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TECHNOLOGY AND USE OF GLASS DURING THE CLASSICAL - HELLENISTIC TIMES:A CASE STUDY OF GLASS KNUCKLEBONES

INTRODUCTION

Ancient Thouria is located in the Messenia region of the Peloponnese close to Kalamata (Fig. 1); the location of Thouria dominates across the fertile plain of Kalamata, offering a unique view, with the Mountain of Ithome to the northwest and the sea to the south. According to the archaeological data, the area was inhabited already in the 3rd millennium BC while during the Mycenaean years in the second half of the 2nd Millennium BC it was flourishing, being part of the territory ruled by the mythical King Nestor[1]. Pausanías the Greek traveler and geographer of the second-century AD identifies the area as the Homeric city of Anthia while Strabo with that of Aepia[2]. Ancient Thouria played an important role in Messenia during the course of the Classical and Hellenistic Times, as it was the most significant city of eastern Messenia, and after 369 BC when Messene was founded, the second in power city after Messene[3].

Fig. 1. Map of the Thouria settlement were also ancient Messene is indicated.

The ruins of the ancient city are located on an elongated ridge, with direction north to south, located approximately 10 km northwest of the city of Kalamata. At the northern

1 MALAPERDAS and ZACHARIAS, 2018, 118
2 ARAFAT, 1992, 397
3 ARAPOGIANNI, 2017, 17

end of the hill, where the ancient acropolis is located, there is a visible part of the ancient fortification walls with rectangular fortification towers that are dated to the 4th century BC, built with care according to the isodomic system. The city included a theater and possibly a gymnasium, while a large rectangular water cistern is visible on the western side, below the acropolis.

During the excavation periods of 2012 and 2014 the archaeologists discovered two glass knucklebones (Fig. 3). The first one, named as THOU-1, (Fig. 3 upper images), was found during the excavation in 2012 in an intact large soil formation, in a depth of 2.75m above modern surface level, in the area in front of the facade of the temple dedicated to Asclepius and Hygeia, on the floor of the temple's foundation, indicating a votive offering to the sanctuary with a given age at the Early Hellenistic period (Late 4th cent. BC) according to the typology of the excavated pottery.

The second knucklebone, named as THOU-2, (Fig. 3 lower images), was found in the 2014 excavation period during the leveling of the eastern vertical side of the excavation trench that had collapsed. The find had intense traces of burning, but its precise dating is not possible due to its accidental discovery in a non-stratified archaeological context. Nevertheless, a broad age spanning the Late Classical to Early Hellenistic Times (Early - to Late 4th cent. BC) should be given for the artefact[4]

The size of the knucklebones is around 2 cm in width and they were mold-made, a common practice for such artefacts during antiquity. At mid-point they preserve a thin seam where the two parts of the mold are joined (Fig. 3, upper right image, indicated with an arrow). In general, knucklebones served both secular and religious purposes. However, due to the fragile nature of glass we may assume that these glass knucklebones served only religious purposes since they are also found in funerary contexts.

HISTORY OF THE KNUCKLEBONES

Knucklebones, known as *astragaloi* (singular *astragalos*) in Greek and *tali* in Latin, may be one of the longest surviving game pieces, being used in many cultures, ranging from the distant past to today. There are several depictions showing the use of the *astragaloi* as a game in antiquity e.g. the early Hellenistic terracotta figures known as "knucklebone players" in the British Museum and a Greek coin with a scene of a young woman throwing knucklebones (Fig. 2)[5].

Fig. 2. Depictions of women throwing knucklebones. From left to right the early Hellenistic terracotta figure known as "knucklebone players" and a Greek coin with a scene of a young woman throwing knucklebones[6].

Except from the gaming nature of knucklebones the presence of knucklebones can also be found as offerings in the context of areas identified as sanctuaries, clearly points to practices associated with fortune

4 ARAPOGIANNI, 2017, figure 61 therein

5 TAHBERER, 2012, 6

6 TAHBERER, 2012, 6

and good health like in this case of the Temple of Asklepios[7].

