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Glass as a chronological indicator. Macroscopic and compositional features of Hellenistic, Roman and modern glass fragments from Idalion (Cyprus)☆

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ABSTRACT

We present compositional data on glass vessel fragments excavated at the East Terrace of ancient Idalion, a part of the site thought to be predominantly of Hellenistic and early Roman date. Among the samples are several of clearly modern date, while the majority of the ancient glass matches the manganese-rich glass known from other late Hellenistic to Roman glass assemblages. We document a systematic difference in wall thickness between Hellenistic, early Roman and modern glass, reflecting changes in glass forming technology.

1. Introduction

It is long known that the composition of glass differs between different periods, reflecting changes in raw materials and recipes used in the primary production centres. Following the seminal papers by Freestone et al. (2000) and Foy et al. (2003) that helped establish the main compositional mineral natron-based glass groups of the 1st millennium CE, research on glass found in Cyprus has focussed mostly on Late Antique and Byzantine glass. Only a few studies concern earlier glass (e.g., Cosyns et al. 2018), and mainly from the coastal areas of Cyprus. The only inland archaeological site where early glass fragments have been excavated is ancient Idalion (Cosyns 2010). The purpose of this study is to add to the picture of early glass on Cyprus, and to contribute to the discussion of the chronology of the East Terrace area in ancient Idalion, one of the major cities of the 1st millennium BCE that continued to flourish into the Roman and Byzantine period (Fig. 1). Additionally, we use this opportunity to highlight the information potential of small assemblages and typologically non-diagnostic fragments. We explore new ways to characterise such glass fragments using wall thickness as indicators for glass working practices and to recognise modern glass intrusions in archaeological contexts. In view of the complex archaeological situation at this site, we also use the chemical composition of non-diagnostic fragments to help determine the approximate date ranges of their production and likely discard, in this way providing additional independent chronological information to the ongoing assessment of individual contexts.

1.1. Archaeological context

Settlement at ancient Idalion, on the site of modern-day Dali just south of Nicosia and not far from the eastern foothills of the Troodos mountains, goes back to the Late Bronze Age. Its existence is likely connected to the copper trade that played a major role in LBA Cyprus. During the Iron Age, in the early to mid-1st millennium BCE, it had two acropoleis (Fig. 2), with the western one holding a fortified palace while the eastern acropolis was dominated by temples dedicated to Adonis, the Great Goddess of Cyprus, and other deities. Private dwellings and workshops formed most of the Lower City. In the mid-1st millennium, Idalion was taken over by the rulers of Kition, one of the ten Cypriot city-kingdoms, located in modern-day Larnaca. Its importance focussed on the eastern acropolis and the temple area of Adonis Temenos and the Great Goddess.

The Classical and Hellenistic workshops in grid squares NW 1, 2, 11, and 12 of the Terrace of the East Acropolis, for short East Terrace, are very like the architecture in the Lower City at Idalion (Fig. 3). Walls composed of field stones laid with mud mortar are set into shallow

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foundation trenches cut into the bedrock. The founding levels of the structures in grid squares SW 1 and 2 have not been reached. However, the construction of the walls in these squares is identical to the Classical and Hellenistic structures in the other trenches listed.

The structures in SE31 and NE31 that we interpret as the altar area are entirely different from the structures of either the workshops or the perimeter walls and gateway. There are two distinct phases once again visible here. The Hellenistic platform that appears to be the altar in that period is a broad, square platform with rounded corners faced with stone and packed with limestone chips and small stones creating a filling of extreme compactness.

This Late Classical and Hellenistic installation was laid over an earlier complex of walls, altar, and ash pits dating to the Archaic period. These renovations would appear to coincide with the change in orientation visible in the workshops in NW 12, as well as the refurbishing visible in the gateway, NW 3 and NE3. It is important to note that a number of the workshops must have remained unroofed. This particularly applies to those in which burning installations and/or ovens were found (NW12). The material under study here is from excavations at the East Terrace (Fig. 3); work is ongoing to link it to more specific contexts, and no clear glass workshop has been identified yet. Other craft-related material from this area awaiting study includes numerous slag fragments; our initial assessment has identified both iron and copper metallurgy.

1.2. Glass in Cyprus

Cyprus is situated close to major eastern Mediterranean glassmaking regions of the LBA, Iron Age and Roman to Byzantine periods (Rehren 2024), but no evidence has yet been found that would indicate local glassmaking on the island in any period. Following a period of intense research in the past ten years, most published data on glass found on Cyprus is currently from Late Roman to Byzantine contexts (Freestone et al. 2002; Ceglia et al. 2015, 2016, Ceglia et al., 2019; Bonnerot et al. 2016; Cosyns et al. 2021). Relatively little is known about early mineral natron glass, with the exception of Cosyns et al. (2018) focussing on Hellenistic and Roman core-formed, cast or slumped vessel fragments from a much larger assemblage of glass finds in Paphos; fragments of blown vessels were set aside in that study for later research. Therefore, we focussed in our initial study of glass from ancient Idalion on an excavation area known to have predominantly such early layers and contexts.

2. Samples and methods

The East Terrace excavation area yielded relatively few recorded glass finds, even though several numbers included multiple fragments. Since much of this area is thought to cover relatively early contexts, we decided to select the entire assemblage of 23 pieces for analysis. As the excavation is still ongoing and the final stratigraphic assessment of layers and contexts remains to be done, the chronology of some of them was not easy to be defined. In many cases, we relied on the Terminus Post Quem (TPQ) attributed to the locus and the pottery. Matching the overall limited amount of finds, most were small fragments that were not diagnostic shapes. While this made the necessary sampling and removal of small pieces of glass for full analysis easier, it also meant that we were not able to rely on typological dating for the individual fragments.

