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# The Analysis of Glass from Shipwrecks

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Analyses of glass from shipwrecks suggest that most glass in the Aegean was not manufactured there, but reformed into artefacts in a local style. The late Roman period sees a similar phenomenon; glass produced probably somewhere in present day Israel or Egypt was shipped to secondary glassworking centres elsewhere, evidence of which was found on numerous shipwrecks throughout the Mediterranean. The stylistic and compositional analysis of glass from shipwrecks helps explore the nature of trade and exchange, the technology of materials and processes, and the forming of social relationships through material transfer.

*Key words:* shipwrecks, glass, production centres, glass artefacts, glassworking

## The archaeological record

Throughout history thousands of ships have sailed across seas and oceans, transporting all manner of peoples and merchandise. Some of these vessels sank during their passage depositing a wealth of material evidence which can inform us about seafaring, trade, production and consumption of material goods and of daily life. The systematic investigation of this valuable material resource has increased in recent years with a greater sophistication in both diving and recovery methods and of archaeological investigation and conservation. This has led to an increase in material recovered for study by archaeologists.

One area which has such a body of material is the Mediterranean Sea, an area of water bounded by many different and diverse cultures throughout the past. In the Mediterranean it is estimated that, in two of the busiest periods for maritime trade in history, there are more than one hundred known Roman wrecks<sup>1</sup> and a sim-

ilar number from the late sixteenth to early seventeenth centuries around the Adriatic coast alone.<sup>2</sup> This paper will explore the value of such material evidence to archaeologists through the study of one such commodity; that of glass. Particular emphasis will be placed on a study area located in the Mediterranean and Adriatic Seas from the Late Bronze Age to the seventeenth century AD.

## Why use ships for transport?

Ships have been used as containers to transport people and goods over both short and long distances for many thousands of years. What and why they transport is influenced by the political, economic, social and technological context at the time of sailing. However, three primary reasons for the transport of goods (and people) by sea can be highlighted. The first is speed; in territories which had few roads travel by land was often difficult or hazardous. Even when road trans-

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1 Gabriel de Donato, *Mare Nostrum, the Roman Sea* (London: Periplus publishing, 2003), ix.

2 Zdenko Brusić, »Tre naufragi del XVII o XVIII secolo lungo la costa Adriatica orientale,« in *The Heritage of the Serenissima*, eds. Mitja Guštin, Sauro Gelichi, and Konrad Spindler (Koper: Inštitut za de- diščino Sredozemlja), 2006.

port was more developed, transport by sea was much faster. Second is economy; it was more economical by sea as a greater quantity and weight of material could be transported in a single cargo. Third is security; travel by land was often through difficult, hostile or politically unsafe territory and so it was more secure to transport valuable or fragile goods by sea than by land, especially over long distances. Ships were therefore considered a relatively fast, safe and convenient way to transport people and goods. These factors, singly or in combination depending upon the period in question, would favour the transport of commodities by sea rather than by land and so it is no surprise that many shipwrecks discovered and excavated have substantial material evidence on board.

### Why are shipwrecks important to archaeologists?

The large number of wrecks available for study, and the subsequent increase in recovery of material evidence because of developments in diving, underwater excavation and preservation techniques, means that shipwrecks provide a huge resource for archaeologists. Yet, this is a unique and very important resource for other reasons. The first reason is preservation of material. Despite ships being sunk in treacherous seas or through mishandling, and so subject to a violent deposition, the wrecks themselves and many of the items found aboard are often near the surface and so extremely well preserved, a legacy rarely paralleled in terrestrial assemblages.

Dating is a second reason. The material held on board often provides a clear or even precise date of sinking, or *vice versa*; the date of sinking is recorded which enables a refining of the date of the material on board. The evidence provides a snap-shot of the existence and association of material at a specific point in time. Some of the artefacts may of course be heirlooms, older goods moving because of their value, or even personal possessions, but the vast majority of artefacts will have been 'newly' manufactured.

Third, the number and association of different goods can be used to study assemblage diversity and value. Large numbers of similar objects were often carried together, goods which were in the process of being moved from production and distribution centres to points of consumption. These 'sets' of similar objects allow not only a greater number of the same type or style of material to be studied, but also the diversity within assemblages to be examined. As well as sets of material, the association of different types of artefacts of a similar date gives an idea of what goods were contemporary, and a notion of 'trading packages', those which may have been manufactured in neighbouring centres or were distributed or consumed together. These goods would have been in transit as gift exchange,<sup>3</sup> to service armies,<sup>4</sup> for secondary working elsewhere or en-route<sup>5</sup> or for general sale (pre-ordered, commissioned or trade goods) at larger commercial centres. Thus, the association of different goods may also give an indication the status or value of specific goods or the ship.

