The Raw Materials of Ancient Roman Glass in Egypt and Jordan: a Comparative and Analytical Study

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Abstract. *Abstract. The aim of this work is to compare the initial raw materials used for glass manufacture in Roman period (1st to 3 rd cent. AD) in both Egypt and Jordan. Many samples of opaque, transparent, and translucent Roman glass of different typology and colors found at different archaeological sites in Egypt and Jordan have been analysed to identify their compositions and characterize their main raw materials. Furthermore, the colorizers, deodorizers and pacifying agents of these glass samples have been identified. The qualitative and quantitative chemical analyses are carried out using X-ray fluorescence technique (XRF). It can be concluded that, with few exceptions, the ancient Roman glass found in Egypt was mainly soda-lime-silica glass, whereas that found in Jordan was potash-lime-silica glass.*

Introduction

Glass is one of the oldest man-made materials and is most valuable and versatile. Yet glassmaking remains, even today, one of the most empirical and least understood of technologies. The oldest known glass made articles have been estimated to be 9000 years old. But it is accepted that glass manufacture as an industry began somewhere between 3000 BC and 1500 BC when a fairly high standard of glassmaking had been reached. Early work was crude. Glass vessels were formed around a core of sand or clay which was scraped out after the object was finished (Goffer 1980).

During the first century AD, the invention of glass blowing in the Roman period, probably in Syria, turned glass into a large-scale industry and cheap commodity which could be mass produced; and it, no doubt, provided the stimulus for the proliferation or increasing of glasshouses throughout the Roman Empire. At its height the Roman Empire included the countries which are now the United Kingdom (except Northern Ireland), France, Spain, Portugal, Switzerland, Eastern Europe, Turkey, the Middle East, and North Africa. Thus all the major glassmaking centers came under the domination of Rome. In addition, the art of glassmaking was spread, and important centers were established throughout the Empire. However, the glass production remained essentially Roman with only minor regional variations until the collapse of the Roman Empire in the west soon after AD 400 (Newton 1989).

Most modern authorities and studies have confirmed that Mesopotamia or Egypt was the birthplace of glass. Furthermore, political, commercial and industrial relationships or connections existed between Egypt and Mesopotamia, along with other surrounding regions, especially Jordan. Naturally, one can find some forms of analogy or similarity of glassmaking and glass production among them. On the other hand, it was noticed that 1st-3rd century and later specimens showed evidence of different sources of glass raw materials in Egypt and those countries (Tait 1995).

Excavations carried out at various Roman locations dated from the 1st to 3rd century

Issue No. 14 July 2006
ISSN: 1319-8947 (pp. 23 - 32)

AD in Egypt such as, Tuna el-Geble/ Tawness; Wadi el- Natron; Tel Abu-Safi /Tharo; Kom Oshem/ Karanees; and Tel Aba-Yazed have provided the museum's collections with numerous glass objects and artifacts. At the same time Jordanian museums are rich in great collections of Roman glasses coming from various archaeological cities in northern and central Jordan, known as the region of Decapolise; a union of the cities of Tabaqat Fahl/ Pella; Beit-Ras/ Capitolias; Umm-Qeis/ Gadara; Quweilbeh/ Abila; Jarash/ Gerasa; Amman/ Philadelphia and Husn/ Dion in the Roman times starting from the 1st to 4th AD century (Tait 1991).