Instead, in a reversal to common practice, we use here the glass composition to gain broad chronological information. This approach is based on the understanding that the main compositional glass groups of the late 1st millennium BCE and the 1st millennium CE have each been produced only for a relatively limited period, of typically one or two centuries. Accordingly, it should be possible to reliably distinguish late 1st millennium BCE glass from Byzantine glass, and to use an assessment of the relative proportion of the number of such glass compositions among the fragments as an indication for the dominating period of activity represented in a given context, and / or the likelihood of major disturbances. The nature of the site and comprehensive sampling meant that there was also the possibility that modern glass fragments were included in the selection. Since this is a common problem in many excavations, we consciously did not remove two clearly modern bottle fragments from the analysed assemblage, to obtain a reference point for other visually unidentified modern glass fragments. Thus, the present pilot study has two aims. Firstly, it aims to determine the chemical composition of the entire glass assemblage from this area of the site and their contextualisation in a larger frame of ancient glass studies from Cyprus. Secondly, on a methodological level it explores two less-commonly used approaches of looking at glass fragments, by using their composition and wall thickness as chronological markers.

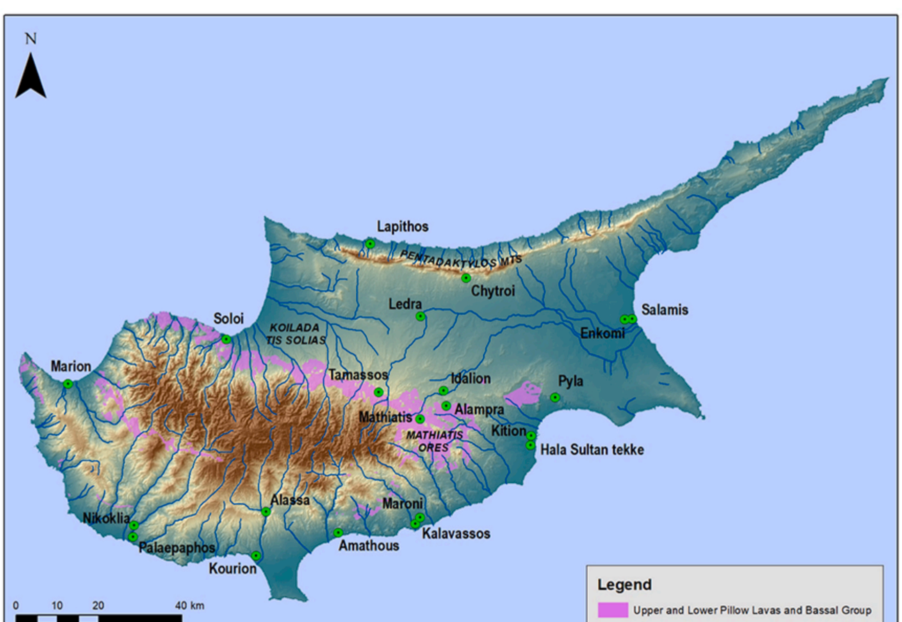

Fig. 1. Map of Cyprus with the main Iron Age sites. Idalion is situated near the centre of the island, just to the east of the Troodos mountains. Map © A. Agapiou.

2.1. Samples

All samples were small fragments of various colours and thickness (Table 1); some examples are shown in Figs. 4 and 5. All 23 samples were embedded in epoxy resin and prepared as polished blocks for subsequent SEM-EDS analysis through a series of grinding and polishing steps down to 1 μm.

2.2. Methods

The analyses to determine the chemical composition of the glass were carried out at the A. G. Leventis Archaeological Materials Science Laboratories of the Cyprus Institute using a Zeiss EVO 15 Scanning Electron Microscope with attached Energy Dispersive Spectrometer from Oxford Instruments, operated by the current AZtec software. Operating conditions for analysis were high vacuum, a working distance of 8.5 mm, 20 kV accelerating voltage, and a beam current of 2.5 nA. For the analysis, three full scan areas at 100 x magnification of homogenous glass areas were selected for each sample and analysed for 30 s. The processing of the raw data used a factory-provided quantification based on a combination of fundamental parameters, a database of detector parameters, and empirical standard measurements. We used a fixed element list for quantification, determining oxygen by stoichiometry and allowing for the carbon coating. The results are reported as averages of the three individual areas for each sample, normalised to 100 wt% to compensate for any fluctuations of the beam current in the SEM, or the presence of bubbles/voids in the sample. To monitor and document data quality, Corning B glass was analysed before and after each analysis session using the same conditions; Table 2 reports the results for the compounds of interest for Idalion samples and their associated errors in wt%.

For most oxides present at concentrations above 0.1 wt% the accuracy was better than 5 % relative to the absolute value; for lower concentrations, the accuracy deteriorated as expected. We do not report numerical values below 0.05 wt% as their uncertainty is too great. However, for statistical purposes such as plotting results against comparative data we followed guidance provided by the Royal Society of Chemistry (2001). Thus, we used the quantified values where the software provides them even if they fall below 0.05 wt%, and half this value (i.e. 0.025) for those where the EDS quantification gave a zero value.

3. Results

3.1. Chemical compositions

The first two samples reported in Table 3 are not glass and therefore irrelevant for this study; one of them is a rock fragment, while the second one is a piece of quartz. The remaining 21 samples are all soda-lime-silica glasses with minor amounts of alumina; all other compounds were found only below 2 wt%, with the exception of GR5009 which has about 4.5 wt% MgO.

3.2. Discriminating modern from ancient glass

The 21 glass fragments can be divided into two main groups based on their chemical composition. Specifically, nine samples have values of Cl and MnO below the detection limit, clustering close to the origin of the graph in Fig. 6; these samples are defined as modern glass fragments, following Barfod et al. (2024) and Fogarizzu et al. (2025). As mentioned before, two of these samples include the logo of modern beverage companies (GR324 = Keo, GR674 = Pepsi), and their chemical composition serves as a reference point for modern glass compositions. Five further samples are analytically identical to GR674, indicating that the entire set GR670 to GR687 is from the same bottle (see also Fig. 5). Thus, the nine fragments with Cl and MnO below detection limit represent only four different objects. The remaining 12 samples are defined as ancient glass and discussed here further, characterised by a significant presence of chlorine (between 0.7 and 1.2 wt% Cl) and a wide range of MnO, from below the SEM-EDS detection limit up to 2.2 wt%. All of the ancient glasses were made using natron as a flux. This is shown by the values of K_2O and MgO, with both below the cut-off value of 1.6 wt% used to discriminated between natron glass and plant ash glass (Freestone 2021).

