

Byzantine glass mosaic tesserae: some material considerations¹

Liz James

Department of Art History, University of Sussex

Issues about the manufacture of Byzantine mosaics and the implications of these in wider terms relating to social and economic questions about the art form have been little discussed. This paper brings together evidence about Byzantine glass mosaic tesserae gathered from archaeology, glass technology and glass analysis, and synthesizes these into a discussion of three aspects: distribution; manufacture; trade and price. It looks to examine how these different elements can be used to form a more detailed composite picture about the production and distribution of Byzantine mosaics. It also proposes ways in which glass analysis can be used in a more coherent way to extend our understanding of mosaic glass production.

Byzantine mosaics are often said to be the most elaborate and expensive form of mural decoration.² Yet little is known about how Byzantine mosaics were made and where the materials for making them came from.³ The study of Byzantine glass mosaics tends to fall into the gap between mosaic studies, dominated by Roman floor mosaics, and glass studies, concerned with vessels and window glass. Discussions about mosaics tend to focus on questions of style and iconography; discussions about glass tend to make little reference to mosaics. Excavation reports sometimes separate glass and mosaics widely; and within the context of Byzantine glass studies, the fabrication of glass tesserae for wall and roof

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2 See for example *Oxford Dictionary of Byzantium*, ed. A. Kazhdan *et al.* (Oxford 1991) 1412–13, and A. Cutler, 'The industries of art' in *The Economic History of Byzantium, Seventh to Fifteenth Centuries*, ed. A. Laiou, II (Washington 2002) 557–61.

3 Much of what is said is based on assumptions about early Italian mosaics, drawn from C. Harding, 'The production of medieval mosaics: the Orvieto evidence' *DOP* 43 (1989), 73–102.

mosaics has barely been mentioned.⁴ This paper brings together and synthesizes material from a range of secondary sources in order to create a composite picture of the production of Byzantine mosaic glass tesserae within the context of the distribution of mosaics and the making of glass in the Late Antique and Byzantine worlds. It restricts itself to glass; a study of the other materials of Byzantine mosaics is beyond its scope.

Through a clearer understanding of the raw materials of mosaics, a broader picture of mosaic manufacture can be developed. Four key areas are investigated: the spread of glass mosaics in the Byzantine world; the manufacture of glass and its implications for making mosaics; the uses of chemical analysis in dating and locating glass tesserae; and issues of cost. Simply by examining the spread of glass mosaic within the Byzantine world, it becomes possible to explore often unspoken assumptions about the extent of mosaics, and what this might say about their significance as an artistic medium. By investigating questions about the production of glass and tesserae, a clearer picture of the availability of glass tesserae as a medium becomes apparent and, from this, a sense of how easy or difficult it might have been to obtain the materials for a mosaic. A consideration of where the glass for mosaics came from offers some insights into how mosaics were actually put up — the availability of colours, for example, must have dictated, in part, the appearance of a mosaic. Further, such reflections are not only relevant in the context of artistic practices, but also feed into a wider debate about the nature of trade, exchange and the movement of objects within the Mediterranean during the Byzantine period.

Sites of mosaics

One crucial area of enquiry is that of how widely glass mosaics might have been employed, across both space and time, and the implications that this distribution has for our understanding of the significance of the medium. It is almost a truism within Byzantine studies to think of wall mosaics as relatively scarce, as limited to the major cities of the empire and as expensive, afforded only by the very wealthy, above all, by emperors in Constantinople and popes in Rome. Related to this is the apparently logical corollary

4 The two standard accounts of Byzantine glass are both over thirty years old: J. Philippe, *Le Monde byzantin dans l'histoire de la verrerie* (Bologna 1970), and A. Grabar, 'La verrerie d'art byzantine au Moyen Age', *Fondation Eugène Piot. Monuments et Mémoires* 57 (1971) 89–128. Both are concerned almost exclusively with 'luxury' glass and objets d'art. A. von Saldern, 'Byzantine glass: Problems of terminology and chronology', in *Gilded and enamelled glass from the Middle East*, ed. R. Ward (London 1998) 1–3, is equally concerned with these questions, though he does acknowledge the existence of other sorts of Byzantine glass. V. François and J.-M. Spieser, 'Pottery and glass in Byzantium', in *Economic History of Byzantium* 593–8, barely discuss mosaic. Elsewhere, Philippe, 'Reflections on Byzantine glass', *1st International Anatolian Glass Symposium 1988* (Istanbul 1990) 43, notes that it is 'beyond doubt that glass was present in the Byzantine treasuries' yet fails to mention the tons of glass that filled churches throughout the city. A notable exception to this trend is M. Mundell Mango and J. Henderson, 'Glass at medieval Constantinople: Preliminary scientific evidence', in *Constantinople and its Hinterland*, ed. G. Dagron and C. Mango (Aldershot 1995) 333–58.