Several studies on Roman glass, found in Egypt and Jordan of archaeological, technological and artistic interests, have been performed. However, some questions concerning the origin of the raw materials are still open, and some issues involving the production technology have not yet been solved. A study of the glass and glassmaking processes at Wadi el-Natron, Egypt, during the Roman period, showed that this site can be considered one of the great centers of glass production in the Roman period in Egypt. In addition, the analytical study indicated generally that the remaining glasses (frit, objects and artifacts) are soda-lime-silica (Na_2O- CaO- SiO_2) glass (Saleh et al. 1972). Several successive studies are approximately in agreement with this study and confirm that this composition is the most common for the earlier Egyptian glass (Henderson 1985, Goffer 1990 and Brill 1990). On the other side, studies carried out on Jordanian Roman glass revealed a few discrepancies of glass compositions due to differences of raw material resources. A recent study presented the chemical and technological aspects of Roman glasses excavated from Yasileh archaeological site in Jordan. The resulting data of this study showed differences in glass contents from one case to another (Al-Ahmed and Al-Muheisen 1995). Nevertheless, this study was in agreement with previous ones carried out by (Sayer and Smith 1961; Henderson 1985; Dussart and Veld 1990; and Brill 1999) which indicated that the Jordanian Roman glasses are mainly potash-lime-silica (K_2O- CaO- SiO_2) and rarely of soda-lime-silica (Na_2O-CaO- SiO_2) glass.

Experimental

Glass samples

Many samples of opaque, transparent and translucent Roman glass of different typology (mosaic tesserae, vessels, artifacts and frits) and colors (red, green, yellow and blue) coming from different archaeological sites in Egypt and Jordan, have been collected. These samples are cleaned and prepared for chemical analysis to identify their compositions and main raw materials. Photographs of these samples are shown in figures 3 and 4.

Maps 1 and 2 show the sites where these glass samples were found. Furthermore, Tables 1 and 2 summarize the visual description of these samples. For the XRF measurements, the glass samples were perfectly powdered.

Analytical methods

Compositional analyses of archaeological glasses were performed using the qualitative and quantitative technique XRF; X-ray fluorescence spectrometry is a non-destructive technique which is now widely used for the chemical analysis of materials because it is rapid and accurate, and can be carried out

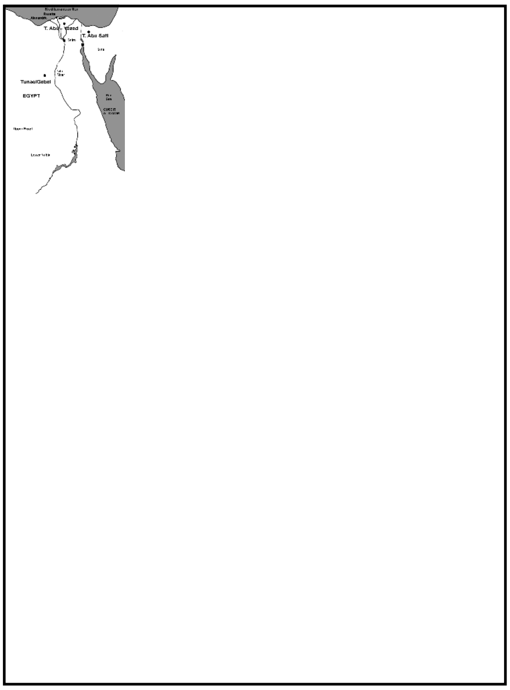

Fig. 1: Map of Egypt showing sites of the Egyptian glass samples.

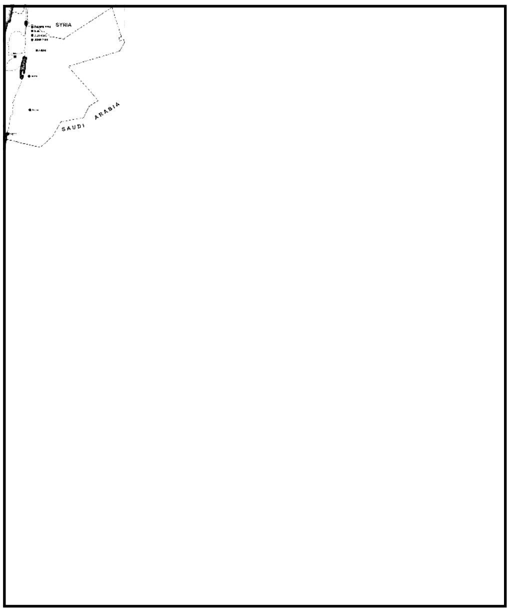

Fig. 2: Map of Jordan showing sites of the Jordanian glass samples.