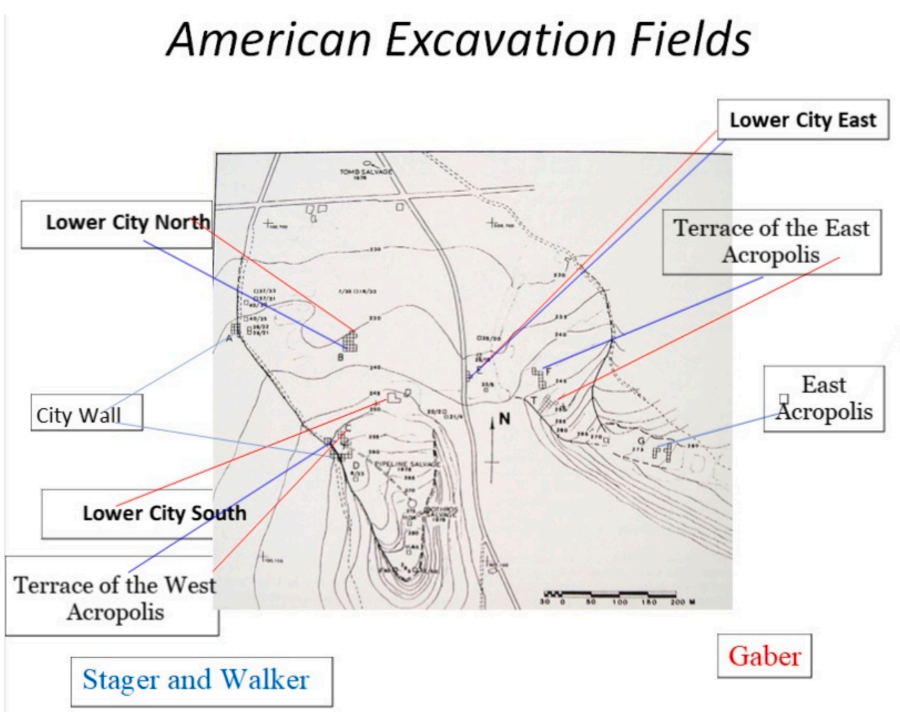

Fig. 2. Overview plan of the excavation areas in ancient Idalion.

4. Discussion

The 12 ancient glass fragments represent various compositional groups. The discussion will be based on their comparison with literature data in order to define a classification of types of glass excavated in the East Terrace of Idalion. The first section will focus on the presumed Roman material, particularly the early-first millennium CE decoloured glass and the typical early to mid-first millennium CE glass categories, such as Roman Mn-decoloured glass or HIMT glass; the second one will focus on presumed late Hellenistic to Early Roman glass, while in the third part we will discuss the thickness of the samples in relation with their chronology.

4.1. Roman glass in Idalion

4.1.1. Decoloured glass

Seven of the ancient glass fragments have medium to high contents of MnO and/or Sb_2O_5 and appear visually nearly colourless. Both components are decolourants used to oxidize the iron, present as an impurity in the sand, from its more reduced oxidation state Fe^{2+} to Fe^{3+}, which has a lower colouring effect on the melt (Freestone 2021). In the literature, these types of glasses are reported mostly from contexts dated to the early to mid-first millennium CE and recognised by their contents of manganese oxide and antimony oxide. Here, five samples are manganese-rich with between 1 and 2 wt% MnO, one is antimony-decoloured (GR680), and one is a mixed Mn/Sb-decoloured glass (GR2725), probably due to the mixed recycling of Mn- and Sb-decoloured glass (Table 4). For further discussion see Schibille et al. (2017), Gliozzo (2017) and Freestone et al. (2025).

Significantly, these two decolourisers can be associated to specific periods and geographical contexts. The use of antimony oxide as decolourant has been attested from the 7th century BCE until the 1st century BCE (Angelini et al. 2019) primarily for Egyptian glass production (see Schibille et al. 2017), while the use of MnO as decolourant made its appearance in the 2nd century BCE, typically but not exclusively in Levantine-made glasses. With the advent of glassblowing technology in the 1st century BCE, antimony oxide emerges again in the middle of the 1st century CE (Freestone 2021, and references therein).

Among the five manganese-rich glass samples, it is necessary to discuss several compositional groups including Roman Manganese decoloured (Rom-Mn), Levantine I, and Foy’s *Série* 2.1, all of which can present a significant amount of MnO. In line with the discussion in

Table 1
List of the samples with their relative thickness and colour. The thickness has been measured with a Vernier caliper, while the colour has been defined by naked-eye observation through the freshly-cut edge of the glass into the body.

