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Analytical Studies of Ancient Egyptian Glass*

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Glass objects have been manufactured in Egypt in significant quantities since the period of the New Kingdom. In earlier periods some small glass beads and ornaments were undoubtedly produced; however in New Kingdom tombs sizable numbers of beautifully formed and decorated glass vessels and inlays have been encountered. These first hollow glass vessels were not blown. Instead they were formed by placing glass over a sand core, which was possibly held originally within a cloth bag. The glass and core are thought to have been heated repeatedly and rolled over a stone surface to form a smooth uniform body wall. Surface decorations were then applied as thin rods of variously colored glass which were pushed into the surface by rolling. Figure 1 shows an example of such an early sand core vessel.

By the period of Roman rule, glass blowing had been introduced along with a wide variety of techniques of surface engraving, scratching, cutting on a lathe, and the forming of complex multilayered structures. During the late Hellenistic and early Roman centuries Alexandria was probably the most productive center of fine glass objects in the ancient world. Figure 2 shows an example of one type of elaborate glassware which is thought to have been produced at Alexandria. The tradition of fine Egyptian glassmaking continued throughout the Islamic centuries.

The specimens analyzed in this compositional study of Egyptian glass range in date from the New Kingdom down through the early Islamic centuries, i.e., roughly from the fourteenth century B.C. through the twelfth century A.D. The Egyptian specimens were part of a much larger group of specimens of similar dates from the entire Eastern Mediterranean, Western Asian, and European regions. The specimens were first analyzed by means of emission spectroscopy. Recently a majority of them have been reanalyzed by neutron activation. The details of the analytical techniques used for these analyses are given in the

appendix. It is expected that the entire analytical study with complete analytical data will be published soon.

Second Millennium B.C. Glass

Most of the New Kingdom glass specimens we have analyzed are excavated fragments furnished us through the courtesy of the Metropolitan and the Brooklyn Museums of Art. They included material from the Brooklyn Museum's excavations at the Palace of Amenhotep III and the tomb of Tutmosis III at Thebes and from the Metropolitan Museum's excavations at Thebes and at Lisht. An early first millennium B.C. specimen, an opaque red inlay from a plaque at the Brooklyn Museum datable to the reign of Scher-ib-re (late 6th-early 5th century B.C.) is included with the second millennium B.C. specimens as an example of early opaque red glass.

In selecting the specimens for analysis an effort was made to sample glass of the various colors normally encountered for this period, with relatively rare examples of uncolored, transparent glass being particularly sought out for comparison to the colored or opacified specimens. The colorants and opacifying agents were usually added in only low concentrations, that is, in the range of fractions of a percent to a few percent at most. A possible exception to this are the opaque, "sealing wax" red glasses which sometimes contain fairly high concentrations of copper and lead oxides. Accordingly, as a rule, the basic composition of the glass had been little affected by the addition of colorant. One observes that the basic composition of all of the early specimens analyzed is essentially the same.

Second Millennium Egyptian glass has been found by us, as it has been by others,¹ to be basically a soda-lime glass, not greatly different in composition from common modern glass of this type. It has a sodium oxide content of from fifteen to a little over twenty percent, a calcium oxide

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content of five to ten percent, a silica content of about sixty to seventy percent plus relatively small concentrations of a number of minor component oxides. It consistently has relatively high magnesia (2 to 5 percent) and potash (1 to 3 percent) contents. Second millennium B.C. glass specimens from Western Asia and the Aegean have been found to be nearly identical in their basic compositions to Egyptian glass. Figure 3 shows a comparison between the basic components in glasses of this period from these three regions. One sees that the standard deviation ranges of concentrations, indicated by extended diamonds in the figure overlap for the three regions. It is interesting to note that the Chinese glass of this period is very different in composition, being largely composed of lead and barium oxides.²

Compositional comparison between the relatively colorless, transparent specimens and colored or opacified ones reveals the additives used to produce the optical change desired. However, not only do the colorant oxides themselves show up with enhanced concentrations but often a small number of other oxides will be present in the colored glass at significantly higher concentration levels than in the colorless comparison base. These other elements with higher concentrations presumably were accidentally added along with the primary colorant oxides. Such accompanying impurities often indicate the nature or source of the colorant. For example, Figure 4 shows that certain blue specimens, which have been colored by the presence of about a percent of copper oxide, also have much higher tin and manganese concentrations than were found in colorless specimens. In fact the ratios of enhanced tin concentrations to copper concentrations is roughly similar to the ratio of tin to copper found in New Kingdom bronze. New Kingdom bronze has been found to be a simple binary alloy of copper and tin with about twenty percent tin.³ Geilmann⁴ has pointed out that many Roman copper blue glasses have copper, tin, and lead

concentrations in the relative proportion they are encountered in Roman bronze, and has argued that a bronze corrosion product was used to color them. It seems very possible that a bronze corrosion product could have been used to color these earlier glasses also.

Both of two cobalt blue New Kingdom glasses we analyzed had definitely enhanced concentrations of manganese, nickel, and zinc in the same order of magnitude as the cobalt itself. The high concentrations of zinc oxide are particularly noteworthy as we very seldom have found zinc at a detectable level in ancient glass. These elements serve to characterize the cobalt ore used to color the glass. In analyzing some cobalt blue Mycenaean rosettes, see Figure 5, it was most interesting to find the cobalt oxide accompanied by the same additional elements in the same relative concentrations. Thus the same cobalt source appears to have been used to color these Mycenaean glasses as was used in the corresponding New Kingdom glasses. Since the basic compositions of both glasses are nearly identical too, one cannot help but speculate that the glasses themselves came from the same source. Although the rosettes are definitely Mycenaean and not Egyptian in style, the glass out of which they were made could have been imported from Egypt to be reformed in the Aegean region.

Analyses of two second millennium B.C. cobalt blue glasses from the Mesopotamian region have been reported in the literature. Figure 6 which compares the colorant affected oxide concentrations in all of these early cobalt containing glasses indicates that a different source of cobalt was used for the Western Asiatic glasses.

Analyses of two transparent violet colored glasses confirms that, as was to be expected, the color was due to manganese. It is worth noting however that special control of melting conditions is required to leave the manganese

ions present in the glass at exactly the correct state of chemical oxidation, the trivalent state, to produce this color. In more recent specimens we shall see examples of colorless glasses that contain even more manganese than these strongly violet colored glasses.

