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Recent Advances in Science and Technology of Materials, no. 3. New York: Plenum, 1974. pp. 9-27. © Springer.

LEAD ISOTOPES IN SOME ANCIENT EGYPTIAN OBJECTS

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The determination of isotope ratios in lead extracted from a variety of archaeological materials is very useful for classifying the objects according to their geographical origins. On the basis of data for lead from about 450 ancient objects and galena ores, geographical patterns have been established. Our previous studies have included metallic leads, bronze alloys, silver and gold coins, pigments, glazes and glasses from many areas of the Ancient World. In this study we have investigated specimens of ancient Egyptian glasses and glazes containing the colorant-opacifier $Pb_2Sb_2O_7$, samples of kohl (which consist of powdered galena) and a few ores from Egypt. The leads used for making the pigment and kohl are similar to one another, but very different from leads from other parts of the Ancient World, and are almost certainly made of locally-occurring galena ores. Relatively small differences among the ancient Egyptian kohls separate those dating from different dynasties. Glasses and bronzes of the Ptolemaic and Roman Periods excavated in Egypt do not contain the same type of lead found in the earlier glasses and kohls. The later leads are of the Laurion, "Levantine" and Italian types. The authenticity of one very important glass object of the XVIIIth Dynasty has been verified by this technique.

INTRODUCTION

The determination of lead isotope ratios has become a routine method for investigating lead-containing ancient objects.[1] The isotope determinations yield information on possible geographical sources from which the lead found in archaeological objects might have come.

The usefulness of the method results from a three-fold coincidence. Geologically, and most importantly, lead is one of the few chemical elements which varies markedly in its isotopic composition depending upon the geological circumstances under which its minerals were formed. Historically, lead was among the first metals made by man, and because it is abundant in nature and relatively inexpensive, lead is found on a great many archaeological sites of different periods and in widespread locations. Technologically, lead was used in the ancient world not only in its metallic form, but also in a variety of other forms, combined into alloys, glasses, glazes, pigments and cosmetics. The fortuitous coincidence of these geological, historical and technological factors has led to the development of a valuable tool for archaeological studies.

One disadvantage of the method is that although individual mines or deposits of galena ore are characterized by definite isotopic ratios, these ratios are not necessarily unique and mines from different areas drawing upon ores deposited under similar geological circumstances, may have similar isotope ratios. The other difficulty is that scrap lead was often salvaged, melted down and reused in ancient times, just as it is today (and just as were many other materials), so that leads from different sources could have become mixed together. On the other hand there are several very favorable aspects of the method. For example, it is one of the few methods which gives direct information on geographical origins of a material. Also, the method is ordinarily independent of the chemical history or final state of the objects studied, so that for the very great majority of lead-containing objects, the ratios determined today should be nearly identical to those of the original ores from which the leads were extracted.

Since the earliest studies were carried out, major improvements have been made in the instrumentation by which the isotope ratios are determined.[2] The results attainable now are not only far more accurate and precise, but the data are obtained in a much less laborious way, and from very small samples. It is these analytical improvements which have allowed the investigation of large numbers of specimens and converted the method into a practical working tool.

The results of our previous studies are summarized in Figure 1. Data from some 400 specimens of various types of archaeological materials and ores from all over the ancient world were used to construct this graph. The loop L contains about 30 specimens of early artifacts, most of which are known with near certainty to have been made of Laurion lead. The loop E encloses subgroups of two types of Italian leads, English leads, lead extracted from Persian silvers, and some Near Eastern leads. (The "Persian silvers" tend to overlap the others, but the other three subgroups are readily distinguishable from one another.) Between the L and E types are several south Italian and "Levantine" specimens, and a small cluster of leads from Asia Minor. Beyond the S group, which contains some leads from