The astragaloi game was played as follows: the Astragaloi were thrown upward and then were valued, referring to the sides that were seen face up. The four relevant sides of the knucklebones were commonly known as *koon* (flattish, worth 6), *chios* (s-shaped, worth 1), *yption* (concave, worth 3) and *pranis* (convex, worth 4). If all 4 astragaloi showed different sides, then the throw was called *venus* and the player won the game. Showing only one point on all sides was called *canis* (dog) and that was the worst throw[8].

Fig. 3. Upper row images of the THOU-1 knucklebone. Heavily corroded areas are observed. On the upper right image, the joining point of the two molded parts is indicated with an arrow. Lower row images of the THOU-2 knucklebone with heavily corroded areas.

Another game played with astragaloi is similar to modern "jacks" and involved throwing one knucklebone up in the air and before catching it as it falls, picking up as many knucklebones on the ground as possible in one hand. This simple game called pentalitha or five-stones and is still played in Turkey as well as in other countries (Beş Taş in Turkish)[9].

MATERIALS AND METHODS

The studied *astragaloi* (Fig. 3), having dark blue (THOU-1) and green (THOU-2) colours, were investigated with a combination of four different techniques in order to acquire the non-destructively the most analytical information. In particular, the FOM type i-scope, Moritex[10] was applied on both samples aiming at distinguishing the pristine and corroded surfaces of the glass samples. The p-XRF set up of type Bruker Tracer III SD and S1PXRF software[11] was used for a non-destructive scan of the surface. The beam diameter is around 3 mm and due to the heavy corrosion on the surface the p-XRF did not provide much information[12]. The SEM/EDS was mainly used to determine the major and minor elements. A JEOL (JSM-6510LV) coupled with EDS (Oxford Systems) was used and the analyti-

7 ALESHIRE, 1989, 316
8 TAHBERER, 2012, 7-8
9 TAHBERER, 2012, 6
10 ZACHARIAS et al., 2018, 405
11 PALAMARA et al., 2018, 3
12 ZACHARIAS and PALAMARA, 2016, 234

Table 1: Major and minor oxides in the two knucklebones acquired by LA-ICP-MS analyis; values given are in %wt. Values of major oxides which accompany the sand raw material are highlighted in bold.

	THOU-1		THOU-2
SiO_2	**69.2±0.1**		**66.2±0.2**
Al_2O_3	2.34±0.02		2.10±0.03
Fe_2O_3	**1.1±0.1**		**0.393±0.009**
CaO	**6.56±0.03**		**11.1±0.2**
MgO	0.422±0.006		0.68±0.01
Na_2O	18.26±0.07		18.0±0.1
K_2O	0.776±0.005		0.702±0.007
TiO_2	0.054±0.001		0.052±0.001
MnO	0.52±0.03		0.744±0.008

cal data were obtained by INCA software[13]. The instrument was set at 20 kV accelerating voltage, and at least three measurements were taken for each sample on different areas (both pristine and corroded surfaces) with a count time of 300 sec. The accuracy and detection limits of the EDS setting is described in detail elsewhere[14]. Finally, LA-ICP-MS was the main analytical tool providing a full compositional analysis including trace elemental analysis. The ICP technique proved to be the most appropriate one since due to the laser ablation the analysis was performed under the corroded surface on the pristine glass matrix. A full range of trace elements for the 2 samples were detected using an LA-ICP-MS instrument an Agilent 7500 series ICPMS coupled with a NewWave UP193FX excimer (193 nm) laser system. More information regarding the experimental conditions, accuracy and precision can be found in a recent publication by the author[15] and the experimental protocol is described analytically in Henderson et al work [16].

RESULTS AND DISCUSSION

According to the analytical data acquired by the LA-ICP-MS analysis the glass used to manufacture the two knucklebones falls into the general silica-soda-lime category (Table 1). Major and minor oxides have typical levels for Hellenistic period glass. Sand was used as primary raw material and was fused with a mineral source of alkali such as natron which is indicated by the low amounts of both potash (K_2O) and magnesium (MgO) oxide (lower than 1.5 % wt.). The dark blue knucklebone was coloured with a combination of copper and cobalt mineral (THOU-1) while the greenish one (THOU-2) was naturally coloured (iron present in the sand).

