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Υαλίτις γῆ: Egyptian glass production and trade between the seventh century BC and the ninth century AD

Marie-Dominique Nenna¹

KEYWORDS: — Archaeology; Archaeometry; Glass; Egypt; Mediterranean

ABSTRACT: — Our understanding of Egyptian glass production and trade has greatly improved over the last thirty years, thanks to archaeological and archaeometrical studies. In this communication I address the issues of primary glass production in Egypt and trade between the seventh century BC and the ninth century AD. I draw on textual sources (literature and papyrology), study of artefacts, archaeological discoveries of primary glass production centres coming from surveys and excavations in the Mareotis area, Wadi Natrun, Sinai and Middle Egypt. Further the development of our understanding of glass compositions now allows defining the major steps of glass industry from a discrete and small scale production to mass production, supplying local consumption on one side and raw glass and luxury vessels for exports on the other. Five main phases can be distinguished with moments of technological changes and shifts in the modalities of trade and in the taste of the customers: at the end of the third c. BC, at the end of the first c. AD, in mid fourth century AD and in mid seventh century AD.

Considering recent published works and our own fieldwork and archaeometry studies, we try here to draw an overview on the primary glass production in Egypt and the trade of raw glass and finished products between the seventh century BC and the ninth century AD. Five main phases have been defined matching technological changes and shifts in modalities of trade and the consumers' market. Glass production is commonly divided in two stages: raw glass making from sand and soda of mineral or vegetal origin (primary glass workshops) and production of finished products (secondary glass workshops). In the first millennium BC and AD, these two activities were geographically separated. In the last 25 years, provenancing glass by chemical analysis has made a lot of progress, specially using LA-ICP-MS (laser ablation inductively coupled plasma mass spectrometry, hereafter abbreviated as LA-ICP-MS) analysis together with the search for neodymium, strontium and hafnium radiogenic isotopes signatures.

1. From seventh century BC to the end of the third century BC: opaque glass, a speciality of the Egyptian workshops

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Three main categories of objects help tracing the history of Egyptian glass production in the first millennium BC: 1. Wooden elements of religious furniture showing glass inlays dated by the name of the pharaohs or by their excavation context, as well as glass inlays discovered in workshop contexts or carefully stored after the destruction of their support; 2. Foundation plaques; 3. Glass beads and pendants.

The first category is deeply rooted in the second millennium BC glass craft tradition, of which the most famous examples are the furniture as well as the jewels of Tutankhamen (Broschat, 2021), and the jewels of the pharaohs of the 22nd Dynasty (e.g. pectoral de Sheshonq I, 943-922 BC). The rear panel of a naos of Amasis (570-525 BC) is the most ancient testimony of the series of wooden elements decorated with glass inlays (Arveiller-Dulong & Nenna, 2011, cat. no. 585). Monochrome flat rectangular and square plaques as well as monochrome and bichrome plaques (made by fusing two elements of deep blue and red glass) in the form of feathers were made in a limited range of glass hues. The colours were restricted to pale blue, deep blue and red, imitating respectively turquoise, lapis lazuli and jasper, in line with what was already known in the New Kingdom. Other identified decorated wooden elements dedicated to Amasis are known from Saqqara: a fragment of a cornice (Insley Green, 1987, cat. no. 8) and a fragment of openwork wood showing the goddess Khouit protecting the cartouche of Amasis (fig. 1), discovered in 2018 during the excavations of the Franco-Swiss Mission (Bianchi, 2022). In this piece, light green glass feathers appear next to those in pale and deep blue and red glass. Bichrome elements are noticeable in the feathers of the wings of the deity, but also in the necklace that shows the juxtaposition of pale and deep blue threads.

Next in time come two elements inscribed for Petubastis IV (c. 522-518 BC) (Kaper, 2015, note 10): an openwork wood showing a winged goddess protecting the pharaoh; and a right-hand door wing in which the body of the kneeling pharaoh was probably entirely formed by glass inlays, though not preserved (Arveiller-Dulong & Nenna, 2011, cat. no. 587).

In the back panel of the naos of Darius I (520-486 BC), the figures are partially carved in hollow, the rest of the body must have been covered with gilded stucco reliefs (Curtis & Tallis (Eds.), 2005, cat. no. 266 with reconstruction). The same colour palette is still used, but another technique is attested, also already known in the second millennium BC, which consists in moulding inlays with a flat side and a relief one.