A fourth and important point concerns who was supplying whom and what route was taken? The material on board provides a link between manufacturing centres, if known, to consumption centres, via specific trade routes. These links may not necessarily be direct ones, but through the hands of different political entities, nations or traders. This provides us with a greater understanding of the movement of material and the number of hands it may have passed through before reaching its final destination.

Finally, in addition to the cargo, material remains from shipwrecks can provide a unique insight into the lives of the sailors, merchants and diplomats who carried this cargo. Some items recovered from shipwrecks represent the personal effects of the crew or passengers aboard. These types of artefacts can shed light on the nature of

<sup>3</sup> George F. Bass, »Oldest known shipwreck reveals splendors of the Bronze Age.« *National Geographic* 172, no. 6 (1987): 692–733.

<sup>4</sup> De Donato, *Mare Nostrum, the Roman Sea*.

<sup>5</sup> Caroline M. Jackson and Peter Thomas Nicholson, »The Provenance of Some Glass Ingots from the Uluburun Shipwreck.« *Journal of Archaeological Science* 37 (2010): 295–301.

the voyage, the ethnicity of the crew and potentially their status (sometimes diplomatic voyages carried gifts accompanied by envoys), beliefs and sometimes diet.

The study of material remains from shipwrecks, as well as the ships themselves, is a unique resource available to archaeologists; a time capsule. By examining this material a new dimension is added to our understanding of material culture, and gaps in our understanding of specific materials at particular points in history can sometimes be filled. One material which was carried extensively by ships throughout history is glass. Its raw materials were carried to manufacturing centres and as primary glass it was moved as ingots or chunk glass to be reworked elsewhere. In its finished state it was transported for widespread consumption. At certain points in its history it had high intrinsic value, at others it held value in its contents. At all times in its finished state, as vessels or flat glass, it was a fragile artefact. For these reasons glass was carried extensively by sea, and so is not a rare occurrence on shipwrecks. Glass, as with other materials, is a very valuable medium to address archaeological questions relating to provenance, gift exchange and trade, status, the organisation of the industry, movement of comestible commodities and to explore technological transfer. These are discussed below.

### Why study of glass from shipwrecks?

The invention and adoption of glass, and changes in the way it is assimilated and used within society, mimics the development and growth of many different societies through time. Glass is a very unusual commodity; its status, use and acquisition changes depending upon the society in which it is used, and through time. Yet *within* each of these chronological phases its production and consumption is similar across large tracts of geographical space, often cross-cutting different cultural boundaries. This is in contrast to commodities such as pottery, but similar to that of metals. For instance in the Late

Bronze Age Mediterranean (including politically diverse cultures such as Egypt, the Aegean and Mesopotamia), glass was a high status commodity, being consumed primarily by an elite and manufactured at a limited number of centres.<sup>6</sup> By the Roman period glass production was still centrally controlled. However, in broadly the same region glass consumption had changed dramatically, it was used both to display wealth and as a utilitarian commodity, and was used by all sections of society – similar forms being manufactured across the empire. By the late medieval and renaissance periods glass was manufactured at many different centres, each producing very different styles and qualities of glassware using different materials and production processes. These finished goods were then widely traded throughout the Mediterranean as both containers for liquids, as drinking vessels, window glasses and mirrors, scientific glassware, and as high quality fashionable items.

Glass studies have been hampered by a lack of evidence for production and trade on which to examine those ideas which interest archaeologists; the people behind the processes. With ceramics the picture is different. Manufacturing locations are often visible in the archaeological record. Stylistic traits and clay geology are often regional and closely defined, enabling the location of these artefacts in the landscape. Consequently, the production, movement and consumption of pottery can then be traced. Unlike ceramics, glass manufacture involves two or more raw materials which may derive from different, distant locations, which are melted together. It often involves more than one stage in its manufacture from raw materials to finished artefact, and it can be recycled. The organisation of production, the number of people or centres involved and the network of raw materials and manpower may vary and, furthermore, be very complex.