that mosaicists themselves must have been based in these key centres and that where mosaics are found outside the empire, in, say, Kiev or Venice or even Georgia, they must reflect an import or a borrowing of techniques, workmen and materials by foreign powers in order to assert themselves in relation to Byzantium. The nature of the buildings in which wall mosaics survive and of the written Byzantine sources describing mosaics suggests a use of the medium as a sign of status and acculturation, as an indicator of wealth and prestige, and as one increasingly restricted to rulers.

However, this emphasis on important sites with well-known patrons may not offer an entirely accurate picture. Lesser buildings than the great churches of Rome and Constantinople also contained mosaics. On Cyprus, for example, three apparently small and insignificant churches, Livadia, Lythrankomi and Kiti, all contained extensive mosaics in their apses, dating between the sixth and seventh centuries, and at Durrës, a small mosaic is known from a tiny church inside the galleries of the amphitheatre, dated to the same period.⁵ There is considerable archaeological evidence to suggest that mosaics were more common than has previously been recognised. In Turkey, mosaic glass tesserae have been found at a wide variety of sites. These range in scale and size from large churches in the city of Amorium, dated between the seventh and tenth centuries, in Dereağzı in the late ninth century, and in Sardis during the thirteenth century, to small churches in Cilicia and Isauria, such as Anazarbus, Meryemlik, Dağ Pazarı, Corycus, Yemişküm, and Çiftlik, all dating between the fifth and ninth centuries.⁶ In the Pontos, glass mosaic tesserae have been reported from Aşağı Akçale (perhaps early sixth century), Koloneia (early tenth century), and the Chrysokephalos church in Trebizond (possibly tenth–eleventh century but more probably 1214–35).⁷ This distribution of glass mosaic is not restricted to Asia

5 A.H.S. Megaw, 'Byzantine architecture and decoration in Cyprus: Metropolitan or provincial?', *DOP* 28 (1974) 57–88. Livadia: A.H.S. Megaw and E.J.W. Hawkins, 'A fragmentary mosaic of the Orant Virgin in Cyprus', *Actes du XIV Congrès International des études byzantines*, Bucharest 1972, III (1976) 363–6. Kiti: A.H.S. Megaw, 'Early Byzantine monuments in Cyprus in the light of recent discoveries', *Akten des XI Internationalen Byzantinistenkongresses*, Munich 1958 (1960) 345–51. Lythrankomi: A.H.S. Megaw and E.J.W. Hawkins, *The church of the Panagia Kanakaria at Lythrankomi in Cyprus* (Washington 1977). Durrës: N. Thierry, 'Une mosaïque à Dyrrachium', *Cahiers Archéologiques* 18 (1968) 227–9, and A. Ducellier, *La Façade maritime de l'Albanie au Moyen Age* (Thessaloniki c.1981) 32–4.

6 Amorium: M.A.V. Gill, *Amorium Reports, Finds I: the Glass (1987–97)* (Oxford 2002) esp. 14, 105, 262; J. Witte-Orr, 'Fresco and mosaic fragments from the Lower City Church', in *Amorium Reports II: Research Papers and Technical Reports*, ed. C.S. Lightfoot (Oxford 2003) 139–56. Dereağzı: J. Morganstern, *The Byzantine Church at Dereağzı and its Decoration* (Tübingen 1983). Sardis: H. Buchwald, 'Sardis Church E: A preliminary report', *JÖBG* 26 (1977) 265–99. Anazarbus: M. Gough, 'Anazarbus', *Anatolian Studies* 2, (1952), 115. Cilicia and Isauria: S. Hill, *The Early Byzantine Churches of Cilicia and Isauria* (Aldershot 1996). Çiftlik: S. Hill, 'Çiftlik', *Anatolian Studies* 45 (1995) 224–5. It should be noted that in the majority of cases cited in this paper, the presence of tesserae is simply recorded and little or no information is provided about quantity, weight or colour.

7 For the Pontos, A.A.M. Bryer and D. Winfield, *The Byzantine Monuments and Topography of the Pontos* (Washington 1985) 150, 176, 238. It is possible that Bessarion's description of the palace at Trebizond includes a description of mosaics (*ibid.*, 184).