The excavations in Ain Manawir, south of the Kharga oasis, offered another chronological head of a series, the one of mosaic glass series (Nenna, 2015a). Glass inlays were found in the north-west corner of the hypostyle hall of the temple in front of the F-F' chapel, but the

majority of them were found in a small jar (fig. 2), which had been stored in one of the service rooms of the temple (room O), next to a series of ostraka and unexpectedly luxurious items for such a remote site (an Attic lekythos, a New Year's flask and a censer holder). This set of objects is contemporary, or later than, the foundation of the temple in the years 500-490 BC. They are earlier than the years 410-400 BC, – if one considers the *ostraka* of a certain Harsiesis, dated between 410 and 400 BC founded in the same room –, or at the latest earlier than the years 380 BC, which mark the end of the temple activity. Aside from rectangular plaques of various modules, the jar contains elements of different formats belonging to the decoration of cornices moulded in groups as indicated by a plaster mould from Tebtynis workshop (Nenna, 2015a, fig. 1), as well as monochrome body and dress elements. Some inlays show the combination of threads for the loin clothes, but also evidences of cutting slices from rods of blue and red (red has turn green) glass for the dress of the winged deity and of their placing on a flat white glass plaque.

The introduction of new glass hues, such as yellow, orange, and white took place in the middle of the fourth century, as can be seen in the back panel of the naos of Nectanebo II (359-341 BC), which features glass plates in these colours in the ornamentation of the cobras and the divinity and in the border friezes, whereas the large palace façade motifs were decorated with mosaic glass plaques (<https://www.brooklynmuseum.org/opencollection/objects/3998>). By the end of the fourth century BC, the well-known wooden sarcophagi of Petosiris and his brother, show hieroglyphs in monochrome glass, as well as the ones of birds, baskets, and divine signs made of mosaic elements combined in a single compartment for the whole figure and resting, as in the case of the female deity of Ain Manawir, on a monochrome glass support.

The glassworkers producing these elements for religious objects were surely Egyptians. Working on commissions from different communities or individuals, they were probably itinerant, as shown by raw glass chunks, semi-products and moulds discovered in various sites of the Fayum and Delta (to the sites enumerated in Nenna, 2015a, add Dionysias [Davoli & Faisal, 2020]) and maybe Taposiris Magna [Hawass & Goddio, 2010, p. 206], and in the Mut precinct in Karnak (Bettineschi et al., 2019, p. 519). The raw glass production structures could be the same as those excavated and reconstructed by P. Nicholson (2007) in royal context in Tell el-Amarna, i.e. furnaces with crucibles. Their equipment could have been very light, as their only need was to reheat powdered glass which was put in the moulds. Chemical analysis on raw glass and semi-products glass used in Tebtynis workshop show a wide range

of recipes with either natron or plant ash as flux (Nenna & Gratuze, 2009; Bettineschi & Angelini, 2022 and 2023).

The metallic elements belonging to sculpture or religious furniture, adorned with glass inlays are not easily tracked and the coloured material used in these artefacts is not always clearly identified as glass (Arveiller-Dulong & Nenna 2011, p. 356-357; Masson-Berghoff 2019, p. 138, fig. 4).

Another religious use of glass is the making of red and blue glass plaques bearing dedications which were placed during the third century BC in the foundation deposits of temples (Arveiller-Dulong & Nenna, 2011, cat. no. 563-564 with anterior bibliography), as shown by recent discoveries in Alexandria in the Boubasteion (Ptolemy III and Berenike II) and in Taposiris Magna (Ptolemy IV) (Abd el-Maksoud et al., 2015).