A large fraction of the early glasses were deliberately made opaque. Among the cobalt and copper blue glasses we have analyzed there are included an example of each which are opaque. Figure 7 compares antimony and lead concentrations in second millennium B.C. opaque white, yellow and blue glasses to that in colorless glasses. Comparison of the analyses of all three colors of early opaque glass shows that they are all characterized by relatively high antimony oxide concentrations (ranging from 0.4 to 2.4 percent). X-ray diffraction studies carried out by Rooksby⁵ have established that separated opaque phase in the New Kingdom opaque, blue and white glasses is a white calcium antimonate. In the case of the blue glasses the transparent glass matrix is colored blue, while the opacifying separated phase is colorless. The opaque yellow phase has been similarly found to be a bright yellow lead antimonate, and indeed the analysis of them show a relatively high lead as well as antimony content.

In the opaque lead glasses the separated phase is usually found to be a mixture of finely divided copper metal and reduced copper oxide, cuprite. In the early first millennium Egyptian glass inlay we found eleven percent copper oxide accompanied with about two percent antimony oxide and two tenths of a percent lead oxide. In post second millennium B.C. opaque red glasses one usually encounters a relatively high lead oxide concentration which appears to help control the solubility of copper oxide in the glass so as to produce a uniform opacification arising from phase separation upon cooling. It would seem likely that the antimony oxide would serve a similar function in this very early opaque red glass.

All recently acquired data, both structural and compositional, indicate that antimony compounds and not tin compounds were the opacifying agents in most opaque second millenium B.C. glass. However, one often encounters in the literature dealing with ancient glass the statement that the opacifying agents in glass of this period are tin compounds. The source of this misinformation appears to be a set of analyses of ancient glass reported by B. Neumann⁶ in 1929. In this set of analyses Neumann analyzed some opaque copper blue glasses. He found these glasses to contain a significant concentration of tin just as we have found some opaque copper blue glass which we have analyzed to contain tin. However the glass we have analyzed contained more than ten times more antimony oxide than tin oxide and hence appears to be a glass rendered opaque by means of calcium antimonate and rendered blue by a copper compound which brought with it a significant amount of tin. It would appear to be very likely that the same situation existed in the opaque copper blue specimens analyzed by Neumann, that he determined the accidental amount of tin present but for some reason overlooked the antimony, and not unreasonably inferred that the opacification was due to tin.

The course of coloration in the amber and "black" glass cannot be directly inferred from the analyses. The amber glass differs very little in composition from the colorless glasses for all elements while the "black" has somewhat higher iron and aluminum concentrations, and as revealed by neutron activation several times higher concentrations of a number of rare earth and rare earth related oxides and chromium oxide. The concentrations of all of these oxides however lie in the less than one hundred parts per million range and hence should not in themselves visually affect color.

It would seem likely that the glass was rendered amber and very dark green, which is the true color of the "black" glass, through the addition of sulfur containing material to the glass melt of a type capable of transforming the iron compounds present in the glass into iron sulfide which can produce the colors observed. In modern technology glasses are darkened in this way, and the addition of sulfur, an element we do not determine, to the glass melt would be consistent with the lack of difference in analysis we observe. Perhaps the enhanced amounts of rare earths found in the "black" glass will eventually provide an indication of the precise material added to darken this glass.

Egyptian Glass with "Roman" Composition

When we consider the total assemblage of our analyses of ancient glass we find that they can be divided into two distinct types. This division is primarily based upon the concentrations of magnesium and potassium oxides. Figure 8 shows this division into a group that has relatively high concentrations of both magnesium and potassium oxides and a second group with relatively low concentrations of both components. In Fig. 8 it is to be understood that the same specimens constitute the high and low concentration groups respectively for all four components plotted. Figure 8 also shows that both types of glass are still basically of soda-lime formulation with sodium remaining the predominately present alkali in both types of glass.

It was at one time suggested by Matson⁷ that the difference between the two types of glass might be explained upon the assumption that dolomite, calcium magnesium carbonate, was used in the formulation of one and calcite, calcium carbonate, in the other. However the consistent

correlation between potassium and magnesium in the two glasses plus the nearly equal concentrations of calcium oxide in both glass types would make it more likely that the differences reflect the use of basically different types of alkali in the two different types of glass. It is interesting to note that natron from the Wadi Natrun mixed with an appropriate sand would produce glass compositionally similar to the low magnesia-low potassia glass and that the alkali carbonate residue one obtains by evaporating Nile River water mixed with sand could produce the high magnesia-potassia glass. Pliny mentions the formation of a natron by evaporation of Nile water. These observations, of course, do not prove that these materials were indeed the alkalis so used but they do indeed indicate them as logically being materials that might have been used.

All of the second millennium B.C. and early first millennium B.C. specimens we have analyzed have been of the high magnesia type. From the mid-first millennium B.C. on in Europe, Anatolia and the Eastern Mediterranean coast down through all of the centuries of Roman rule one encounters only glass of the low magnesia type. Because all glass of probable origin from within the Roman empire has had this formulation we have chosen to call it the "Roman" composition. We wish it to be well recognized, however, that glass of this "Roman" composition was introduced some centuries before Rome achieved political predominance in many of the regions in which it was made and that it continued to be made in some areas for centuries after Roman control had ended there.

The earliest specimens of glass found in Egypt with the "Roman" low magnesia-low potassia composition are samples supplied by the Brooklyn

Museum from glass inlays from funeral objects associated with the late pharaohs Necthnebo II (360-341 B.C.) and Ptolemy V (205-180 B.C.). The first of these is rendered opaque red with a high reduced copper content with the usual accompanying high concentration of lead oxide and the second colored blue with copper and rendered opaque with calcium antimonate. This specimen also contains about 0.3 percent tin oxide which is about one tenth the copper and the antimony oxide concentrations and probably again indicates the addition of copper in the form of an oxidized bronze.