Minor. In the Levant, glass wall mosaic tesserae have been found on an equally extensive range of sites, and covering a similarly broad chronology. These include Kartmin and Shikmona, and a series of lesser-known buildings such as the church of the Theotokos on Mt Gerizim and the fifth- to seventh-century church at Khirbat al-Karak, on the south-west tip of Lake Tiberias.⁸ Although glass tesserae, including gold, were recorded here, the excavators did not believe the church to have been particularly rich or important, suggesting that the architecture was insubstantial and poor, and noting that there was no means of identifying to whom the church was dedicated.⁹ In Croatia, it has been claimed that in the Early Christian period, ‘almost all ruins of palaces, villas, basilicas, baptisteries, mausoleums and baths [...] have traces of wall mosaics’.¹⁰ Similarly, on Cyprus, Megaw has stated that wall mosaic tesserae were found among the remains of ‘many’ early churches on Cyprus and that many more churches would ‘certainly’ have been decorated with wall mosaics, going so far as to suggest that Cyprus could and did support its own mosaic workshops.¹¹ Elsewhere, in Greece, evidence for wall mosaics stretches beyond the familiar sites such as Hosios Loukas, Nea Moni and Daphni to include Corinth, Amphipolis, Philippi, Knossos and Athens, and in Italy, Irina Andreescu-Treadgold’s corpus has revealed the considerable extent of mosaic decoration over both time and place.¹²

8 Kartmin: E.J.W. Hawkins and M. Mundell, ‘The mosaics of the monastery of Mar Samuel, Mar Simeon and Mar Gabriel near Kartmin; with a note on the Greek inscriptions by Cyril Mango’ *DOP* 27 (1973) 280–96. Shikmona and other sites: A. Ovadiah, *Corpus of the Byzantine churches in the Holy Land* (Bonn 1970) and B. Bagatti, *Ancient Christian villages of Samaria* (Jerusalem 2002), e.g. 72, where Bagatti records picking up gold tesserae.

9 P. Delougaz and R.C. Haines, *A Byzantine Church at Khirbat al-Karak* (Chicago 1960) esp. 26–7, 49 and 56.

10 M. Buzov, ‘Early Christian mosaics on the Adriatic coast’, *Acta XIII Congressus Internationalis Archaeologiae Christianae*, III (Split 1998) 175–86.

11 Megaw, ‘Byzantine architecture and decoration in Cyprus’, 74. Disappointingly, he nowhere expands on this statement. Examples include Kourion and Kalavassos: E. Herscher, ‘Archaeology in Cyprus’, *American Journal of Archaeology* 99 (1995) 291. For mosaic workshops, A.H.S. Megaw ‘Interior decoration in early Christian Cyprus’, *Acts of 15th International Byzantine Congress* (Athens 1976) 3–29.

12 Corinth: R. Scranton, J.W. Shaw and L. Ibrahim, *Kenchreai, Eastern Port of Corinth, I: Topography and Architecture*, I (Leiden 1978) 105; J.M. Shelley, ‘The Christian basilica at the Cenchrone Gate at Corinth’, *Hesperia* 12 (1943) 166–89. Amphipolis: K. Hattersley-Smith, *Byzantine Public Architecture between the Fourth and Eleventh Centuries AD, with Special Reference to the Towns of Byzantine Macedonia* (Thessaloniki 1996) 106 and refs. Philippi: E. Kourkoutidou-Nikolaïdou, ‘Vitreaux paléochrétiens à Philippes’, *Corsi sull’arte Ravennati* 31 (1984) 277–96. Knossos: W.H.C. Frend and D.E. Johnston, ‘The Byzantine basilical church at Knossos’, *ABSA* 57 (1962) 190. Athens: A. Frantz, *The Athenian Agora, vol 20: The Church of the Holy Apostles* (Princeton 1971) 13, and n. 22; the British Museum owns tesserae from the Byzantine church in the Parthenon. Italy: I. Andreescu, ‘Les mosaïques de la lagune vénitienne aux environs de 1100’, *Acts of 15th International Byzantine Congress* (Athens 1976) 15–30, and Andreescu, ‘A corpus of wall-mosaics, Venice, Greece, St Sophia: progress and prospects’, *Byzantine Studies Congress Abstracts* 5 (1979) 51–2. Also A. Gasparetto, ‘Matrici e aspetti della vetraria veneziana e veneta medievale’, *Journal of Glass Studies* 21 (1979) 76–97.