Samples	Thickness (mm)	Colour
GR678	Irregular shape	Black
GR685	Irregular shape	Beige-brownish
GR2660	3	Green
GR324	4.5	Brown
GR5009	2	Colourless
GR670	4.5	Colourless
GR671	4.5	Colourless
GR674	4	Colourless
GR675	5	Colourless
GR682	5	Colourless
GR687	4	Colourless
GR3726	2	Green
GR2725	2.5	Very light blue
GR1192	1	Colourless
GR686	5	Colourless
GR680	1	Colourless
GR683	3	Blue-green
GR1136	3	Pale green
GR3945	4	Brown
GR3638	2.5	Light blue
GR12971	1	Very light blue
GR12501	1	Very light blue
GR13416	3	Green

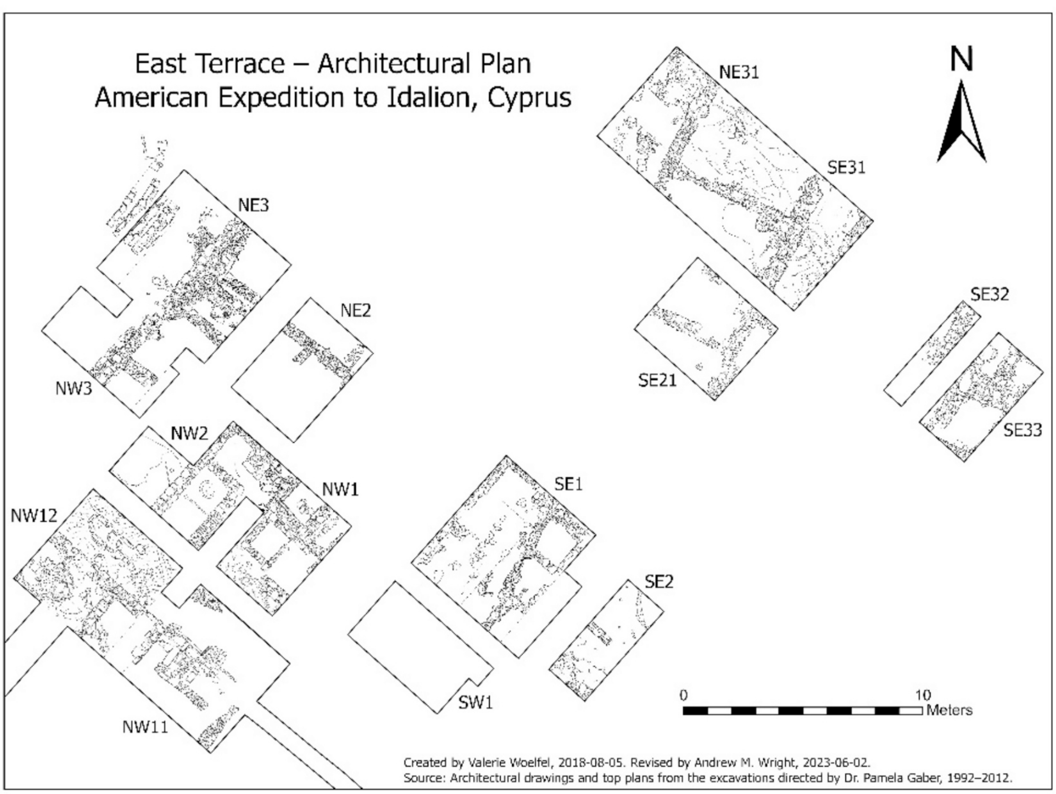

Fig. 3. Plan of the East Terrace excavation area of the American Expedition to Idalion.

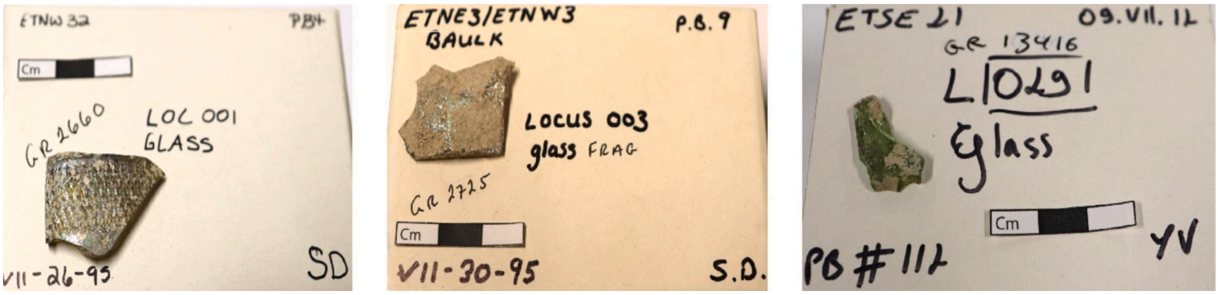

Fig. 4. Examples of three different glass fragments selected for this study, from the left GR2660, GR2725, and GR 13416.

Fig. 5. Fragments of modern bottles found in the archaeological site of Idalion. In both of them, it is possible to easily identify the inscription of the production company. On the left a fragment of a bottle of Keo beer, sample GR324, and on the right, sample GR674, a broken Pepsi bottle.

Table 2
SEM-EDS results for Corning B, concentrations in wt%. Data for some elements irrelevant here are not reported, resulting in the low total from data originally normalised to 100 wt%. Corning B data from Adlington (2017).

	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	MnO	Fe_2O_3	BaO	PbO	Sb_2O_5
Published data Adlington (2017)	17.00	1.03	4.36	61.55	0.82	0.49	0.16	1.00	8.56	0.089	0.25	0.34	0.077	0.61	0.46
Average (n = 13)	16.6	1.00	4.2	62.2	0.75	0.56	0.17	1.02	8.7	0.07	0.25	0.31	0.04	0.57	0.4
Accuracy (AE)	−0.4	−0.03	−0.2	0.6	−0.07	0.07	0.01	0.02	0.1	−0.02	−0.01	−0.03	−0.04	−0.05	−0.1
Accuracy (RE%)	−2	−3	−4	1	−9	15	4	2	1	−26	−2	−10	−53	−7	−20
Precision (SD)	0.2	0.03	0.06	0.9	0.04	0.03	0.01	0.02	0.1	0.06	0.03	0.02	0.07	0.04	0.05
Precision (RSD%)	1	2	1	1	4	5	4	2	1	91	11	7	193	8	12

Schibille et al. (2017: 1232) we see the Mn-rich glasses from Dali straddling the stepwise increase in alumina content from the Rom-Mn glass to the Levantine I composition (Fig. 7a). The comparative dataset have been chosen to cover different geographical areas surrounding Cyprus and match the period of interest. Specifically, the Mn-decoloured glass ('Rom-Mn') has been dated between the 1st and 4th centuries CE and attributed to a Levantine production. The samples from Beirut (Freestone et al. 2025) date to the late Hellenistic-Early Roman period and are predominantly thought to be of Levantine production. The glass from Carthage (Schibille et al. 2017) dates to the 3rd to 6th century CE and includes both Egyptian-produced and Levantine glass. HIMT glass is typically found in 4th century CE contexts, the Levantine I group ranges from the 4th to the 6th centuries CE, while Foy's *Série* 2.1 has been dated to the 6th-7th centuries CE and is thought to have originated in Egypt.