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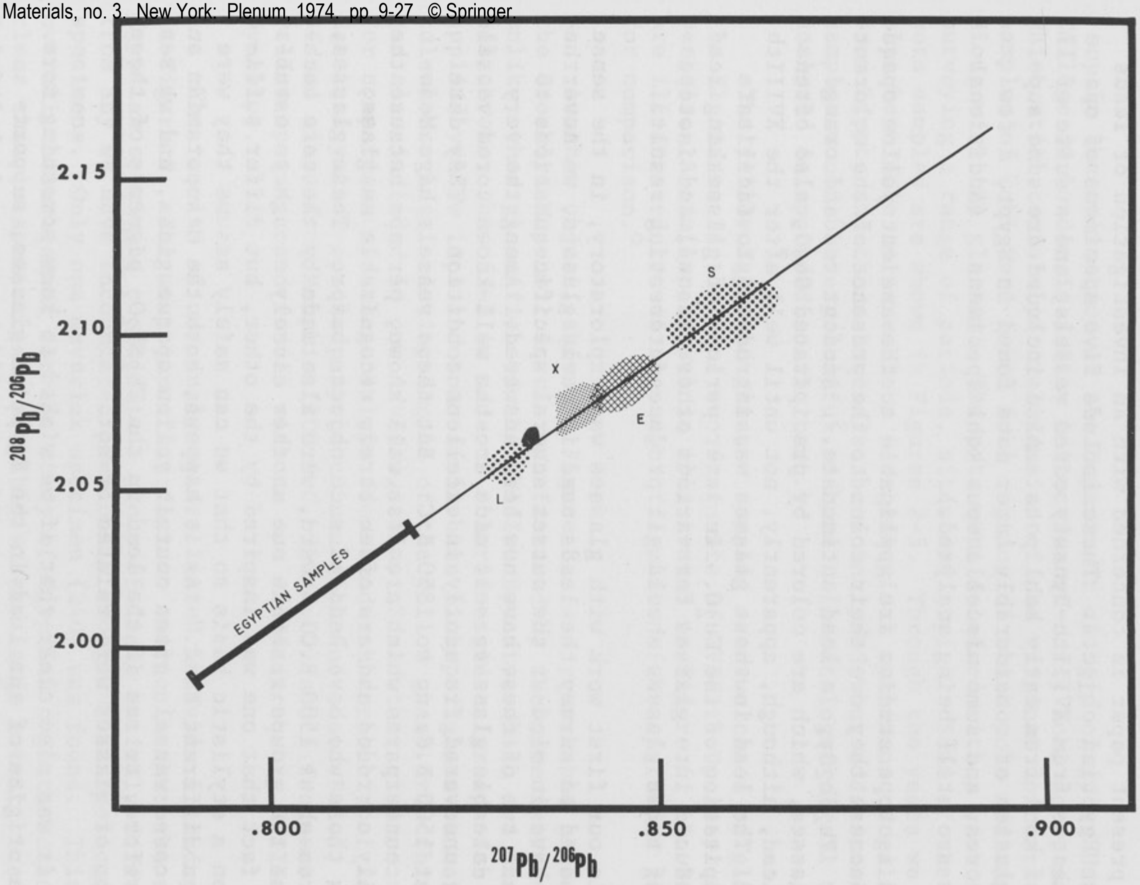

Fig. 1: Summary of data for about 400 specimens of lead from ancient sources.

Spain, Wales, and Sardinia, and ranging well off to the right, are some geologically older East Asiatic leads. The point of special importance to our current study is that more than 95% of all of the ancient leads studied so far fall between the loops marked L and S.

Our present paper is concerned with an investigation of leads in ancient Egyptian objects. These include five specimens of opaque yellow glasses from XVIIIth-Dynasty cored vessels, and a suite of 17 samples of kohl from early kohl pots. Also included are some supporting glasses of considerably later date found in Egypt, a few Egyptian ores, and some miscellaneous kohl specimens. (Additional specimens are still being analyzed.)

Lead isotope studies are applicable to the ancient yellow opaque glasses because they owe their color to the presence of the colorant-opacifier $Pb_2Sb_2O_7$, a lead antimonate.[3] Ancient red and orange opaque glasses, which are colored by precipitated Cu_2O, also often contain lead, although, apparently, not until well after the XVIIIth Dynasty.[4] The lead in these glasses was introduced to facilitate the precipitation of the Cu_2O. In later periods of glassmaking lead was introduced into glasses for various other reasons, and isotope studies of those glasses should all produce interesting results.

While our first work with glasses was exploratory, in the sense that we hoped to survey the leads used in early glasses, we nevertheless did have in mind at the outset several specific questions to answer, and two of these have now been answered. Among the very earliest dateable glass vessels made are the well-known cored vessels of Egypt, uncovered frequently in excellent condition. They date from about 1500 B.C. up to 1350 B.C. But these vessels have Mesopotamian counterparts which are less well known, perhaps because they are heavily corroded and are often barely recognizable as glass, except by those who have handled such objects before. These glasses, dating from about 1500 B.C. onward, were also made by the core technique. The two groups resemble one another closely enough to establish the fact that one was inspired by the other, but differ sufficiently on a stylistic basis so that we can safely assume they were made "by a different hand." As it happens, both the Mesopotamian and Egyptian cored vessels often contain yellow opaque glass, and we set out, therefore, to see if the lead in the $Pb_2Sb_2O_7$ pigments of these two groups of glasses were related or not.

