RESEARCH LABORATORY FOR ARCHAEOLOGY
AND THE HISTORY OF ART

TEL. 55211

6 KEBLE ROAD
OXFORD

ETH/CAB

17th February 1967.

Miss E.K. Ralph,
University Museum,
University of Pennsylvania,
33rd and Spruce Streets,
Philadelphia,
Pennsylvania, 19104.

Dear Beth,

Martin has handed me your letter concerning the metal analysis of 100 samples. Our trouble is that we are very heavily tied up with our own work at the moment and I think that, on an ordinary basis, we would not be able to do your samples for something like twelve months.

However, I have spoken to Mrs. Millett and she would be willing to do the samples on a semi-commercial basis in her spare time at weekends etc. I have thought that £1 per sample would be reasonable.

We would require some 20 mg of metal drilled in such a way that the corrosion layer is first of all thrown away. If it proves impossible to let us have 20 mg, less might suffice, although the accuracy would be diminished pro rata. The elements we would look for would be as follows:- copper, lead, tin, antimony, arsenic, nickle, bismuth, gold, silver and iron, & zinc

There is one point that I should make and that is that we do, in fact, in our bronze analyses, always ratio all elements to copper. This is a more realistic way of expressing results in that it obviates the necessity for adding an internal standard and also does not complicate the picture when extraneous matter gets in to the drillings, such as sand etc.

If you were interested in such a proposal, Mrs. Millett says she can finish the 100 samples within about six weeks of the samples arriving in this country.

Incidentally, I am not surprised that your commercial company got in to trouble doing fluorescence. It sounds as though they got muddled up between the tin and lead lines. This is easy to do when you are not prepared.

With best wishes.

Yours sincerely,

Carol Bennett

for E. T. Hall

January 23, 1968

Dear Mrs. Millet:

About a year ago, we had some correspondence about your doing spectrographic analyses of samples of Egyptian brouzes. I am wondering if your offer of doing them in your spare time for £ 1 per sample is still in effect, or whether you are now too busy with other things. Also, perhaps, the charge should be adjusted for devaluation.

If you do have the time, we should like to send about 50 samples around the middle of February, 1968. Most of them are now mounted in plastic for the metallurgical examinations which will have been completed. In other words, the mountings may be destroyed. If you prefer, we can destroy the mountings here, but one advantage of sending them this way is that they are numbered clearly on the plastic.

Sincerely yours,

Elizabeth K. Ralph

EKR/ek

March 13, 1968

Mrs. A. Millet
Research Laboratory for Archaeology and the History of Art
6 Keble Road
Oxford, England

Dear Mrs. Millet,

With the thought that my letter of January 23rd may have gone astray due to some secretarial difficulties here, I am writing again to ask if you are still willing to do some spectrographic analyses of samples of Egyptian bronzes and c coppers in your spare time at a cost of £ 1 or more per sample.

If you do have the time, we should like to send 50 to 100 samples around the end of March. Instead of sending the mounted samples, we shall plan to resample the objects and send you 20 mg of each. Do you need drillings, or could we send you the 20 mg in one or two pieces (after the removal of the corrosion layer)?

Sincerely yours,

Elizabeth K. Ralph

EKR/abn

RESEARCH LABORATORY FOR ARCHAEOLOGY
AND THE HISTORY OF ART

TEL. 55211

6 KEBLE ROAD
OXFORD

March 25,1968.

Miss.E.K.Ralph.
The University Museum,
University of Pennsylvania,
33rd and Spruce Streets,
Philadelphia,
Pennsylvania 19104. U.S.A.

Dear Miss Ralph,

Thank you for your letter of the 13th inst. I did not receive the earlier letter you mentioned so as you presumed it must indeed have gone astray. I will undertake to do the analyses you request. How quickly would you need this work doing?

If you are wanting them done quite quickly and you could manage to get them to the laboratory in time I could do the bulk of them in the Easter vacation. This would mean them arriving here before the 10th of April if possible.

The samples would be perfectly alright sent as you suggest. Will you want the complete bronze analysis I normally do i.e. Cu,Sn,Pb,As,Sb,Ni,Bi,Fe,Zn,Ag and Au? Also will you want the analyses expressed as percent or as parts per 100 parts of Cu?

With the number of samples in the region of your quotation of between 50 and 100 the work should be completed in 6 or 8 weeks.

Yours Sincerely

anne Millett.

Anne Millett.

~~March~~ April 2, 1968

Mrs. A. Millett
Research Laboratory for Archaeology and the History of Art
6 Keble Road
Oxford, England

Dear Mrs. Millett,

Thank you for your reply of March 13th. Under separate cover we are mailing today 38 samples from Jordan, Egypt, and Mesopotamia as listed on the enclosed sheets. For the 4 samples contained in the bakelite mountings, no more material exists. You may destroy the mountings and do whatever you wish with them. If you find that there is insufficient non-corroded metal, please donnot bother to analyze them.

We should like to have the complete bronze analysis that you usually do - Cu, Sn, Pb, As, Sb, Ni, Bi, Fe, Zn, Ag, and Au. We should prefer to have the analyses expressed as percent of the total alloy.

Shall we send a purchase order for £ 38 or for more than this amount?

Many thanks for your willingness to do these analyses. If we may bother you with another series at a later date, would the summer or fall suit you better?

With best regards,

Elizabeth K. Ralph

EKR/abn

4/1/68

Jordan Series

1	91 mg
2	86 mg
3	62 mg
4	26 mg, 3 pieces
5	50 mg
6	223 mg
7	144 mg
9	85 mg, from large diameter of longer of 2 parts
10	47 mg
11	41 mg, from least corroded piece of 4 pieces
12	140 mg, from larger of 2 parts
15	41 mg
17	42 mg, from largest piece
18	116 mg
19	100 mg
20	75 mg
21	41 mg
22	272 mg
23	59 mg
34	53 mg, section from back of knife; cutting edge missing; some deep corrosion left on one side
46	206 mg, piece may contain some corrosion

Totally destroyed in bakelite mountings: 13, 25, 26, 31

4/1/68

Egypt

E 9996
E 9586
E 9997

E 14224
E 10884
29 - 65 - 651
E 2235
E 9699
29 - 65 - 652
E 9598

Mesopotamia

31 - 17 - 186
53 - 11 - 303
31 - 17 - 243

4/1/68

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21	41 mg
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23	59 mg
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46	206 mg, piece may contain some corrosion

Totally destroyed in bakelite mountings: 13, 25, 26, 31

Egypt	Mesopotamia
E 9996	31 - 17 - 186
E 9586	53 - 11 - 303
E 9997	31 - 17 - 243

E 14224
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Egypt	Mesopotamia
E 9996	31 - 17 - 186
E 9586	53 - 11 - 303
E 9997	31 - 17 - 243

E 14224
E 10884
29 - 65 - 651
E 2235
E 9699
29 - 65 - 652
E 9598

April 23, 1968

Mrs. A. Millett
Research Laboratory for Archaeology and the History of Art
6 Keble Road
Oxford, England

Dear Anne,

That was a good idea to drop the formal ~~manners~~ names We didn't expect a report of your analyses so soon, but we are certainly glad to have it. It arrived just in time before our spring term ends when people go off on expeditions or disappear for other reasons. I am sending copies around to the various archaeologists who are concerned with this project, and I am sure that they will be very happy with the analyses.

We do not want any of the material returned. Mr. P.C. Shumaker (201 Laboratory for Research on the Structure of Matter, Department of Metallurgy, University of Pennsylvania) is sending you a purchase order for 45. If there is any trouble or it doesn't arrive, please don't hesitate to write to him. I am leaving for Greece this Friday, so I won't be of much help until July.

We'll plan to send you another series in September or sooner. Many thanks for these.

With best regards,

Elizabeth K. Ralph

P.S. It would be useful to know the limits of detection, but there is no hurry about it.

EKR/abn

July 27, 1968

Mrs. A. Millet
Research Laboratory for Archaeology & the History of Art
6 Keble Road
Oxford, England

Dear Anne:

We were so pleased with your spectrographic analyses, that we should like to send you more samples.