The five samples from Idalion span several compositional groups. The sample with the highest MnO content (GR12501) has compositional similarities to the Foy *Série* 2.1, including a relatively high TiO_2 content (Foy et al. 2003; Cholakova et al. 2016); however, due to its low MgO and Na_2O contents we are reluctant to firmly assign it to this group, and instead assume it is an extreme Levantine I sample, together with GR683 (see Table 3).

Two samples (GR12971 and GR1192) fall in the transitional zone between Roman Mn-decoloured and Levantine I data. Finally, for sample GR1136 the amount of titanium oxide was below the detection limit, placing it far from the other groups of samples; plotting it with an assumed titanium oxide content of half the detection limit places it near to the group of Early Roman glass from Beirut.

4.1.2. HIMT glass

A single sample (GR3726) has more than 2 wt% MnO, well above 1 wt% MgO, nearly 0.6 wt% TiO_2 more than 1.5 wt% Fe_2O_3 and 6 wt% CaO; these characteristics identify it without doubt as High Iron Manganese Titanium (HIMT) glass (Freestone, 2021), known also as *Série* 1 (Foy et al. 2003), see Table 5. This is a well-studied Egyptian glass composition typically found in 4th century CE contexts (Freestone et al. 2018 and references therein; de Juan Ares et al. 2019).

Table 3
SEM-EDS results for all analysed samples, in wt%. Values that were quantified as being below 0.05 wt% are reported as bdl (below detection limit). The first two samples are not man-made glass. The following nine samples are most likely modern glass; sample GR324 is the 'Keo' beer bottle fragment, and samples GR670 to GR 687 are fragments of a single Pepsi bottle. The remaining 12 samples are ancient, including one HIMT (sample GR3726), seven decolourised samples, and four likely Hellenistic to Early Roman ('Hell/ER') samples (GR3945, GR686, GR13416, GR3638).

Samples (average n = 3)	F	Na_2O	MgO	Al_2O_3	SiO_2	SO_3	Cl	K_2O	CaO	TiO_2	MnO	Fe_2O_3	Sb_2O_5	Type
GR678	bdl	2.8	4.65	13.7	61.4	bdl	0.07	0.23	5.54	0.24	0.34	11.1	bdl	Rock
GR685	bdl	bdl	bdl	bdl	99.8	bdl	bdl	bdl	bdl	bdl	bdl	0.17	bdl	Quartz
GR2660	bdl	15.2	1.11	1.5	70.7	bdl	bdl	0.31	10.8	bdl	bdl	0.22	bdl	Modern
GR324	0.37	12.9	0.36	2.0	72.3	bdl	bdl	1.01	10.8	0.11	bdl	0.12	bdl	Keo
GR5009	bdl	13.4	4.48	0.6	73.9	0.29	bdl	0.19	7.2	bdl	bdl	bdl	bdl	Modern
GR670	0.10	12.4	0.30	2.2	71.8	0.28	bdl	1.65	11.2	bdl	bdl	bdl	bdl	Pepsi
GR671	bdl	12.4	0.31	2.3	71.9	0.23	bdl	1.66	11.3	bdl	bdl	bdl	bdl	Pepsi
GR674	bdl	12.4	0.32	2.2	71.9	0.25	bdl	1.68	11.2	bdl	bdl	bdl	bdl	**Pepsi**
GR675	0.21	12.4	0.32	2.3	71.7	0.22	bdl	1.64	11.3	bdl	bdl	bdl	bdl	Pepsi
GR682	0.14	12.4	0.30	2.2	71.8	0.25	bdl	1.67	11.2	bdl	bdl	bdl	bdl	Pepsi
GR687	0.13	12.3	0.32	2.3	71.8	0.21	bdl	1.65	11.3	bdl	bdl	bdl	bdl	Pepsi
	F	**Na_2O**	**MgO**	**Al_2O_3**	**SiO_2**	**SO_3**	**Cl**	**K_2O**	**CaO**	**TiO_2**	**MnO**	**Fe_2O_3**	**Sb_2O_5**	**Type**
GR3726	bdl	17.6	1.14	3.0	66.1	0.28	0.97	0.43	6.0	0.59	2.21	1.68	bdl	HIMT
GR12501	bdl	16.0	0.72	2.7	67.3	0.25	0.85	0.85	8.6	0.14	1.84	0.68	bdl	Lev I?
GR12971	bdl	15.8	0.56	2.8	68.4	0.27	0.85	0.78	8.6	0.07	1.44	0.46	bdl	Lev I
GR1192	bdl	16.4	0.57	2.7	68.4	0.23	0.92	0.82	8.1	0.08	1.38	0.43	bdl	Rom-Mn
GR1136	bdl	15.9	0.66	2.7	67.1	0.34	0.76	0.52	9.1	bdl	1.25	1.54	bdl	Rom-Mn
GR683	bdl	14.8	0.64	3.0	69.3	0.04	1.10	0.39	8.8	0.11	1.11	0.72	bdl	Early Roman
GR2725	bdl	18.5	0.54	1.9	69.9	0.32	1.11	0.62	6.4	bdl	0.25	0.40	0.4	Mn/Sb-dec
GR680	bdl	18.0	0.41	1.9	71.6	0.39	1.05	0.54	5.8	bdl	bdl	0.32	0.6	Sb-dec
GR3638	bdl	17.6	0.38	1.9	69.9	0.23	1.18	0.51	7.1	bdl	0.85	0.44	bdl	Hell/ER
GR686	bdl	16.0	0.40	2.3	72.0	0.16	1.11	0.50	6.9	bdl	0.46	0.24	bdl	Hell/ER
GR13416	bdl	16.9	0.61	2.1	69.7	0.26	0.92	0.68	8.3	bdl	0.14	0.35	bdl	Hell/ER
GR3945	bdl	18.4	0.52	2.3	67.9	0.36	0.87	0.70	8.5	bdl	0.11	0.33	bdl	Hell/ER

