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Archaeometric analysis of copper swords from Kerma (Nubia)

Abstract

One hundred thirty swords were found by George A. Reisner on his Harvard-Boston Expedition to the Sudan from 1913 to 1916. The date of these swords ranges between 2040 - 1674 B.C. The form, microstructure, and chemical composition of two of these swords are described, and the technology of their production and their possible sources are discussed.

Introduction

After surveying Lower Nubia in 1907 and 1908, George A. Reisner excavated at Kerma in Nubia, Sudan from 1913 to 1916. He believed he was excavating remains of a Middle Kingdom Egyptian (2040-1674 B.C.) colony at Kerma. Reisner called Kerma a "military colony" (Reisner 1923). However, when its essentially non-military nature was acknowledged, Kerma was described as an Egyptian trading post which was established under the protection of the King of Kush (Säve-Söderbergh 1960, 1963). Hintze (1964) suggested that subsequently it was not Egyptian, but rather part of the palace of the King of Kush. It was possible that Egyptian artisans were employed there late in the Second Intermediate Period (1800-1570 B.C.). This theory explained the heavy Egyptian influence seen in the design and techniques of manufacture using many materials, including metals, ceramics, and stones, and it caused Reisner to interpret the site as Egyptian, although no Egyptian graves were found.

Reisner found numerous copper and/or bronze objects at Kerma. They included weapons, tools, vessels, inlays, bracelets, rings, toilet implements, and other articles (Reisner 1923). Daggers and knives were commonly found in graves. A total of one hundred thirty copper daggers were found at Kerma. They are distinct local variants of standard Egyptian ones (Trigger 1976). Two of these daggers are the objects of analysis in this paper.

Most of the classes of bronze and/or copper objects from Kerma are Egyptian in form and technique. The number of ivory handles imply an abundant supply, the source for which could only have been the Sudan. This fact led Reisner to the conclusion that at least the handles of the daggers were fitted at Kerma. This indicated that copper was worked in Kerma. But the place in which the blades were manufactured was in question. At first Reisner suggested the blades were imported from Egypt and assembled in Kerma workshops. But when it became clear that in the region of the Third Cataract, copper oxide beds, which had certainly been worked in ancient times, and other copper beds in Sudan, which certainly would have been found in the quest for gold, existed, Reisner concluded that copper was easily obtained at Kerma. Therefore, the blades could also have been forged there by Egyptian artisans. The development of the other crafts and the discovery of custom-made personal objects at Kerma support this view.

The abundance of ivory at the site caused Adams (1975) to suggest that Kerma was the major collection point for raw materials from the south, some of which may have been sent north from there to be traded with Egyptians. The handles on the blades would have been made of this ivory. If Kerma was, indeed, a collection point for goods, it does remain possible that the blades were imported from the north. Copper was known in Egypt by the fifth millennium B.C.. Copper objects first occurred in Nubia at Khor Bahan in the fourth millennium B.C.. Copper was mined by Egyptians at Abu Seyal by ca 1950 B.C. The Nubians were producing it extensively at Kerma (ca 1750 B.C.) after the decline of the Egyptian Middle Kingdom (van der Merwe 1980). Statues of Middle Kingdom Egyptian kings were probably either booty that Kushites carried off from Egyptian sites in Lower Nubia (Säve-Söderbergh 1941) or traded objects (O'Connor 1974). Kushites admired the Egyptian culture; therefore, they manufactured imitations of Egyptian objects such as jewellery, furniture, architecture, and weapons. Trigger (1976) has suggested that "the development of greater social complexity at Kerma led to the acquisition of a veneer of Egyptian material culture by the Kerma elite". It is probable the sources of the copper are in Sudan. It is now certain that smelting was practiced in Kerma since copper or bronze workshops, and furnaces, have been found (Bonnet 1982).

Though fortified by massive walls and dry ditches, the town resembles a large agricultural settlement with mostly modest domestic architecture rather than an Egyptian style fort or an Egyptian Middle Kingdom style workers' village. Strong hierarchy is revealed in the cemetery by differing proportions and values of grave goods. The urban organization and the size of some tombs led Bonnet (1992) to suggest that Kerma may be seen as the capital of the kingdom, so the town was a part of the economic and political centre. Numerous seal impressions found by Bonnet support exchange with Egyptian sources which involved an administrative apparatus.

After fifteen years of excavation by Charles Bonnet, his data and his work has considerably enriched knowledge of the site, but there is certainly much that still remains to be analysed, and there is doubtless much left to be discovered.