The next truly datable Egyptian glass we have analyzed was furnished us by the Kelsey Museum of Archaeology of the University of Michigan from material excavated from Karanis and datable from content of find to the 2nd to 4th centuries A.D. All of these specimens were of "colorless", transparent glass of typical "Roman" composition. Four specimens were characterized, however, by having high manganese oxide concentrations of the order of one percent, while three were characterized by having similarly high antimony oxide contents, about one half to one percent. It is important to note that these glasses were neither colored nor opaque. It can be demonstrated that when appropriate manganese or antimony compounds are incorporated into glass in such a way that they themselves are reduced but in becoming so have oxidized the iron present in the glass they tend to remove the "bottle green" discoloration which results from the presence of reduced iron in glass. In contrast to these conditions opacity results from the presence of oxidized (pentavalent) antimony compounds in glass and violet coloration from the presence of trivalent manganese. We have presented evidence at length⁸ in previous publications that antimony compounds appear to have been used as a decolorant in glass from the

early first millennium B.C. on and manganese compounds as decolorants from the end of the first millennium B.C. In these glass specimens from Karanis one has evidence indicating that both types of decoloration was used in glass of probable Egyptian manufacture at this time.

The Metropolitan Museum supplied us with a set of four "colorless" glass fragments of definite Roman style which had been found during excavations at the palace of Amenhotep III at Thebes. These fragments had typical "Roman" composition as well as style. Three of them had been decolorized with manganese while the fourth had a mixture of manganese and antimony compounds added to it. We have found this combined use of both manganese and antimony as decolorants in a number of Roman glass specimens from other regions.

Few ancient glass objects can be dated as precisely as the Islamic glass weights. These weights, examples of which are shown in Fig. 9 bear inscriptions that often relate them to specific public officials who were in power at the time the weights were made. Also the geographic region in which such officials served is often well known and it can be assumed that the weights were produced in that region. We were very fortunate in having a sizable number of these glass weights furnished us for study by the American Numismatic Society. Dr. George Miles generously interpreted the inscriptions upon them or otherwise identified them as to date and origin. The weights shown in Fig. 9 were probably used to check the weights of coins. Other larger weights were made for the metering of various forms of produce. The earliest of these Islamic weights were found to have typical "Roman" composition without any decolorant substance having been added to them. Four of these early glass weights are compositionally unusual, however, in that they have the same exceptionally low calcium contents

which were found in the late ptolemaic inlay and in some of the Roman glass specimens. The weights contain on the average only about two percent lime while most glass of "Roman" composition has at least twice and more often several times this concentration of lime. Two other specimens with this very low calcium oxide content were both associated with the Wadi Natrun. One is a factory waster taken directly from the site of an early glass factory in the Wadi. The second is a glass chalice which was found in a sealed room in a Coptic Monastery at Wadi at Natrun. Figure 10 presents the calcium and magnesium data for these low calcium specimens and compares them to the average of these concentrations in more usual glass of "Roman" composition. All of the glass objects of basically "Roman" composition with this low calcium content have been of highly probably Egyptian origin. In light of the match with the Wadi Natrun factory material and chalice it would seem likely that glass with these compositional characteristics, such as the earlier inlay, were actually manufactured in the Wadi Natrun. A fifth glass weight of highly probably Egyptian origin, based upon decipherment of its inscription, did not have this characteristic low calcium content. This contrasting composition would indicate the likelihood of there having been more than one Egyptian site for the manufacture of these weights.

The last group of "Roman" composition glass of probably Egyptian origin are three specimens with similar elaborate multi-colored lustre designs fired onto their surfaces, see Fig. 11 for an example. The designs are judged to be early Islamic in style and since all three pieces were purchased in Egypt an Egyptian origin for them is moderately

likely. All three pieces have typical "Roman" composition. From these fragments one can infer that glass vessels as well as weights were manufactured in the Roman tradition of glass components as late as the early Islamic centuries.

The Introduction of an Islamic High Magnesia

Formulation in Egyptian Glass

We have analyzed twelve additional Egyptian Islamic glass weights which range in date from the middle of the ninth century through the eleventh century into the Mameluke period. All of these more recent glass weights have had a soda-lime composition characterized by relatively high magnesia and potash concentrations. Clearly a distinct change occurred in this formulation of these glass weights, and presumably other glass objects, at the middle of the ninth century. Figure 12 shows the occurrence of this change by means of a potassium-magnesium correlation plot.

The composition of this glass is ^{so} similar in all respects to that of the second millennium B.C. glass that one wonders whether it might not have been made from the same type of materials. It is to be noted that we have found some of the glass specimens from sites along the Tigris River which in date span the Roman period to continue to have this same high magnesia composition. It seems fairly likely that the early tradition of glass formulation continued to be followed in this more Eastern region and returned to more Western sites of manufacture when Islam once again brought the entire region of Western Asia and North Africa into close interaction. However this may be, we have found

the preponderate majority of Islamic glass specimens we have analyzed to have this characteristically high magnesia-high potash composition. Accordingly we have referred to it as the Islamic composition, without meaning to imply by this designation that all Islamic glass has this composition or that this composition is found only in Islamic glass.

It is interesting to note that three of the twelfth century weights we have analyzed were rendered opaque white through tin oxide. These tin white glasses also contain significant lead oxide concentrations. This change from antimony compounds to tin in opaque white glass reflects an earlier similar change in more Western glass. In glass found in Italy one first encounters tin oxide opaque white glass in specimens datable to the fourth century A.D. We have encountered another example of an Islamic lead rich glass rendered opaque white with tin oxide in a mosaic cube from the Great Mosque at Damascus dated to the early eighth century.

Most of the Islamic glass of probably Egyptian origin we have analyzed has had a high magnesia formulation similar to the later glass weights. These specimens include some cut glass fragments found at Fostat and a group of very similar cut fragments purchased in Cairo of very probable Egyptian origin. A group of three fragments with similar relatively simple monochromatic lustre designs have had this composition. One of these is shown in Fig. 13. In consideration of the evidence of chronological compositional change in the glass weights one would consider this more simple type of lustre ware to be of more recent date than the type previously described with "Roman" composition.

A most interesting group of specimens were three fragments of clear glass vessels with a bright green outer layer which had been carved

through to produce a cameo relief. Two of these fragments were purchased in Cairo and one we received from the Museum of Islamic Art in Cairo. In each instance the basic colorless supporting glass was of the typical "Islamic" soda-lime formulation. However in each instance the outer green layer was a high lead glass, colored green with copper oxide. Data for these specimens and some compositionally similar green high lead glasses from outside Egypt are given in Fig. 14. It is surprising that the under soda-lime and outer high lead glass would have been dimensionally compatible under the heating and cooling conditions required to melt the outer layer. The outer layer would, of course melt at a lower temperature than the support base and probably was fused on as an "enamel" at a later stage of formation.