Under separate cover, I am sending you 48 from Egypt. These have all been mounted in plastic for metallographic examination. The mountings (and the samples) can all be destroyed, and some may be too small. If they are not suitable for your use in this form or if you are too busy, please don't hesitate to send them back. The list of samples is as follows:

E 6
E 289
E 954
E 1055
E 2355
E 2535C
E 2900
E 4660
E 9202
E 9374
E 9588
E 9521
E 9736
E 9747
E 9749
E 9753D
E 9754
E 9999
E 10304
E 10342A
E 10866
E 10885
E 11000
E 11116
E 11127
E 11134
E 12512

E 13144
E 13156
E 13379

29-65-629
29-65-633
29-65-642
29-65-650
29-65-656
29-66-763
29-85-83
29-85-111
29-85-171
29-85-187
29-85-240
29-85-289
29-85-322
29-85-366

31-27-140
32-42-28
32-42-68

Our grant expires on September 30, so if you are free to do these, we shall appreciate it if you can send us the bill in early September.

With best regards,

Elizabeth K. Ralph

EKR:kw

RESEARCH LABORATORY FOR ARCHAEOLOGY
AND THE HISTORY OF ART

TEL. 55211

6 KEBLE ROAD
OXFORD

August 20th 1968.

Miss E.K.Ralph,
The University Museum,
University of Pennsylvania,
33rd & Spruce Streets,
Philadelphia, Pennsylvania 19104.

Dear Beth:

Thank you for your letter of the 27th of July. I returned to Oxford from a working trip to Greece only this morning, hence the delayed reply.

I am glad that the analyses I did for you proved so satisfactory and will be pleased to do the further 48 which were also waiting for me on my return.

I have only quickly inspected them, but as far as I can tell, all seem sufficient and suitable for analysis, though I will be more certain on this when I have weighed them all out.

You ask me about a bill for them before the end of September. It will be a little difficult for me to complete the work before then, as t the technician who makes my carbons is away until September. However if we cost them the same as the previous batch the bill will be £60. I hope that this arrangement is satisfactory, meantime, I shall start on the preliminary preparation so that when I have all the necessary materials, the delay will not be too long for you.

With Very Best Wishes.

ANNE MILLETT.

August 28, 1968

Mrs. A. Millett
Research Laboratory for Archaeology
and the History of Art
6 Keble Road
Oxford, England

Dear Anne,

Hope you enjoyed Greece as much as I did in May. I was glad to hear that most of the samples seem to be sufficient for analysis. One went astray in our shipping room - no. 32-42-68, and I'll send it either with this letter or separately.

The business office is arranging to send 60, but if it or the order does not arrive, please let me know.

Please don't feel too pressed about completing the analyses and do them when convenient for you.

With very best regards,

Elizabeth K. Ralph

EKR/mhr

October 30, 1968

Dr. M. J. Aitken
Research Laboratory for Archaeology
6 Keble Road
Oxford, ENGLAND

Dear Martin:

Thank you for the reprints which you have sent from time to time.

At the moment I am wondering about Mrs. Millett and the spectrographic analyses. Stuart Fleming mentioned that she was leaving Oxford, which I was sorry to hear. Could you or she let me know whether she had or will have time to finish the last batch of Egyptian samples which we sent to her? Second question is: may we send you a new lot - 35 samples of Urartian bronzes, and if so, will the charge be the usual £ 1 per sample? Sorry to bother you with these queries. ✓

We enjoyed seeing Dr. Hall in Atlantic City and Stuart here; now it's your turn.

Best regards,

E. K. Ralph

EKR/emf

RESEARCH LABORATORY FOR ARCHAEOLOGY
AND THE HISTORY OF ART

TEL. 55211

6 KEBLE ROAD
OXFORD

November 15th 1968

Miss. E. K. Ralph
The University Museum
University of Pennsylvania
33rd & Spruce Streets
Philadelphia 4
Pennsylvania, U.S.A.

Dear Beth:

Martin passed over to me your query about your analyses. I am very sorry indeed that I have taken so long to complete them, and that I haven't kept you informed of the progress of them. I have had some delay in getting the special carbons I need to do them, in fact they have arrived this morning as I write this. It occurs to me that if you want a further lot analysing, I could well include them in the same run as the outstanding batch. The cost per analysis would be as usual £1 + £7 for materials.

As you have heard it is quite true that I will shortly be leaving Oxford though my connections with the laboratory will not be severed. I have much outstanding work and at the moment I am firing plates only so that I can complete the calculations and statistics on them away from the laboratory.

Best wishes to you, looking forward to hearing from you shortly.

Yours;

Anne

A. Millett

November 21, 1968

Mrs. A. Millett
Research Laboratory for Archaeology
6 Keble Road
Oxford

Dear Anne,

Many thanks for your letter. I was glad to hear that you are not leaving Oxford completely, and will take advantage of your kind offer to include another batch of bronzes.

Under separate cover I am sending 35 samples of Urartian bronzes, and a new purchase order (or check) will follow.

Best of luck in your new location.

With best regards,

Elizabeth K. Ralph

EKR/mrb

January 22, 1969

Mrs. A. Millett
Research Laboratory for Archaeology
6 Keble Road
Oxford, England

Dear Anne,

Thanks for your letter of November 15th. We sent to you the additional series of Urartian bronzes, I think, in November, and I arranged for payment, whihh, I hope, has arrived.

The Egyptologists are very eager for the results of the Egyptian series. Is there any chance of our receiving them before March 1st to meet a publication deadline?

With best regards,

Elizabeth K. Ralph

EKR/mrb

April 3, 1969

Mrs. A. Millett
"Aynhoe"
28, Kings Moor Road
Stockton-on-the-Forest
YORK YO39TY
ENGLAND

Dear Anne:

Many thanks for all the analyses. We had a lot of snow here in February and March, but, unfortunately, I missed it because I was in southeastern Mexico where it was much too hot and humid.

I I was glad to hear that you are happy in York. I spent five days there while with the U.S.A. hockey team in 1953 and I thought it was very beautiful. I should very much like to visit again, and hope that I can find an excuse before long.

With best regards,

Elizabeth K. Ralph

EKR/mrb

RESEARCH LABORATORY FOR ARCHAEOLOGY
AND THE HISTORY OF ART

TEL. 55211

6 KEBLE ROAD
OXFORD
OX1 3QJ

14th March, 1972

Dr. Elizabeth K. Ralph
Museum Applied Science Center for Archaeology
University of Pennsylvania
33rd & Spruce Streets
Philadelphia
Pa 19104
U.S.A.

Dear Beth,

Martin has passed your letter to me concerning spectrographic analysis. The situation at the moment is that although we continue with the analysis of ceramics we have for a long time been of the opinion that the analysis of trace impurities in bronzes rather a waste of time - at least we have this opinion until somebody shows us some evidence to the contrary. For this reason we are spending our effort on the former type of activity and are not set up for bronze analysis.

We have recently recalibrated our instrument for ceramics, but have not done this for bronzes. Since recalibration is probably two months work, we are obviously loath to do this even for you. If at a later date we get round to doing this recalibration we would be very happy to undertake your work, but cannot say when this would be (i.e. this year, next year, sometime, never). I fear, therefore, that you will have to tell whoever it is that this is the case.

Hope to see you somewhere, sometime soon.

With best regards,

Teddy

E.T. Hall

Tues & Thurs
8-10 class

Geo Bass told

Philip Betancourt from Temple
to call you 787-7837

Re: Bronzes CA5-7575
ext 49

home 609-

Fri morn, ~~home~~ 461-9291

Gerald- Ash 3.4 m = semi-quantative st'd

Minoan period

Trace elements - Quant.
Majors too } not quant.
Objects - ~ 12
Drill holes -

Next week OK - ~~up to 3 x 3~~ 2½ x 2" high

Also meas. Th/U ratios or concs.
" " C^{13}/C^{12} "

Mr. Robert White 8718 208 LRSM
Matthew Kresz - 7917

March 8, 1972

Dr. M.J. Aitken
Research Laboratory of Archaeology
6 Keble Road
Oxford, England

Dear Martin,

Many thanks for the notices of your conference, etc. I wish that one of us could come, but we are hoarding what little travel money we have and it is too early for field trips.

We have another request for bronze analyses - emission spectographic. I am wondering if Mrs. Millett or some one is still willing to do these and if so, is the cost still about 1£? We have roughly 12 objects in this series, representative of Minoan Periods.