Fig. 3: Photograph of a few Roman glasses found at Egyptian Roman sites selected for chemical analyses

Fig. 4: Photograph of a few Roman glasses found at Jordanian sites selected for chemical analyses.

Sample No.	*Location/ Site*	*Date/ Cent.*	*Visual description*
E. 1	Tuna el-Gebel	1st	Fragment of transparent , colorless glass vessel
E. 2	tel Abu-Safi	1st- 2nd	Small block of semi-transparent, light green glass frit
E. 3	tel Abu-Safi	1st- 2nd	Fragment of transparent, yellowish glass bottle
E. 4	tel Abu-Yazed	3rd	Fragment of semi transparent, light green glass bottle
E. 5	tel Abu-Yazed	3rd	Fragment of semi-transparent, light blue glass bottle

Table 1. The selected samples of Egyptian Roman glass from different locations.

Sample No.	*Location/ Site*	*Date/ Cent.*	*Visual description*
J.1	Beit-Ras	1st- 3rd	Fragment of semi transparent , deep green glass object
J. 2	Beit-Ras	1st- 3rd	Fragment of opaque, light green glass bottle
J. 3	Johfiyeh	1st- 3rd	Fragment of dark black ,opaque Mosaic glass bead
J. 4	Johfiyeh	1st- 3rd	Fragment of dark blue, opaque glass bead
J. 5	Quweilbeh	1st- 3rd	Fragment of semi transparent, yellowish glass bottle

Table 2: The selected samples of Jordanian Roman glass from different locations.

Oxides Wt%	*Egyptian glasses*					*Jordanian glasses*				
	E.1	*E. 2*	*E. 3*	*E. 4*	*E. 5*	*J. 1*	*J. 2*	*J. 3*	*J. 4*	*J. 5*
SiO2	73.01	73.43	68.22	72.47	67.51	67.00	67.00	64.00	69.00	68.00
Na2O	5.58	3.42	9.02	-----	2.10	-----	-----	-----	-----	-----
K2O	2.65	2.22	2.68	5.27	7.55	1.70	1.90	4.30	5.90	1.60
CaO	3.48	5.28	9.20	2.02	1.07	21.60	20.80	22.10	9.70	20.60
Al2O3	5.41	5.65	2.15	13.43	6.94	-----	-----	-----	-----	-----
Sb2O3	-----	-----	-----	-----	-----	0.40	0.30	-----	0.70	-----
Fe2O3	1.79	1.13	-----	3.51	4.97	1.92	1.50	2.20	3.18	2.08
TiO2	0.66	-----	-----	-----	1.27	0.20	0.10	0.20	0.20	0.20
MnO	1.31	-----	-----	-----	6.70	0.14	1.10	0.26	-----	-----
P2O3	-----	-----	3.31	-----	-----	-----	-----	-----	-----	-----
MgO	1.33	1.46	3.71	1.73	-----	2.08	2.93	1.86	2.71	3.22
Cl2O	4.60	4.01	0.58	0.45	1.47	1.90	2.00	2.20	2.50	2.40
Co3O4	-----	-----	-----	0.85	-----	-----	-----	-----	0.43	-----
SO3	0.19	3.40	-----	-----	1.47	-----	-----	-----	-----	-----
CuO	-----	-----	-----	-----	0.42	0.059	0.090	0.068	3.00	0.051
PbO	-----	-----	-----	-----	-----	-----	-----	0.21	0.33	-----

Table 3: Analysis results of ten Roman glasses from Egypt and Jordan obtained by XRF.

on equipment that is available commercially (Newton 1989). Furthermore, this system is used for qualitative and quantitative analysis of a wide range of archaeological, crystalline and amorphous substances. Moreover, XRF instruments are able to detect all elements with an atomic number of about 11 and higher (Shugar and Rehren 2002). Minipal 2 XRF equipment located at the faculty of Archaeology and Anthropology, Jordan, was used for micro analysis to determine the chemical compositions of the selected Egyptian and Jordanian glass samples (see table 3).