The lack of well-dated contexts for beads and pendants in Egypt between the seventh and the third century BC and the lack of recent interest for their study (see however Xia, 2014 [1940]), p. 127-136, building on the bead collection kept in the Petrie Museum) make it difficult to know to which extant glass bead manufacture was widespread in Egypt. In Naukratis (Thomas & Acosta, 2018), eye beads (20 ex.) account for 91% of the Late Period (664-332 BC) decorated glass beads, most of them made with the stratified glass technique, which was complex and labour intensive. Considered as imports by Thomas & Acosta (2018, § 6.6, without precision of the origin), and not local products (for Spaer 2001, 81-83, stratified eye-beads demonstrate “both the diffusion of similar fashions and, thanks to small but unmistakable regional differences, the very considerable spread of the craft of beadmaking” during the sixth-fourth century BC in the whole Mediterranean), the eye beads represent 11% of the beads dated to the Late Period, whereas in Egypt, they amount to 1,4% (Xia, 2014 [1940]). No monochrome glass beads of the Late Period are listed in those two studies, and the same image would appear in the study of other museum collections (see for the Louvre, Arveiller-Dulong & Nenna, 2011, p. 175-209). These very low occurrences of monochrome beads are surprising, if we compare them to the evidence offered by the analytical results on glass beads discovered abroad. They show that Egyptian raw glasses were traded towards Italy and Western Europe since the ninth century BC (Conte et al., 2018), as well as in the Aegean, even if the number of analyses is lower for this region (Oikonomou & Triantafyllidis, 2018). The point of importance is the appearance in North and South Italy during the Early Iron age (ninth-eighth century BC) and in the Orientalizing/Archaic period (last quarter of eighth-sixth century BC) of different groups of Egyptian origin natron glass which were absent in the Final Bronze Age (end of the twelfth-tenth century BC). Glass from Egyptian origin is

also attested during the sixth century-mid fifth century BC in different European sites (Chérel & Gratuze, 2018).

In continuity, glass from Egypt was traded towards Europe and used in the secondary glass workshops of the La Tène period within the Celtic world for the production of arm rings and beads. The term continuity is not fully adequate : the correlations between the Iron Age glass groups and the La Tène groups have not been performed, and it seems, following Bernard Gratuze (pers. comment) that there is a very high chemical variability, even inside identified groups. The huge work of collecting glass bangles in the Great-River area in the east of the Netherlands (Roymans et al. 2014) and in France (Rolland (2021) led to a corpus of 11,655 arm rings. Analysis of 2,607 samples kept in the Nijmegen museum using p-XRF (portable X-ray fluorescence) showed that most of the samples were made of Syro-Palestinian glass, and identified a small lot of Egyptian origin. The 1,163 LA-ICP-MS analyses by B. Gratuze and J. Rolland on arm rings, beads from France as well as on raw glass from shipwrecks, enables a precise identification and characterization of the colours – blue, opaque yellow, opaque white, natural colour (light green), colourless – of Egyptian provenance (fig. 3). Two Egyptian groups (corresponding to two primary production sites) were identified:

	very low oxide percentages	medium oxide percentages	high oxide percentages	very high oxide percentages
Egyptian group 1	aluminium, manganese, magnesium, strontium, barium, potassium	calcium	Zirconium	
Egyptian group 2	strontium	manganese	magnesium, zirconium	aluminium, titanium

The shipwreck of su Pallosu on the western shores of Sardinia, near Oristano dated to the third century BC contained 20 kg of yellow glass and little less than 20 kg of blue glass (Egyptian group 1 for the three samples), consisting of small lumps of glass maybe stored in an amphora (Rolland, 2021, p. 35).

The important point brought by Rolland's study is the shift from Egyptian glass towards Syro-Palestinian glass to supply the La Tène workshops and consumers' market at the end of

the third century - beginning of the second century BC. This result was further confirmed by the analysis of 60 raw glasses samples from the secondary glass workshops of Němčice of the third-second century BC and of Staré Hradisko in Moravia dated to the second-first century BC (Roland & Venclovà, 2021). This does not mean that coloured glass production ceased in Egypt, as we will see later, but that the trade was interrupted and that the western Europe secondary glass workshops had to find new supply sources out of Egypt (Rolland, 2023).

From a wider viewpoint in the history of glass, it can be stressed that Egypt which was a top producer of core-formed glass in the second millennium BC did not participate to the shift which led to the creation of core-formed containers widely distributed in the whole Mediterranean from the end of the sixth century BC. The question of the localization of their workshop (s) remains open till today. The glass itself seems of Syro-Palestinian origin, but no primary glass workshops of this period has been yet identified in this region, and the recorded finished objects are very low in numbers (Arletti et al., 2015; Blomme et al., 2017). On the basis of the high number of discoveries in tombs, Rhodes has been long thought to be a production centre, but this does not exclude the existence of other production centres in the Aegean.