But it was also clear that if we wished to know something more about the origins of the lead in the Egyptian glasses, supporting data from ores and related artifacts would be extremely helpful. Lead was not abundant in ancient Egypt, according to most authors who have written on the subject, and our efforts to obtain early Egyptian specimens have borne this out. But there is one excellent source of comparative material in ancient cosmetics, because the black kohl and eye medications of ancient Egypt were very often finely-powdered galena ore.[5] Thus, by investigating the ancient kohls it is possible to establish at least some of the types of galena ores which were available to early Egyptian craftsmen and technologists.

In the collection of the Department of Egyptology at University College in London is a fine collection of early kohl pots, many of which still contain partial remains of the original contents. Minute samples of kohl were taken from a group of these pots and analyzed along with the glasses. The pots were selected with a view towards surveying a range of periods, sites and styles. Some of the kohl pots sampled are shown in Figures 2-5. Through the years we have also been able to assemble a few geological specimens of galena ores from Egypt, and these have also been analyzed, but additional ore samples would be very helpful to have. (A catalogue of all samples analyzed is appended to the text.)

The yellow Egyptian glasses sampled are two canes of glass from the El Amarna factory and two fragments of XVIIIth-Dynasty cored vessels. A similar vessel is illustrated in Figure 6. In Figure 7 are illustrated two of the eight fragments of Mesopotamian glass used for comparison.[6]

Another object, shown in Figure 8, is a remarkable glass fish in the Brooklyn Museum. It was manufactured by the core technique, but unlike other glass fish of the XVIIIth Dynasty, which are usually polychrome, this fish is made of colorless glass, except for the applied yellow lips and some small blue blobs of glass beneath the colorless glass. A tiny sample of the yellow glass from this fish was also included in our investigation. Some other glasses analyzed for comparison are three inlays from Denderah (probably of Roman date), a yellow-opaque papyrus column (4th-2nd cent. B.C.), a lump of red glass from Memphis (100 B.C.-300 A.D.) and a fragment of a yellow-opaque cored vessel with an eye motif (probably XVIIIth Dynasty).

The results of our analyses are listed in Table 1, and plotted in Figure 9. The most important fact to emerge is that the early Egyptian specimens constitute a group of leads entirely different from any we have encountered previously among our archaeological specimens. Only one maverick specimen (240) was found. This offers overall encouragement for the study of Egyptian objects because it is clear that to some extent, probably a very large extent, leads from Egyptian objects are not likely to become confused with leads from the rest of the ancient world. It should be easy to identify imports into Egypt, and to recognize the "Egyptian" type of lead as an import, if it is ever encountered elsewhere in future studies.

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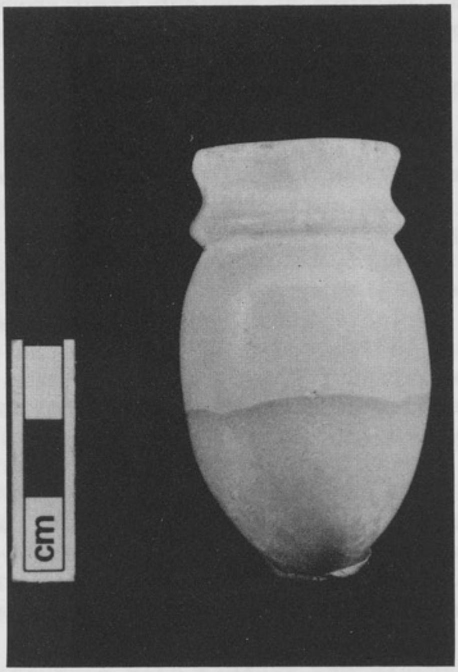

Fig. 2: Kohl pot, Dyn. VI-VIII. (Sample 239.) (Fig. 2-5 Courtesy Dept. Egyptology, University College, London.)

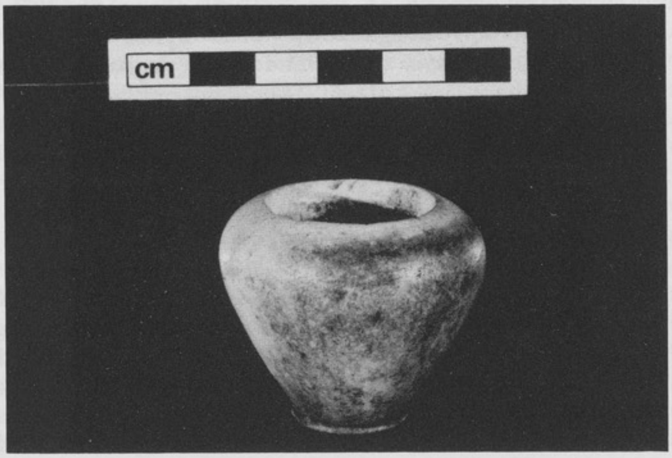

Fig. 3: Kohl pot, Abydos, Dyn. XI. (Sample 291).