With best regards,

Elizabeth K. Ralph

EKR/mm

EGYPT

April 10, 1967

Metallurgy Project-Progress Report

The Egyptian Section, in association with the Department of Metallurgy, has undertaken a technological and historical study of some 58 Egyptian metal objects. All of the artifacts have been analyzed both metallographically and spectrographically. Hopefully, the end result of this project will be at least a tentative assessment of the sophistication and complexity(or lack of same) of the techniques involved in making these pieces. At the same time the archaeological background of each object has been ~~checked~~ studied, so that any changes in metal-working techniques which might have occurred over time could be recorded.

The following results have been obtained up to this point:

(1) Egyptian metal-working techniques were not significantly improved through the course of pharaonic history. This is not to be construed as implying some innate Egyptian conservatism, however, but rather as indicating that metallurgical techniques had developed as far as was practical and necessary at the time.

(2) The Egyptians never fully understood the exact details of the annealing process, as can be seen by the fact that metal objects were rarely ever annealed for the proper length of time. In this connection it should be noted that the metal objects were most often under-annealed.

(3) The removal of all of the impurities from the copper ore was rarely attempted, or at least this is a possible explanation of the situation whereby only a handful of objects were considered as "clean" by the metallurgist. On the other hand it is also possible that the Egyptian smelting techniques were not good enough to remove all the impurities.

(4) The Egyptians differentiated in their metal-working techniques between those objects which would be subject to heavy stress in normal use, and those objects which would encounter much less stress. For example, mirrors were almost invariably only cast, hammered, and annealed, while axeheads were cast, hammered, annealed, and then re-hammered.

[11/28/67]

ANALYSES OF EGYPTIAN COPPER OR BRONZE OBJECTS.

The analyses were made as a check on certain spectrographic and x-ray fluorescence analyses done by W.B. Coleman Co., which in some cases seemed to contradict each other.

It was assumed that the spectrographic analyses were qualitatively correct. Since the x-ray fluorescence analyses gave results for only copper, tin and lead, these three metals were determined for each specimen analyzed here (except lead in E-9374), but in some cases one or more of the elements iron, silicon and nickel were determined also.

Several procedures for determining copper were tried and in the absence of facilities for the electrolytic method the determination as cuprous thiocyanate was selected as being most reliable. Tin was determined as oxide, lead as sulphate, iron as oxide (ferric), silicon as silica and nickel as nickel dimethylglyoxime.

In the usual analysis of a copper alloy tin is left as insoluble stannic oxide while the other metals go into solution, but the stannic oxide invariably is contaminated with small amounts of other metals such as copper or iron. The recommended methods for purifying the impure stannic oxide are tedious and often unsatisfactory, and results given here are from unpurified or partially purified tin oxide. This is indicated by the symbol $<$.

Results:

Specimen Constituent	Wire E-9374	Arrow Head 29-85-171	Axe E-14224	Mirror E-10866	Fragment E-12512B
Copper	99.00	66.33	94.26	93.13	88.57
Tin	<0.17	<16.64	<0.12	<0.08	<7.53
Lead	-	5.23	N.F.	N.F.	0.76
Iron	-	0.16	1.07	0.46	0.54
Silicon	-	-	-	-	0.21
Nickel	-	0.16	-	-	-
Total found	99.17	88.52	95.45	93.67	97.61

Figures are percentages, N.F. means the constituent was not found, while a dash means it was not determined.

Conclusions:

In general the results support the spectrographic analyses except for some minor discrepancies in tin and lead. The x-ray fluorescence results in some cases differ considerably from those obtained here, and it is evident that x-ray fluorescence analyses are reliable only when the optimum sample required by the analysis is available.

A.E. Parkinson A.E.P.
November 28, 1967

June 28, 1968

Metallurgical-Archaeological Project
Egyptian Section Final Report
by James Weinstein
Supervisor: Mr. David O'Connor

Fifty copper/bronze artifacts in the Egyptian Collection of the University Museum were selected for metallographic and spectrographic analysis. In addition, eight objects were selected for spectrographic analysis only. The dates for this material ranged from the First Dynasty (ca. 3200-2900 B.C.) to the end of the New Kingdom (ca. 1085 B.C.). Included within this material were a variety of metal types: mirrors, axe-heads, wire, pins, needles, adzes, and chisels.

The metallographic analyses were made by Mr. Dan Tomalin, a graduate student in the Department of Metallurgical Engineering, University of Pennsylvania. The spectrographic analyses were carried out by Mrs. Ann Millet, Laboratory for Archaeology and the History of Art, Oxford University. The information obtained from these technical studies was correlated with the archaeological and lexicographical evidence on Egyptian copper metallurgy by Mr. James Weinstein; the results will shortly be submitted to the Department of Oriental Studies at the University of Pennsylvania as a Master's Thesis.

The most significant conclusion to be drawn from the metallographic analyses is that there is no noticeable improvement in the complexity or sophistication of the metallurgical techniques practiced in Egypt in the two thousand year period covered by this project. The same mistakes made by the Egyptian coppersmith in 3000 B.C. were being made in 1200 B.C.: e.g., annealing an object for an insufficient length of time, or excessive hammering (as evidenced by internal cracking). Most Egyptian artifacts, whether made of copper, arsenical-bronze or tin-bronze, were made by the same technique of casting, hammering, annealing, and final re-hammering; there was no correlation between the type of artifact and the method of production, or between the chemical composition and the method of production.

The spectrographic analyses have shown that the use of arsenical copper preceded that of tin-bronze in Egypt. Although not all of the analyses are available at the time of this report, it seems likely on the basis of the present material that arsenical copper came into use in Egypt towards the end of the Old Kingdom (ca. 2400-2300 B.C.), while tin-bronze cannot be indisputably attested until the beginning of the Middle Kingdom (ca. 2000 B.C.). This situation parallels the precedence of arsenical-bronze over tin-bronze elsewhere in the ancient world; it also shows that developments in Egyptian metal-working may be related in some cases to developments in metallurgy in other areas.

A considerable amount of archaeological, geological, and lexicographical evidence has been collected to supplement the evidence obtained from the analyses themselves. Among the most important conclusions drawn from this research are:

(1) The Egyptian word for tin-bronze (and arsenical-bronze?), ḥsmn, was not introduced until the Fifth Dynasty; this is about the same time as the first documented use of arsenical-bronze. There may possibly be some connection between the two events, but no firm conclusions can yet be drawn.

(2) The Egyptian language contains relatively few terms relating to metal-working techniques. In a number of cases the words which were applied to metal-working were simply derived from already existing words. For example, the word which means "to melt (copper)", <u>nbi</u>, has a much earlier history in the Egyptian language as the word <u>nbi</u>, "to swim."

(3) There is no definite evidence for the importation of copper from foreign lands in the third millennium B.C. The sources which the Egyptians exploited at this time were on the Sinai peninsula, in the Eastern Desert, and in the northern Sudan.

(4) Analysis of geological reports reveals that both Egypt and the northern Sudan contain tin deposits; hence, the commonly accepted theory that Egypt has no tin resources, and that, therefore, the Egyptians must have imported all of their tin in order to make tin-bronze, is no longer valid.

(5) The source of arsenic minerals -- such as realgar or orpiment -- needed to produce arsenical-bronze is a complete mystery. The Egyptian words for realgar and orpiment do not appear until almost 800 years after the introduction of arsenical-bronze, and the few times that these minerals are referred to in later times give no hint of their provenience. There are no known deposits of realgar or orpiment in Egypt. Another possible source of arsenic, the sulf-arsenate ores, are not known to occur in Egypt. The meager evidence now available suggests that the sulf-arsenate ores or non-

cupriferous arsenic minerals were obtained by the Egyptians through trade.

EN-1026-ES REV. 5-64

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INCORPORATED
WILMINGTON, DELAWARE 19898

ENGINEERING DEPARTMENT
EXPERIMENTAL STATION

2/2/72
Will come in near future

September 6, 1968

Miss Elizabeth K. Ralph, Associate Director
Museum Applied Science Center for Archaeology
The University Museum
University of Pennsylvania
33rd and Spruce Streets
Philadelphia, Pennsylvania 19104

Dear Miss Ralph:

I am transmitting herewith a summary report covering my metallurgical examination of the eleven Mesopotamian and Egyptian artifacts received from you. These have been of considerable interest to me, particularly from the standpoint of the oxidation and corrosion phenomena which they display, and also from the level of technology indicated in their manufacture. I have been reluctant to do much destructive examination of the artifacts and in each case only a small piece of copper or bronze was cut out for metallography from a site where a larger sample had already been removed by others.