It is interesting to note that the two knucklebones most likely were manufactured using different raw materials and especially different sands. We cannot exclude that they might share the same provenance within a broad technological framework. In other words, technological differences in terms of major, minor and trace elements might indicate either change in technology within a period of half a century either different workshops using different raw materials in the same broad geographical region. There are substantial differences in major oxides such as silica (SiO_2), lime (CaO) and iron (Fe_2O_3) all of which, usually are derived from the sand (Table 1, bold values) either as basic components or as impurities (e.g. lime exists in sands as part of crushed shells). However, possibly but not likely, deliberate-

13 MOROPOULOU et al., 2016, 173
14 PALAMARA et al. 2016, 2-3
15 OIKONOMOU and TRIANTAFYLLIDIS, 2018, 494-495
16 HENDERSON et al. 2016, 135-137

Table 2: The trace element composition of the two knucklebones. The values are expressed in ppm. Major differences in trace element data are highlighted in bold.

	Li	B	P	V	Cr	Co	Ni	Cu	Zn	As	Rb
THOU-1	3.6	172.5	373.4	11.2	9.1	**1018.0**	22.8	**1466.4**	55.4	26.5	11.4
THOU-2	4.1	127.8	416.6	15.1	14.8	**5.9**	9.7	**8.0**	16.0	3.0	11.5

	Sr	Y	Zr	Nb	Mo	Sn	Sb	Cs	Ba	La	Ce
THOU-1	**396.6**	5.8	35.6	1.3	2.6	26.0	586.7	0.1	250.3	5.3	9.7
THOU-2	**691.8**	8.9	32.7	1.3	4.4	4.2	24.4	0.1	250.9	7.1	12.9

	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb
THOU-1	1.3	5.2	1.0	0.3	1.0	0.1	0.9	0.2	0.6	0.1	0.5
THOU-2	1.7	6.9	1.4	0.4	1.5	0.2	1.4	0.3	0.8	0.1	0.7

	Lu	Hf	Pb	Th	U
THOU-1	0.1	0.9	**4483.6**	0.7	1.0
THOU-2	0.1	0.8	**30.8**	0.7	0.8

ly addition of lime[17] and iron[18] maybe our paper discussing the glass from THEBES) has been suggested. In particular, sample 1 contains 69.2 % wt. of silica (SiO_2) compared to the 66.2% wt. of sample 2 (THOU-2). In addition, lime (CaO) in sample 2 (THOU-2) is elevated having value of 11.1 % wt. while sample 1 (THOU-1) has a more characteristic lime (CaO) levels of 6.6% wt. Finally, Fe_2O_3 is elevated in sample 1 (THOU-1) (1.1 %wt.) compared to sample 2 samples (0.4% wt.). The elevated value of Fe_2O_3 might be associated with the colorants used, especially cobalt bearing minerals such as skutterudite ($(Co,NI,Fe)As_3$)[19].In addition to the above the elevated lime and strontium noticed in sample THOU-2 should be associated with the presence of sea shells in the glass batch providing further evidence for manufacturing differences between the two artefacts.

17 DEGRYSE et al. 2014, 229
18 HENDERSON 1985, 283
19 HENDRESON 2013, 69

The last 20 years, trace element analysis has proven to be a very powerful tool in glass characterisation and provenance studies as it was demonstrated by various scholars [20].. It has been suggested that trace elements such as zirconium (Zr), titanium (Ti), chromium (Cr), and lanthanum (La) can provide differences in the original raw materials[21]. These trace elements are expected to have regional variability making them suitable for provenance studies for two main reasons: first, they are non-volatile and not affected from firing conditions and second, they vary accordingly to the geochemistry of every region. Furthermore, they are often used as compositional discriminants in igneous geochemistry[22].