Results and discussion

Table 3 gives the qualitative and quantitative results obtained by XRF of ten archaeological glass samples collected from several Roman locations in Egypt and Jordan which were previously described in tables 1 and 2.

a) Egyptian glasses

The first observation concerning the chemical composition of the Egyptian glasses is that the samples E.1, E.2 and E.3 have a tight chemical composition with a slight variation in its major and minor components. This indication means that these glasses were made using the same main ingredients; silica (SiO_2 avg. 71.5%), lime (CaO avg. 5.98%) and soda (Na_2O avg. 6.0%) It indicates that these glasses are identified as soda-lime-silica (Na_2O-CaO-SiO_2) glass, and characterized by low potassium and magnesium content. So these reveal that the raw materials from which these glasses were prepared are:

1- Quartz sand as a source of silica; the glass former and main component of ordinary glasses. The sources of sand that had been utilized in ancient Egypt could have been from the nearby desert since the Egyptian glasses contained a substantial amount of iron which is comparable to that of their deserts.

2- Soda or natron salt as a mineral source of alkali or flux; the glass modifier, which lowers melting point of the silica by changing its structure. Natron salt is a mixture of (Na_2CO_3, $NaHCO_3$, Na_2SO_4 and NaCl). Egyptian natron was the predominate source of Alkali for glass makers from the 9 th century BC through the 9 th century AD, and almost all ancient Roman glasses were natron glasses (Mass et al. 2001 and Lucas 1954). Natron salt is widely spread at Wadi el-Natron, the famous ancient site located at the northern west of Egypt.

3- Lime or limestone powder as a source of calcium, the glass stabilizer which is added to decrease the solubility of soda glasses and improve their chemical durability.

Although soda, lime and silica are the main ingredients of these glasses, other components such as alumina (Al_2O_3 avg. 6.60%) and magnesia (MgO avg. 2.16%) are also usually present. Alumina improves the chemical durability and reduces the tendency of glass to crystallize during forming operations. Magnesia decreases the solubility of glass in a similar way to lime (Goffer 1980). In general, these glasses are characterized by their normal silica, moderate soda, moderate alumina, moderate lime, low magnesia, and low potash levels.

The second observation concerning the chemical composition of the samples E.4

and E.5, coming from Tel Aba-yazed in the middle region of the Nile delta, is that these glasses are mainly composed of silica (SiO2 avg. 70.12%), lime (CaO avg. 1.54%), and potash (K2O avg. 6.41%). It can be concluded that these glasses are potash-lime-silica (K2O-CaO-SiO2) glasses and characterized by their high potash, high alumina, and very low soda levels, which point to the use of plant ash as a source of alkali (potash) instead of natron salt (soda) beside quartz sand and lime (fig.5-a,b,c and d). Although potassium oxide was not the main alkaline oxide of glass samples E.1, E.2 and E. 3, it was present in all cases in low content (K2O avg. 2.55%), and played an important role as a flux or a melter of silica in the process of glass melting, in a parallel role to sodium oxide.

The common observation of all glass samples indicates that iron oxides (Fe2O3 avg. 2.28%) are present as associate impurities with sands and are almost responsible for coloring glass with light green and yellowish green colors. Manganese oxide (MnO avg. 4.0%) is used as decolorizer or neutralizer for the effect of iron oxides in producing transparent glass.

b) Jordanian glasses

The results of the chemical composition of all glass samples under study (Fig. 6- a, b, c ,d and table 3) show that based on the major components of these glasses-- silica