As I state in the Recommendation Section, there is some more work that would provide new and useful information and I would be interested to continue the examination of several of the pieces in the collection. It would also be possible for me to undertake further work on other artifacts, if this can be done over some extended period of time.

I thought at one time that I might have found a unique example of early Egyptian soft solder work but Cyril Stanley Smith has cast cold water on that idea. He, in fact, stated that he would have to be present at the discovery of the artifact and follow it to the laboratory to be convinced that the XII Dynasty Egyptians used Pb-Sn alloys for soft soldering (I have found several references to the use of lead as a soft solder in Egypt and in Mesopotamia as early as 3000 B.C. but not to tin-containing lead).

The artifacts and metallographic mounts made can be returned whenever you wish.

Sincerely yours,

ENGINEERING RESEARCH DIVISION

Norm Nielsen

N. A. Nielsen, Research Fellow
Engineering Materials Laboratory

NAN:pko

METALLURGICAL EXAMINATION OF ANCIENT BRONZE AND COPPER ARTIFACTS

A metallographic examination of eleven ancient bronzes and coppers is in progress to provide information on the metallurgical history of the artifacts as well as on the level of metals technology and metal-working craftsmanship in existence at their time of manufacture. The items under examination are listed in Table I below:

Table I

Museum Number	Description
31-17-186 (U.14238)	Socketed axe from PB1687, (Mesopotamia)
53-11-303 (3N187)	Pin, Nippur Ur III, (Mesopotamia)
31-17-243 (U.14244)	Chisel, ED III, (Mesopotamia)
E9996	Flat axe blade (Egypt)
E9586	Square sectioned chisel (Egypt)
E9997	Flat adze blade (Egypt)
E14224	Curved sharp edged weapon (Egypt)
E10884	Mirror (Egypt)
E2235	Mirror (Egypt)
29-65-651	Mirror (Egypt)
E9598	Bowl (Egypt)

In Table I the first six items are dated from 3000 B.C. to 2000 B.C. The three Mesopotamian artifacts are true bronzes (copper-tin alloys). The remaining eight artifacts are coppers of varying purity as shown in Table II. Compositional differences which affect microstructure will be discussed in the individual summary sections which follow.

Mesopotamia

31-17-186 Bronze Socketed Axe

This is a fine example of a cast, shaft-hole axe with intentionally designed thickening of the metal at the ends of the socket. It appears sound but is extremely severely embrittled by interdendritic oxidation which has completely penetrated the thickness section of the socket end, about 4 mm. A heavy layer of Cu_2O has formed at the original external and internal surfaces of the socket. Corrosion and oxidation occurring over a 4000-year time span have caused a sharply segregated distribution of copper and tin corrosion products. It appears also that a "destannification" process has taken place. Tin may have preferentially ionized and oxidized leaving behind a copper-enriched matrix. There is also visible evidence of metallic copper in the corrosion product layers.

In the "sound" areas of the casting are many microcracks which can be interpreted as intracrystalline stress-corrosion cracks. (If confirmed, these may be the oldest stress-corrosion cracks yet documented!)

Another feature of interest is some mineralized wood residue present in the shaft hole. In polished cross section, the original cellular structure of the wood handle of the axe can be seen. The residue is separated from the metal by a well-defined interfacial zone of Cu_2O. Photomicrographs showing this as well as microstructural characteristics of the bronze appear as Figure 1.

53-11-303 Pin, Nippur III

The pin is heavily encrusted with corrosion product (a thick layer of malachite overlying an equally thick layer of cuprous oxide, Cu_2O) which is coated with embedded particles of sand and fragments of mineralized organic material. Originally cast, it has been given sufficient forging and annealing to eliminate the dendritic cast structure. The end of the pin shows an equiaxed grain structure. Oxidation penetration of this structure has been much less severe than in the porous bronze axe casting. Nevertheless, intergranular oxidation has occurred to a depth of about 0.5 mm in the surface. As the photomicrographs in Figure 2 show there is a well defined subsurface zone of oxidation paralleling the surface of the pin.

The high lead content of this bronze, 3.2 percent, makes this alloy unique in the group of three. Compositionally it is quite similar to some present-day leaded tin bearing bronzes. The gray inclusions in the microstructure are believed to be lead. Confirmation could be obtained by micro spot testing or with the electron probe microanalyzer.

31-17-243 Bronze Chisel

This tool is over 23 cm. long and about 4 cm. wide at the sharpened end. It is a cast, forged and annealed piece. Forging did not completely break down the cast structure as evidenced by surface indications of dendritic structure. Centerline porosity is also present from the original casting. The hot-working and annealing given the piece did not result in a homogenous composition or a uniform microstructure. Oxidation of the alloy has severely embrittled it (the chisel would probably fracture if dropped upon the floor). Attack has been primarily intergranular and most severe along the central internal zone of the chisel. Preferential oxidation along slip systems in the alloy is very beautifully illustrated in regions of incomplete annealing.

Typical photomicrographs are shown in Figure 3. (The specimen was cut longitudinally from the "striking end" of the chisel).

E9996 Flat Copper Axe

This and all other copper artifacts in this series were initially prepared as castings and subsequently shaped by forging with sufficient intermediate annealings as the metal-worker thought necessary. The present specimen has been crudely hammered to shape; surface indentations are easily seen. The edges to the sides feather out from a central zone thickness of about 4 mm. The "working edge" of the axe is blunt and about 2 mm thick over a distance of 20 mm. The dendritic cast structure is visible here in the surface of the axe. Edge cracking from too severe forging is present in the sharpest feather edges.

The photomicrographs in Figure 4 show the compositional heterogenity of the dendritic copper still superimposed on patches of equiaxed wrought structure. A brittle fracture crack related to the residual stress pattern in the copper was found. Distortion of the cast structure at the working edge of the axe is visible.

E9586 Square Sectioned Copper Chisel

This chisel, about 4.5 mm square, was cast in this shape and size. A crossed diagonal etching pattern can be faintly seen in the polished and etched cross section. At 250X as shown in Figure 5 in photomicrographs of two corners of the specimen, forging on each surface followed by annealing has resulted in a very fine grain-sized structure which still retains the macro-directionality of the casting. Two other photomicrographs show a large elongated slag inclusion before and after etching. With this exception the copper is very clean with a low inclusion content consistent with the spectrographic analysis.

E9997 Flat Copper Adze Blade

This adze had a sharper working edge than the flat axe blade (E9996). On portions of the surface there has been severe interdendritic corrosion-etching leaving the original cast dendritic structure clearly visible. Considering that the piece was probably cast on an open stone mold, the size of the dendrites, some of which are 1 cm or more in length, suggests that the freezing process took place extremely slowly and probably that the mold was intentionally heated. It is unlikely that the blade was cut or sectioned out of a thicker ingot. If a large grained casting was worked down to 3 mm thickness, dendrites of the size found would not be retained.

The poor homogenization (compositional) and annealing are shown in the photomicrographs in Figure 6. The craftsmanship employed in making the blade is better than that used in E9996. The adze is flat and uniformly tapered. Shown also in Figure 6 are the typical inclusions present in the copper. The level appears consistent with the purity of the metal listed in Table I. The photomicrographs indicate also that nodular-shaped portions of the surface have been undermined by corrosion and that these nodules have a higher level of corrosion resistance than the matrix copper. Emission spectrographic analysis indicates that the isolated nodules contain greater than: 0.5 percent lead, 0.5 percent tin and 0.05 percent bismuth. This suggests that the nodular copper is enriched in lead and tin, one or both of which may have slightly enabled the copper to provide a slight degree of cathodic protection.