Therefore our knowledge of production and trade in glass throughout many periods in his-

<sup>6</sup> See papers in Caroline M. Jackson and Emma C. Wager, eds., *Vitreous Materials in the Late Bronze Age Aegean* (Oxford: Oxbow Books, 2008).

tory is fragmentary. Our present knowledge of who produced these commodities, where they were produced and in what context is in its infancy, even for later periods of history – and there are other unanswered questions: How did these commodities reach their destination, who controlled their transport, were they moved *en-masse* or as sets destined for particular markets? This is where the material held in shipwrecks provides a new resource and often provides the missing link between production and consumption.

## Stylistic and Chemical analysis of glass

There are two main avenues through which to explore glasses: by stylistic and chemical means. Stylistic analysis gives an indication of date, assemblage type, function, potential provenance, and possibly about trade when provenance is known. The distribution of specific styles of finished goods often gives a clue to their manufacturing location and, when compared with consumption assemblages, to their final destination. Their prevalence or rarity of specific artefacts and stylistic attributes can suggest status, and give clues to potential consumption context. The transport of semi-finished or fully finished goods provides an insight into the organisation of production and trade. While valuable information is gained from stylistic analysis, it sometimes cannot provide a full picture.

Chemical analysis of the glass can enhance to this picture. The analysis of glass to determine its composition and the subsequent formation of compositional groups can be used to suggest putative provenance and raw materials used to produce different stylistic groups and to link groups of glasses across geographical space.

Whilst still in its relative infancy there are a number of studies of glasses from shipwrecks which have enhanced our understanding of the provenance, trade and consumption of glass. Three such case studies are discussed below to illustrate how the chemical analysis of glass from shipwrecks has been used in three very differ-

ent contexts to answer quite different archaeological questions; Late Bronze Age glass from the Uluburun wreck in the eastern Mediterranean, raw glasses found on Mediterranean shipwrecks from the Roman period and the late 16<sup>th</sup>/early 17<sup>th</sup> century Gnalčić shipwreck found in the Adriatic Sea off the coast of Croatia, to explore questions of provenance, the organisation of the glass industry and to elucidate patterns of trade.

### *Glass on the Uluburun shipwreck – a question of provenance*

In 1986 a Late Bronze Age ship was discovered nearby to Kaş off the Turkish coast.<sup>7</sup> On board the vessel were 175 glass ingots, which were part of a rich cargo which included copper ingots, amber, ivory and other precious items, derived from various regions throughout the Mediterranean and further afield. The ship appears to have been on a continuous ‘point to point’ voyage in an anticlockwise direction, possibly originating on the Levantine coast, with limited stops to pick up local goods or goods from entrepôt ports.<sup>8</sup> The glass ingots would have been picked up at one of these Mediterranean coastal ports and then traded or exchanged to other polities with secondary workshops to re-melt the glass and produce artefacts in a local style.

The provenance of these ingots has been a matter of debate since their discovery. Initially it was thought that the ingots must have been manufactured in Mesopotamia,<sup>9</sup> the area where glass making is likely to have originated sometime in the early Bronze Age (early third millennium). Other scholars suggested they may have come from Egypt because of the dominance of the Egyptian state at the time of the shipwreck and the recent discovery of glass production sites

7 Bass, »Oldest Known Shipwreck Reveals Splendors of the Bronze Age«; Cemal Pulak, »The Uluburun Shipwreck and Late Bronze Age Trade,« in *Beyond Babylon: Art, Trade, and Diplomacy in the Second Millennium B.C.: Exhibition Catalogue*, eds. Joan Aruz, Kim Benzel, and Jean M. Evans (New York: The Metropolitan Museum of Art, 2008), 288–385.

8 Pulak, »The Uluburun Shipwreck and Late Bronze Age Trade,« 298–99.

9 Bass, »Oldest Known Shipwreck Reveals Splendors of the Bronze Age.«

in Egypt of a Late Bronze Age date.<sup>10</sup> Therefore, at the time the Uluburun ship sank there were two main glass producing areas, Egypt and Mesopotamia, and the glass could have originated from either or both of these centres.