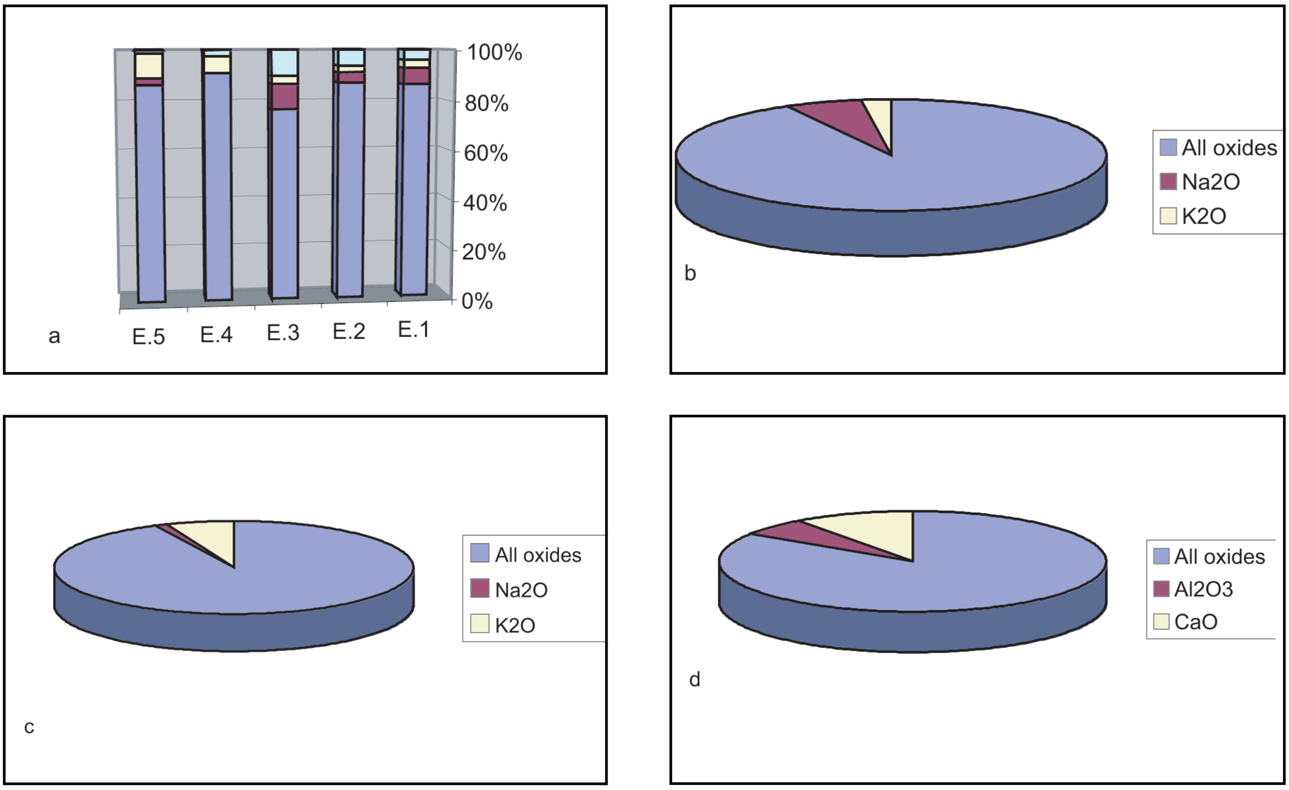

Fig. 5: (a) The main oxides content of Egyptian glass samples. (b) Na2O and K2O (avg.) content (avg.) of Egyptian glass samples E. 1, E. 2 and E. 3.(c) Na2O and K2O (avg.) content of Egyptian glass samples E. 4 and E. 5. (d) Al2O3 and CaO (avg.) content of Egyptian glasses.