E14224 Curved-Edge Weapon

This artifact, about 18 cm long, and having a curved sharpened edge is believed to be the blade of slashing type weapon. Three holes spaced 7.8 cm and 7.65 mm apart and in a straight line (the center hole is 1 mm off line) were presumably drilled to allow the blade to be attached to an appropriate handle or shaft. The three holes are separated by crescent-shaped cut outs in the blade. These cut outs are ridged possibly by rolling or peening. The holes appear to have been pierced through, then reamed to shape from each side employing a tapered tool. The overall level of craftsmanship displaced in this piece is far beyond that shown in any other artifact described in this report. It is a specimen of considerable technical and artistic merit. The photomicrographs in Figure 7 show two of the holes in the blade, the plastically deformed structure in the ridge and a well-annealed, equiaxed grain structure a few mm below the ridge. The writer did not remove a sample from the sharpened edge of the blade for metallographic examination. If this piece was in fact used as a hand-wielded slashing weapon, the working edge would have been hardened by cold work. Its microstructure would be similar to that of the ridge.

E10884 Copper Mirror

This is the heaviest of three Egyptian copper mirrors examined in this study. Its weight is 402 g. versus 95 g. for E2235 and 70 g. for 29-65-651. The disc is not quite circular, but somewhat oval or oblate, about 15 cm across and 13 cm high. Thickness is somewhat greater than 3 mm. If was probably originally inserted in a handle similar to those pictured in Wilkinson[1]. A fitting of copper sheet was riveted to the bottom of the mirror sandwiching the mirror disc and providing a means of attachment to a more ornate handle.

In E10884 three rivets were used in a line to attach this fitting which at some time in the past broke off at the periphery of the mirror. The rivets were presumably manufactured at the same time the mirror blank was cast. They provided a very effective fastener in this case. The rivet heads are mushroomed by hammering or peening and the joint is still very secure.

Examination of this "sandwich" joint construction, however, revealed the presence of lead and suggested that this mirror might provide a documented example of the very early use of soft solder by the Egyptians. Unfortunately, this is not clear-cut. The joint was cathodically cleaned by the writer to remove heavy corrosion product encrustation over both the copper and the lead. It was apparent then on microscopic examination that the solder had been put into the joint to repair a fracture in the riveted copper fitting. The solder has flowed over and wetted some of the fracture surface in the fitting. A small portion of the solder was cut out and submitted for emission spectrographic analysis. It is reported to consist of:

Pb - Major element
Sn - >5%
Bi - ~1%
Cu - >.005%

Thus, it appears to be a low tin lead , an alloy intentionally designed for soft soldering. (Pure lead will not effectively wet copper.)

This soldered joint has been discussed with Professor C. S. Smith who cannot accept it as having been made in ancient times. He believes it represents a modern repair. In the writer's opinion the degree of modernity should be established. The copper on both sides of the lead solder is extremely embrittled and fragile and appears to have become so since the joint was soldered. Also, as mentioned above, there was considerable copper corrosion product coating the lead. The University of Pennsylvania Museum should attempt to document the history of this mirror before and after acquisition.

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[1] J. G. Wilkinson, The Ancient Egyptians; Dodd, Mead and Co (New York) Revised by S. Birch, Vol. II, p. 350-351

Figure 8 contains several photographs showing the riveted-soldered joint as well as the microstructure of the copper mirror. Although the mirror surface contains areas of severe corrosion-etching, few dendrites of the original cast structure are visible. The mirror blank was well wrought and annealed prior to final finishing.

E2235 Copper Mirror

This mirror represents much cruder workmanship than that used in E10884. Of about the same area, the thickness of the copper sheet is now 1 mm or less. In heavily corroded areas of the mirror surface large (about 5 mm long) dendrites are visible. Copper nodules such as those observed in the flat adze blade, E9997, stand in relief in the corroded regions.

The "handle" consists of a 9 cm long strip of thin gauge copper sheet folded back up itself and fastened by two rivets again of copper strip. In Figure 9 one of these rivet heads is shown. The microstructure of the copper shows non-uniform recrystallization and grain growth from the last annealing treatment.

29-65-651 Copper Mirror

The "handle" on this mirror is of the same construction as that of E2225. Three rivets in a triangular pattern were used to fasten the 1 cm wide strip to the mirror disc. The joint is still secure although three rivet heads have been lost by corrosion-fracture.

Appreciable sized areas of the original mirror surface are still intact in the form of a shallow oxidized layer. This surface shows clear corrosion-impressions of the points of long-term contact with cloth fabric.

In areas where the oxidized surface has come off as a patchy sheet or layer there is little indication of dendritic copper in the etched surface. The copper has been well-annealed and at a higher temperature than that used for E2235.

Refer to Figure 10 for photomicrographs of 29-65-651.

E9598 Copper Bowl

The bowl was presumably made by fitting thin, beaten and annealed copper sheet over a form, slitting the sheet radially and overlapping the cut edges to accomodate excess metal. A narrow bead was formed by rolling or hammering along the periphery of the starting circular piece of copper sheet. At some later stage or possibly in use of the bowl, the beaded edge was annealed. There is little evidence of cold work in the microstructure. Intergranular oxidation-corrosion is relatively superficial.

The macroetched texture of the copper sheet is curious. It is not known whether this is the result of museum cleaning or natural corrosion processes. Reasons for the directionality of the etched topography have not been established.

Refer to Figure 11 for pertinent illustrations.

Recommendations

Several of the pieces described in this report merit further study.

1. The bronzes, particularly the shaft-hole axe and the chisel, should be studied further using x-ray diffraction, polarized light microscopy and electron probe microanalysis to provide more detailed information on the nature of the corrosion and oxidation processes which have occurred in the alloy over a 4000-year time span. A better understanding of these processes would have a direct application in present day research on the corrosion and engineering behavior of copper alloys in which the effect of the time factor is only estimated from accelerated corrosion tests.

2. The sharpened "working" edge of E14224 should be metallographically examined to determine if it has an annealed or cold-worked microstructure.

3. Mirror E10884 should be given further study to determine the age of the solder-repair operation on the riveted copper handle. This brings up the basic question of the history of lead-tin alloys and their use in antiquity.

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Wilmington, Delaware

Sept. 6, 1968

Table II*

Sample	Cu	Fe	As	Pb	Sn	Ni	Bi	Ag
31-17-186	89.0	0.069	0.16		10.0	0.73	0.032	0.016
53-11-303	86.9	0.39	0.52	3.2	8.3	0.13	0.028	0.54
31-17-243	88.1	0.17	0.33		10.8	0.49	0.023	0.012
E9996	98.1	0.079	1.7			0.038	0.019	0.030
E9586	98.9	0.18	0.69			0.21	0.025	0.018
E9997	98.9	0.023	0.94	0.039		0.032	0.025	0.020
E14224	96.5	0.66	2.6	0.073		0.059	0.014	0.017
E10884	96.4	0.058	3.3	0.23		0.031	0.020	0.013
E2235	97.6	0.33	1.8	0.075	0.11	0.032	0.011	0.026
29-65-651	96.1	0.33	2.8	0.72		0.024	0.019	0.0068

*Spectrographic data from the Research Laboratory for Archaeology and the History of Art, Oxford, England

NOTES ON METALS IN ANCIENT EGYPT

David O'Connor

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Research into the production and processing of the metals of an ancient literate civilization has two main aspects; firstly the study of texts and depictions relating to metals and minerals and secondly the study of preserved metal objects and the materials associated with their manufacture (ores, furnaces, crucibles, etc.). Egyptology is fortunate in having two well organized, critical and fully documented surveys, with extensive bibliographies, of our present knowledge of Egyptian metals. These are contained in:

Ancient Egyptian Materials and Industries, A. Lucas. (Revised and enlarged by J.R. Harris) London 1962.

Lexigraphical Studies in Ancient Egyptian Minerals, J.R. Harris. Berlin 1961.

These works have greatly clarified the discussion of Egyptian metals and indicate clearly the problems remaining to be solved. The following notes attempt to suggest possible methods of solving some of these problems but as the writer has no background in the technical aspects of the study of ancient metals, he hopes metallurgists will asses the feasibility of these suggestions. A clear statement of which methods are possible and which are not would in itself be valuable.

At this point a few preliminary remarks might be made.

Egypt is of value for the study of ancient metals for the following reasons.

1. The Egyptians used a number of metals, principally copper, bronze, gold and iron, but also electrum, lead, silver and tin.