The quantity of evidence for mosaic that is apparent in this preliminary investigation of sites is surprising. Even a very partial sample suggests that mosaics were considerably more widespread throughout the Byzantine Empire than has previously been recognized and that the medium was employed with some consistency over a long period of time. The conventional time-frame for mosaic-making traces Byzantine wall mosaics from the traditions of Roman wall and pavement mosaics into the sixth and seventh centuries, but sees it as declining in the seventh and eighth centuries and reviving after Iconoclasm in the ninth century on a lesser and more restricted scale, one confined almost exclusively to emperors.¹³ However, this survey suggests that this chronology is not as straightforward as has appeared and that a perceived gap in mosaic-making in the seventh to eighth centuries, which is largely based on Constantinopolitan evidence, may not exist as an empire-wide phenomenon. The archaeological evidence also implies a considerable and diverse pattern of patronage, for it is clear that mosaics were used in both rich and poor churches, large and small buildings.

These findings also raise a great many questions. How did tesserae get to these wide-ranging sites? Were mosaic tesserae made locally or on site or imported (from where?) along with marbles and other fixtures and fittings? Bringing a quantity of either glass or tesserae overland to a place such as Amorium would have been no easy feat, yet at Amorium, there is little incontrovertible on-site evidence of glass working.¹⁴ It has been suggested that mosaic tesserae were perhaps brought in there by itinerant mosaicists, though the quantities involved — over 162 kilograms survive and this is perhaps 1% of the overall amount required — might be seen as an excessive burden on the artist.¹⁵ Finally, what were the cost implications? Can this apparent wide distribution be seen as suggesting that tesserae themselves were relatively inexpensive?

The manufacture of glass

These are questions that can only be answered within the context of glass-making and distribution more generally. The evidence for glass manufacture suggests very strongly that glass for glassware, and thus plausibly for mosaics, was exported as raw glass. Consequently, only secondary glass-working on any particular site needed to be carried out to produce glass objects.

13 For an account of wall and roof mosaics up to the fourth century, see F. Sear, *Roman Wall and Vault Mosaics* (Heidelberg 1977). The re-use of tesserae by Basil I is seen as evidence for a drop in production, Cutler, 'Industries of art', 560.

14 C. Lightfoot and E. Ivison, 'Concluding remarks', in Gill, *Amorium Reports: The Glass*, 259–64, though they feel it plausible that everyday glassware would be of local manufacture.

15 *Ibid.*, citing *Oxford Dictionary of Byzantium*, 1412–13. Witte-Orr, 'Fresco and mosaic fragments', says that the 23,000+ tesserae recovered perhaps made up 1% of the total required.

The acknowledged view of glass manufacture proposes that, during the Roman period, there were numerous glass factories and workshops across the empire, but especially in the Levant, Egypt and Italy.¹⁶ After c.AD 400, glass manufacture appears to have suffered a noticeable reduction in output and quality, with luxury glass produced only within the Sassanian Empire. In this period, glass from the Near East, including the Levant, tended to be ordinary tableware, window glass and tesserae. Between the seventh and tenth centuries, Arab raids in the eastern Mediterranean appear to have affected glass production, though the general impact of this is unclear, for glass continued to be produced in the traditional glass-making centres along the coast of the eastern Mediterranean, and in sites such as Alexandria, Baghdad and Raqqa. Thus glass and glass objects continued to be made in the Levant and Egypt consistently from the Roman period onwards, and production was perhaps disrupted, but not broken by the spread of Islam: glass as a material continued to be relatively easily obtainable throughout the Byzantine age.¹⁷

The glass industry had two stages: the making of raw glass and the manufacture of glass objects. In the Levant, certainly up to the seventh century, and probably beyond, raw glass was manufactured in large amounts at temporary sites. It was produced in blocks or slabs for breaking up, melting down and reforming into objects at another site.¹⁸ At Beth She'arim, a huge tank furnace and a nine-ton slab of glass was discovered in situ, dated originally to the fourth to sixth centuries, but now re-dated to the ninth.¹⁹ At Bet Eli'ezer in the sixth and seventh centuries, seventeen purpose-built short-term furnaces could each have produced at one firing enough glass for one million glass vessels weighing 150 grams.²⁰ At Tyre, the glass factory was made up of at least four furnaces with the overall capacity to make over 140 tons of raw glass. Furnace 1 alone would have produced over thirty-seven tons of glass each time it was used, enough for just under 250,000 glass vessels

16 Y. Goren-Rosen, 'The ancient glass industry in Israel: Summary of the finds and new discoveries' in *La route du verre. Ateliers primaires et secondaires du second millénaire av. J.-C. au Moyen Age*, ed. M.-D. Nenna (Lyon 2000) 49–63, dealing only with Israel, is the nearest thing to a gazetteer of glass factories and workshops.