Previous analytical investigations into major element compositions to determine whether glass from Mesopotamia and Egypt could be differentiated on the basis of their chemistry proved somewhat confusing. Raw materials, in the form of halophytic plant ashes and silica pebble or pure sands, with very similar compositions appear to have been used throughout the Bronze Age Near East, and the glass from the two regions could not be securely differentiated compositionally by either major or minor element chemistry.<sup>11</sup> Although the Uluburun ingots were analysed to determine their major element chemistry they could not be assigned to a provenance in either region.<sup>12</sup> More recent research has suggested that it is possible to discriminate glasses, with respect to broad regions such as Egypt or Mesopotamia, based on trace element analysis.<sup>13</sup> In light of this new work, trace element analysis was conducted on three fragments of ingots

from the wreck; two of cobalt blue and one of turquoise.<sup>14</sup>

The concentrations of lanthanum (La) and chromium (Cr) were found to differ between glasses manufactured in Egypt and those made in Mesopotamia.<sup>15</sup> This is because the local geology of the regions differs, affecting the composition of the silica sources and the plant ashes which were used in local glass manufacture within each region. The three Uluburun ingots analysed all have Cr and La concentrations which fall within the range of concentrations found in glasses from Egypt suggesting an Egyptian origin.<sup>16</sup> No difference in composition between the cobalt and copper coloured glasses was found, suggesting both colours had a common origin. This similarity in compositions would fit the model of colour specific centres based around Royal centres, as has been suggested by a number of authors.<sup>17</sup> Moreover, the trace element compositions are also consistent with some Mycenaean glasses<sup>18</sup> suggesting the movement of glass in ingot form from Egypt for fabrication in the Mycenaean world. Whilst evidence of ingot moulds have been recorded at sites such as Amarna and Qantir in Egypt, no ingots had been recovered in the archaeological record until those found in the Uluburun wreck. Thus the glass on board this shipwreck showed, for the first time, the movement of ingots around the Mediterranean Sea, and chemical analysis has subsequently linked these ingots with glasses manufactured in Egypt for reworking in the Aegean. The evidence recovered from the shipwreck shows a direct link from general regional location of manufacture through the production of ingots to the

10 E.g. see Jacobus van Dijk, »The Amarna Period and the Later New Kingdom (c.1352–1069 B.C.)«, in *The Oxford History of Ancient Egypt*, ed. Ian Shaw (Oxford: O. U. P., 2000), 272–313; Peter Thomas Nicholson, »Glass Making/Working at Amarna: Some New Work«, *Journal of Glass Studies* 37 (1995): 11–9; Thilo Rehren and Edgar B. Pusch, »Late Bronze Age glass production at Qantir-Piramesses, Egypt«, *Science* 308 (2005): 1756–58; Caroline M. Jackson, »Archaeology: Glassmaking in Bronze-Age Egypt«, *Science* 308 (2005): 1750–52.

11 Christine Lilyquist and Robert H. Brill with Mark Wypyski, *Studies in Early Egyptian Glass* (New York: Metropolitan Museum of Art, 1993); M. S. Tite and Andrew J. Shortland, »Production Technology for Copper – and Cobalt-blue Vitreous Materials from the New Kingdom Site of Amarna – A Reappraisal«, *Archaeometry* 45, no. 2 (2003): 285–312.

12 Robert H. Brill, *Chemical Analyses of Early Glasses. Volume II: Tables of Analyses* (Corning: Corning Museum of Glass, 1999); Caroline M. Jackson, Peter Thomas Nicholson, and Walter Gneisinger, »Glassmaking at Tell el-Amarna: An Integrated Approach«, *Journal of Glass Studies* 40 (1998); Caroline M. Jackson and Peter Thomas Nicholson, »Compositional Analysis of the Vitreous Materials Found at Amarna«, in *Brilliant Things for Akhenaten: The production of Glass, Vitreous Materials and Pottery at Amarna Site O45.1*, ed. Peter Thomas Nicholson (London: Egypt Exploration Society, 2007).

13 Andrew Shortland, Nick Rogers and Katherine Eremin, »Trace Element Discriminants between Egyptian and Mesopotamian Late Bronze Age Glasses«, *Journal of Archaeological Science* 34, no. 5 (2007).

14 Jackson and Nicholson, »The Provenance of Some Glass Ingots from the Uluburun Shipwreck.«

15 Shortland, Rogers and Eremin, »Trace Element Discriminants between Egyptian and Mesopotamian Late Bronze Age Glasses.«

16 Jackson and Nicholson, »The Provenance of Some Glass Ingots from the Uluburun Shipwreck.«

17 Nicholson, »Glass Making/Working at Amarna: Some New Work«; Thilo Rehren, »New Aspects of Ancient Egyptian Glass Making«, *Journal of Glass Studies* 42 (2000).