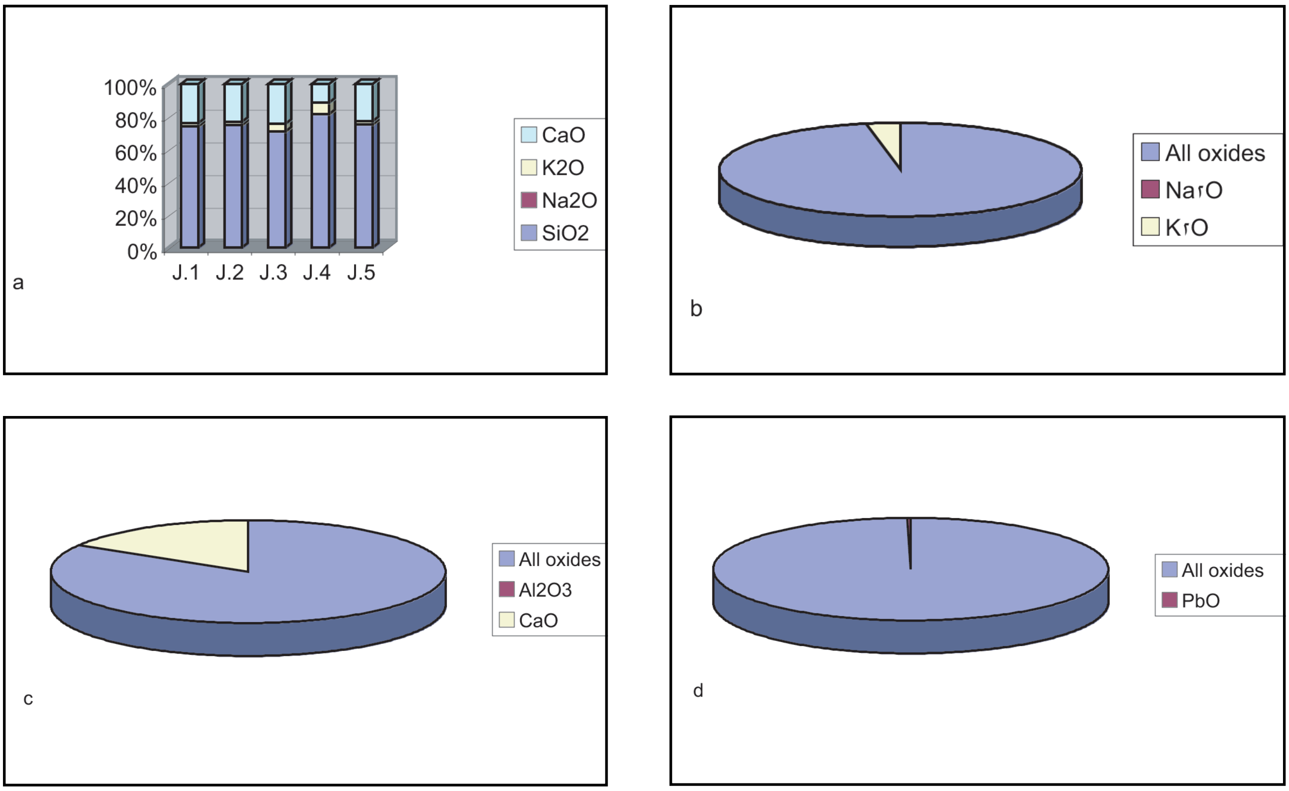

Fig. 6: (a) The main oxides content of Jordanian glass samples. (b) Na2O and K2O (avg.) content of Jordanian glass samples. (c) Al2O3 and CaO (avg.) content of Jordanian glasses. (d) PbO (avg.) content of Jordanian glass samples J. 3 and J. 4.

(SiO_2 avg. 67%), lime (CaO avg. 18.96%) and potash (K_2O avg. 3.08%)-- they can be classified as potash-lime-silica (K_2O- CaO-SiO_2) glass, the common type of the region of Mesopotamia since more than two thousand years (Shugart and Rehren 2002). This composition revealed that the main raw materials from which these glasses were manufactured are quartz sand which most likely had been fetched from the Syrian coast as a source of silica (Sababha 2002), lime or limestone powder as a source of calcium, and plant ash as a source of alkali (potash).

The use of plant ash as a source of alkali instead of soda may be due to a difficulty of obtaining natron salt from Egypt. On the other hand, it was known that these regions are rich in marine plants which, when burned, turned to ash containing a countable amount of potash and magnesia. Therefore, analyzed glasses have high content of magnesia (MgO avg. 2.56%) and potash (K_2O avg. 3.08%). Soda and alumina were not present as trace or low level.