17 See, for example, D.B. Harden, 'Ancient Glass III: Post-Roman', *Antiquities Journal* 128 (1971) 78–117.

18 For the continuation of this industry into the Byzantine period, see I.C. Freestone and Y. Gorin-Rosen, 'The great glass slab at Beth She'arim, Israel: An early Islamic glass-making experiment?', *Journal of Glass Studies* 41 (1999), 105–16. Also Goren-Rosen, 'Ancient glass industry in Israel'; M.-D. Nenna, M. Picon and M. Vichy, 'Ateliers primaires et secondaires en Egypte à l'époque Greco-romaine' in *La route du verre*, ed. Nenna, 97–112; I.C. Freestone, M. Ponting, M.J. Hughes, 'The origin of Byzantine glass from Maroni Petrera, Cyprus', *Archaeometry* 44 (2002) 257–72. My thanks to Ian Freestone for this reference. For some problems and a suggestion of smaller-scale regional centres of production, at least in the West, see C.M. Jackson, M.J. Baxter, H.E.M. Cool, 'Identifying group and meaning: An investigation of Roman colourless glass' in *Échanges et commerce du verre dans le monde antique*, ed. D. Foy and M.-D. Nenna (Montagnac 2003) 33–9.

19 R.H. Brill, 'Beth She'arim', *Notes and News, Israel Exploration Journal* 15 (1965) 261–2, and Freestone and Gorin-Rosen, 'The great glass slab at Beth She'arim'. I.C. Freestone, Y. Gorin-Rosen, and M.J. Hughes, 'Primary glass from Israel and the production of glass in Late Antiquity and the early Islamic period' in *La route du verre*, ed. Nenna, 65–6.

20 Freestone, Gorin-Rosen, Hughes, 'Primary glass' 52–4.

of 150 g.²¹ These sites producing raw glass seem all to have been located near the fuel and raw materials, notably the appropriate sand, necessary for manufacture. Evidence from Beth She'arim and Bet Eli'ezer also indicates that glass-making was an essentially nomadic activity. New furnaces were built in new locations as and when fuel ran out. Access to fuel and to suitable raw materials were the crucial factors in the production of raw glass.

It seems to have been considered more viable to make raw glass and to export it than to ship the materials for glass-making around the Mediterranean. Although at Tyre and, plausibly, Apollonia, raw glass was both manufactured and worked, this is unusual. Many other locations in the Levant reveal evidence either of glass-making or of glass-working.²² Material from a variety of sites, including Sardis, Sepphoris and Jalame, provides evidence only of the latter. These sites also demonstrate that glass-working was common in the Late Roman and early Byzantine periods in both large cities and small settlements, perhaps, but not inevitably, as part of an industrial area.²³ Many workshops simply produced glass objects for daily needs, though it is likely that there were specialist ateliers also responsible for luxury coloured glass objects.²⁴ At Anemurium, it has been suggested that simple glass vessels and windows were produced by travelling glassworkers who moved from site to site according to demand and local needs.²⁵ The site at Jalame appears to have been a transient factory, for when the fuel resources ran out, the workmen moved on, leaving nothing behind but the basic furnace structures.²⁶ Evidence from sites such as Beirut and Jaffa suggests that glass-working continued without interruption in the Levant into the twelfth century and beyond.²⁷

Elsewhere in the empire, evidence for the making of raw glass has not been collated in any way. Fustat (Old Cairo) was one centre of glass production, making both coloured glass and finished products, that also appears to have imported specialised raw glass.²⁸

21 F. Aldsworth *et al.*, 'Medieval glass-making at Tyre, Lebanon', *Journal of Glass Studies* 44 (2002) 49–66.

22 Aldsworth *et al.*, 'Medieval glass-making'. For Apollonia and its production of raw and manufactured glass, see O. Tal, R.E. Jackson-Tal and I. Freestone, 'New evidence of the production of raw glass at Late Byzantine Apollonia-Arsuf, Israel', *Journal of Glass Studies* 46 (2004) 51–66.