18 Mark S. Walton, Andrew Shortland, Susanna Kirk, and Patrick P. Degryse, »Evidence for the Trade of Mesopotamian and Egyptian Glass to Mycenaean Greece«, *Journal of Archaeological Science* 36 (2009).

finished goods, and suggests one possible trade route for the glass ingots from the Uluburun shipwreck.

### *Roman glasses and the organisation of the Roman glass industry*

Glass in the Roman world is arguably the first time glass was produced on an industrial scale. Despite the large quantity of glass recovered from many consumption sites across the Roman Empire, our understanding of where glass was produced or how the glass industry was organised has remained unclear. Many glass vessel styles were ubiquitous across the empire, although some others clearly had some regional identity. In contrast to the Bronze Age, glass at this point in history was used by all sections of society, both as high quality luxury items and low value commodities which were produced and traded for their contents rather than for the glass itself.

Until fairly recently it was assumed that Roman glass was produced in small furnaces located throughout the Empire, and the goods distributed to local and regional markets. This model was one which could be proved both archaeologically and historically for later medieval glass production in Northern Europe, but was in direct contrast to that being developed for colour-specific primary glass manufacturing complexes in Bronze Age Egypt discussed above. The model was reinforced by the wealth of small-scale glass furnaces excavated throughout Britain and the Mediterranean.<sup>19</sup> That these glasses, when analysed, appeared to be compositionally homogenous could not be explained, other than by the use of the same raw materials which were shipped throughout the Roman world or by continued recycling of glasses which would eventually mask any regional differences linked to the use of local raw materials.<sup>20</sup> These regional dif-

ferences would be linked to the different regional sands used to form the glass rather than the alkali, which in the Roman period was of a mineral evaporate, trona, which is thought to have come from the Wadi Natrun in Egypt. Even when slight compositional variations were noted, these could not be traced to particular vessel types or production contexts. An understanding of any slight compositional variation therefore was thought to lay with a better understanding of the archaeology and context of production. It was only through more refined chemical analysis of some of the later Roman glasses and the discovery of material on board shipwrecks that a new model of Roman glass was suggested.

This material discovered was in the form of large blocks or chunks of glass which were assumed to be residues from local production of glass – this material had been known for a number of years but its function not clearly understood. The significance of this material was realised when a number of irregular glass blocks were recovered from shipwrecks around the Mediterranean.<sup>21</sup> These blocks of indeterminate shape, found with fully-formed glass vessels, indicate a trade in ‘raw glass’ chunks, broken from larger slabs. They indicate that glass formation did not necessarily take place in the same location as object manufacture, and that large ‘industrial’ glass slabs appear to have been produced in the Roman Empire and the glass broken up and moved elsewhere for shaping. Trade in chunks (and ingots) suggests centralised production and distribution and a highly political and organised system. Such large glass factories have been recorded at sites in Israel<sup>22</sup> from the 6th century and later. However, whilst large glass factories for the Roman period have not yet been discovered, the movement of chunk glass can be

uen: Association Française pour l’Archéologie du Verre, 1991).

19 eg. see papers in Danièle Foy and Geneviève Sennequier, eds., *Ateliers de Verriers de l’Antiquité à la Période Pré-Industrielle. Actes des Journées d’étude Congrès d’AFAV, Rouen, November 1989* (Rouen: Association Française pour l’Archéologie du Verre, 1991).

20 Jennifer Price and H.E.M. Cool, »The Evidence for the Production of Glass in Roman Britain.« in *Ateliers de Verriers de l’Antiquité à la Période Pré-Industrielle. Actes des Journées d’étude Congrès d’AFAV, Rouen, November 1989*, eds. Danièle Foy and Geneviève Sennequier (Ro-

21 Danièle Foy, Michèle Vichy, and Maurice Picon, »Lingots de verre en Méditerranée occidentale (IIIe siècle av. J.-C.–VIIe siècle ap. J.-C.).« in *Annales du 14e Congrès de l’Association Internationale pour l’Histoire du Verre, Venezia-Milano 1998* (Lochem: AIHV, 2000a).

22 Yael Gorin-Rosen, »The Ancient Glass Industry in Israel: Summary of New Finds and New Discoveries.« in *La Route du Verre. Ateliers primaires et secondaires de verriers du second millinaire av. J.-C. au Moyen-Age*, ed. Marie-Dominique Nenna (Lyon: Maison de l’Orient Méditerranéen-Jean Pouilloux, 2000).

seen from the first century and earlier around the Mediterranean<sup>23</sup> and as far afield as India.<sup>24</sup> These chunks of glass would have been remelted to produce artefacts at any number of smaller facilities throughout the Roman world and beyond.