Thus it can be seen that throughout this entire period of study Egyptian glass remained basically a soda-lime glass. The glass, however, can be divided into three types upon the basis of its magnesium and potassium. The first type, with a relatively high magnesia-high potash formulation was produced in Egypt from the second millennium B.C. through the early first millennium B.C. The second type, with a so-called "Roman" formulation of relatively low magnesia and potash, predominated in this region until the middle of the ninth century A.D. From this time a high magnesia-high potash formulation almost indistinguishable from the second millennium B.C. glass was used in Egyptian Islamic glassware. Throughout the entire period lead oxide was added from time to time to these glasses to produce special effects, but it is moot whether one would call any of these a true lead glass. A variety of colorants, decolorants and opacifying agents were used with great skill. Some of the finest glassware ever produced is ascribed to Egyptian production during these centuries.

Acknowledgments

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Appendix

The specimens were initially analyzed by emission spectroscopy for the elements lithium, sodium, potassium, rubidium, magnesium, calcium, strontium, barium, boron, aluminum, phosphorous, titanium, vanadium, chromium, manganese, iron, cobalt, nickel, copper, zinc, zirconium, silver, tin, antimony, lead, and bismuth. After corroded surface material had been removed by grinding with a tungsten carbide rotating burr samples of glass were removed from the specimens¹⁾ by breaking off small fragments which were then crushed²⁾ by grinding with a carbide burr or³⁾ by chipping with a carbide tipped vibrating tool. Five milligram finely divided specimens were weighed into two types of preformed cup electrodes. For the determination of most elements a graphite cup was used which was arced to complete combustion of the sample and cup in air with a 200 volt, ten ampere D.C. arc. This spectrum was recorded in the ultraviolet region. The alkali elements were determined in the near infra red spectral range. To avoid molecular bond interference in this region the specimens were arced in a helium atmosphere. Because the electrode cup does not burn away in the usual sense in this inert atmosphere it was necessary to heat the specimen and cup to unusually high temperatures to insure complete volatilization of the sample. This was accomplished by using "carbon" rather than graphite cups and arcing at a higher current, 13 amperes.

Twenty to thirty samples were recorded on each spectrographic plate along with a standard glass which contained all of the elements present in the ancient glass specimens in approximately the same concentration range. This standard sample allowed the determination of a plate calibration

constant which would compensate for most overall differences in spectrum exposure and plate development between runs. The spectrographic lines were measured with a photoelectric densitometer. Photographic plate response curves for the various wavelength regions were measured and plate calibration curves for the individual elements were determined using standard glasses furnished by the National Bureau of Standards and the Corning Museum of Glass. From these curves it was estimated that reproducibility of measurement was within twenty percent of the concentration determined.

Recently most of the specimens were reanalyzed by neutron activation analyses for the elements sodium, potassium, rubidium, barium, scandium, lanthanum, cerium, europium, lutetium, hafnium, thorium, tantalum, chromium, iron, cobalt and antimony. The analytical method used was identical to that described in the accompanying paper by Tobia and Sayre in this symposium. It is not necessary to repeat the description of this procedure here except to note that for the glass analyses ten milligram samples of both the glass specimens and all six United States Geological Survey rock standards were activated and counted together rather than the forty milligram samples used for pottery analysis. The precision of measurement ended to be in the range of five to ten percent of the determined values.

Trouble was encountered only with the specimens with relatively high antimony content, in which the antimony activity was so intense as to overpower activities from other elements. In general we concluded that the study could equally well have been carried out with either neutron activation analysis or emission spectroscopy alone, except for the case

of the "black" glass cited where neutron activation revealed a distinguishing difference in the concentration of the rare earth elements which did not show up in the emission spectrographic data.

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Figure Captions

- Figure 1 New Kingdom Sand Core Vessel
- Figure 2 Elaborately patterned first century glass bowl. Alexandria is thought to have been a production center for fine glass-ware of this and other complex types.
- Figure 3 Comparison of the basic compositions of early Egyptian, Aegean, and Mesopotamian glass.
- Figure 4 (caption on figure)
- Figure 5 Mycenaean rosette whose basic composition and cobalt colorant trace impurity pattern is similar to that of New Kingdom Egyptian glass.
- Figure 6 Comparison of colorant impurity patterns in early Egyptian, Aegean, Mesopotamian cobalt blue glasses.
- Figure 7 (caption on figure)
- Figure 8 (caption on figure)
- Figure 9 Islamic glass coin weights.
- Figure 10 Some Egyptian glass specimens "Roman" composition with unusually low calcium concentrations.
- Figure 11 Fragment of early Islamic glass with multi-colored lustre decoration and "Roman" composition.
- Figure 12 (caption on figure)

Figure 13 Islamic lustreware fragment with monochromatic design and typical "Islamic" composition.

Figure 14 (caption on figure)



Figure 1



Figure 2

STANDARD DEVIATION RANGES OF CONCENTRATIONS
 OF "NON COLORANT" OXIDES IN:
 EGYPTIAN , AND
 MYCENAEAN - MINOAN , AND
 SUMERIAN - ELAMITE 
 GLASS OF THE SECOND MILLENIUM B.C.