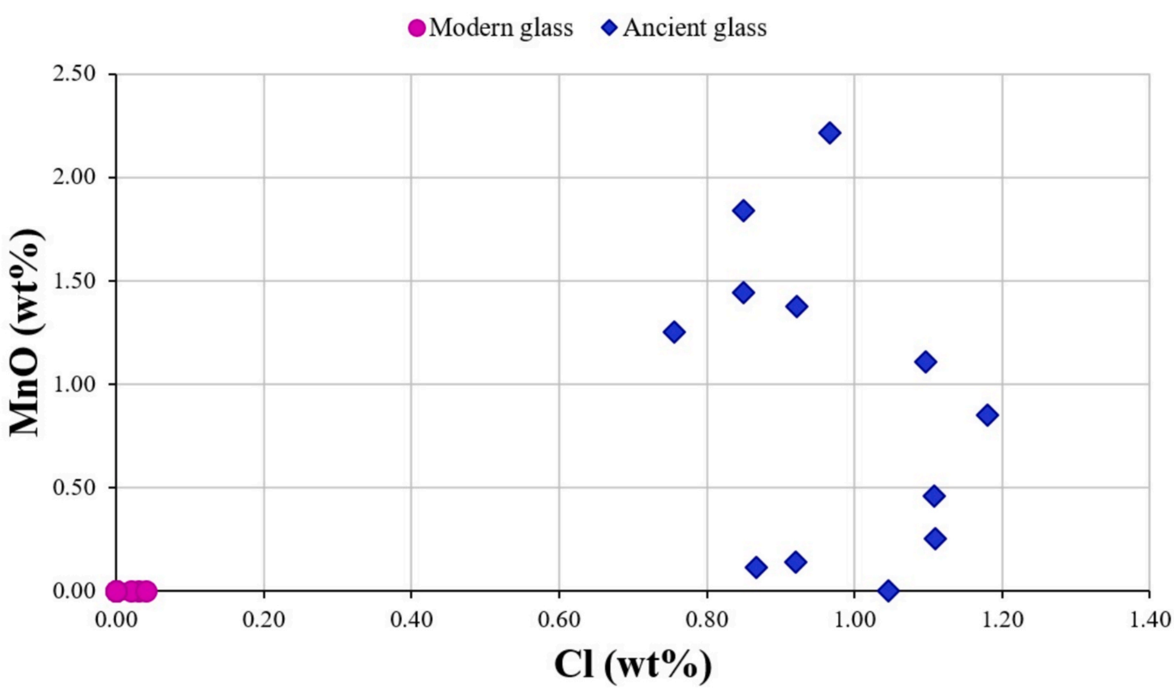

Fig. 6. Plot of the contents of chlorine versus manganese oxide. The group clustered on the origin of the graph includes 9 samples and it is defined as modern glass; the samples on the right of the plot do not cluster tightly, showing elevated chlorine contents as a common feature and a variable content of MnO, as is typical of ancient glass.

4.2. Hellenistic to Early Roman glass in Idalion

The remaining four ancient samples, those in the bottom left corner of the graph in Fig. 7a, do not fit into the groups mentioned above, primarily due to their lower contents of MgO, Al_2O_3, MnO and Fe_2O_3. To test their potential Hellenistic to Early Roman date, we have plotted these samples against some late Hellenistic to Early Roman comparative data (Fig. 7b).

In their alumina to silica ratio, the four ancient fragments from Idalion show close similarity to the Hellenistic glasses from Cyprus and Syria, while the earlier discussed samples of likely Roman date fall just to the right of the Hellenistic data (Fig. 7b). Similarly, Connolly et al. (2012) studied Hellenistic glasses from Pherai near Volos (Greece); these data were not inserted in the graph because their values of TiO_2 are predominantly below the detection limit; however, their alumina to silica ratios also fall between 0.03 and 0.04, similar to the other

Table 4
Assignment of decoloured glasses for seven samples from Dali, based on their analysed values for manganese oxide and antimony oxide. *Sample GR1136: it has been included as Mn-decoloured glass according to its value of MnO but has a high content of 1.54 wt% of Fe_2O_3, which gives a pale green colour and not colourless as expected, showing that the amount of MnO present was not sufficient for decolouring this glass.

	Mn-decoloured		Sb-decoloured		Mn/Sb-decoloured	
	MnO (wt%)	Sb_2O_5 (wt%)	MnO (wt%)	Sb_2O_5 (wt%)	MnO (wt%)	Sb_2O_5 (wt%)
GR12501	1.84	bdl	–	–		–
GR12971	1.44	bdl	–	–	–	–
GR1192	1.38	bdl	–	–	–	–
GR1136*	1.25	bdl	–	–	–	–
GR683	1.11	bdl	–	–	–	–
GR680	–	–	bdl	0.6	–	–
GR2725	–	–	–	–	0.25	0.4