The daggers found at Kerma were thought to be the only metal weapons which would be suitable for warfare. Many of the daggers have lengths far greater than the Egyptian daggers. Some might even be called swords rather than daggers. The long ivory butt may be typical of the sword-butt, as distinguished from the dagger-butt, and may be a modification of a well known Egyptian type of the Middle Kingdom (Reisner 1923). This modification might be due to ease in handling and the abundance of ivory. However, the daggers were assumed to be bronze. Bronze had been discovered in the Middle East, and its use was spreading around the Mediterranean basin by the third millennium (van der Merwe 1980).

The purpose of this paper is to report the archaeometric analysis of two of the daggers found, and thus to address the standing hypotheses about them and to add to the information known about the technology and practices in their time. A comparison of the rivets, which certainly were made at Kerma, and the blades, whose provenance is in question, will be made. The usefulness of these daggers as weapons will be discussed.

Description of the copper swords

The two swords came from a collection of swords found by George A. Reisner during his Harvard-Boston Expedition to the Sudan, 1913 to 1916. Although neither compositional nor metallographic analyses were made at the time, Reisner reported the artifacts in his 1923 site report as possibly imported blades with ivory handles attached in Nubia.

The longer of the two swords (Harvard Peabody Museum - B1301) has a blade of length 36.6 cm, width 1.7 cm at the midpoint, and thickness 0.49 cm at the midpoint (Fig. 1). Its ivory handle has maximum length 14.9 cm, maximum width 6.1 cm, and maximum thickness 1.28 cm. The handle was attached with nine copper rivets - three through the ivory and six through the blade surrounded by wood. The blade was encased in a leather sheath of which only a small fragment has survived.

The shorter sword (Harvard Peabody Museum - B1302) has a blade of length 21.7 cm, width 1.3 cm at the midpoint, and thickness 0.47 cm at the midpoint (Fig. 1). Its ivory handle has maximum length 9.9 cm, maximum width 4.7 cm, and maximum thickness 0.16 cm. The handle was attached with five copper rivets, three through the ivory, and possibly two through the blade that are now missing. The blade was encased in a woven textile sheath of which only a small fragment was preserved.

Microstructure and chemical composition

Small rectangular samples were sawed from the blades near the thick sections at the handles, and from the ends near the points of each sword. A rivet was removed from each handle. The rivets were sawed to examine one flattened top, a cross-section of the shank, and a section cut along the axis of the shank. The

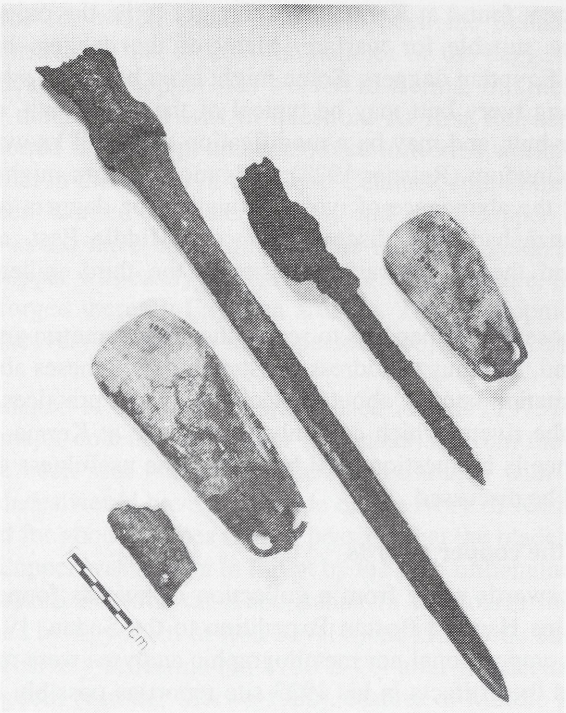


Fig. 1. The swords which were sampled for study.