23 Sardis: A. von Saldern, *Ancient and Byzantine Glass from Sardis* (Cambridge, Mass. 1980); C. Foss and J. Ayer Smith, 'Sardis', in *Economic History of Byzantium*, ed. Laiou, II, 615–22. Sepphoris: O. Dussart, 'Quelques indices d'ateliers de verriers en Jordanie et en Syrie du sud de la fin de l'époque hellénistique à l'époque islamique', in *La route du verre*, ed. Nenna, 91–6, esp. 91. Jalame: *Excavations at Jalame: Site of a Glass Factory in Late Roman Palestine*, ed. G. Davidson Weinberg (Columbia 1988).

24 Goren-Rosen, 'Ancient glass industry in Israel'.

25 E.M. Stern, 'Ancient and medieval glass from the necropolis church at Anemurium', *Annales du 9e congrès de l'association internationale pour l'histoire du verre* (1983) 35–64. The same is suggested for Philippi in Greece: Hattersley-Smith, *Byzantine Public Architecture* 69, 85.

26 *Jalame*, ed. Weinberg.

27 D. Foy, 'Un atelier de verrier à Beyrouth au début de la conquête Islamique', *Syria* 77 (2000) 239–90.

28 E.M. Stern, 'Early exports beyond the empire', in *Roman Glass: Two Centuries of Art and Invention*, ed. M. Newby and K. Painter (London 1991) 151; R. Pinder-Wilson and G. Scanlon, 'Glass finds from Fustat: 1967–1971', *Journal of Glass Studies* 15 (1973) 12–30.

Evidence for glass-working alone is recorded from sites in the Cherson, Kiev (eleventh–thirteenth centuries) and Turnovo (eleventh–twelfth centuries).²⁹ In Italy, at Torcello (seventh–eighth centuries) and at San Vincenzo al Volturno (ninth century), glass waste found on the site was interpreted as evidence not for a glass factory but for the making of objects from glass using cullet (glass refuse) or glass cakes imported from the eastern Mediterranean.³⁰ Venice became a major glass-making centre, manufacturing both raw glass and glass objects, only by the thirteenth century. To achieve this status, however, the city was forced to import a considerable range of raw materials, natron, plant ash, sand and cullet, from elsewhere in Italy and the Levant, and to impose stringent trading restrictions on these materials.³¹ This level of imports suggests that a trade in raw glass alone might have been generally easier and more straightforward than one in the materials for glass manufacture.

The eleventh-century shipwreck at Serçe Limani and another wreck some 30 kilometres to its east provide evidence for such a trade in raw and second-hand glass.³² The ballast of the Serçe Limani ship was made up of a mixture of broken and raw glass, over three tons in all, of which two tons were raw glass blocks and one ton broken vessel glass in very small pieces, broken to fit into the ship. This glass came from a variety of sites in the Levant, and it seems more than likely that it formed a cargo, perhaps brought together by dealers, for export to a glass factory for the manufacture of glass objects. The presence of Syrian glassware in Preslav also appears to suggest a shipping of cullet across

29 A. Bezborodov and A.A. Abdurazakov, 'Newly excavated glassworks in the USSR, third-fourteenth centuries AD', *Journal of Glass Studies* 6 (1964) 64–9; A. Bortoli and M. Kazanski, 'Kherson and its regions', in *Economic History of Byzantium*, ed. Laiou, II, 659–65. On Russian glass, see also Y. Ivachenko, 'Le verre proto-Byzantine; recherches en Russie 1980–1990' in *Le Verre de l'antiquité tardive et du haut Moyen Age*, ed. D. Foy (Val d'Oise 1995) 319–30. Preslav: I. Jordanov, 'Preslav', in *Economic History of Byzantium*, ed. Laiou, II, 667–71. Turnovo: K. Dochev, 'Turnovo', *ibid.*, II, 673–8. I have been unable to get hold of the reports of these finds. Also see the summary by T.S. Noonan, 'Technology transfer between Byzantium and Eastern Europe: A case study of the glass industry in early Russia', in *The Medieval Mediterranean: Cross-cultural Contacts*, ed. M.J. Chiat and K.L. Reyerson (St Cloud, Minn., 1988), 105–11. My thanks to Robin Cormack for this reference.

30 F. Dell'Acqua, 'Ninth century window glass from the monastery of San Vincenzo al Volturno', *Journal of Glass Studies* 39 (1997) 36; A. Gasparetto, 'A proposito dell'officina vetraria torcellana', *Journal of Glass Studies* 9 (1967) 50–75

31 D. Jacoby, 'Research on the Venetian glass industry in the Middle Ages', *Journal of Glass Studies* 33 (1991) 119–20; Jacoby, 'Raw materials for the glass industries of Venice and the Terraferma, c.1370–c.1460', *Journal of Glass Studies* 35 (1993) 65–90.