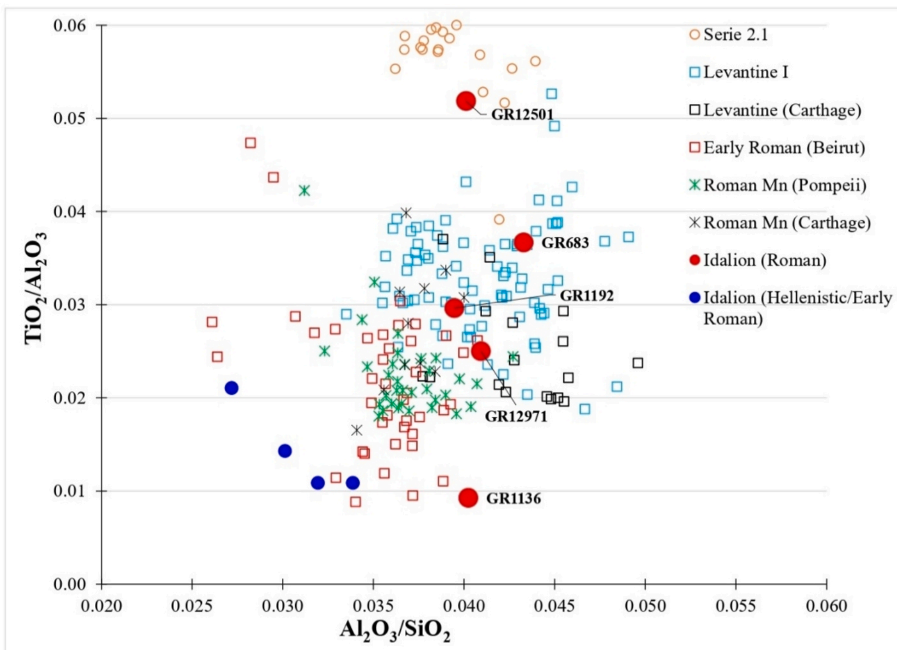

Fig. 7a. Plot of the ratio Al_2O_3/SiO_2 versus TiO_2/Al_2O_3 for a comparison between Idalion glass (filled red circles: high-MnO glass, filled blue circles: Hellenistic/Early Roman) with selected datasets of compositions of high MnO glass groups. Data for Pompeii are from Boschetti et al. (2024), for Carthage from Schibille et al. (2017), Beirut data from Freestone et al. (2025), and the Série 2.1 data are from Foy et al. (2003). In this graph, the high-MnO samples from Idalion do not seem tightly clustered one to each other. The HIMT sample GR3726 has an Al_2O_3/SiO_2 value of 0.045, similar to the other high-Mn samples, while its TiO_2/Al_2O_3 value of 0.197 falls outside the plot area.

Table 5
Comparison between the typical composition for HIMT glass reported by Freestone (2021) and the glass fragment GR3726 from Idalion.

	Na_2O	MgO	Al_2O_3	SiO_2	K_2O	CaO	TiO_2	MnO	Fe_2O_3
HIMT (Freestone 2021)	19.1	1.23	2.9	64.5	0.41	6.2	0.49	2.02	2.28
Idalion – GR3726	17.6	1.14	3.0	66.1	0.43	6.0	0.59	2.21	1.68

Hellenistic glasses. The titania to alumina ratios of these four samples from Idalion (filled blue circles) are lower than those from the comparative Hellenistic data, reflecting most likely the increased uncertainty and under-reporting of TiO_2 in the quantification (see Table 2).[1] Adjusting the reported values by a factor of 1.27 (open blue circles) brings the Idalion samples close to the range of the other Hellenistic glasses, and firmly overlapping the range of compositions reported for Early Roman glass from Beirut (Freestone et al. 2025; see Fig. 7a). This shows that the four glass fragments from Idalion seem to be closer to the composition of Hellenistic to Early Roman glass more generally, with very low presence of titanium oxide and a low alumina to silica ratio.

Significantly, the number of available data for Hellenistic glass from Cyprus is much lower than for Roman glasses. In line with this, there are only four potential Hellenistic to Early Roman glass samples from the East Terrace in Idalion, while another eight samples show more affinity with relatively early Roman glass, while none are from later compositional groups such as Foy *Série* 2.1 or Levantine II.

4.3. *Evaluation of samples thickness*

The transition from the late Hellenistic to the Early Roman period in the eastern Mediterranean took place during the 1st century BCE, coinciding with the invention of glass blowing (Larson 2019). The new method enabled a much more rapid production of glass vessels with less glass per vessel, resulting in significantly thinner walls. The widespread adoption of glass blowing as the dominant method of glass working occurred only gradually, while the older method of slumping continued to be used for at least another century. Thus, while there are no blown Hellenistic glass vessels, there are both blown and slumped Early Roman vessels, with blown vessels dominating only in the Roman and Byzantine

[1] The average measured TiO_2 value for Corning B is 0.07 wt%, well below the published value of 0.089. Multiplying the measured value by 1.27 brings it in line with the published value.