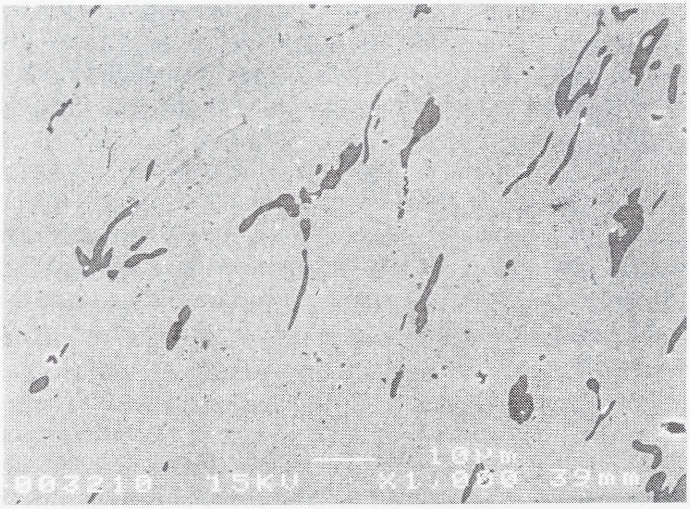
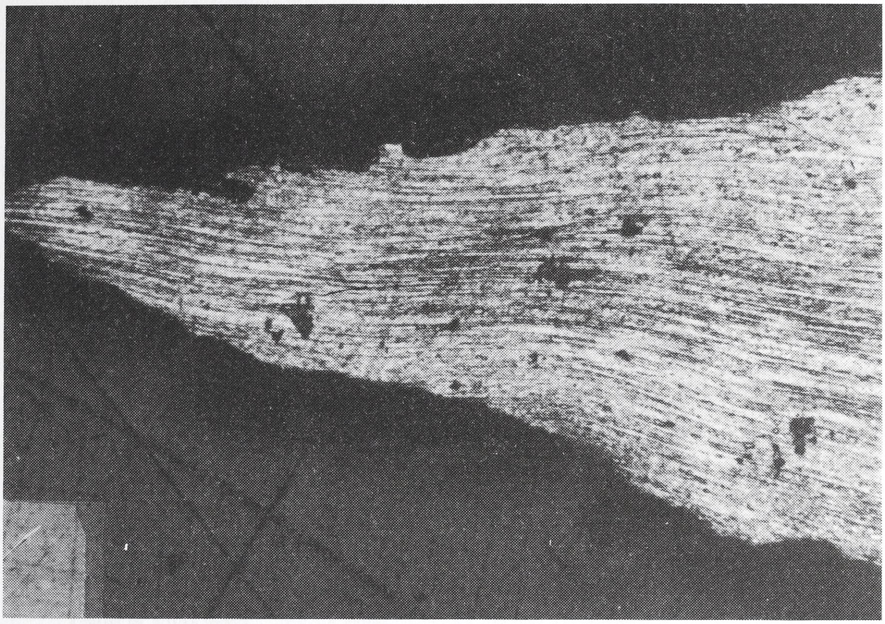


Fig. 2. Scanning electron micrograph using back scattered electrons, showing the non-metallic Cu_2S inclusion as darker than the metallic copper matrix.



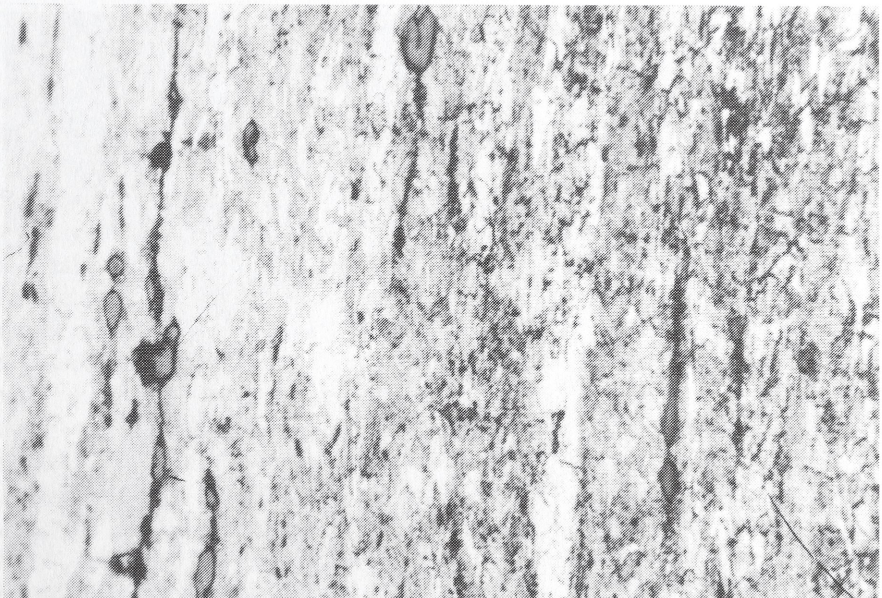


Fig. 3. Photomicrographs of a polished section of the edge of the longer sword in plane polarized reflected light (top) is at 50x, and (bottom) is at 500x. They show the deformed crystals which occur at the ends and edges of the blades.