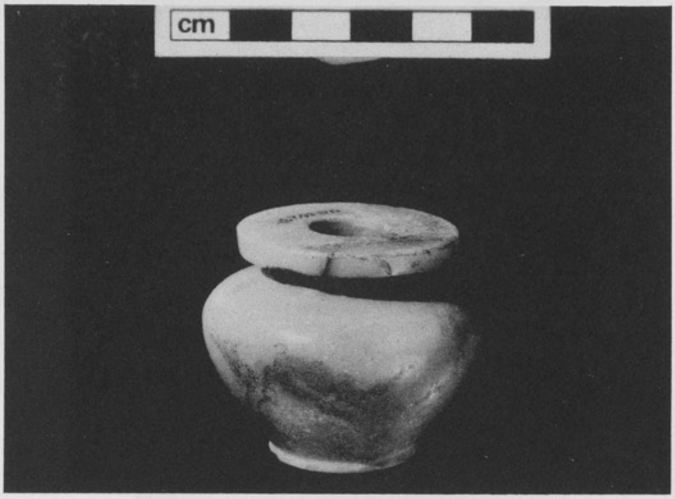

Fig. 4: Kohl pot, Abydos, Dyn. XII. (Sample 290).

Fig. 5: Kohl pot, Lahun, Dyn. XVIII. (Sample 247).

Fig. 6: Egyptian cored glass vessel (Dyn. XVIII) similar to those from which samples 453 and 454 came.

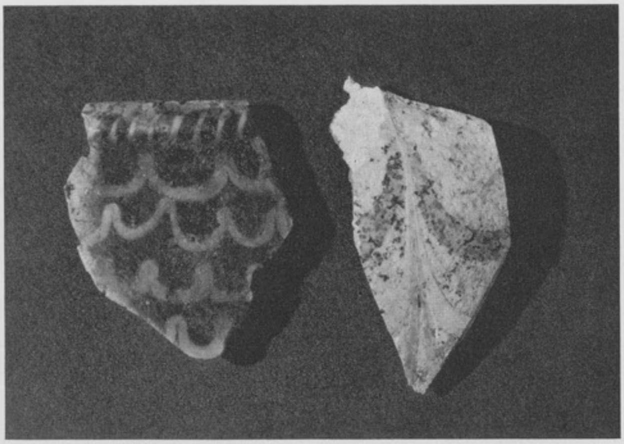

Fig. 7: Mesopotamian cored glass fragments contemporaneous with samples 453 and 454, but containing an entirely different type of lead.

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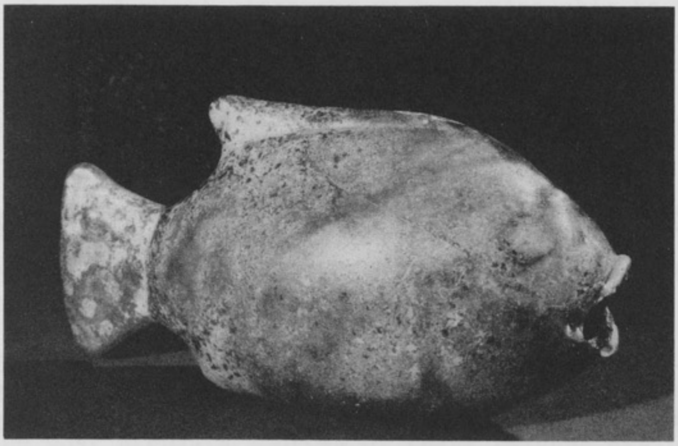

Fig. 8: Egyptian cored glass fish (Dyn. XVIII). The Brooklyn Museum, No. 37.316E. (Photo, courtesy the Brooklyn Museum).