32 G.F. Bass and F.H. van Doorninck Jr, 'An eleventh-century shipwreck at Serçe Limani, Turkey', *International Journal of Nautical Archaeology and Underwater Exploration* 7 (1978) 119–32; G.F. Bass, 'The nature of the Serçe Limani glass', *Journal of Glass Studies* 26 (1984) 64–9. Also A.J. Parker, *Ancient Shipwrecks of the Mediterranean* (Oxford 1992) for other wrecks with glass. For trade in glass in a Roman context, J. Price, 'Trade in glass', in *Roman Shipping and Trade: Britain and the Rhine Provinces*, ed. J. du Plat Taylor and H. Cleere (London 1978) 70–8.

the empire.³³ Recycling glass was a cheap way of using and reusing the material without recourse to fresh supplies.

It is the chemical analysis of glass that has played a key part in elucidating the gap between the manufacture of raw glass and of glass objects. As Julian Henderson has shown in the context of Islamic glass, such research has implications for discussions about trade and the links between areas of production and areas of consumption.³⁴ Analysis of glass from the Serçe Limani shipwreck has suggested that it all came from one factory or from several factories in the same vicinity in the Levant whilst the sixth–seventh century glassware from Maroni Petrera on Cyprus has been identified as being made from raw glass or cullet from two sources, one of which was the Levant.³⁵

Byzantine glass production needs therefore to be set into this context of a continuing Levantine raw glass industry that exported its materials for the fabrication of glass objects. Byzantine glass manufacture (by which Constantinopolitan glass manufacture is often meant) has been variously described as ‘one of the great historical enigmas’, a ‘medieval mystery’ and ‘neglected’.³⁶ Despite the several tons of mosaic glass in Constantinople alone, it has been said of Byzantine glass that ‘almost nothing survives’.³⁷ This baffling apparent shortage of material has even led to suggestions that the Byzantines did not make glass, or, at least, not very much of it.³⁸ However, the apparent lack of material evidence for glass-making in Constantinople is explicable within the paradigm of glass production outlined above. Although no evidence on the ground survives for glass manufactories or for glass workshops, excavations at Saraçhane (St Polyuktos), for example, offer good evidence of ‘local’ glass object production for the Late Roman periods, the twelfth century and the sixteenth century onwards. Window glass from the Kariye Camii and the Pantokrator monastery has been used to suggest a Constantinopolitan glass industry.³⁹

33 F. van Doorninck Jr, ‘Byzantine shipwrecks’, in *Economic History of Byzantium*, ed. Laiou, II, 903.

34 J. Henderson, ‘Glass trade and chemical analysis: A possible model for Islamic glass production’, in Foy and Nenna, *Échanges et commerce du verre*, 109–23.

35 B. Lledó, ‘Mold siblings in the eleventh century cullet from Serçe Limani’, *Journal of Glass Studies* 39 (1997) 44. Freestone, Ponting, Hughes, ‘Byzantine glass from Maroni Petrera’: the other source has yet to be identified. For similar work in Italy, see M. Ubaldi and M. Verità, ‘Scientific analyses of glass from Late Antiquity and early medieval archaeological sites in northern Italy’, *Journal of Glass Studies* 45 (2003) 115–38.

36 Philippe, *Le Monde byzantin*, 4; G. Davidson Weinberg, ‘A medieval mystery: Byzantine glass production’, *Journal of Glass Studies* 27 (1965) 127–41; François and Spieser, ‘Pottery and glass in Byzantium’, 593–8.

37 R. Ward, ‘Introduction’, in *Gilded and Enamelled Glass*, ed. Ward, x.

38 See, for example, Philippe, ‘Reflections on Byzantine glass’, 40–6, an article that does not mention mosaics.

39 Saraçhane: J. Hayes, *Excavations at Saraçhane in Istanbul*, II. (Princeton 1992) 399–421. Mosaic and window glass appear in vol. 1. Kariye and Pantokrator: A.H.S. Megaw ‘Notes on recent work of the Byzantine Institute in Istanbul’, *DOP* 17 (1963) 349–67. J. Lafond, ‘Découverte de vitraux historiques du Moyen Age’, *Cahiers Archéologiques* 18 (1968) 231–8, argued that the stained glass was Western. Most recently see F. Dell’Acqua, ‘The stained glass windows from the Chora and Pantokrator monasteries: A Byzantine “mystery”’, in *Restoring Byzantium. The Kariye Camii in Istanbul and the Byzantine Institute Restoration*, ed. H.A. Klein (New York 2004) 68–78. Von Saldern, ‘Byzantine glass’, 1–3, believes Constantinople must have had specialized glass workshops dealing with ordinary and luxury glassware.