The presence of manganese oxide (MnO) and antimony oxide (Sb_2O_3) as traces in samples J.1 and J.2 probably indicates that it might have been used as decolorizers. Whereas a mixture of copper oxide (CuO 3.00%) and Cobalt oxide (Co_3O_4 0.43%) in sample J.4 probably had been used as colorizer to color glass beads dark blue. Iron oxide (Fe_3 O_4) is always present in sands and gives a green tint to glass, except sample J.3

in which iron oxide (Fe_3O_4 2.20%) could have been used in the form of ferrous ion (Fe^{2+}) to color the glass black or blue, beside the effect of copper oxide (CuO, 0.68%) in the form of cuprous ion (Cu^+) which gives glass a bright blue color (Goffer 1980 and Pollard 1996). Lead oxide (PbO avg. 0.32%) in sample J.3 had probably been used either as an opacifier to produce opaque glass beads or simply existed as an impurity.

Conclusion

By using the non-destructive, qualitative and quantitative X-ray fluorescence technique (XRF) the major and minor/trace composition of a series of 10 Roman glass samples of different types, excavated from several Roman locations in Egypt and Jordan, have been determined. The resulting data show that these glasses can be classified, according to type and content ratio in glass composition, into two categories. It can be concluded that the Egyptian Roman glass studied here are widely soda-lime-silica (Na_2O- CaO- SiO_2) glass, but are rarely potash-lime-silica (K_2O- CaO- SiO_2) glass; in the later case plant ash had been used as a source of alkali instead of natron salt beside quartz sand and lime powder. However, sands, lime and natron salt or plant ashes are regionally the main raw materials used for glass production. However, K_2O and MgO content of the Jordanian glass samples indicate that the Jordanian Roman glasses are in all cases potash-lime-silica (K_2O-CaO-SiO_2) glass; it was made using regional and/or imported raw materials; quartz sands, lime and plant ashes as a source of alkali.

However, we are in agreement with Henderson's point of view (1985): identifying the source of glass raw material is not always a simple issue. Procedures, sorting, mixing, refining and fritting can have an effect on which trace elements are carried out from their final finished glass object. Furthermore, weathering process absolutely affects glass decomposition; alkali may be dissolved and leached out. Therefore, results presented here are not absolute nor general for all Roman glasses; they represent a regional case study in both Egypt and Jordan.

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ملخص: يهدف هذا البحث إلى دراسة المواد الخام المستخدمة فى صناعة الزجاج المصرى القديم فى العصر الرومانى من القرن الأول وحتى نهاية القرن الثالث الميلادى مقارنة بمثيله من نفس الفترة التاريخية فى الأردن، وذلك من خلال نتائج التحليل الكيفى والكمى غير المتلفة للعديد من عينات الزجاج الروماني الممثلة لأوانى وأدوات بأشكال وألوان مختلفة تم جمعها من بعض المواقع الأثرية الرومانية بكلا القطرين. حيث أثبتت نتائج الدراسة أن الزجاج المصرى فى العصر الرومانى عامة كان من النوع المعروف بزجاج سليكات الصوديوم والكالسيوم ومواده الخام الأساسية هى رمال الكوارتز كمصدر للسليكا وملح النطرون كمصدر للقلوى ومسحوق الحجر الجيرى كمصدرللكالسيوم ، وفى إحدى الحالات التى تم رصدها وجد أن الزجاج من نوع سليكات البوتاسيوم والكالسيوم والتى استخدم فيها رماد الأعشاب البحرية كمصدر للقلوى بديلاً عن ملح النطرون . فى حين أثبتت جميع نتائج تحليل الزجاج الرومانى الأردنى من نفس الفترة التاريخية أنه من نوع سليكات البوتاسيوم والكالسيوم وأن مواده الخام الأساسية المحلية أو المستوردة هى رمال الكوارتز كمصدر للسليكا ورماد الأعشاب البحرية كمصدر للقلوى ومسحوق الحجر الجيرى كمصدر للكالسيوم، هذ بالإضافة إلى بعض النتائج الهامة المتعلقة بالمكونات الكيميائية الأخرى بما فى ذلك العوامل الملونة والمزيلة للون والمعتمة.

Note:

The author would like to express his thanks to the archaeologists, at the various sites in both Egypt and Jordan, who generously provided the material samples and the typological classification of the objects.

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