark cuprite inclusions (200 X)

can be gained from a metallurgical analysis of the beads alone.

Acknowledgements

We would like to thank Professor Anthony Ball for access to the microhardness tester and scanning electron microscope in the Department of Materials Engineering, UCT and Mr Stephan Coetzee for his assistance in operating the SEM. We are grateful to Ms Chandra Harris, Department of Geochemistry, UCT, for performing the XRF analyses of the ore sample. The referee's comments are acknowledged with thanks. The Department of Archaeology, UCT, provided research facilities and administrative support. Archaeometallurgy research at UCT is supported by a research grant from Anglo American! De Beers Chairman's Fund Educational Trust.

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