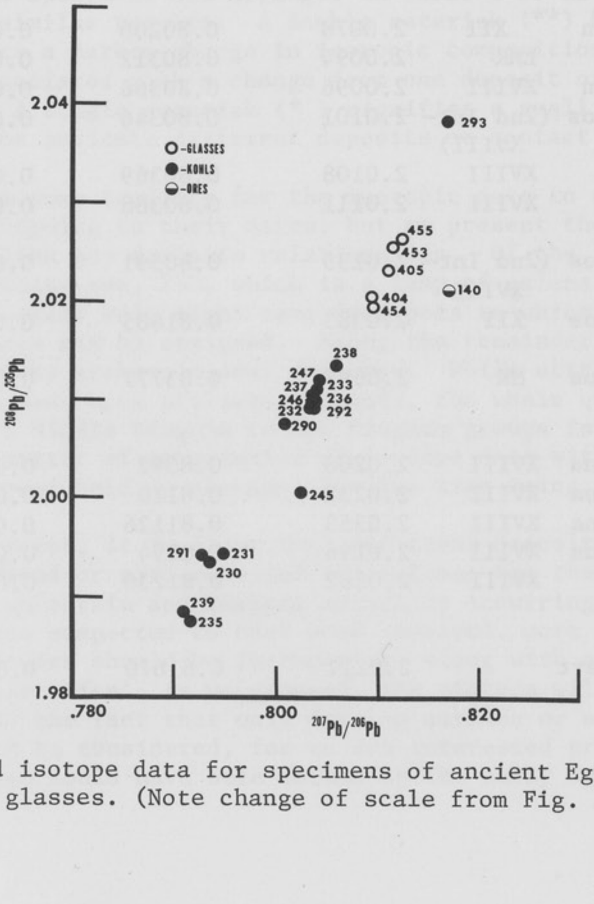

Fig. 9: Lead isotope data for specimens of ancient Egyptian kohls and glasses. (Note change of scale from Fig. 1).

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Table 1

Sample Number	Source	Dynasty	Pb^{208}/Pb^{206}	Pb^{207}/Pb^{206}	Pb^{204}/Pb^{206}
Kohls					
235	?Abydos	VII-XI	1.9878	0.79013	0.050412
239	-	VI-VIII	1.9885	0.79080	0.050476
*					
291	Abydos	XI	1.9942	0.79259	0.050552
230	Qau	VII-VIII	1.9936	0.79354	0.050632
231	Kahun	XII	1.9946	0.79493	0.050742
**					
290	Abydos	XII	2.0079	0.80057	0.051122
*					
292	Abydos	XI	2.0094	0.80359	0.051220
247	Lahun	XVIII	2.0120	0.80409	0.051266
*					
245	Lahun	XII	2.0078	0.80206	0.051303
232	--	LMK	2.0094	0.80312	0.051348
246	Lahun	XVIII	2.0096	0.80366	0.051328
236	?Abydos	(2nd Int- XVIII)	2.0101	0.80346	0.051409
237	--	XVIII	2.0108	0.80369	0.051413
233	--	XVIII	2.0111	0.80388	0.051363
*					
238	Abydos	(2nd Int- XVIII	2.0135	0.80591	0.051506
**					
293	Abydos	XII	2.0383	0.81685	0.052096
**					
240	?Abydos	MK	2.0698	0.83777	0.053596
Glasses					
404	Amarna	XVIII	2.0208	0.8092	0.05171
405	Amarna	XVIII	2.0232	0.8110	0.05184
453	Amarna	XVIII	2.0253	0.81126	0.051757
454	Amarna	XVIII	2.0196	0.8094	0.05164
455	--	XVIII	2.0262	0.81230	0.051965
Ore					
140	E.Desert		2.0211	0.81670	0.052352

From the geological specimens we have been able to study so far, it seems likely that the kohls and pigments were made from locally occurring Egyptian ores. There is no exact match between artifacts and ores, so that we cannot claim to have identified the exact source of the lead in any of the kohl or glass colorant specimens, but the data clearly are related.

Although the early Egyptian specimens can be construed as a group, this is not a tightly defined group, as for example are the Laurion or English leads. The spread of the kohl specimens is, in fact, almost as great as the range covered by the majority of all the other archaeological specimens noted above as falling between the L and S Groups. Therefore, there is considerable isotopic heterogeneity among the kohls. But this does not necessarily imply that all the kohls came from or were imported from widely separated geographical areas. The most probable sources of these galenas are the Red Sea coastal deposits, and the geology there is sufficiently complicated that a good deal of the observed heterogeneity could exist within that single region itself.

The kohl specimens are arranged in Table 1 so as to group specimens with similar results. A double asterisk (**) between specimens signifies a marked change in isotopic composition, almost certainly associated with a change from one deposit or mining region to another. A single asterisk (*) signifies a small change which may or may not indicate different deposits or contact levels.

There is some tendency for the isotopic data to separate the kohl pots according to their dates, but at present the data are too few to establish any definite relationships. Of the 17 kohls analyzed so far (including one, 230, which is a lump of galena, rather than powdered material) only eight came from pots to which reliable dates and provenances can be assigned. Among the remainder, none are solidly dated by archaeological evidence. While attributions of dates can be made upon stylistic grounds, the whole question of typologies of Middle Kingdom to New Kingdom groups is in a state of flux so the matter of association of isotope data with dates or provenances is best held in abeyance for the time being.