2. A considerable amount of evidence, limited in some ways but well preserved because of the dry climate, has survived. Summarily, this consists of:

a. Textual references to metals and minerals, consisting largely of lists of tribute, possessions, etc., short texts accompanying depictions of metals and metal working and inscriptions left by working parties in or near ancient mines. There appear to be no surviving detailed descriptions of Egyptian mining and processing techniques until classical times.

b. Depictions, often coloured, of metals and metal working.

c. Numerous metal objects and material connected with their manufacture.

3. The continuity of Egyptian history, in its general lines, is well established and the absolute chronology of Egypt is firmly fixed from about 2000 B.C. onwards. Less certainly, the beginning of Dynasty I is dated to about 3100 B.C. Developments in metal precessing can therefore be arranged in their proper sequence (dated to some extent in absolute terms) and be related to a known cultural development.

4. Egypt was less disturbed than other areas of the Neqr East by fofeign political and cultural influences. Foreign influences in the arts and technology can in some instances be fairly easily detected. On the other hand, Egypt served as a cultural link between Western Asia and Africa and played a role in the diffusion of ideas and techniques which is by no means clear and needs much more study.

The Egyptian collections of the University Museum offer several advantages for the study of Egyptian metals.

1. We possess large numbers of metal objects (principally of copper and bronze, but with some iron and other metals) of different types, e.g.

tools, weapons, statuettes, jewellery, etc.

2. This material ranges in date from prehistoric (c. 4000 B.C.) to the end of Roman times (c. A.D. 300) and comes from sites all over Egypt.

3. The bulk of the metal objects is from excavated sites and the associated textual and archaeological material is accessible in various publications and in the field records of the University Museum Expeditions. The objects can therefore be fairly closely dated.

4. Much of the metal material has no aesthetic value and there is considerable duplication so sample-taking should not be a problem.

If a serious research programme was begun I believe we could get more dated objects for examination and analysis from other American and foreign collections.

Survey of Some Problems

1. Analyses. There is a serious lack of a large series of analyses of Egyptian metal objects and more analyses alone would be a valuable contribution. According to Lucas (1962, p 483-89) of objects of copper, bronze and various alloys of copper and other metals only some 140 have been analyzed. A breakdown of the dated specimens shows serious chronological disproportions.

Predynastic	(= 500 years?)	3 objects
Dynasties I - II	(= about 420 years)	22 "
Dynasties III - VI	(= about 500 years)	10 "
Dynasties XI - XII	(= about 345 years)	20 "
Late Second Intermediate	(= about 107 years)	11 "
Dynasties XVIII - XX	(= about 670 years)	13 "
Dynasties XXI - XXVI	(= about 560 years)	5 "
Ptolemaic	(= 275 years)	2 "
"Ptolemaic-Roman"		25 "
Roman	(= 425 years)	3 "

Of iron objects, which are common in Egypt from at least 650 B.C. on, apparently only about 13 have been analysed (Lucas, 1962, p 242).

2. Origins of metals used in Egypt. An essential preliminary to this problem is to ask; is it possible by analysing a metal object to dixcover from what area(s) the ore(s) used in its manufacture came? Lucas' remark that Sinai copper is characterised by the presence of manganese suggests that at least in some instances this approach is possible (Lucas 1962, p 209).

Granted this assumption, the problem may be stated as follows:

a. We know the Egyptians secured metals from sources within Egypt and from foreign sources.

b. Egyptian sources. These are indicated by relatively rare and generalized textual references and more decisively by the association of ancient ore-workings with datable inscribed or archaeological material left by working parties. A number of ancient ore-workings (but by no means all) are known but due to a lack of field work it is difficult to establish at what period(s) most of them were worked.

Possibly analyses of metal objects could show from which specific parts of Egypt the ores producing the metal came. The location of these arease would depend on having ores from areas throughout Egypt analysed and here the situation is unsatisfactory as few such analyses have been made. (Lucas 1962, p 206). Possibly Egyptian, American and foreign geological collections could be useful.

Although it may not be possible to secure ore-analyses and the precise geographic location of the sources, it is possible that metal-analyses might provide significant geographical or chronological distribution patterns and give indirect evidence concerning Egyptian organization of the distribution of raw materials. To give a specific example, evidence now suggests strongly that in the Old Kingdom the Egyptians used copper derived from at least two sources, the Sinai peninsula and a Nubian source some 400 miles to the south. Ore from the Nubian source (the exact location of which is unknown) is available in London and Khartoum and possibly Sinai ore could be secured from collections. It would be revealing if it could be shown that objects made of "Sinai copper" and objects made of "Nubian copper" were distributed throughout Egypt or restricted to certain areas.

c. Metal from Foreign Sources. From textual references we know that metals from the Sudan and Western Asia were imported into Egypt. (see Lucas 1962, pp 209, 227, 240)

Possibly metal analysis, by discovering elements not found in Egyptian ores, might reveal Egyptian objects made of foreign metals and it may even be possible to tie these metals down to specific foreign sources. Again the geographic and chronological distribution patterns of foreign metals in Egypt would be significant.

An interesting point would be to analyse objects of apparently foreign type found in Egypt to see if the metal composing them was of foreign origin and to determine, if possible, at what date these objects began to be copied and made in Egyptian metal. (Although conceived with a different material, a perhaps parallel case is a recent comparison of the spectographic analyses of apparently foreign pottery found in Dynasty I Egypt with those of contemporary Early Bronze Age Palestinian pottery of similar type. This demonstrated that some of the Egyptian examples were in their analyses "indistinguishable" from the Palestinian material and therefore were probably direct imports. See Spectographic Analysis of the Foreign Pottery from the Royal Tombs of Abydos and Early Bronze Age Pottery of Palestine, J.B. Hennessy and A. Millet in Archaeometry, Vol 6, 1963.)

3. Lexigraphical Study. Concerned with the essential study of the actual Egyptian names for metals and minerals this has recently been treated in detail by Harris in Lexigraphical Studies. More analyses and detailed examinations of metal objects would certainly be very useful for further

lexigraphical research.

Harris also brings out some points which it might be revealing to follow up. For example:

a. The Egyptians distinguished several varieties of some metals (at least 8 kinds of copper were distinguished, though not all at the same periods. cf. Harris 1961, pp 50-58): the bases for these distinctions were sometines colour or place of origin and it would be interesting to determine to what extent technological processes influenced the Egyptians in making these distinctions.

b. Some common terms for metals dropped out and were replaced by others, e.g. the New Kingdom word for bronze was replaced by others in the Graeco-Roman period. (Harris 1961, p 64) Possibly this could be related to technological changes which might be revealed by objects of the different periods.

4. Earliest appearance of various metals in Egypt. This is an important problem in Egyptology and has implications for the history of metal-working techniques and the technological links between Egypt and her neighbours.

Some specific points are:

a. It has been suggested that the earliest copper objects found in Egypt, as well as numerous stone beads covered with a copper-derived glaze of the same period, were imported. (Review of Predynastic Development in the Nile Valley, A.J. Arkell and P.J. Meko in Current Anthropology, April 1965, p 150.) Analysis perhaps not of the metal objects which are rare and small. but possibly (?) of the glazed beads might establish whether the copper was derived from Egyptian or foreign sources.

b. It has also been suggested that copper objects made in Egypt as late as Dynasty I (c. 3100 B.C.) were made of native copper and not copper derived from ores. Lucas argues strongly against the use of native copper, but the question has not been decisively settled. (Lucas 1963, pp 200-201) Analysis of early objects may contribute to a solution.

c. Bronze does not seem to be an Egyptian discovery (Lucas 1962, p 217), but the date of its earliest appearance in Egypt is unsettled. Lucas summarizes the present evidence which suggests bronze <u>may</u> occur in Wgypt as early as Dynasty VI (c. 2345-2181 B.C.), but only more analyses will solve the problem. (Lucas 1962, pp 218-220.)

d. Lucas points out that the production of iron from ores was not apparently discovered by the Egyptians themselves (though for a contrary opinion see Lucas 1962, pp 242-3), although meteoritic iron and iron ores were used in Egypt from an early date. (Lucas 1962, pp 235-7) The evidence for the use of iron derived from ores is discussed in Lucas 1962 pp 236-240, and here again analysis has an important role to play.

e. An important question concerns the introduction of iron working into the Meroitic kingdom (c. 660 B.C. - A.D. 350.) of the Sudan, from whence it appears to have been diffused into other parts of Africa. One aspect of the problem is that iron appears to haveebeen worked earlier in the Sudan then in Egypt itself. (Lucas 1962, pp 240-1) This is perhaps more a problem of archaeological research, but it should be noted that the technological aspects of the iron industry of Meroe and its relationship to those of Africa is a most important area of research. (see G.A. Wainwright in <u>Sudan Notes and Records XXVI</u> (1945) pp 18-36, and in <u>Mganda Journal XVIII</u> (1954) pp 113-136.)