Chemical analysis of the glasses has supported and added to this picture of Roman glass production. Large scale production would explain the compositional homogeneity of many of the glasses. Slight differences, especially in trace element compositions, within this very constant generalised composition could also be explained using this model. In fourth century glasses it was noted that concentrations of iron, titanium, manganese were higher than those of earlier Roman glasses.<sup>25</sup> These compositional characteristics were also observed in chunks of fourth century glass found at Carthage and within late Roman Mediterranean shipwrecks.<sup>26</sup> Moreover both Foy *et al.* (2000a and 2000b) and Freestone (2003) showed that there were two very distinctive glass compositions in circulation in the Mediterranean and Northern Europe in

the mid to late first millennium AD which they could now suggest came from two differing geological regions based upon trace element compositional data, one using sands from the Syro-Palestine region, the other probably manufactured using sands from the Nile delta. The archaeological evidence from shipwrecks and the compositional analysis of these glass chunks from the wrecks alongside fully formed glasses suggest a highly organised glass industry with a small number of primary glass making centres located in the eastern Mediterranean who shipped glass in a raw form to secondary manufacturing centres through the Empire in the fourth century.

This model can also be projected to the early Roman world (first century AD to first century AD) when glass was a different commodity, of higher status and more highly prized. Recent work has highlighted that early Roman glasses have compositional characteristics which can be related to their colour, but which are not dependent upon the colouring compounds.<sup>27</sup> This is best illustrated by emerald green and red glasses (typical of first century glasses but rare in later periods), both coloured with copper. Unlike the other glasses of this period and later, these glasses are made using plant ashes for at least part of the flux, whereas the blue, purple and amber glasses are all typical of a glass made using natron / trona. The compositional consistency within these different groups indicate a production location which is common for each colour, and is supported by the incidence of vivid-coloured blue 1st-century glass chunks identified in the from first century shipwrecks.<sup>28</sup> It is likely these glass chunks were coloured during manufacture at a primary location and then distributed to other

23 Marco Verità, »Sand and Glass,« in *Pompeii, Life in a Roman Town*, eds. Annamaria Ciarallo and Ernesto de Carolis (Milan: Electa, 1999), 109; Danièle Foy, Michèle Vichy, and Maurice Picon. »Lingots de verre en Méditerranée occidentale (IIIe siècle av. J.-C.–VIIe siècle ap. J.-C.).«

24 Marianne Stern, »Early Exports beyond the Empire,« in *Roman Glass: Two Centuries of Art and Invention*, eds. Martine Newby and Kenneth Painter (London: Society of Antiquaries, 1991), 149.

25 Pjero Mirri, Antonella Casoli, and Lorenzo Appolonia, »Scientific Analysis of Roman Glass from Augusta Praetoria,« *Archaeomet* 77 35 (1993).

26 Ian C. Freestone, »Appendix: Chemical Analysis of 'Raw' Glass Fragments,« in *Excavations at Carthage. Vol. II, no. 1: The Circular Harbour, North Side: The Site and Finds other than Pottery: British Academy Monographs in Archaeology no. 4*, ed. Henry R. Hurst (Oxford: Oxford University Press, 1994), 290; Danièle Foy, Michèle Vichy, and Maurice Picon. »Lingots de verre en Méditerranée occidentale (IIIe siècle av. J.-C.–VIIe siècle ap. J.-C.);« Danièle Foy, Michèle Vichy, and Maurice Picon, »Les matières premières du verre et la question des produits semi-finis: Antiquité et Moyen Âge: Arts du Feu et productions Artisanales: XXe Rencontres Internationales d'Archéologie et d'Histoire d'Antibes« (Antibes: Editions APDCA, 2000b); Danièle Foy, Michèle Vichy, Maurice Picon, and Valérie Thirion-Merle, »Caractérisation des verres de la fin de l'Antiquité en Méditerranée occidentale: L'émergence de nouveaux courants commerciaux,« in *Echanges et commerce du verre dans le monde Antique: Actes du colloque de l'AIHV, Aix-en-Provence et Marseille, juin 2001*, eds. Danièle Foy and Marie-Dominique Nenna (Montagnac: Monique Mergoïl, 2003).