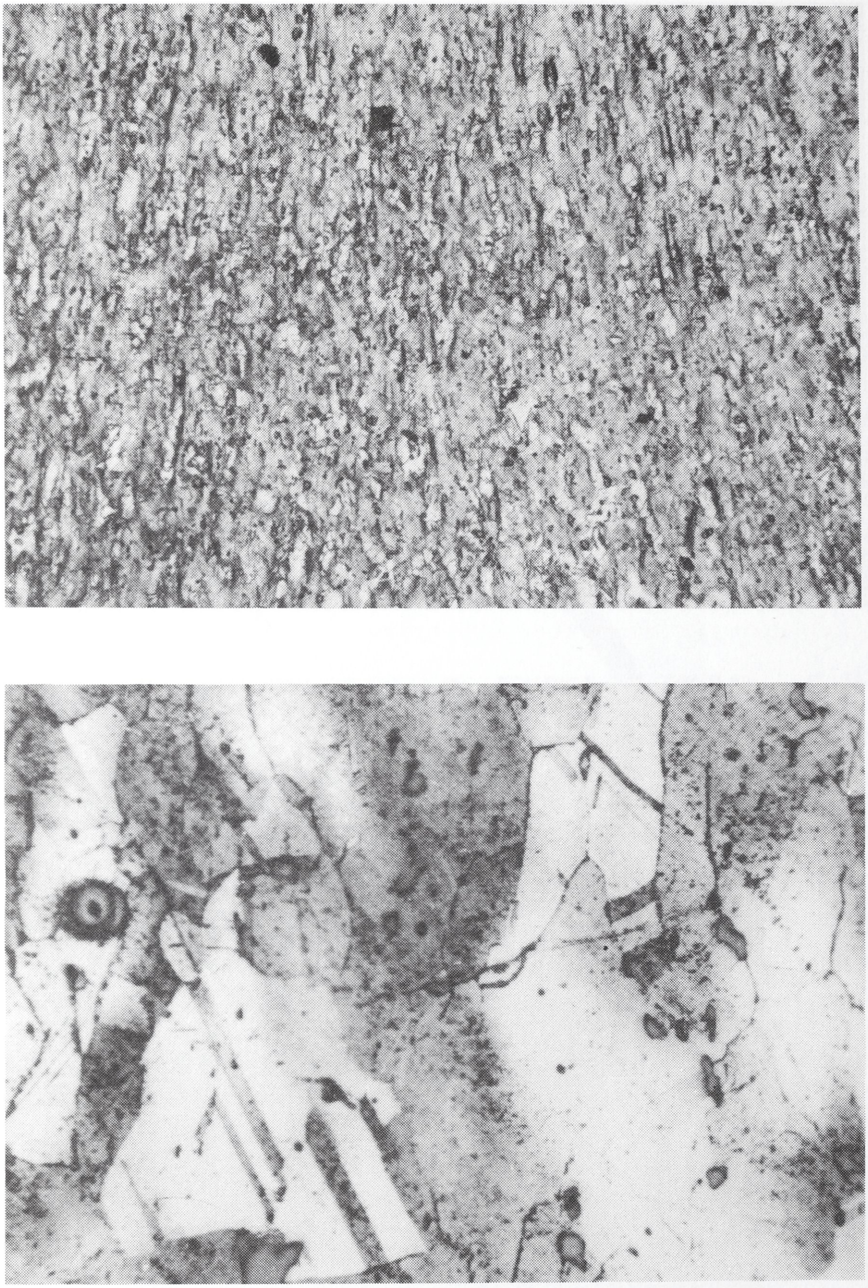


Figure 4. Photomicrographs of a polished section of the center region of the longer sword in plane polarized reflected light (top) is at 50x, and (bottom) is at 500x. They show the annealed crystals which are typical of the center of the blades.

TABLE A (i)

SAMPLE	↕	↔
Long Rivet (LR)	112.9	108.2
Long Blade Thick (LT)	101.8	99.64
Long Blade End (LE)	124.2	126.4
Short Rivet (SR)	104.5	99.66
Short Blade Thick (ST)	84.41	82.39
Short Blade End (SE)	111.3	110.6

Vickers Diamond Pyramid Microhardness (HV). Mean values of ten tests at 200 grams for 30 seconds in Table A (i).
The ends of both blades have a trend of increasing hardness toward the edge.
Hardness of single points at the end edge of each are given in Table A (ii).

TABLE A (ii)

SAMPLE	↕	↔
End of long blade	175.3	173.8
End of short blade	144.3	146.0

samples were mounted in epoxy and polished for metallographic examination. The samples were studied in reflected polarized light from 50x to 1550x.

Two phases were noted optically and confirmed using Backscattered Electron Microscopy (Fig. 2). The matrix is copper metal. The copper grains are severely deformed near the edge and tip of the blade indicating cold working with no final annealing (Fig. 3). The same is true of the flattened ends of the rivets. Toward the centre of the blades and rivets annealing twins are found (Fig. 4). The blades and rivets were clearly worked to near their final shape, annealed, then cold worked at the edges. There is no evidence of the original casting. Darker parts which contain higher concentration of arsenic are seen lined up horizontally at edges and patchily toward the centre where the crystals are also deformed. The metal is very hard, with increasing Vickers diamond pyramid microhardness (HV) from 88.60 to 175.3 in the longer sword and from 84.37 to 146.0 in the shorter sword. Mean values of 10 tests at 200 g load for 30 seconds are given in Table A. Typical hardness range for work-hardened copper with 0 to 2.0 % As is 120 to 140 (Tylecote 1986).