20 FREESTONE et al. 2000, 73-74; SILVESTRI 2008, 1494-1499; SILVESTRI et al. 2008, 335-339; SHORTLAND 2012, 155-161; HENDERSON 2013, 85-88; DEGRYSE 2014, 69
21 SHORTALAND et al. 2007, 786-788; SHORTLAND 2012, 155-161; DARDENIZ 2018, 100-101
22 SHORTLAND et al. 2007, 787; SHORTLAND 2012, 157-158

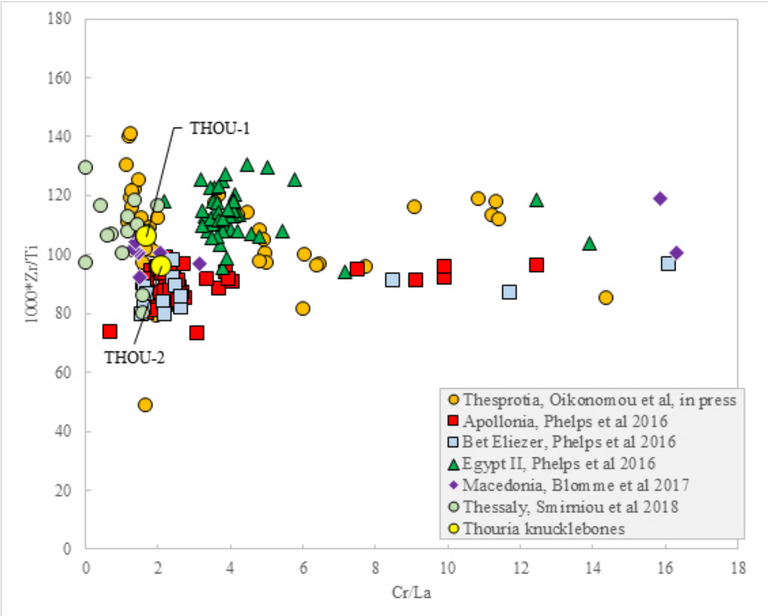

*Fig. 4. The correlation of the 1000*Zr/Ti and Cr/La ratios. The majority of the "Greek" samples (low Cr/La samples) have a rather elevated 1000*Zr/Ti ratio. The Thouria samples are clearly distinguished.*

The correlation of various elements in biplots, which apparently correspond to the chemical fingerprint of the objects, allows us to detect similarities and/or differences between the objects providing thus useful information regarding the technology and provenance of the glass. Trace element ratios such as Cr/La and Zr/Ti can serve as good discriminants in glass provenance studies[23]. As it is presented in Fig. 4 the Thouria glass is compared with coeval glass objects from Greece and more particularly Hellenistic glass from Thesprotia, 3^{rd}-2^{nd} cent. BC[24], Hellenistic glass from Thessaly, 3^{rd}-1^{st} cent. BC[25] and Classical glass from Macedonia, 6^{th}-4^{th} cent. BC[26] . In addition, in the same plot we compare glass of later period and mainly from Late Antiquity which was excavated in the Levant and more particularly from Bet Eliezer and Apollonia[27] . These samples even though they belong to a much later period we may assume that the source of the raw materials has not changed geochemically in such short geological time period. Moreover, they share the same technology since they were also manufactured with natron. In addition, we should take into consideration that most of the comparative objects are glass vessels and there is only one glass knucklebone from the Thessaly assemblage.

According to the graph the "Greek" samples show elevated values of the Zr/Ti ratio compared to the Levantine ones. This can be also shown when comparing the mean value of Zr/Ti for the corresponding assemblages (Fig. 5). It is interesting to note that the two knucklebones have a rather distinct position on this graph (Fig. 4 inset); THOU-1 sample has elevated Zr/Ti ratio and overlaps with the majority of the "Greek" samples while the contrary happens to the THOU-2 sample which is better correlated with the Levantine glass. Furthermore, we should note that the Egyptian samples have a very distinct position in the plot with higher Cr/La ratios above 2. Therefore, the Egyptian origin of the knucklebones is ratherdubious.