In any event, it is clear that different deposits (whether widely separated or not) supplied the galenas for these kohls. As soon as we can obtain and analyze naturally occurring ores from the mining regions suspected to have been involved, more direct answers as to the origins should be forthcoming, along with a proper geological interpretation. As we proceed, the picture will be distinctly simplified by the fact that only data on surface or near-surface deposits need be considered, for we are interested primarily in those deposits which could have been worked by the early Egyptian miners.

While the galena deposits in the Eastern Desert, especially the Red Sea coastal deposits, come quickly to mind, ores from other accessible areas cannot be ignored. Ores from the Sinai, Midian,[7] coastal deposits on the Arabian Peninsula and ores from mines well up the Nile should still be considered as possible sources of Egyptian leads. Some of the sources closer by, in which we are especially interested, are Gebel Russas, Um Gheig, Um Samiuki, the Bahram Mountains, Mons Claudianus and Gebel Kutum in the Sudan. (Additional samples of galena obtained as a result of this conference will be run as soon as possible to see how they fit into the picture.

Our survey of early Egyptian texts which might offer clues as to the origin of the galenas or leads used is as yet incomplete. There are a few references[8] in the tribute lists and elsewhere which mention kohl and lead, some of which refer to specific places such as Djahi, Retenu, Isy, and Naharin. From the present state of our knowledge one would guess that the leads in use in the above areas would probably be of the type we have been calling Levantine leads. These are the leads which were in use during later periods in those same regions. These Levantine leads differ considerably from the actual early specimens of Egyptian kohl we have dealt with here. Coptos[9] may have served as an entrepot for materials such as kohl. A thorough study of this topic is being undertaken by Ms. Laverne Schnare on behalf of The Corning Museum of Glass.

Although the small differences among the Egyptian glasses are significant experimentally, the results are very similar and the leads in these glasses can be regarded as being far more alike than unlike. There are no exact matches with any of the kohl specimens, but it seems safe to say that the leads in the glasses probably originated in a geological context similar to those which produced the galena in our group of XVIIIth-Dynasty kohl specimens.

Most important, however, is the fact that the lead in the Egyptian glasses is so very different from that in their Mesopotamian counterparts. This establishes an unambiguous technological and geographical distinction between the two groups. The results establish beyond reasonable question that the yellow pigments were manufactured at different places, the Egyptian in Egypt and the Mesopotamian elsewhere. Our best possible current guess is that the lead in the latter cam from Iran. So the yellow pigment itself was not--in this instance--an article of commerce. This, of course, says nothing about who made the pigment, for Egyptian craftsmen could have worked in Mesopotamia with locally available lead, or vice-versa. While this is the result predicted beforehand it nonetheless is valuable to have unequivocal experimental data confirming that expectation. These data bear upon the relationship between the two very earliest types of glass vessels known, so they are particularly welcome to glass scholars.

The results on the Brooklyn Fish illustrate a practical application.[10] One of the authors (RBH) had always had some doubts about the XVIIIth-Dynasty attribution of the object, based not upon stylistic grounds, but simply upon the fact that the core residue is not the typical XVIIIth-Dynasty material, and, more particularly, upon the relative scarcity of colorless, transparent glass in Egypt. But the virtual coincidence of the lead in the yellow lip of the fish and that in two other XVIIIth-Dynasty glasses, establishes the early date of the object beyond doubt. This confirmation was obtained at the sacrifice of a tiny speck of the yellow glass, the removal of which inflicted no perceptible damage on the object.

Earlier data on lead in about 25 miscellaneous glass specimens of Hellenistic, Roman and Byzantine origins, spread out over the range between the L and S groups. In most instances these relate in reasonable geographic ways to metallic leads and leads in bronze coins. The six specimens of late glass from Egypt also fall in this general range and are entirely different from the leads in early Egyptian glasses and kohls. It is obvious that the lead came from different sources, as is to be expected, because there is no reason to believe that the later glasses were made along the Upper Nile. It is probable, in fact, that the old mines in the Eastern Desert (if that is where the early leads came from) had long since fallen into disuse. The latter glasses are a part of a "Mediterranean" glassmaking tradition, and were probably made in Alexandria, Italy or in the Levant, where glassmaking (or at least glass trading) was then flourishing. Table 2 lists the glasses found in Egypt and specimens of other types of lead-containing materials which resemble each of them in the isotopic makeup of the lead they contain.