The rivets both contain very clean copper. In the longer sword's rivet, there are non-metallic inclusions (with areas of less than 60 microns^2) of copper sulfide that contain selenium and tellurium. The rivet of the shorter sword contained no visible non-metallic inclusions.

TABLE B (i)

	S	Fe	Cu	Zn	As	Ag	Sn	Sb	Pb	tot %
ST	nd	nd	98.96	nd	0.55	nd	0.06	0.05	nd	99.62
STi	19.14	0.04	77.54	nd	nd	nd	nd	nd	0.35	97.07
SE	nd	0.01	98.29	nd	0.54	nd	0.05	0.05	nd	98.94
SEi	19.29	nd	76.88	nd	nd	nd	nd	nd	0.31	96.48
SR	nd	0.04	98.61	nd	0.82	nd	nd	nd	nd	99.47
LT	nd	0.41	97.46	nd	1.52	nd	nd	nd	nd	99.38
LTi	20.98	2.14	74.62	0.01	0.11	nd	nd	nd	nd	97.86
LE	nd	0.39	96.82	nd	1.50	nd	nd	nd	nd	98.71
LEi	20.10	3.07	74.48	nd	0.19	nd	nd	nd	0.11	97.96
LR	nd	nd	99.42	nd	0.20	0.04	nd	nd	nd	99.66

Electron microprobe analyses (weight percent) of the copper matrix (labeled as in Table A) and non-metallic inclusions (labeled with i's following the sample label) of each sample. See the text for details of the experiment and descriptions of the inclusions and copper matrix. Concentrations lower than the detection limits are marked as nd (no detection) in the tables.

Table B (ii)

	S	Fe	Cu	As	Se	Ag	Te	tot %
LR	nd	0.02	99.26	1.21	nd	nd	nd	100.49
LRi	14.08	0.06	73.78	0.03	7.30	nd	3.33	98.58

The copper metal of both blades is densely crowded with non-metallic inclusions of Cu_2S which appear as small rounded gray areas in plane-polarized light. The inclusions are isotropic. As the microscope stage is rotated under cross-polarized reflected light, the colour is maintained. Most of the inclusions are elongated in the direction of working. This is also true of the flattened copper crystals. A typical inclusion area is 4.5 microns^2. Very small, round white specs seen at 1550x or higher magnification proved to be particles of lead.

The relative abundance of the two major phases was estimated by point counting (1000 points each blade with 0.05 mm increment). The composition by volume is 86.4% metallic copper and 13.6% non-metallic copper (I) sulfide for the longer sword, and 88.8% metallic copper and 11.2% non-metallic copper (I) sulfide for the shorter sword.

The composition of the inclusions was investigated by electron microprobe at 15 keV accelerating potential, 25 nA beam current, and point spot mode (ca. 1 æ radius). Pure element standards were used for Fe, Cu, Ag, Sn, and Sb, pure GaAs for As, Cu_2S for S, ZnS for Zn, and PbS for Pb. The analyses are given in Table B. The composition of the metal matrix was also examined. (The lower

Table C (i)

Sample	LR (long rivet)	LB (long blade)	SR (short rivet)	SB (short blade)
V	5825	8116	3331	7257
Cr	115	326	66	205
Fe	2898	5597	1268	2734
Mn	19	45	12	30
Ni	1060	1876	1631	283
Co	51	550	320	40
Zn	931	3945	838	1928
As	3900	17974	1	11363
Se	1254	1724	739	1929
Ag	262	137	253	307
Cd	004	14	4	7
Sn	130	796	391	63
Sb	138	235	379	126
Ba	15	67	753	30
Hg	215	283	142	295
Pb	91	625	750	237

Inductively-coupled plasma quadrupole mass spectrometry (ICP-MS) results of trace element concentrations in ppm (parts per million). Two runs per sample were measured. See the text for details of the experiment. Types of groups are summarized in Table C (ii).