A quite similar behavior is also noticed in Fig. 6 in which the correlation between neodymium (Nd) and zirconium (Zr) is pre-

23 SHORTLAND et al. 2007, 787
24 OIKONOMOU et al., in press
25 SMIRNIOU et al. 2018, 508-510
26 BLOMME et al., 2017, 137
27 PHELPS et al. 2016, 58

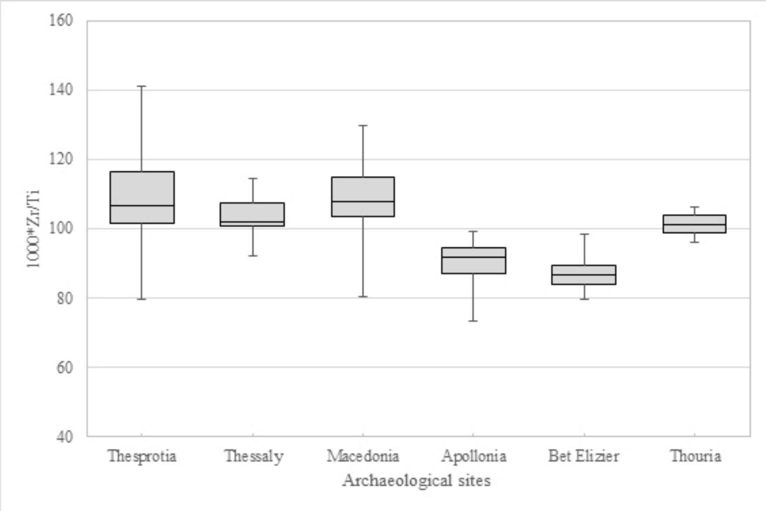

*Fig. 5. Box plots of the 1000*Zr/Ti ratio for the samples of various sites showing the minimum, maximum and the median values with each error bars. The Thouria samples have similar median value with the "Greek" samples.*

sented for the above mentioned objects from Greece and the Levant. Both elements are often considered as markers for tracing and distinguishing between possible sand sources[28] ; Zr is expected to be primarily present as zircons in sands[29], while Nd in glass is likely derived from the non-quartz minerals fraction in the silica raw materials[30].

In this graph the two samples from Thouria are well separated. The THOU-1 sample shows lower Nd content compared to the THOU-2 sample (5.2 against 6.9 ppm). It seems also from the graph that the THOU-1 sample is better correlated with the "Greek" samples and THOU-2 sample clusters with the Levantine glass. The elevated amount of Nd in THOU-2 sample might be also reflect the deliberate addition of shells (due to the elevated amount of both lime and strontium in THOU-2 sample). According to Brems et al [31]shells the absolute Nd content can be between 0.5-10 ppm and this could be responsible for the position of THOU-2 in Fig. 6.In this graph also the Egyptian samples have a very distinct position with elevated Zr values.

It seems that the two knucklebones were manufactured with different raw materials that strengths the hypothesis of manufacturing differences and, further, of a different provenance. There are various differences in the major and minor composition and especially in lime and strontium content as well as in specific trace elements which associated with the sand raw material. There are also differences in elements such as cobalt, copper and lead but all these are associated with the colorant used for the dark blue THOU-1 sample which due to the presence of cobalt should be characterized as a cobalt-blue glass.

According to the graphs the "Greek" samples and THOU-1 knucklebone show a lot of similarities in their trace element composition. Therefore, we may assume a common origin between THOU-1 sample and the majority of "Greek" glass. Primary glass production in Greece has not been attested yet archaeologically during the Hellenistic period, however it cannot be excluded. Hypothesizing that the glass during this period was mass produced in tank furnaces (there is the example of the late Hellenistic tank furnace in Beirut[32], the early Roman tank furnaces in Egypt[33] and more examples of later

28 SHORTLAND et al. 2007, 787; Degryse 2014, 53
29 DEGRYSE 2014, 76
30 DEGRYSE and SCHNEIDER 2008, page numbers; BREMS et al., 2014, 53-53;
31 BREMS et al. 2014, 53