A number of other samples are now being analyzed which will have some bearing on the interpretation of the data presented here. Because of the necessity for completing this paper for publication, however, the additional samples cannot be discussed here. The authors hope that a third Cairo Solid State Conference may be held in the future and that the continuation of this research may be presented then. Our additional samples include Egyptian ores, more glasses and kohls, a few modern kohls, some Mesopotamian kohls and Egyptian faiences. Another promising area is the investigation of ancient Egyptian silvers and those Egyptian golds which may contain traces of lead.

ACKNOWLEDGEMENTS

The authors thank D.M. Dixon and H.S. Smith of University College London, and W.R. Sheilds of the National Bureau of Standards for their encouragement and valuable assistance. The chemical preparations and mass spectrometric determination were carried out by

Table 2

Sample No.	Glass from Egypt	Objects Containing Similar Lead	Agreement
407	Cored vessel, unusual eye motif, yellow glass. Prob. Dyn.XVIII.	Mesopotamian glass subgroup (15th-3rd cent. B.C.)	Fair
		Metallic lead from Nimrud	Very Close
415	Papyrus column, yellow glass. 4th-2nd cent.B.C.	Glass mosaics. Sh.Z. 4th-5th cent. A.D.	Very Close
		Bronze coins: Alexandria Rome, Constantinople, Heraclea. 1st-4th cent. A.D.	Close
416	Lump of red glass. 100 B.C.-300 A.D.	Some Italian Bronzes.	Fair
		Yellow glass waste, Hellenistic bead factory, Rhodes	Close
417	Glass inlay, red Denderah	Several Roman bronze coins, n. Italy 2nd-3rd cent. A.D.	Close
		Mosaic glass vessel, Rimah, *ca.* 1500 B.C.	Fair
		Lead net sinker, El Amarna(?) Dyn. XVIII(?)	Fair
419	Glass inlay, yellow (Same)	Several Roman bronze coins, "Levantine," 2nd-4th cent. A.D.	Close
		Bronze coin, Alexandria, 311 A.D.	Very close
418	Glass inlay, orange (Same)	Several Roman bronze coins, "Levantine" or Constantinople 3rd-4th cent. A.D.	Close

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Glasses (Table 2, cont.)

404 - Cane of yellow opaque glass. El Amarna factory, Dyn. XVIII.

405 - Similar to 404.

453 - Yellow opaque threading from glass cored vessel. El Amarna, Dyn. XVIII. UC.22938.

454 - Similar to 453. UC.22937.

455 - Yellow opaque glass threading from lip of colorless glass fish made by core technique. Dyn. XVIII. Brooklyn Museum no. 37.316E.
Ref.: E.Riefstahl, Journal of Glass Studies, Vol. XIV, pp.11-16, 1972.
We thank Mrs. Riefstahl and Dr. B. von Bothmer for allowing us to sample and analyze this object.

Ores

140 - Sample of galena ore from Um Gheig, Eastern Desert. (25°30'; 34°30') Provided by Mr. P.E. Desautels of the Smithsonian Institution. (His sample 115378.)

Note: Additional ore samples from Egypt analyzed earlier by less precise methods are not listed here. Some fall within the same of isotopic compositions as our Egyptian artifacts, but are being run again by the improved techniques.

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CATALOGUE OF SAMPLES

Kohls

All kohl samples are fine, black powders which remained as traces of the original contents of kohl pots. The descriptions below are of the pots themselves. All are made of alabaster (calcite) unless otherwise noted. The UC numbers refer to the catalogue of the Department of Egyptology, University College, London. W numbers are designations from the Wellcome Collection objects, mostly from the MacGregor Sale at Sotheby's, 1922. When enclosed in parentheses, the date has been attributed on stylistic considerations. If no source is listed the source is unknown.

230 - UC.20646 Lump of galena from Qau. Tomb 4903, Dyn. VII-VIII. *Ref.*: *Qau and Badari*, I & II, pl. LXII.

231 - UC.7321 Serpentine kohl pot. Kahun, Tomb group, no number. (Dyn. XII)

232 - UC.2370 Anhydrite kohl pot. (Late Middle Kingdom?)

233 - UC.2392 W 334 4115. (Dyn. XVIII)

235 - UC.2387 W 3912 & 1001/9. Abydos, *MacGregor Catalogue of Egyptian Antiquities*, 1922, no. 1001. (Dyn. VII-XI)

236 - UC.2388 W 4117 & 366. Abydos Tomb(?), 1907. *MacG. Cat.*, no. 999. (2nd Int. -Dyn. XVIII)

237 - UC.2390 W 4118 & 285. (Dyn. XVIII)

238 - UC.2391 W 999. Abydos Tomb(?), 1907. *MacG. Cat.*, no. 999. (2nd Int.-Dyn.XVIII)

239 - UC2393 WA.129003. Collar Vase. (Dyn. VI-VII)

240 - UC.2394 Anhydrite kohl pot. W 1001, 3.15.0. Abydos(?) *MacG. Cat.*, no. 1001. (Middle Kingdom?).