5. Precesses involved in metal working. Well documented summaries of our present knowledge are given by Lucas, but apart from studies related to specialized aspects of metal-working (Roeder 1937; Williams 1924) a

detailed investigation of the material does not seem to have been attempted. Some specific points are:

a. Few Egyptian metal objects appear to have been examined in detail (e.g. microscopically) for evidence of the processes involved in making them. A considerable amount remains to be discovered in this way concerning, for example, the casting and hammerinc of copper and bronze (Lucas 1962, pp 213-14 and p 220 ff.), casting in closed moulds (ibid pp 214-15), soldering (p 215), the use of alloys (ibid p 223) and the development of iron working techniques, (ibid p 242).

b. The remains of objects associated with metal-working require further study and a synthesis of the evidence they give should be made. Some furnaces for smelting metals are known, the best preserved probably being the Nubian Old Kingdom examples (see Kush, Vol. XI p 116f) and apart from the evidence provided by the furnaces themselves, it might be interesting to compare them with ovens used in pottery and faience (glazed objects) making. Other material, such as crucibles, moulds, bellows-nozzles, etc. also exists in various collections.

If a metallurgist is interested in following up any of these points or wishes to investigate any points he may have thought of himself, the writer of these notes would be most interested in:

a. discussing and organizing a plan of research with the metallurgist, elgl whether to develop research along geographic, chronological or simply technological lines.

b. collect the relevant material from our stores (and contact toerh institutions with regard to further material) together with the associated data relevant to the material's date, provenance and significance.

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Proposed Research on Egyptian Metals

Summary

David O'Connor, Assistant, Egyptian Section

1. Material available in the Egyptian Collection, University Museum, provides a good chronological and geographic coverage of Dynastic and Graeco-Roman Egypt. This material provides a basis for a systematic study of the evidence presented by Egyptian copper and bronze objects concerning the processes involved in their manufacture. Such a systematic study has not yet been attempted.

Research along these lines should provide valuable evidence on the metallurgical methods developed and practised in one of the great cultural centers of the ancient Near East and contribute to our knowledge of early metallurgy as a whole.

2. Study should be concentrated on material covering Dynasties I to XIII (c.3100-1630 B.C.), which represents the earliest period of metal working on a large scale in Egypt.

3. The purpose of research would be:
    i) to assess the complexity and sophistication of the metallurgical techniques practised in Egypt
    ii) to trace chronologically any improvements in techniques
    iii) to observe any possible regional variation in techniques
    iv) to observe differences in manufacturing processes dictated by the varying functions of the objects made
    v) to date if possible the earliest appearance of bronze in Egypt
    vi) to relate the evidence of the objects themselves to the other available evidence (mines, copper working sites, depictions of copper working and lexigraphical study).

Proposed Course of Research on Egyptian Metals

A systematic study, by means of technical examination, of the evidence presented by Egyptian copper and bronze objects concerning the processes involved in their manufacture, has never been attempted. Such research should provide valuable evidence on the metallurgical methods developed and practised in one of the great cultural centres of the ancient Near East and contribute to our knowledge of early metallurgy as a whole. Material in the Egyptian collections of the University Museum provides a good basis for such a study.

Material available:

Period	Number of objects (approximate)
Predynastic	2
Dynasty I	16
Dynasty II	24
Dynasty III	30
A group of mirrors, axes and other objects, mostly of Dynasty VI-Dynasty XII date.	
Dynasty XII-XIV	19
New Kingdom (Dynasties XVIII and XIX)	43
together with an as yet unascertained number of New Kingdom objects from Thebes and Nubia.	
A considerable amount of late dynastic, Ptolemaic and Graeco-Roman material.	

Geographic Range of Dynastic material (excluding late dynastic, Ptolemaic and Graeco-Roman.) This is shown on the accompanying map, and covers the whole length of Egypt, with a concentration on southern sites.

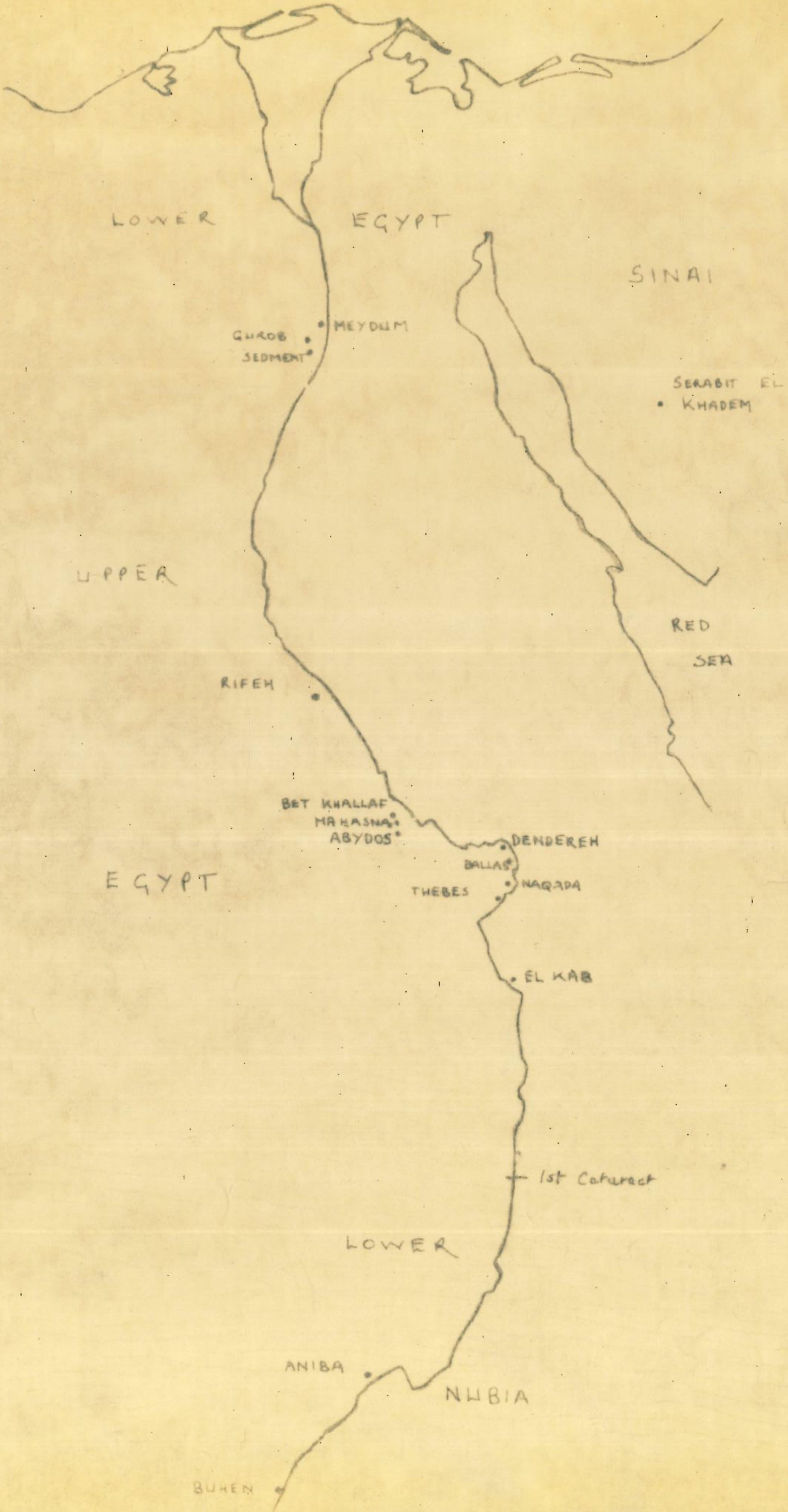
Types of objects available: functional tools and weapons, vessels, mirrors, jewellery and model tools.