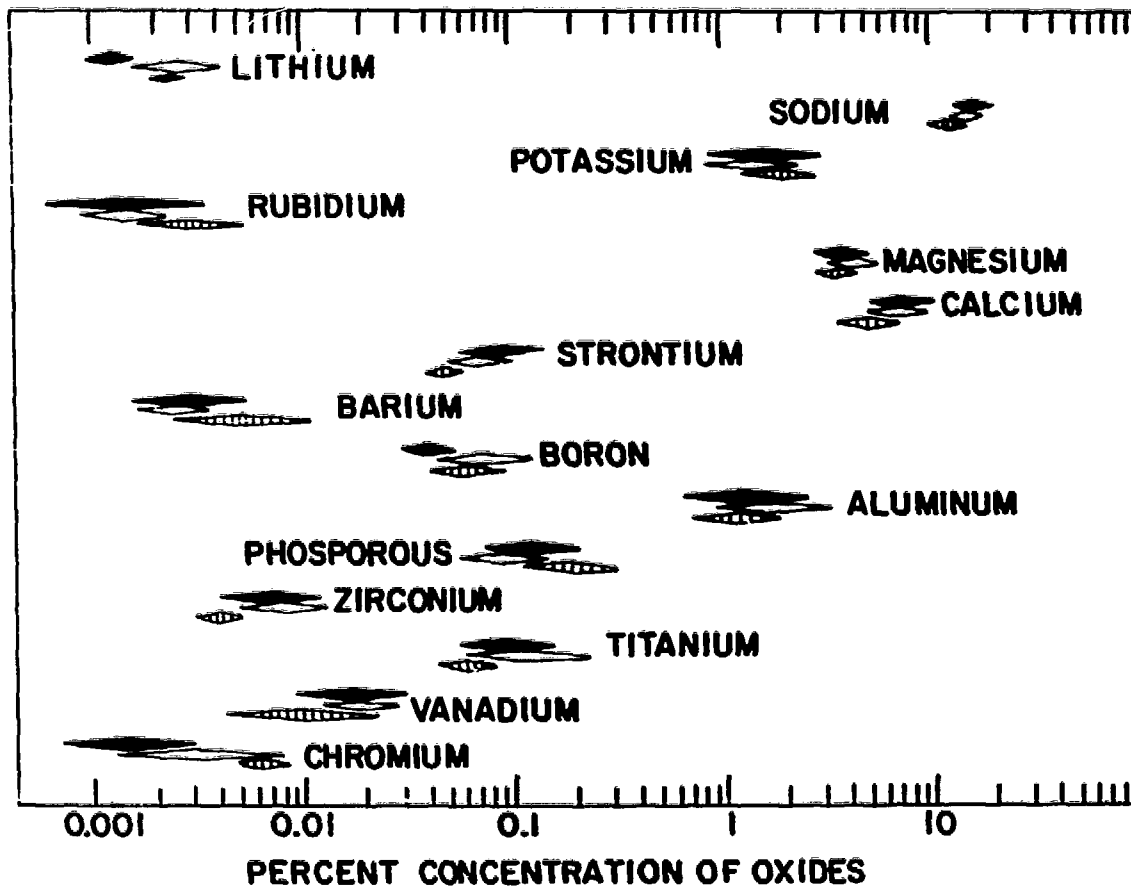


Figure 3

COMPARISONS BETWEEN THE DISTRIBUTIONS
 OF TIN AND MANGANESE OXIDES IN SOME
 SECOND MILLENNIUM B.C. "COLORLESS" AND COPPER
 BLUE GLASSES