245 - UC.6729 Lahun, (Dyn.XII). *Ref.*: Petrie, *F.F. & S.V.*, pp. 22, 673(?)

246 - UC.6756i Lahun, Dyn. XVIII. Grave K1-5, Amenhotep III. Ref.: *Lahun* II, p. 35 and *Sedment*, II, p. 23, XLVIII, 7.

247 - UC.6742 Horn Kohl pot, with wooden base, *etc*. Same source as 246. *Ref.*: *ibid.*, XLVIII, 6, LXIII.

290 – UC.16231	Andydrite kohl pot. Abydos, Dyn. XII. S II, Tomb 817. Ref.: Tombs of the Courtiers, p. 11, XXX, 8 (1925).
291 – UC.2384	Limestone kohl pot. Abydos, Dyn. XI. Tomb 197. Ref.: ibid., p. 10, and Petrie Tomb card, unpublished.
292 – UC.2385	Abydos Dyn. XI. Tomb 197. Ref.: ibid., p. 10, and Petrie Tomb card, unpublished.
293 – UC.2386	Abydos Dyn. XII. Tomb 81. Ref.: Petrie, Tomb card, unpublished.

T.J. Murphy, J.M. Wampler (then a guest scientist), K.M. Sappenfield, and their colleagues at the National Bureau of Standards, Gaithersburg, Md.

REFERENCES

1.(a) R.H. Brill, J.M. Wampler, "Isotope Studies of Ancient Lead," AJA LXXI 63-77 (1967).
(b) ibid., "Isotope Ratios in Archaeological Objects of Lead," in Application of Science in Examination of Works of Art, W.J. Young, ed. Boston Museum of Fine Arts, Boston (1967).
(c) R.H. Brill, "Lead Isotopes in Ancient Glass," Annales du 4e Congrès des Journées Internationales du Verre, Int. Assoc. for the History of Glass, Liège (1969) 255-61.
(d) ibid., "Lead and Oxygen Isotopes in Ancient Objects," in The Impact of the Natural Sciences on Archaeology, T.E. Allibone et al., eds. The British Academy, London (1970) 143-64 (also appears in Phil. Trans. R. Soc. Lond. A2694 143-64, 1970).
(e) R.H. Brill, W.R. Shields, J.M. Wampler, "New Directions in Lead Isotope Research," in Application of Science in Examination of Works of Art, W.J. Young, ed. Bostom Museum of Fine Arts, Boston (1971).

2.(a) E.J. Catanzaro, T.J. Murphy, W.R. Shields, E.L. Garner, J. Res. NBS (US) 72A (Phys. and Chem.) No. 3, 261 (1968).
(b) I.L. Barnes, T.J. Murphy, J.W. Gramlich, W.R. Shields, "Lead Separation by Anodic Deposition and Isotope Ratio Mass Spectrometry of Microgram and Smaller Samples," Anal. Chem. (in press).
(c) E.J. Catanzaro, Earth and Planetary Science Letters 3 343-46 (1967).
(d) E.C. Kuehner, R. Alvarez, P.J. Paulsen, T.J. Murphy, Anal. Chem. 44 2050-56 (1972).

3. For general information on the chemical aspects of early glasses see R.H. Brill, "The Scientific Investigation of Ancient Glasses," Proc. of the 8th Int. Cong. on Glass, Society of Glass Technology, Sheffield (1968) 47-68.

4. R.H. Brill, "The Chemical Interpretation of the Texts," in A.L. Oppenheim et al., Glass and Glassmaking in Ancient Mesopotamia, The Corning Museum of Glass, Corning (1970) 105-28.

5. A. Lucas, Ancient Egyptian Materials and Industries (Revised by J.R. Harris), Edward Arnold, London (1962) 80-83. See also ref. 4, 117-18.

6. See ref. 1, Brill, 1970, for a preliminary report.

7. Sir R.F. Burton, The Gold Mines of Midian, London (1878) 204, 390; The Land of Midian, London (1879) _I_ xxii, 266: _II_ 191-92.

8. For example: J.H. Breasted, Ancient Records of Egypt I, 281; II, 109, 196, 199, 206, 208, 210, 212, 223, 265, 272.

9. W.M. Müller, Egyptological Researchs.

10. E. Riefstahl, "A Unique Fish-shaped Glass Vial in The Brooklyn Museum," Journal of Glass Studies XIV 11-16 (1972).