In view of the material available and the problems involved, I suggest the following specifics.

1. Study should be concentrated on material covering the period Dynasty I to XIII (c.3100-1630 B.C.), which represents the earliest period of metal-working on a large scale in Egypt and includes the period when bronze first comes into use. If time and resources permit, research could later be extended into the New Kingdom.

2. The purpose of research would be:

   i) to assess the sophistication and complexity (or otherwise) of the techniques involved in making Egyptian objects
   ii) to trace chronologically any possible improvements in techniques
   iii) to observe any possible regional variations in the techniques
   iv) to observe differences in manufacturing processes dictated by the varying functions of the objects made.
   v) to date if possible the earliest appearance of bronze in Egypt.


LOWER
EGYPT
SINAI
MEYDUM
GUROB
SEDMENT
SERABIT EL
KHADEM
UPPER
RED
SEA
RIFEH
BET KHALLAF
MAHASNA
ABYDOS
DENDEREH
BALLAS
NAQADA
THEBES
EGYPT
EL KAB
1st Cataract
LOWER
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Metallurgy project: Egyptian Section

The Egyptian copper metallurgy research project was continued this past year and a number of re-analyses as well as analyses of previously unanalyzed artifacts were carried out. At this point the Egyptian Section has limited its concentration to some 50 objects whose dates range from Dynasty I (c. 3200 B.C.) to Dynasty XX (c. 1200-1085 B.C.). These artifacts have now been analyzed metallographically, and will shortly be submitted to the Oxford Laboratory for spectrographic analysis. Hardness tests have been made on most of the objects.

Some of the preliminary results of the metallographic analyses are presently being incorporated into a Master's thesis. The topic of this thesis is "Copper and copper metallurgy in Egypt from the Predynastic Period to the beginning of the Bronze Age." It is hoped that this thesis may be submitted to the department of Oriental Studies in May of 1968.

James Weinstein
Egyptian Section
University Museum

Samples From Egypt

20X 200 gr Load

Spec.								
29-65-629	KHN	222	172	164				
	BHN	171	137	130				
	Rb	94	83	80				
29-65-633	KHN	196	134	114				
	BHN	154	107	90				
	Rb	89	68	56				
29-65-642	KHN	108	116	107	114			
	BHN	84	91	83	90			
	Rb	51	57	50	56			
29-66-650	KHN	120	117	132				
	BHN	95	92	106				
	Rb	60	58	67				
29-65-651	KHN	123	126	136				
	BHN	96	99	109				
	Rb	61	63	69				
29-65-656	KHN	193	183	154	144			
	BHN	151	145	124	114			
	Rb	88	86	77	72			
29-66-763	KHN	130	126	139				
	BHN	104	101	110				
	Rb	66	64	70				
29-85-83	KHN	64.5	68.	67	85			
	BHN		54	53	66			
	Rb		2	0	28			
29-85-111	KHN	99.4	62	52	61	78	65	87.5
	BHN	76				60		67
	Rb	42				17		30

Spec.							
29-85-240	KHN	107	101	95	106	91	126
	BHN	83	78	73	82	70	99
	Rb	50	44	38	49	34	63
29-85-171	KHN	119	100	175	131		
	BHN	94	77	140	104		
	Rb	59	43	84	66		
29-85-187 - Bad Spec.							
29-85-289	KHN	102	88	91	102	94	
	BHN	79	68	70	79	72	
	Rb	45	31	34	45	37	
29-85-322	KHN	166	230	227	277		
	BHN	133	179	175	255		
	Rb	81	96	95	RCO25		
29-85-366	KHN	180	178	156			
	BHN	142	140	124			
	Rb	85	84	77			
31-27-140 - Bad Spec.							
32-42-28	KHN	106	86	107			
	BHN	82	66	83			
	Rb	49	28	50			
32-42-68	KHN	92	107	100	99		
	BHN	71	83	77	76		
	Rb	35	50	43	42		
32-42-569 - Bad Spec.							
E6 - Bad Spec.							
E289	KHN	106	100	98.5			
	BHN	82	77	75			
	Rb	49	43	41			
E954	KHN	150	179	153	160		
	BHN	120	142	122	128		
	Rb	75	85	76	79		

Spec.								
E1055	KHN	241	224	160	133			
	BHN	189	173	128	106			
	Rb	98	94	79	67			
E2355	KHN	133	131	120	127			
	BHN	106	104	95	101			
	Rb	67	66	60	64			
E2535C	KHN	237	239	213	224	161	194	184
	BHN	184	189	163	175	128	151	145
	Rb	97	98	92	95	79	88	86
E2900	KHN	178	213	128	136			
	BHN	140	163	101	107			
	Rb	84	92	64	68			
E4660	KHN	137	131	137	124	126		
	BHN	109	104	109	98	99		
	Rb	69	66	69	62	63		
E9202	KHN	152	145	117	112			
	BHN	122	116	92	89			
	Rb	76	73	58	55			
E9374	KHN	68	80	104	74.5	110	106	89.5
	BHN	54	61	80	58	86	82	69
	Rb	2	19	47	13	53	49	33
E9521	KHN	106	122	113	74.5	98	96	
	BHN	82	96	89	58	75	74	
	Rb	49	61	55	13	41	39	
E9586	KHN	154	132	129	129			
	BHN	124	106	102	102			
	Rb	77	67	65	65			
E9588	KHN	104	126	140	147	139		
	BHN	80	99	112	118	110		
	Rb	47	63	71	74	70		

Spec.							
E9598	KHN	90	102	106			
	BHN	69	79	82			
	Rb	33	45	49			
E9736	KHN	96.5	90	92.5	94.5		
	BHN	74	69	71	73		
	Rb	39	33	35	38		
E9747	KHN	105	124	123	137	123	121
	BHN	81	98	96	109	96	95
	Rb	48	62	61	69	61	60
9749 7 E9753D	KHN	107	102	127	108	120	116
	BHN	83	79	101	84	95	92
	Rb	50	45	64	51	60	58
E9754	KHN	188	158	122	115		
	BHN	148	126	96	91		
	Rb	87	78	61	57		
E9996 (Thin)	KHN	190	155	138	150		
	BHN	151	124	109	120		
	Rb	88	77	69	75		
E9996 (Thick)	KHN	134	130	118			
	BHN	106	102	94			
	Rb	67	65	59			
E9997	KHN	99	95	100	91	99	
	BHN	76	73	77	70	76	
	Rb	42	38	43	34	42	
E9999	KHN	156	154	143	136	115	117
	BHN	124	124	114	107	91	92
	Rb	77	77	72	68	57	58
E10304	KHN	162	139	143	184	149	175
	BHN	128	110	114	145	120	140
	Rb	78	70	72	86	75	84

Spec.							
E10335B	KHN	240	206	179			
	BHN	189	160	142			
	Rb	98	91	85			
E10342A	KHN	143	142	120			
	BHN	114	114	95			
	Rb	72	72	60			
E10866	KHN	132	107	112			
	BHN	106	83	89			
	Rb	67	50	55			
E10884	KHN	88	92	112			
	BHN	68	71	89			
	Rb	31	35	55			
10885 ? E11000	KHN	152	150	139	149		
	BHN	122	120	110	120		
	Rb	76	75	70	75		
E11116	KHN	137	123	123			
	BHN	109	98	98			
	Rb	69	62	62			
E11127	KHN	132	129	122			
	BHN	104	102	96			
	Rb	66	65	61			
E11134	KHN	128	112	101	204	164	123
	BHN	102	89	78	160	130	98
	Rb	65	55	44	91	80	62
E12512	KHN	102	115	105	88.5		
	BHN	79	91	81	68		
	Rb	45	57	48	31		

Spec.							
E13144	KHN	130	127	162	157		
	BHN	102	101	128	126		
	Rb	65	64	79	77		
E13156	KHN	120	110	132	122	117	
	BHN	95	86	104	96	92	
	Rb	60	53	66	61	58	
E13379	KHN	116	107	113			
	BHN	92	83	90			
	Rb	58	50	56			
E14224	KHN	148	133	202	220	154	155
	BHN	118	106	157	171	124	124
	Rb	74	67	90	94	77	77