Table C (ii)
Minor Elemental Principal Impurities (all containing >0.1%)

type	definition	sample	% V	% Fe	% As
A	V > As > Fe	LR	0.5825	0.2898	0.3900
B	As > V > Fe	LB	0.8116	0.5597	1.7974
B	As > V > Fe	SB	0.3331	0.1268	0.6001
B	As > V > Fe	SR	0.7257	0.2734	1.1363

Table D (i)

sample	$^{206}Pb/^{204}Pb$	$^{206}Pb/^{207}Pb$	$^{208}Pb/^{207}Pb$
LR	18.35	1.194	2.477
LB	18.26	1.187	2.473
SR	16.08	1.194	2.501
SB	18.84	1.197	2.476

ICP-MS results of stable lead isotope ratios. The mean of ten tests per sample are shown. See text for details of the experiment. Tables D (ii) a and b show the results plotted in the standard way.

limits of detection for elements being analysed under the operating conditions are 0.01-0.07% by weight.) The inclusions proved to be Cu_2S. It should be noted that the lead values reported are unreliable, because the lead is not uniformly dispersed throughout the copper matrix.

Small portions (about 13 mg) of each blade and a rivet from each sword were dissolved in 10 ml HNO_3 (trace element grade) and 10 ml HCl, and then were appropriately diluted and spiked with In for an internal standard, in order to detect trace element concentrations and stable lead isotopes on an Inductively-coupled Plasma Quadrupole Mass Spectrometer (ICP-MS). The trace element results (mean of two runs each) are reported in Table C. The stable lead isotope results (mean of ten runs each) are reported in Table D (Table D (ii) a and b show the results plotted in the standart way). The lead isotopes show a possible common source for the copper in the longer sword blade and its rivet.

Discussion of smelting technology

Pure copper melts at 1150°C. An open camp-fire produces a maximum temperature of 700°C (Tylecote 1986). So a method to produce a higher temperature had to be used, such as inserting a pair of bellows in such a position in the ordinary camp-fire to raise the temperature in at least a portion. Bellows are seen in an Egyptian drawing of a bronze casting or smithing fire dated 1450 B.C. (Coghan 1951). Suitable skins for making such bellows were readily obtainable. A very early introduction of this technique is probable.

Pure copper carbonate (malachite) requires a temperature of 700-800°C for reduction, but the correct CO/CO_2 ratio is also needed. If the ratio is not high enough, only CuO and no metal will be produced. With sufficient air, charcoal will burn to carbon monoxide:

$2\,C + O_2 - 2\,CO$

and malachite will be reduced to copper:

$CO + CuCO_3 - 2\,CO_2 + Cu$

Table D (ii)a Stable Lead Isotopes

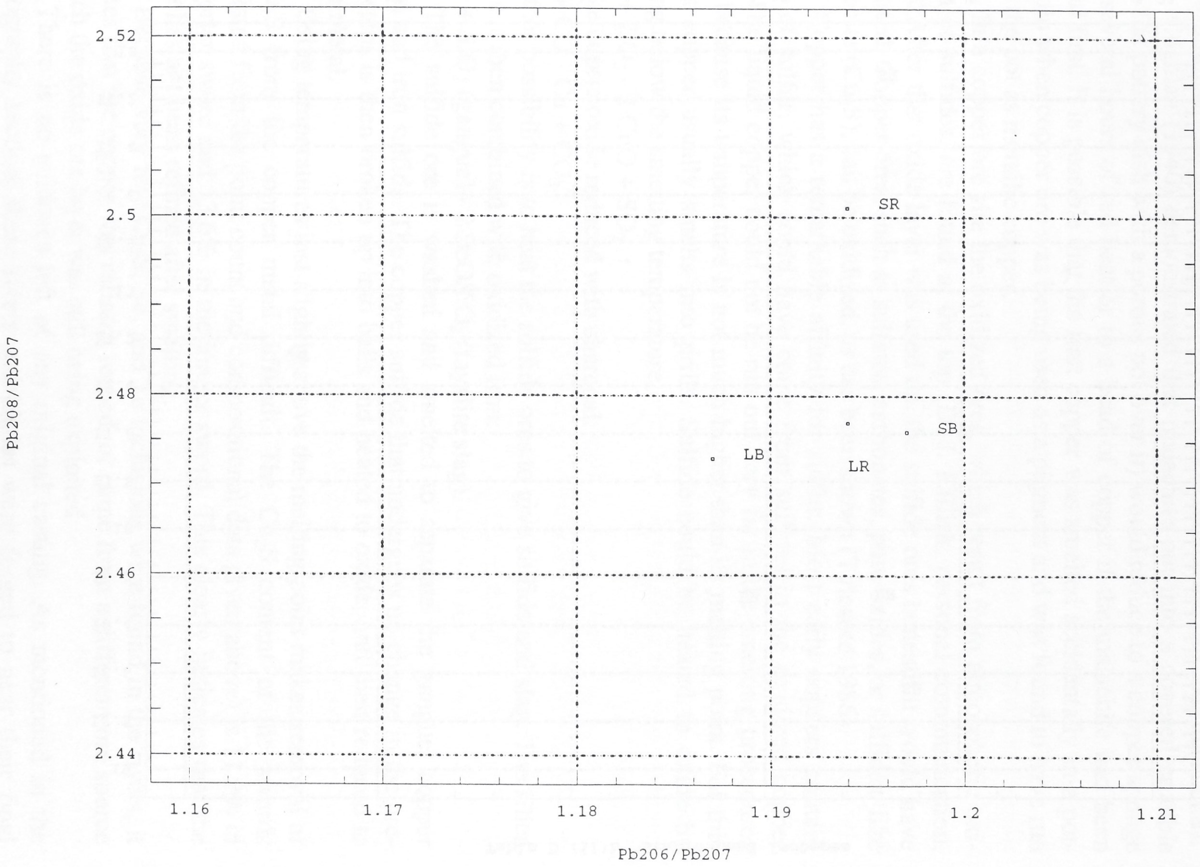
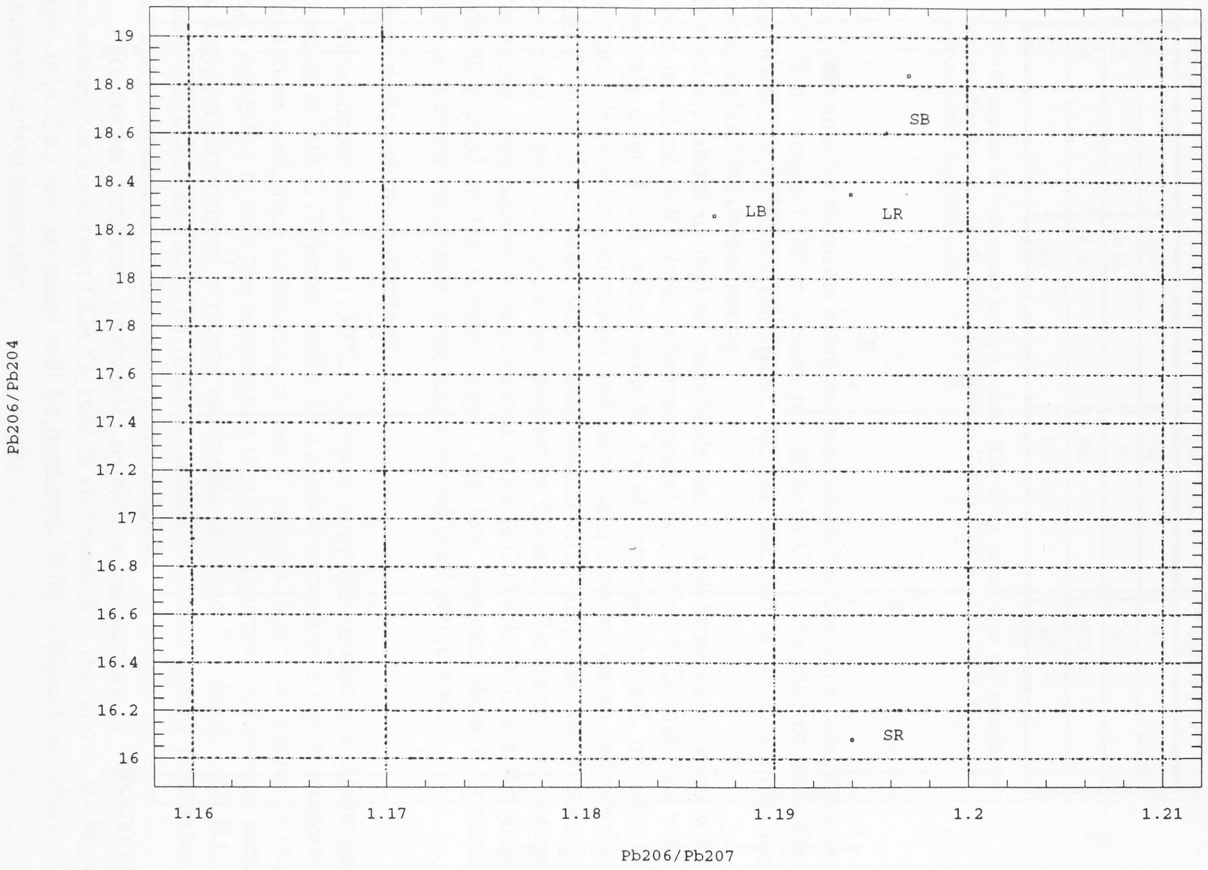


Table D (ii)b Stable Lead Isotopes



However, if there is too much air, carbon monoxide will burn to carbon dioxide:
$2 CO + O_2 - 2 CO_2$.
This would leave an insufficient amount of CO to reduce the $CuCO_3$ (malachite).