Neither does Egypt participate in the development of luxury colourless glass vessels which is exemplified by discoveries in Macedonia (Ignatiadou, 2013), Asia Minor (Ignatiadou, 2021), and in Rhodes (Triantafyllidis, 2000), dating from the mid fourth-third century BC.

The reasons why Egypt missed these two shifts remain obscure.

II. From end of third century BC to end of the first century AD

This period saw the rise of glass tableware in monochrome and polychrome glass. It is very probable that the mosaic glass bowls which appear in rich funerary contexts, in Italy at the end of the third century BC (e.g. Manconi, 2015, here fig. 4) were manufactured in Egypt, though this statement is based on the premise that such production requires a savoir-faire and the use of good quality coloured opaque glass not known and practised elsewhere at this period. On the opposite, the origin of sandwich gold glass bowls sometimes thought by some as being of Alexandrian manufacture, and other monochrome translucent bowls should be searched elsewhere, may be in South-Western Asia Minor and Rhodes.

Nevertheless, the development of pictorializing style mosaics from the end of the third century BC in Alexandria, implied the use of artificial material such as faience, Egyptian blue and glass tesserae of opaque or translucent colours. This fashion will spread in the other Hellenistic kingdoms (Mosaics of Pergamum), and by the end of the second century BC in the

rich houses of Aegean and Mediterranean world (Guimier-Sorbets & Nenna, 1992 and 1995). A speciality of Egyptian workshops was the production of sealing wax red glass, which will be distributed in Italy till 40-60 AD (Boschetti, 2011). The craft of glass inlays is technically further refined by using very elaborate bars presenting complex motives such as theatre masks of Greek inspiration as well as religious figures of the Egyptian tradition (fig. 5) (Arveiller-Dulong & Nenna, 2011, p. 384-391). Objects, such as beads or amulets (Arveiller-Dulong & Nenna, 2011, 175, 267-296) are more numerous than before and distributed to a wider clientele, but it is worth reminding that we are still, in Late Hellenistic Egypt, reasoning on a reduced corpus of artefacts.

The evidence brought by the examination of glass waste found in Denderah, tentatively dated, in the absence of discovery context, to the second half of the 1st century BC shows that crucibles kilns were still used at that time in Egypt (Boschetti, 2018). There is no evidence in Egypt of primary furnaces with a pouring hole, as implied by part of the glass chunks (550 kg retrieved) from the Sanguinaires A shipwreck dated to the beginning of second century BC (Rolland, 2021, p. 25-26). No evidence either of the secondary kilns used to produce slumped bowls, whether in mosaic or monochrome glass. Given the increase in raw glass production implied by the substantial increase of monochrome translucent glass tableware in the Syro-palestinian workshops and its distribution over the Eastern Mediterranean region at the end of the second century BC - beginning of the first century BC, we still have few clues of the development of glass industry in Egypt at that time. We rely mainly on textual sources, principally by Cicero, who, in his *Pro Rabirio Postumo* (XIV, 40) written in 54 BC, evokes Egyptian glass as common and cheap and by Strabo who writes about the *hyalinê puelos* (glass sarcophagus) of Alexander the Great (XVII, 1-8) which replaced the gold sarcophagus stolen by Ptolemy X in 88 BC. Strabo further writes about natron (*ualitin gen*), indicating that Egypt was known for its ability to produce polychromy in glass (XVI, 2, 25-26) (Nenna, 2021, p. 24 for comment). Chemical analysis gives also a glimpse on the Egyptian productions, still made of opaque vivid colours glass (Gratuze, Nenna, 2009, p. 203), but also on the appearance of colourless glass decolorized with antimony (Foy et al. 2004, p. 170, lot A regarded as Egyptian in origin by Paynter & Jackson, 2019, p. 1535-1536, see also *infra*).

The Augustan period marks a great turn in the glass craft, with the appearance of the Italian secondary workshops. Polychrome and monochrome vases are no longer counted in tens but in hundreds (Nenna, 2018). No workshop dating from the Augustan period has been found, but it is most likely that Rome was an important production centre. The 37,953 moulded glass fragments of the Gorga collection formed in Rome, as well the many pieces which delighted

collectors at the end of the nineteenth century and are now kept in European and North American museum collections, all come from Rome or its surroundings (fig. 6). At that time, there was certainly a significant transfer of manpower from the provinces toward the capital of the Empire, and it is likely that part of this manpower could have originated from Egypt. New shapes inspired by Italian sigillata appear, new colours for tableware such as emerald green or peacock blue, as well as new motifs (marbled glass, ribbon glass) are first used in the Augustan period (Petrianni, 2003).