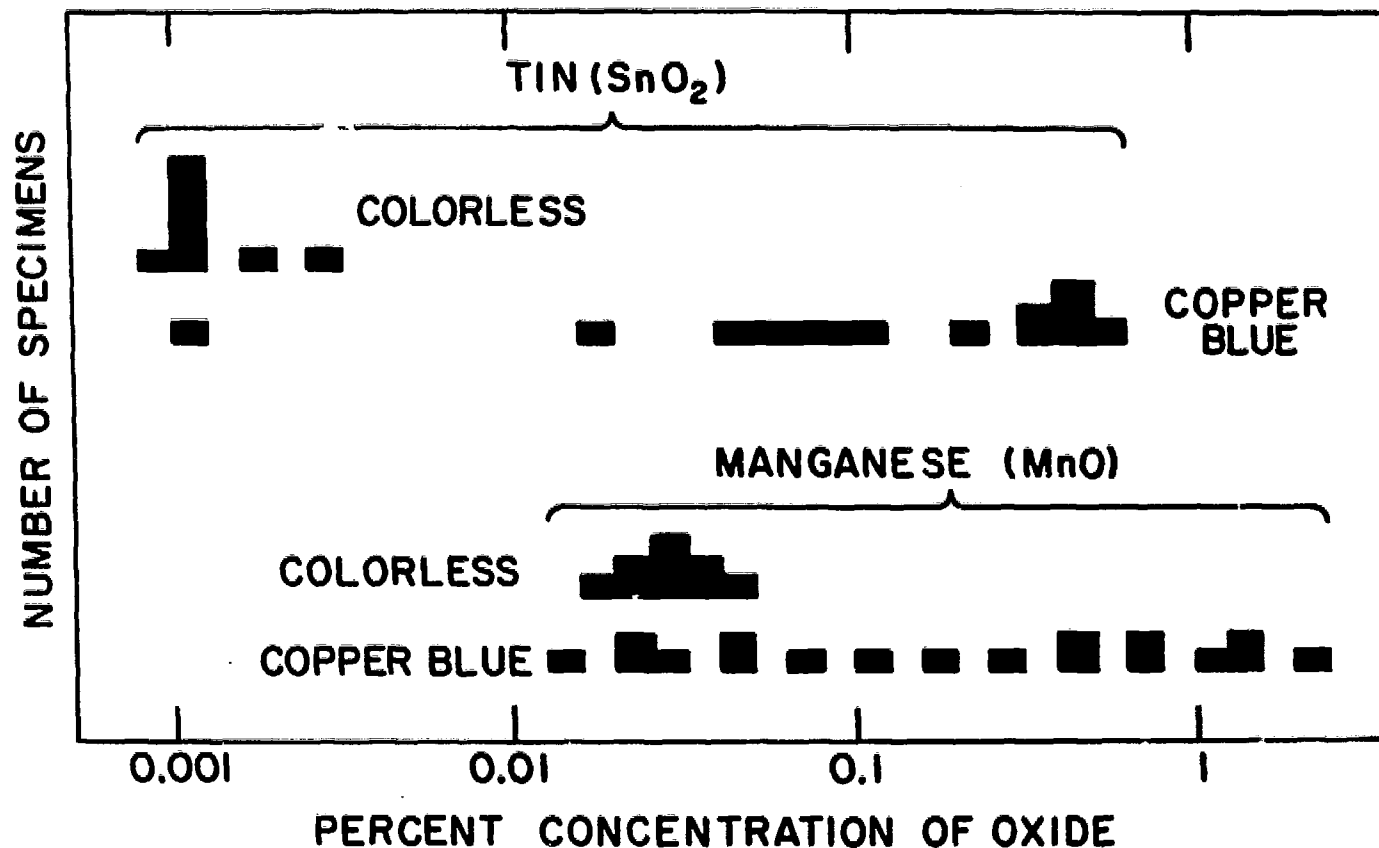


Figure 4

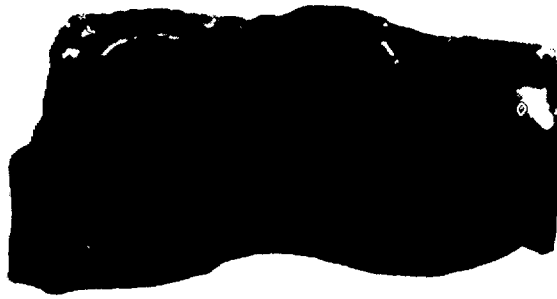
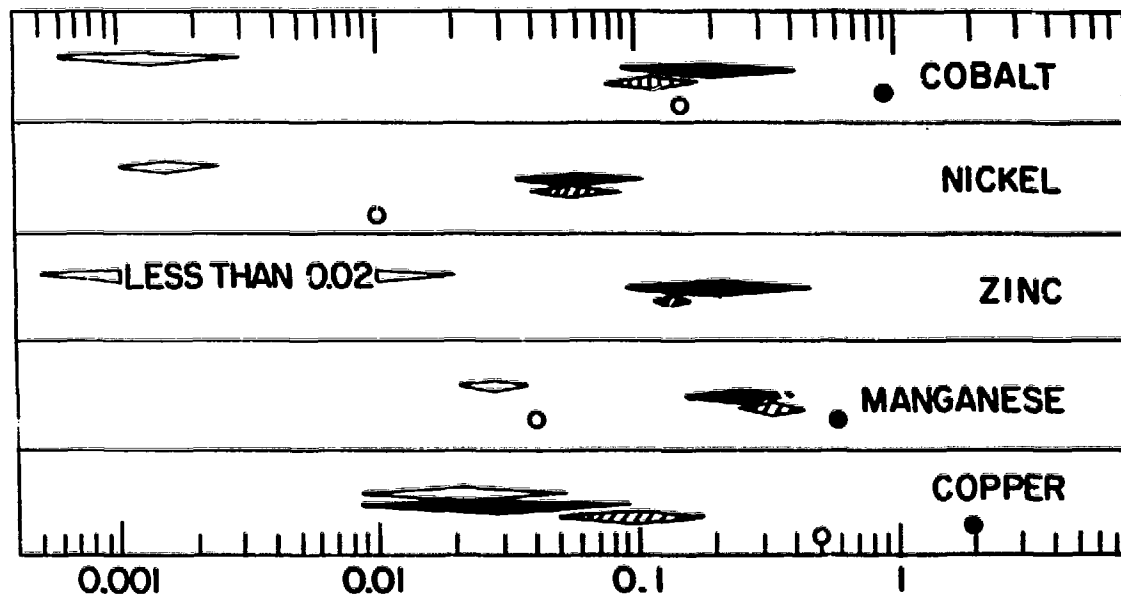


FIGURE 5

**COLORANT ELEMENT PATTERNS IN COBALT-
BLUE SECOND MILLENNIUM B.C. GLASSES.
STANDARD DEVIATION RANGES OF OXIDES
PRESENT IN SIGNIFICANTLY INCREASED
CONCENTRATIONS IN THE COLORED GLASSES**










- PERCENT CONCENTRATION AT OXIDES**
-  COLORLESS SECOND MILLENNIUM B.C. GLASS
 -  EGYPTIAN COBALT BLUE GLASS
 -  MYCENAEAN COBALT BLUE GLASS
 -  A COBALT BLUE GLASS FROM NIPPUR
(NEUMANN-HOFFMAN ANALYSIS)
 -  A COBALT BLUE GLASS FROM ERIDU
(GARNER ANALYSIS)

Figure 6

COMPARISONS BETWEEN THE DISTRIBUTION OF
 ANTIMONY OXIDE  AND,
 LEAD OXIDE 
 IN SOME SECOND MILLENNIUM B.C.
 "TRANSPARENT" AND OPAQUE GLASSES