27 Caroline M. Jackson, Jennifer Price, and Christopher Lemke, »Glass production in the 1st century A.D.: Insights into glass technology,« in *Annales de 17e Congrès de l'Association Internationale pour l'Histoire du Verre, Antwerp, September 2006* (Leuven: AIHV, 2009); Marie-Dominique Nenna and Bernard Gratuze, »Étude diachronique des compositions de verres employés dans les vases mosaïqués antiques: résultats préliminaires,« in *Annales de 17e Congrès de l'Association Internationale pour l'Histoire du Verre, Antwerp, September 2006* (Antwerp: AIHV, 2009).

28 Danièle Foy, Michèle Vichy and Maurice Picon. »Lingots de verre en Méditerranée occidentale (IIIe siècle av. J.-C.–VIIe siècle ap. J.-C.).«

locations for artefact production. The first century glasses also support the primary/secondary glass production model outlined for fourth century glasses, above, but at present the locations of primary manufacture are not known. The use of plant ashes in the production of emerald green and red glass may indicate a manufacturing complex with different traditions of manufacture, similar to glass production from the late Bronze Age.

Thus, although initially these studies aimed to seek the provenance of Roman glasses, they have resulted in an understanding of how the Roman glass industry was organised at certain points in history. The production of large volumes of glass at one location near to the specific and unique raw materials required to make Roman glass, which was then shipped to smaller working centres, is indicative of a highly organised trade network and of transferable skills in glassworking of a particular composition of glass across the Empire.<sup>29</sup> These secondary centres would presumably be nearer points of glass consumption and so the needs of the local market could be easily adjusted to what was required at a particular time, rather than relying on communication networks to relay this to more centralised glass working centres. The movements of chunks of glass, rather than vessels, by sea would also require less careful packaging or space on board the ship. A greater volume of glass could be transported in a single movement. Specialist vessels could of course be made in dedicated centres, but the demand for these would be less and the market more specific. The key to unlocking this evidence again has been the material recovered from shipwrecks which showed the movement of raw glasses across considerable distances.

### *Exploring 17<sup>th</sup> century trade in glass, through the Gnalčić shipwreck*

In 1967 the remains of a merchant ship with a rich cargo was found, just off the rocky islet

of Gnalčić, a location at the entrance of a busy shipping route in the Adriatic.<sup>30</sup> The ship was thought to have sunk sometime in the 1580s, and was thought to be sailing from Venice to Constantinople<sup>31</sup> based upon the initial stylistic analysis of the finds on board the ship, although other routes have been proposed. The cargo included a very large consignment of glass. In excess of 6500 fragments have been recovered to date, consisting mainly of vessels, but also windows, half-finished products such as mirrors and a small number of speciality wares.<sup>32</sup>

There were few glass artefacts for which a putative provenance could be suggested; most were of undiagnostic and common forms, and so the origins of the glass assemblage have been debated. Early suggestions favoured a Venetian origin, based on stylistic analysis of a few diagnostic vessels, and the proximity of the wreck to the glassmaking centre at Venice.<sup>33</sup> This has more recently been questioned and more local manufacturing centres, or multiple centres, proposed on the basis of stylistic analysis.<sup>34</sup> Whilst the majority of vessels were goblets which had no stylistic attributes linking them to a specific provenance, others were typologically English and Islamic in style.<sup>35</sup> It was not clear whether these were produced elsewhere or within Italy (Venice) for a specific market. Compositional analysis was conducted on a selected number of vessels, windows and mirrors to ascertain whether these were of a common origin or from diverse centres.<sup>36</sup>

29 Harriet E. Foster and Caroline M. Jackson, »The composition of 'naturally coloured' late Roman vessel glass from Britain and the implications for models of glass production and supply,« *Journal of Archaeological Science* 36 (2009).

30 Astone Gasparetto, »The Gnalčić Wreck: Identification of the Ship,« *Journal of Glass Studies* XV (1973).

31 Gasparetto, »The Gnalčić Wreck: Identification of the Ship,« 81; Sofia Petricioli, »The Gnalčić Wreck: The Glass,« *Journal of Glass Studies* XV (1973): 92.

32 Irena Lazar and Hugh Willmott, *The Glass from the Gnalčić Wreck* (Koper: Univerza na Primorskem, Znanstveno-raziskovalno središče Koper, 2006); Lazar, this volume.