The revolution of glass blowing, – an invention dated from the mid first century BC spreading later on by 40-60 AD in the whole Mediterranean and western provinces – does not change for a while the taste for polychromy and vivid colours in pieces which can be qualified as luxury pieces, given the high cost of colouring glass technique. At the same time, the use of blue-green glass, sometimes called naturally coloured glass, spreads widely for the more common table ware pieces as well as for the containers. This kind of translucent glass, long called « Roman Glass » is now firmly attributed, based on chemical analysis, to the Syro-Palestinian region which is a main provider of raw glass for the first century AD onward. In Egypt, no closed contexts yielding a sufficient number of glass vessels is dated to the Augustan period or the Tiberio-Neronian period, and it thus remains difficult to understand what was the development of the local glass blowing industry till 70 AD.

III. From end of the first century AD to mid-fourth century AD

The last third of the first century AD witnesses, both in the East and in the West a unification of tastes and a disappearance of bright colours. Blue-green glass is commonly used whereas colourless glass is reserved for tableware. Elaborate pieces such as faceted goblets (fig. 7) or moulded shallow bowls appeared in most of the provinces of the Empire and beyond. Until the end of the fourth century, colourless glass remained the dominant medium for cold-decorated vases, cut in high relief or in hollow. This is also true for painted glass vessels, which are preferentially made of colourless glass, after having been made of deep blue or emerald green until the 70's. Beyond these luxury pieces produced in Egyptian workshops and travelling over long distances (Nenna, 2015c, p. 258-263), colourless glass was also used in simpler tableware within the whole Empire (Foy et al., 2018, Lepri 2022). The division between blue-green and colourless glass called “Alexandrian”, and the higher price of the latter, is established by the Edict of Diocletian dated 301, both for raw glass, undecorated vessels and windowpanes which were sold by weight. Decorated vessels seem to have been sold by the piece.

The provenance of colourless glass has been a disputed question for many years, two decolorizers, antimony (Sb) and manganese (Mn), and an important number of analyses tackling the question of remelting in secondary workshops of objects made following the two manufacturing recipes are the main reasons of this. Compositional evidence today confirms an Egyptian provenance for Roman Sb glass (Gliozzo 2017; Schibille, Sterrett-Krause & Freestone, 2017 ; Gratuze 2018; Paynter & Jackson, 2019). This hypothesis was proposed more than 20 years ago by M. Picon (Nenna et al., 2005) based on one of the glass groups “wnc [Wadi Natrun c]” identified from raw glass samples unearthed in the Beni Salama primary glassworkshops. Roman Sb glass shows clear similarities with “wnc” group in terms of titanium oxide, alumina and silica ratios, but tends to have lower soda and higher lime contents than the Wadi Natrun groups including wnc. Recent research revealed that hafnium isotopic data clearly distinguish Roman Sb glass from Levantine glass, providing other evidence for the Egyptian origin of Roman Sb glass (Barfod et al., 2020).

Through pedestrian surveys in the surroundings of Alexandria, and in Wadi Natrun, we identified five primary glass workshops sites, two in Mareotis area —Taposiris Magna and Marea-Philoxenite—, and three in the depression of Wadi Natrun —Zakik, Bir Hooker and Beni Salama (Nenna et al., 2000). These three sites are located along or on top of a sand dune neighbouring the natron-producing lakes where reed collected for fuel grows. We proceeded to field and geophysical surveys which indicated that the sites were all three abandoned at the end of the second or beginning of the third century AD. Beni Salama was selected for further excavations which unearthed four tank furnaces, built parallel along the same orientation, three of them showing at least three phases of activity. These tank furnaces remain till today the oldest of their kind and size, since they are dated by the ceramic and the associated material to the first and second centuries AD. The melting chambers are large — internally of six to seven meters by two meters— and have extremely thick brick walls, of an average of two meters (fig. 8). The different spaces of the furnace: firing-chamber and melting chamber were placed in line along a Northwest-Southeast axis corresponding the dominant winds. A paved zone, —clean space for the deposition of the sand and natron mix and a loading platform— was settled on one of the sides of the tank. After the melting of the batch, the glass slab weighing between 15 and 20 tons was broken in blocks and chunks which could be transported by camel to Terenouthis on the Nile and then shipped to supply the secondary glass workshops. In the next work season the furnace was rebuilt at the same place, with raising of the walls of the tank, reconstruction of the firing chamber, of the wall which had been dismantled to break the glass slab and of the vault (for details, Nenna, 2015b).