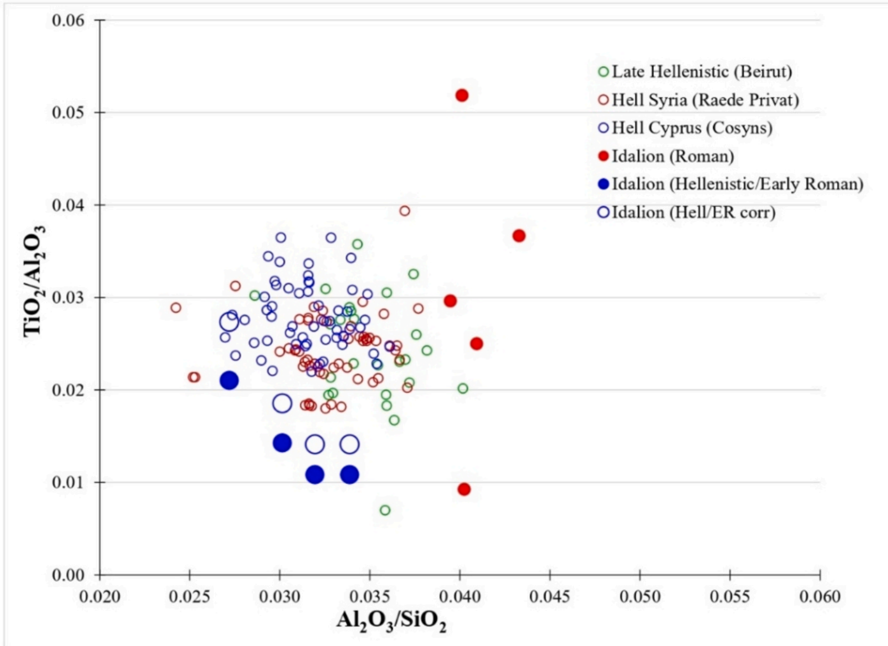

Fig. 7b. Plot of the ratio Al_2O_3/SiO_2 versus $TiO_2/Al2O_3$ (filled red circles: high-MnO Roman glass, filled blue circles: Hellenistic/Early Roman). Note the generally higher Al_2O_3/SiO_2 ratio of the Roman glasses. The four Idalion glasses of potential Hellenistic to Early Roman date (GR3945, GR686, GR13416, and GR3638) match the comparative Hellenistic glass groups. Data for Late Hellenistic Beiruti glasses are from Freestone et al. (2025); for Syrian Hellenistic glass from Reade and Privat (2016); and for Cypriot Hellenistic glass from Cosyns et al. (2018).

period. This section aims to relate macroscopic evidence, specifically thickness of the samples, with chemical evidence. From the results and the discussion, we have been able to categorise the East Terrace glass samples in three wide chronological categories: modern, Roman, and Hellenistic / Early Roman. Rearranging Idalion samples in accordance with these categories identifies systematic differences in terms of thickness (Fig. 8).

On average, the Hellenistic to Early Roman glasses are thicker than the Roman glasses. This is predictable considering that the glassblowing technique, which allows to make really thin glass objects, has been introduced only around 50 BCE (Larson 2019 and references therein), while the Hellenistic glass has a thickness similar to modern glass. In some cases, it might be easy to identify modern glasses, as in the case of the samples GR324 and GR674 shown in Fig. 5, but in other cases it might be more challenging, as exemplified by the samples GR5009 and GR2660 (the latter is shown in Fig. 4), whose thickness overlaps with the

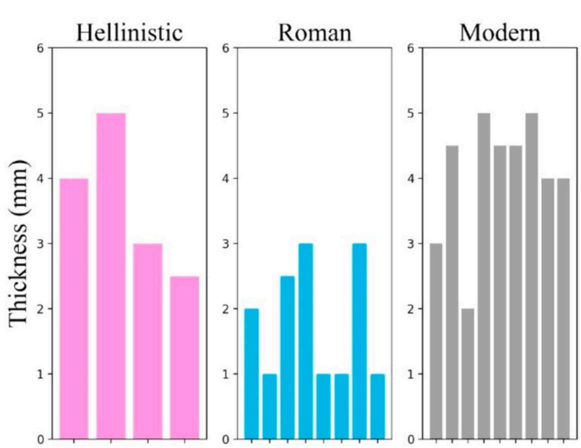

Fig. 8. Values of thickness (in mm) of Idalion samples grouped accordingly to the chronological interpretation of their chemical composition

Hellenistic glass fragments. Therefore, thickness alone cannot be the only discriminating factor, even though it can give a broad idea, especially during the sampling at the excavation to distinguish ancient and modern glass fragments. However, this parameter can be combined with analytical techniques that can be used also *in situ*, such as hhXRF. This will allow also a statistical study on the correlation of these two characteristics in an archaeological excavation with more numerous glass fragments than encountered in this pilot study, facilitating sampling strategy and reducing time and costs for archaeometric studies of these materials.

5. Conclusions

In this pilot study on glasses excavated from the East Terrace of the archaeological site of ancient Idalion we make several considerations on ancient and modern glasses that can be found during an archaeological excavation, and the chronology of glass in relation to their macroscopic and chemical features.

Firstly, the distinction between modern and ancient glass fragments can be made based on the contents of chlorine and manganese oxides. For this reason, it might be useful to report these values in all archaeometric publications on glass studies, even though some methods such as LA-ICPMS do not routinely report chlorine concentrations.

Regarding the archaeological context of the East Terrace area of ancient Idalion, it was possible to attest the presence of several types of ancient glasses. Out of the 12 analysed ancient glasses, one is a clear HIMT composition and was most likely produced in the 4th century CE. Five samples match the broad spectrum of Roman Mn-decoloured to Levantine I glass compositions, tentatively placing them in the first third to mid-1st millennium CE. Another two samples are antimony-decoloured and mixed antimony-manganese decoloured, placing them in a similar time frame and indicating the recycling of decoloured glass. Finally, the presence of four samples of glass with a composition matching Hellenistic / Early Roman eastern Mediterranean glass is consistent with an earlier occupation of the East Terrace area, during the 1st centuries BCE/CE. To gain a more detailed view on the chemical composition of decoloured and weakly-coloured Hellenistic glass, it is necessary to collect and publish more data, so that the gap in our knowledge compared to the more frequently analysed Late Roman / Byzantine glass of the mid-1st millennium CE will be overcome and a more substantial comparison can be done.

More generally, we have shown that the glass composition can be a useful tool to narrow the date assigned to individual glass fragments where typological features are missing and / or the chronological context might be uncertain due to the complexity of the archaeological site. In addition, the combination of thickness and chemical composition (using portable instruments, for example hhXRF) can be a useful approach to guide sampling and archaeological contextualization already during the excavation work at the site.

CRediT authorship contribution statement

Giulia Fogarizzu: Writing – original draft, Investigation, Formal analysis, Data curation. **Pamela Gaber:** Writing – review & editing, Resources. **Andrew M. Wright:** Resources. **Thilo Rehren:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Funding acquisition, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data are contained in the manuscript

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