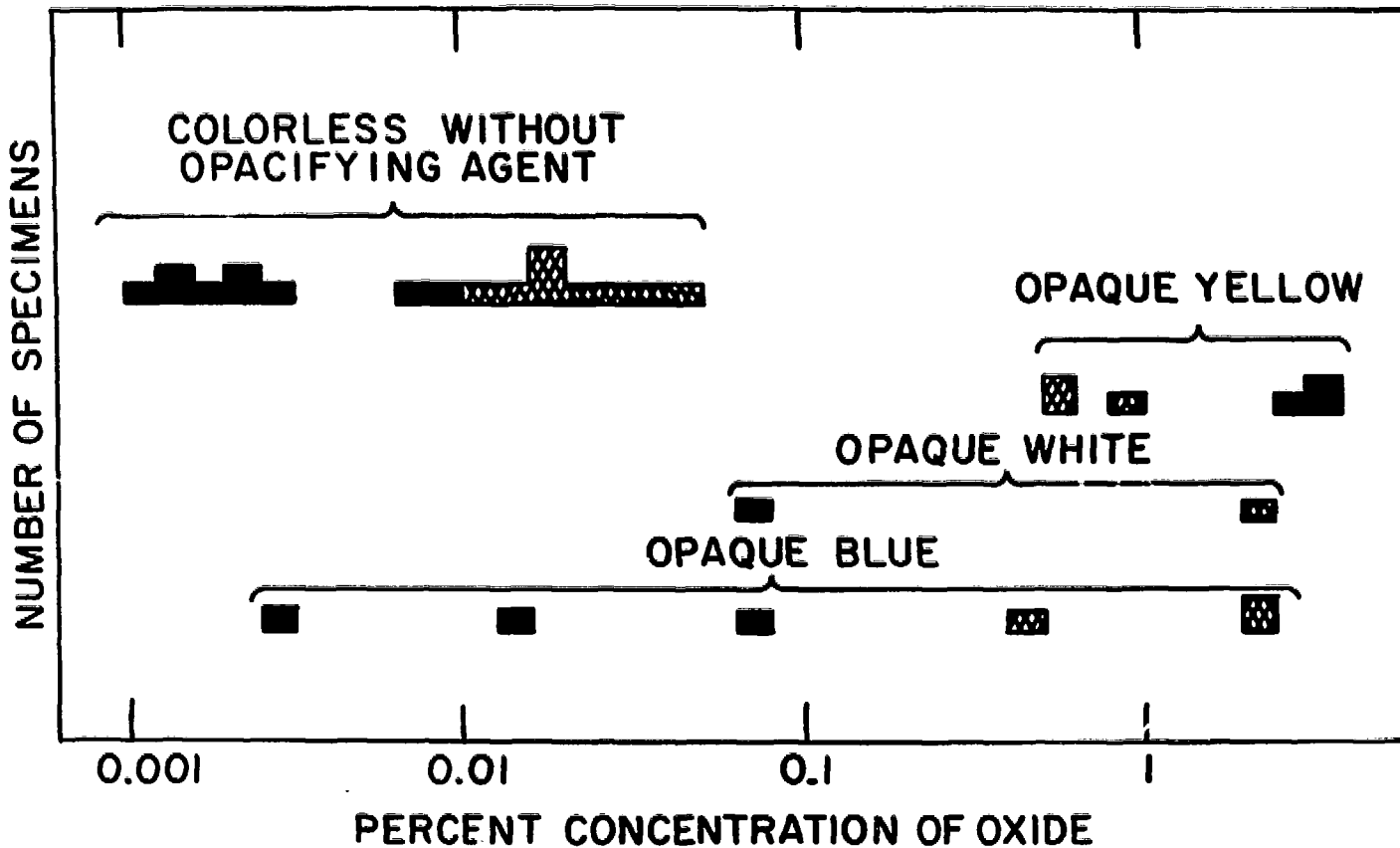


Figure 7

COMPARISON OF COMPOSITIONAL DISTRIBUTIONS FOR HIGH MAGNESIA AND LOW MAGNESIA GLASSES.