32 KOWATLI et al. 2008, 106-115
33 NENNA 2015, 3-11

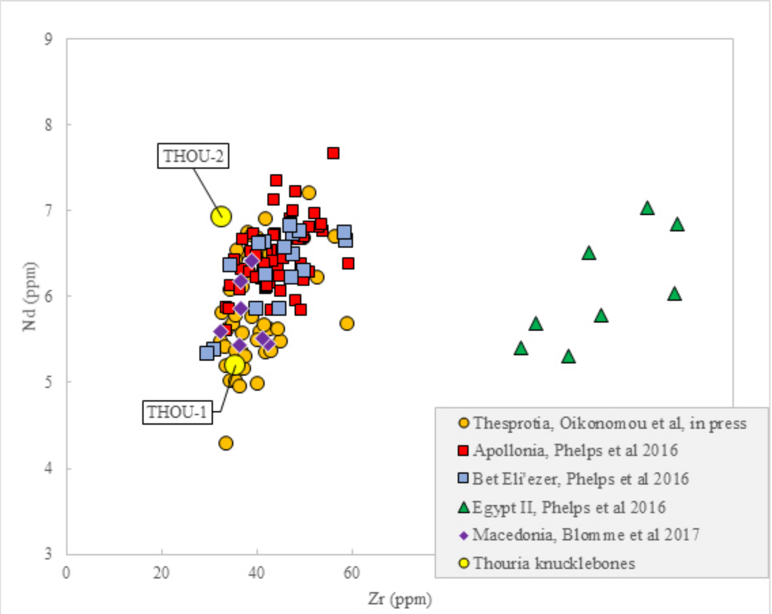

Fig. 6. The correlation between Zr and Nd for Thouria samples. The two knucklebones are well distinguished suggesting possible different raw materials and therefore different manufacturing locations/workshops.

periods in Israel[34] and taking into consideration that the Levantine glass workshops have been supplying with glass the south east Mediterranean lands including Greece and beyond, then we could hypothesize that the glass used to produce THOU-1 sample comes from there. The chemical fingerprint of THOU-2 sample has more similarities to the Levantine glass and can be attributed with more certainty to a Syro-palestinian glass workshop; this workshop potentially used the same raw materials (i.e. sand) as the later tank furnaces in Bet Eli'ezer and Apollonia (in modern Israel). Where the formation of glass into the object happened still remains a mystery; as far as the authors' knowledge in the archaeological record no knucklebone molds have been recovered. In addition, certainly the Egyptian origin should be excluded since the Egyptian glass shows totally different chemical characteristics.

The slight differences noticed between the two knucklebones reflect regional variability of the glass. As it was demonstrated earlier the origin of THOU-1 and THOU-2 glass must be sought somewhere in the Levantine coast. Levantine coast extends from modern Syria to Lebanon and Israel offering various possible sand sources as raw materials. Therefore, this can be extrapolated to the two knucklebones' glass composition which differs in terms of major, minor and trace elements even though the glass comes from the broad area of Levantine coast.

The significance of the sanctuary and the socioeconomical level of the city are highlighted by a very recent and welcomed event, that of the recovery of another three knucklebones. These have the same macroscopical characteristics, namely similar shape and size and were found in the vicinity of the Temple of Asklepios during the 2018 excavation campaign. This can also provide a statistical measure for the continuation of the research based on a total of 5 items to assist for more clear conclusions regarding their origin and therefore the relations of the city within the spirit of the era and the site under study.

CONCLUSIONS

Concluding, glass knucklebones are rare objects found in the archaeological record and most likely served both secular and

34 GORIN-ROSEN 2000, 52

religious purposes. This study is the first systematic multidisciplinary research on glass knucklebones. The combination of a set of four non- to quasi-destructive techniques provided new insights into the technology of glass during the Hellenistic period. Even though FOM microscopy and p-XRF did not provide with analytical data, initial observations were made on the basis of the state of preservation of the artefacts and pristine glass areas were identified. SEM/EDS and especially LA-ICP-MS proved the appropriate tools to further characterize non-invasively the glass objects.

The analytical results obtained showed that the samples from Thouria have a typical chemical concentration of the Hellenistic period and they fall in the general soda-lime-silica category. According to the trace element data there are solid indications that the glass from Thouria, either as a raw material or as finished object, most likely has a Levantine origin.

Finally, the study of strontium (Sr) and neodymium (Nd) isotopes would be essential for confirming the provenance of these samples but unfortunately due to their uniqueness we cannot get any samples. Maybe in the future a non-destructive analytical equipment might give new insights about the provenance of unique glass artefacts non-invasively.

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