33 Petricioli, »The Gnalčić Wreck: The Glass,«; Brill, »Analyses of Some Finds from the Gnalčić Wreck,«

34 Lazar and Willmott, *The Glass from the Gnalčić Wreck*, 77.

35 Lazar and Willmott, *The Glass from the Gnalčić Wreck*, 76.

36 Caroline M. Jackson, »Results of the Analysis of the Gnalčić Glass,« in *The Glass from the Gnalčić Wreck*, eds. Irena Lazar and Hugh Willmott (Koper: Univerza na Primorskem, Znanstveno-raziskovalno središče Koper, 2006); Caroline M. Jackson, »Compositional Case

The results of analysis suggested that *all* the glass, regardless of form, was of a common compositional type – *vitrum blanchum*, a glass composition found widely across Europe and possibly manufactured at many different places. This is rather surprising given the diverse nature of the cargo, which included mirrors, windows, common goblets and a smaller number of higher status items. The composition can be explained by the use of very specific raw materials. This glass is thought to have been manufactured using imported alkalis, possibly from Syria or Egypt, but made using local sands, which would account for the similarity of compositions between the different stylistic groups.

More detailed interpretation has revealed that, within this general glass composition, a number of slightly different compositional groups can be discerned, which related to trace elements (barium (Ba), zirconium (Zr) and sometimes strontium (Sr)) associated with the use of different sand or silica sources. Some of these compositional groups could be linked to specific styles of goblets which would indicate a common manufacturing location. Lion stem beakers found on board had quite a wide compositional distribution which would support their manufacture at many different production locations, as has been suggested by stylistic analysis. The ladder stem goblets appear to have been manufactured at a single production site, although stylistically it is thought they originated from England. The mirrors appear to cluster together indicating potentially a similar provenance, the window glasses have a wide compositional distribution suggesting potentially more than one provenance. However, the location of production of these, and other identified groups, is relatively enigmatic. de Raedt (2001) suggests that glasses made in Venice have low concentrations of Zr compared to *vitrum blanchum* glasses manufactured elsewhere in Europe. The glasses from the Gnalić wreck displayed similar low Zr concentrations which might indicate their provenance was around Venice or on the Ital-

ian mainland. What may be suggested from this analysis is that it is likely the cargo consisted of a consignment of vessels from different manufacturing centres, possibly within Italy, all producing a very common glass composition. The analysis of the glass, whilst not providing a provenance of the material held on board the wreck, has indicated a putative manufacturing area and has surprisingly suggested that the glass is all of the same type, despite the mixed stylistic assemblage. The glass from the Gnalić wreck is one of many lying within the Adriatic and it would be interesting to see if similar patterns are seen in other assemblages.

## Comment

The glass we have from shipwrecks from the Bronze Age to the modern day is diverse, comprising raw materials, glass ingots and raw glass fragments, through to semi-finished goods and fully formed artefacts. All of these different forms of evidence can provide new knowledge, not only on trade routes, consumption paths and the movement of specific items at specific times in history, but also can give us an insight into technology and the organisation of the glass industry. Through the analysis of glass from shipwrecks we can now trace the movement of glass from Egypt in the Bronze Age to secondary working centres in the Aegean – and suggest that most glass in the Aegean was not manufactured there, but reformed into artefacts in a local style. Archaeologically we can see the linking of two elite systems in the Late Bronze Age, that of the Aegean Palaces and the royal centres of New Kingdom Egypt. The late Roman period sees a similar movement of glasses, in this case, controlled within a larger Roman industry. This ‘industry’ was a highly organised and efficient system supplying goods to different parts of the Roman Empire which, to that date, was unrivalled. The production of glass en-masse at centres probably located somewhere in present day Israel or Egypt, broken down and shipped to secondary glassworking centres elsewhere can be seen in evidence found on numerous shipwrecks

Studies: Glass from the Gnalić Wreck, « *Quaderni friulani di archeologia* 19 (in press).

throughout the Mediterranean Sea, and explains the compositional similarity of different styles of glasses throughout the Roman world. Trade in glass in the 17<sup>th</sup> century around the Mediterranean is rather different. By this time glass is relatively commonplace, although still sought after, and the movement of finished goods is more usual and commonplace. Different centres are known to specialise in different types of glass and glass as a commodity is used in a variety of different ways from vessels and bottles to windows, mirrors and even for scientific instrumentation. The trading patterns of glass consignments found on shipwrecks can be traced through compositional analysis and potential provenances suggested.

Thus the stylistic and compositional analysis of glass from shipwrecks provides another layer of archaeological information, and is sometimes the key by which to explore the nature of trade and exchange, the technology of materials and processes, and the forming of social relationships through material transfer.

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