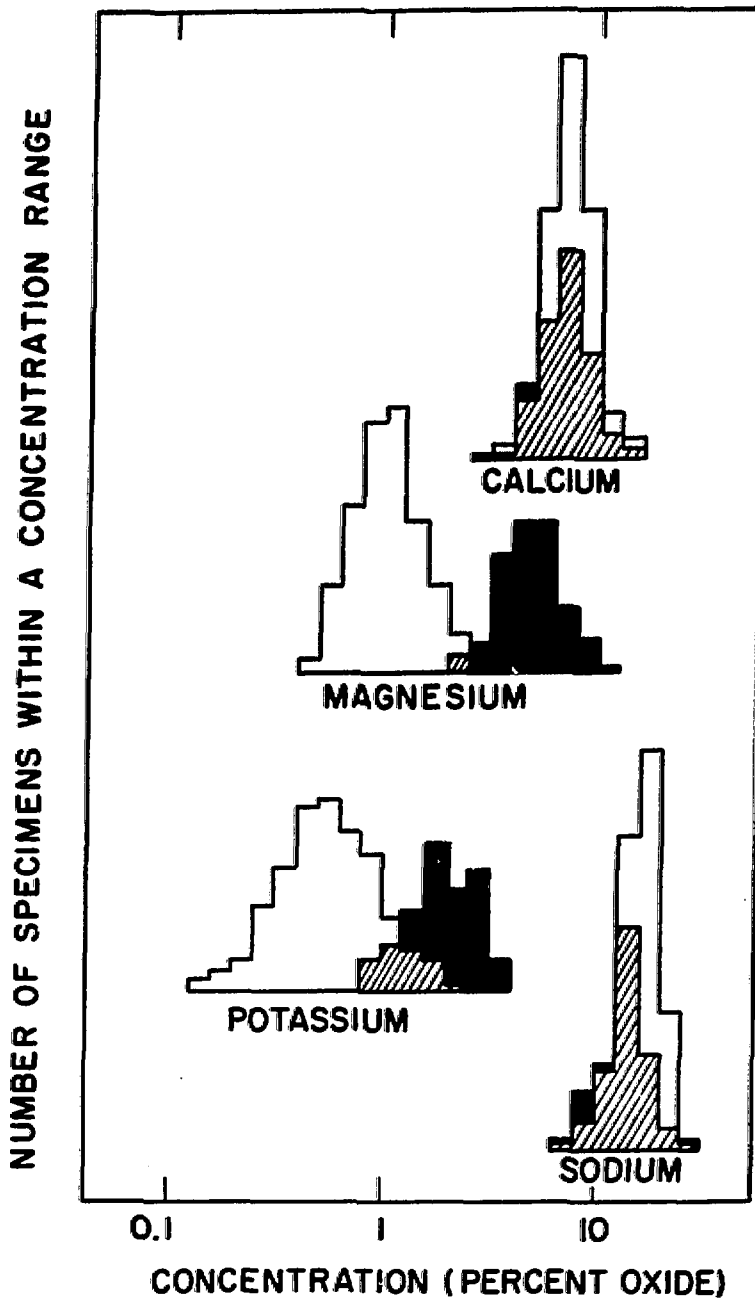


Figure 8

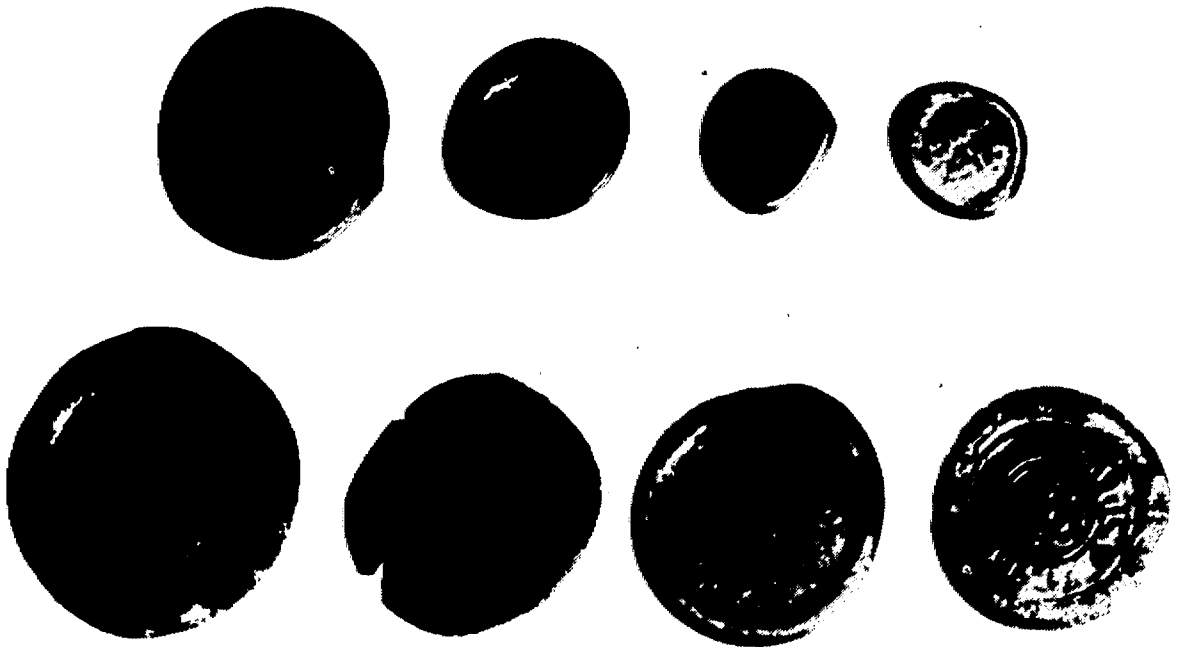


FIGURE 9

Specimen No.	Description	Percent concentration		
		Magnesium MgO	Calcium CaO	Ratio CaO/MgO
820	Blue-green inlay from reign of Ptolemy V (205-180 B.C.)	0.81	3.8	4.7
784	Roman fragments excavated at the	0.94	3.7	3.9
785	palace of Amenhotep III	1.01	4.9	4.8
786	(uncertain date)	1.06	4.2	4.0
668	Egyptian weight (101 AH=719/20 A.D.)	0.92	2.9	3.1
324	" " (111 AH=729/30 A.D.)	1.36	4.5	3.3
326	" " (743-749 A.D.)	1.26	3.5	2.8
671	" " (778-781 A.D.)	1.39	3.1	2.2
715	Glass from ancient kiln at Wadi Natrun (uncertain date)	1.35	3.8	2.8
961	Chalice from Wadi Natrun	1.15	2.6	2.3
	Means	1.11	3.6	3.3
	Mean values of 120 low magnesium glasses from Near Eastern sites	0.98	6.97	7.11
	Specimen 604, Syrian glass weight of the Walters Art Gallery	0.79	5.8	7.4

Figure 10



FIGURE 11

CHRONOLOGICAL DIVISION OF
EGYPTIAN ISLAMIC GLASS WEIGHTS
INTO HIGH MAGNESIUM AND LOW
MAGNESIUM TYPES

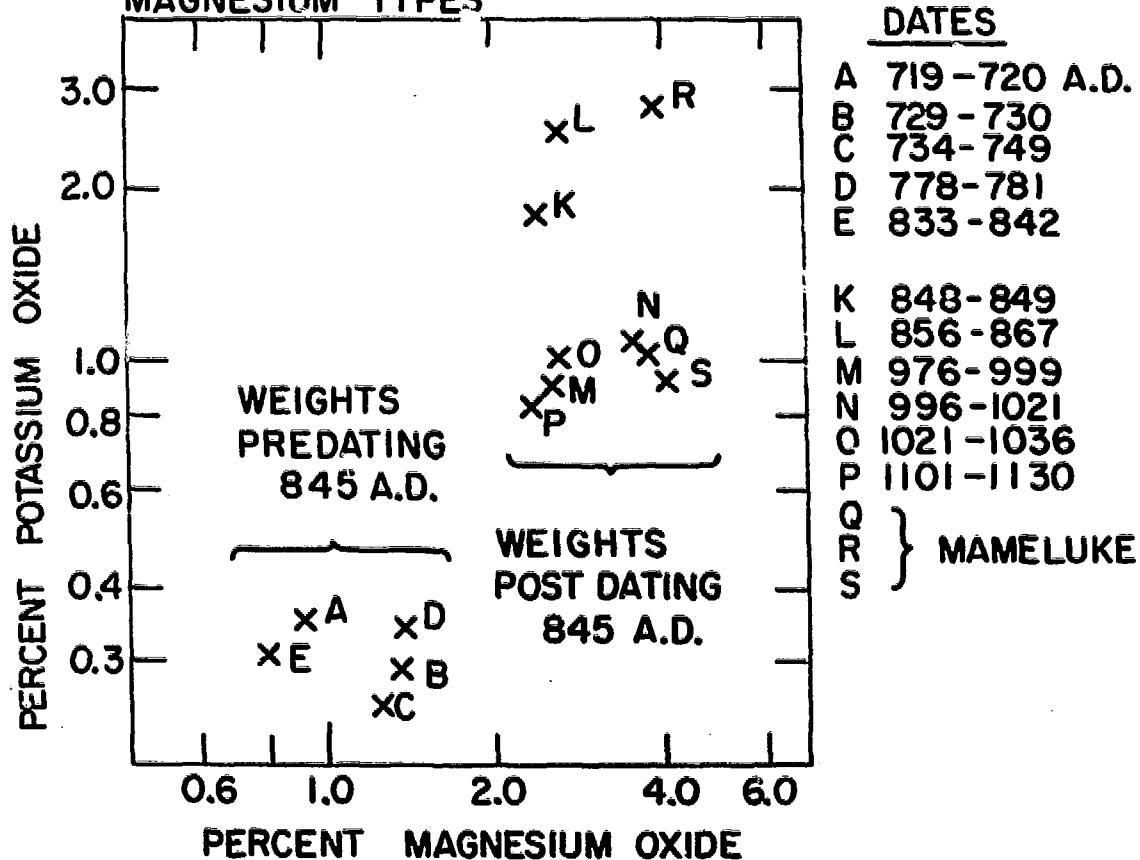


Figure 12



FIGURE 13

Components in Some Clear Green Islamic Lead Glasses

<u>Percent Concentration</u>						Specimen number	Description
Copper CuO	Lead PbO	Sodium Na ₂ O	Potassium K ₂ O	Magnesium MgO	Calcium CaO		
<u>Homogeneous Green Objects</u>							
0.70	42	2.9	0.016	0.25	0.23	615	Possibly a coin weight
0.52	35	2.6	0.023	0.28	0.42	620	Persian fluted bowl
0.29	42	1.5	0.034	0.54	0.69	727	Bowl in treasury of San Marco, Venice
<u>Outer Green Layers of "Cameo" Bowls</u>							
1.12	32	2.9	0.094	0.21	0.25	616 (1)	Decorative layers on bowls listed below
1.33	35	2.5	0.140	0.47	0.53	622 (1)	
2.00	34	1.9	0.074	0.37	0.58	623 (1)	
<u>Inner Colorless Layers of "Cameo" Bowls</u>							
0.0080	0.0018	12.5	1.57	4.9	6.3	616 (0)	Supporting body of bowls
0.0041	0.0020	16.5	1.84	5.2	4.9	622 (0)	
0.0033	0.031	14.4	2.60	3.7	5.9	623 (0)	

Figure 14