Coghlan (1940) demonstrated that malachite put into a covered crucible (i.e. a flat pottery dish with a porous pot over it) would reduce to a copper sponge after several hours of red heat or to a bead of copper if the malachite had been ground first. It is possible that the first copper was smelted accidentally in a pottery kiln when copper ore was being used as a pigment and was found to have run down the pot as metallic copper.

In a copper ore site the oxidized ores, which result from atmospheric oxidation of sulfides, are found at the top (D. J. Killick, personal communication, 1992). After that oxide layer was used up, the sulfide ores beneath it would have been used. Copper ores, such as sulfates, carbonates, pure oxides, or sulfides, like chalcocite (Cu_2S), can be oxidized, as has been shown (Tylecote 1986).

Copper has a remarkable affinity for sulfur. Most early coppers contain traces of sulfur, which could have come from sulfates in the oxidized copper ores. The liquid copper could not be run out very far in the smelting procedures used, because its temperature is not much higher than its melting point. For this reason copper usually smelts into prills. Sulfide could be heated to oxide by roasting below the smelting temperature:
$Cu_2S + 2 O_2 - 2 CuO + SO_2$
then the cupric oxide reduced with charcoal:
$CuO + CO - Cu + CO_2$.
The other possibility is to heat the sulfide ores to give sulfide and slag. The silica gangue is then combined with oxidized iron:
$2 FeO + SiO_2$ (gangue) - $2 FeOSiO_2$ (fayalite slag).

The sulfide ore is washed and smelted to separate the gangue, copper sulfide, and iron sulfide. The copper sulfide that undergoes no change in the previous steps is then broken up into balls and heated to oxide, and then reduced to copper metal.

Using temperatures just slightly above the melting point makes removal of all Cu_2S from the copper metal difficult. The Cu_2S content of the swords (calculated from the point count and compositional data given above) is 11.2% in the shorter sword and 13.6% in the longer sword. This clearly indicates that the copper has not been refined after smelting.

Because very few Cu_2S, Se, and Te inclusions were found in the rivets, it indicates that the copper was refined, reused, or came from a different ore source in which the oxide ore layer was still being exploited.

There is no evidence left of any original casting. As mentioned in the metallography section, these rivets and blades were forged to near their final shape, then cold worked.

Conclusions

Provenance

As stated, the lead isotopes show a possible common source for the copper in the long sword blade and its rivet. If the sources are the same, it would require accepting that the rivets had been refined while the blade had not. This does not seem reasonable. The two pieces also fit into the same subgroup of minor element concentrations. If the two are from the same source, there are only three reasonable scenarios. One, the rivets were made by a different smelter who took greater care and extra time in his work. But then he should be making blades, not rivets. Two, the rivets were reworked left-over material. Three, which seems most likely, all four pieces came from different copper sources, probably in Nubia. The two with similar lead isotope ratios and trace element concentrations could come from different outcrops of the same ore vein. It also seems unlikely that the blade and the rivet came from the same copper source because there is Se and Te in the inclusions of the rivet, but not in the inclusions of the blade. Much lead isotope work remains to be done on all the small copper sites that would have been found when looking for gold, remains to be done. When it is completed, these, and possibly other lead isotope analyses of this site, may be compared to locate exact sources.

Function

The final step of cold hammering only the edges and end produced the hardest blade that could be made with copper. As copper hardens, it also becomes more brittle. The fact that the centres of the blades contain annealed crystals does provide some additional stability (i.e. to keep the blade intact when force is applied). These blades indeed took a lot of effort to make and were the best blades that could be made with only copper at hand. However, by the third millennium, bronze was being exploited in the Middle East and around the Mediterranean basin (van der Merwe 1980). Bronze weapons are a good deal harder and sturdier than copper. Since the swords studied are all copper, it could indicate either that they were ceremonial in use (all were found in graves) or that Nubians had no access to tin. However, it seems unlikely that they had no access to tin, since trade was certainly taking place at this time. In addition, the handle-blade connection looks particularly susceptible to breaking if force were applied in any direction. All of the evidence, therefore, indicates a ceremonial use, or as suggested by Mahmoud El-Tayeb (personal communication, 1992), they may in life have been worn decoratively.

Appendix

Samples were drilled out of the center of each ivory handle. Carbon and nitrogen stable isotopes were to be measured on the Light Isotope Prism Mass Spectrometer. No collagen was preserved, so no measurements could be made. Apatite was then prepared; but only one sample survived preparation and only a small sample of CO2 was obtained, because the ivory was very contaminated. No reliable value could be obtained.

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