Three glass varieties were produced in Wadi Natrun: blue-green glass, colourless glass decolourized with manganese and colourless glass decolourized with antimony. These workshops were probably mainly supplying the Egyptian market. To date, very few glass objects found outside Egypt have shown similar compositions to the glass groups produced there. Schibille (2022, p. 36) interprets the differences between “wnc” glass and Roman Sb glass in terms of chronology, the “wnc” group being for the author a predecessor to the Roman Sb glass, we would rather interpret it in terms of geography, and suggest to search elsewhere in Egypt for the location of the primary glass workshops which produced Roman Sb glass, which were not identified till now.

Technically, “the composition of the natron base glass produced in Egypt was ideally suited to the production of antimony decolourised glass. The high levels of sodium, combined with low levels of calcium and aluminium oxides, will readily dissolve several wt% of antimony oxide, producing a brilliant, refined, colourless glass” (Paynter & Jackson, 2019, p. 1548). Shipwrecks provide evidence for the trade of Roman Sb glass all around the Mediterranean, such as the Embiez wreck dated to the late second-beginning of third century AD, which contains raw glass, window glass, and bowls and goblets (Fontaine & Foy, 2007).

At the same period in Egypt, other production centres were active: in Taposiris Magna 45 km west of Alexandria, we have fragmentary remains of glass primary workshops, which seemingly date, according to the pottery mixed with the dumps of the primary workshops, before the middle of the second century AD. This glass which has a very high percentage of calcium has not been recognized in analyses performed on raw glass in workshops, or on glassware in Europe or elsewhere. Other primary glass workshops, working with plant ash, are attested in Wadi Natrun itself (Bir Hooker and Zakik sites samples, Picon et al., 2008) and eother Regions of Egypt, as shown by analysis made of glass discovered in Bubastis (Rosenow & Rehren, 2014) and in Armant (Rosenow & Rehren, 2018). These workshops produced a quite impure blue-green glass used to make utilitarian wares such as unguentaria and khol containers, which are a trademark of the second-third centuries Egyptian contexts, but are very sparsely distributed out of Egypt (fig. 9). Further, we should not forget also that discrete quantities of opaque glass were still produced and used in polychrome glass vessels as well as in architectural decorations (mosaic tesserae, opus sectile pavements or mural decorations, Gasparini, 2022, 144-156).

To sum up for the Roman period, Egypt was certainly a place where raw glass was produced, in diverse centres and with diverse scopes, for local manufacture and consumption, but also for trade abroad (Roman Sb colourless glass and vivid colour glasses). Egypt offers

the only testimony of mastering the manufacture of raw glass, in huge volumes, in furnaces of a type not known elsewhere at the same period. The quality of the sands, and a higher sodium content than elsewhere, thanks to the proximity of the natron sources, allowed the production of a glass which could be remelted and worked at lower temperatures, thus providing lesser costs in terms of fuel and manpower (Freestone, 2021, p. 254). No specific research has been conducted till today on the antimony decolourizer in the Roman period, but it might be a good key to better understand the implantation of the primary glass workshop of Roman Sb glass.

IV. Mid-fourth century to seventh AD

At the end of the third century AD, we witness a general rise of new colours, such as brown, violet and various shades of yellow-green and also a taste for the use of different colours for the body and handle or for the applied decoration in more common tableware. There is a marked decrease of the use of glass to store perfume oils, whereas glass vessels are now used as lighting device.

Colourless glass vessels decolorized by antimony are still produced during the fourth century AD, but in lesser quantities. Chemical composition of this glass shows a decrease of the content of antimony, which may reflect a shortage or a difficulty to obtain it. In the same way, after having been applied to opacify glass for long, antimony is now replaced by other chemicals, such as tin-based opacifiers, calcium phosphate (crushed bones), or by adding quartz (Paynter & Jackson, 2019).

After a period of vacuum, may be just resulting from our current state of knowledge and the lack of well-dated context in Egypt for the third century and the beginning of the fourth, new primary glass workshops rise in Egypt at least in mid-fourth century. After its first recognition in the beginning of the 1990s', HIMT (High Iron Manganese and Titanium) glass characterised visually by its yellow-green colour (fig. 10) and analytically by its high and intercorrelated oxides of iron, magnesium, manganese and titanium, was thought in the early 2000s' to come from Egypt, on the basis of its abundance at Egyptian sites and of its high sodium level, common to other Egyptian glass types (Foy et al., 2003). Since then, numerous studies dedicated to Italy (e.g. Maltoni et al., 2018; Coscarella et al. (eds.), 2021), Great Britain (e.g. Foster & Jackson, 2009, HIMT 1 and 2), Cyprus (e.g. Cosyns & Ceglia, 2018) and Black sea sites (e.g. Cholakova & Rehren, 2018) have helped drawing a more precise image of the importance of Egyptian workshops and their wide trade of raw glass between the fourth and beginning of the seventh century AD (Nenna, 2014). HIMT glass (= Foy et al. 2003, Group 1; Foster & Jackson, 2009, HIMT1) is considered to have been deliberately

tinted yellow-green by a manganese addition to the batch, in order to distinguish it from the blue-green glass of the Levant, where it has never been exported. “The colour branding of the raw glass allowed glass workers to distinguish it from the more viscous, high working temperature blue-green Levantine glass” (Freestone et al., 2018). Two subtypes, HIMTa and an iron-rich HIMTb, further distinguished by different iron to titanium ratios, are found to a greater or lesser extent throughout the Mediterranean and Europe secondary workshops; HIMTa generally dates to the fourth and fifth centuries, while HIMTb seems to have emerged only at the beginning of the fifth century AD. The appearance of HIMTb indicates furthermore the exploitation of different manganese deposits than the ones used in HIMTa. These two glass compositions disappeared from the record by mid-sixth century AD.

Fifth, but maybe also fourth according to the finds, century Egyptian workshops equally produced colourless glass by adding manganese (Cholakova & Rehren, 2018, = Foy et al., 2003, group 3.2). The appearance of the finds varies from almost colourless glass to pale yellowish, bluish or purplish tinged glass. Inversely, a clear blue glass (HIT High Iron Titanium) —due to the absence of added manganese— is seldomly attested. Also deep blue glass —when coloured with copper and/or cobalt— is rarely used for complete vessels, but more commonly for applied decoration (Maltoni et al., 2018, raw glass chunk from Aquileia). The same is true for purple glass.

In the beginning of the sixth century AD, appears yet another glass group of yellowish colour, distinguished by its high CaO content, frequently in the 7– 9 per cent range, as opposed to the 4– 7 per cent of HIMT (Foy et al., 2003, Group 2.1 = Freestone et al., 2018, 162 = HLIMT, High Lime Iron Manganese Titanium). It becomes predominant in the second half of the sixth century and will last till the seventh century AD.

The location of the primary glass workshops of this period is not precisely known. The analytical results suggest the use of a very impure sand, rich in accessory minerals, as that of the Egyptian coast between the Nile delta and North Sinai, Pelusium and Ostrakinè are potential candidates (Nenna, 2014). The high demand of glass to supply huge amounts of glass tesserae necessary to make wall and vault mosaics in early Christian buildings opened a new market, beside the one for glass vessels and elite *opus sectile* panels (Gasparini, 2022), which implied a mass production. In mosaics from the fifth and sixth centuries, Egyptian glasses such as HIMT and Foy 2.1 were more common than Levantine glass types (Freestone, 2020, p. 346)

Another Egyptian glass tradition was also pursued, with the plant ash-glass, as attested by Magby (Magnesium Byzantine glass) group attested in the sixth and seventh century, a natron

glass to which a plant-ash component was added and which circulated up to Spain and Great Britain (Schibille, 2022, p. 42-43) and in other more regional distribution groups (Rosenow & Rehren, 2018; Oikonomou et al., 2021).

V. From seventh century to ninth century

The Egyptian story with glass does not stop with the end of Classical antiquity and the Muslim conquest, as shown by the last phases of the use of mineral soda in glass and the final phases of its trade on a more regional level, than before. Analytical results in consumption sites in Israel indicate an influx of glass of an Egyptian composition, so called Egypt 2 in the late seventh-early eighth centuries (Phelps et al., 2016). Furthermore, archaeological testimony of the glass trade between Palestine and Egypt is provided by the cargo of the Ma'agan Mikhael B shipwreck at c.35 km south of Haifa (Natan et al., 2021). The shipload yielded lumps of raw glass from both Egyptian and Levantine origin and glass vessels fragments dated to the early eighth century AD, which were probably intended for recycling. Egypt continued to produce natron glass for up to a century after its demise in Syro-Palestine, where local plant ash glass is first encountered in the late eighth-early ninth century AD. In Egypt, itself, this change can be traced precisely through the examination of the glass weights, with the disappearance of natron-based glass around the end of the ninth century AD (Schibille et al., 2019, here fig. 11). The most distinctive feature of the Egypt 2 compositional group is the exceptionally low strontium to lime ratio which suggests a continental silica source rather than seashells introduced as components of sands from the coastal regions of Egypt.

Conversely, another compositional group, called Egypt 1 (repeatedly but wrongly assigned to the Wadi Natrun workshops), shows the use of shell-bearing raw materials. The latter, subdivided in chronological sequences by Schibille (2022, 49-56) does not seem to have been massively traded towards the Western Mediterranean. The few isolated vessels that so far turned up in Spain, in South Italy and Sicily demonstrate the import was limited to finished products excluding the supply of secondary glass workshops with raw glass chunks. On the other hand, the Egyptian glass workshops were able to meet the huge demand represented by the decoration of mosques, such as the Damascus Mosque and the Dome of the Rock, or by the elite residences in Syria-Palestine. There too, movements of skilled glassworkers are attested by textual sources (Fiorentino, 2020; Schibille et al., 2022).

Once again, we have no idea of the precise whereabouts of the primary workshops. Middle Egypt, in the vicinity of the cities of Antinoopolis and Hermopolis Magna could be a candidate for Egypt 2 compositional group as indicated by the remains of a primary glass

workshop in Antinoupolis and secondary glass workshops in the same town (Silvano, 2015, no analysis useable) as well as the presence of Egypt 2 glass in Hermopolis (El-Ashmunein) secondary (?) glass workshop (Bimson & Freestone, 1987). Recent analyses (Nenna, Schibille, unpublished) of raw glass chunks collected by Jean-Raymond Périchon at the end of the nineteenth century in Hermoupolis and now in the Musée des Beaux-Arts in Limoges (Nenna, 2023) confirm the presence of primary workshops producing glass of this composition in the town.

For 18 centuries Egyptian glass was mainly produced using natron as a flux (Shortland et al., 2006) and this raw material was the key to its success (Freestone, 2021). Natron from Egypt was also a key to the development of glass industry in Syro-Palestine for many centuries, as stressed by the legendary invention of glass narrated by Pliny the Elder and by abundant finds of primary and secondary furnaces (Gorin-Rosen, 2021; Saïd & Gorin-Rosen, 2022). The sands from Egypt and Syro-Palestine had their own advantages; the search for other sources of sands inspired by Pliny the Elder's writings in Spain and in the Gauls showed that suitable glass making sands are relatively rare (Degryse, 2014, p. 113-114) out of these two regions. If ever other sands were used, they certainly did not produce the bulk of the glass needed in the Roman and Late Roman secondary workshops. The same conclusions can be drawn from the research on natron from outside Egypt: natron from Macedonia could not have been used in glass manufacture (Devulder et al. 2014). For the glass produced with a mineral soda obtained through evaporation from soda springs associated with local boron deposits, found in Western Anatolia (Tite et al., 2016) and used from the sixth to the twelfth century, there is little evidence that it was widely traded beyond Anatolia, the only exception being its use in the Cordoba mosque (Gómez-Móron et al., 2021). Natron exploitation and trade is one of these mineral activities, which does not leave archaeological traces, but which should not be kept off the record (Agut, 2022), as more widely known colorizers, decolorizers and opacifiers that gave to glass all its brilliance.

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