Further, several textual sources indicate glass-working in the city.⁴⁰ This would fit a model wherein raw glass was made near the sources of raw material and then exported more widely. It is perfectly plausible that raw glass was never made in Constantinople but rather was imported from the Levant and worked in the city; no evidence has been found for raw glass manufactories in Constantinople because there is none to find.

Since the evidence for workshops with the sort of kilns needed for the manufacture of glass is limited, it has been suggested that Constantinople manufactured enough glass to meet the needs of the empire.⁴¹ This suggestion is unnecessary. Rather, glass objects, of whatever sort, could have been manufactured throughout Constantinople and the empire as a whole in small-scale workshops. Evidence from sites such as Jalame indicates that glass-working could be, and was, carried out on a small scale, with only a simple furnace required to heat the glass. A great deal of glassware could be produced from a furnace with a very small ground-plan and, because the waste could be re-used, evidence on the ground may be scarce.⁴² In addition, the model of imported raw glass and localized glass-making sites suggests that there is no need to hypothesize a major industry in Constantinople responsible for the needs of the whole empire. The nature of glass-working itself allows for a very different picture. Megaw's perceived Cypriot mosaic workshops might well have imported their glass directly from the Levant, with no reference to Constantinople whatsoever.

Mosaic tesserae

What, then, of mosaics in this context? Although the material for glass-working is relatively common, evidence for the making of glass tesserae appears almost non-existent. Little has appeared at the major sites from where there is evidence of the manufacture of glass objects. Despite the scale of the glass finds from Sardis, very little coloured glass was found and these were only collections of single tesserae, none in any setting.⁴³ Material for the manufacture of tesserae comes instead from sites where mosaic was being used. At Jerash (Gerasa), some evidence of mosaic-making comes from the so-called 'Glass Court', where over a hundredweight of roughly circular cakes of glass, generally between 30 and 5 mm thick and up to 40 cm in diameter, were found. In colour and quality, these were like

40 The *Miracles* of St Eugenios imply that monks from Trebizond obtained their glass lamps from Constantinople and from Phasiane in Armenia: J.O. Rosenqvist, 'Lamps for St Eugenios: A note on Byzantine glass', *Eranos* 92 (1994) 52–9, miracles 5 and 18, which Rosenqvist dates to the ninth or tenth centuries. The *Life* of St Photeine mentions a glass-smelting workshop in ninth-century Constantinople: A.-M. Talbot, 'The posthumous miracles of St Photeine', *AB* 12 (1994) 88–104 and M. Mundell Mango, 'The commercial map of Constantinople', *DOP* 54 (2002) 202.

41 C. Bouras, 'Aspects of the Byzantine city, eighth to fifteenth centuries' in *Economic History of Byzantium*, ed. Laiou, II, 517.

42 Price, 'Trade in glass'.

43 Von Saldern, 'Byzantine glass from Sardis', 92–4.

the glass tesserae found on the site, and it is feasible that they were the sheets from which tesserae were cut. There are similar finds from Petra.⁴⁴ At Beth Shean, containers of previously used tesserae, seemingly gathered together for re-use, have been dated to between the fifth and seventh centuries.⁴⁵ A glass factory, with glass tesserae, was believed to have been discovered on Torcello, dating perhaps to the seventh or eighth centuries.⁴⁶ However, the site is so close to the church of Sta Maria Assunta that the factory could not have been in use when that church was put up, and analysis of the tesserae indicates that the glass was not made in the region and that the tesserae consisted of recycled and re-used glass, probably imported from elsewhere.⁴⁷ All of this suggests that mosaic tesserae were made on location from coloured glass brought to the site. As with glass workshops, few traces of this remodelling of glass would survive.

The problem in making glass tesserae is in their colouring, a difficult process for a variety of reasons. The first was knowing what ingredients to add. Some colours were easy enough to produce, most notably pale transparent blues and greens, made by adding copper scrap. Others, particularly opaque colours, were far more complex. Opaque yellows and greens required much skill in preparing the intermediate compounds; dark blue needed the addition of cobalt, a relatively rare component; dark opaque red called for control of the oxygen content of the glass melt. The heat of the furnace, the base composition of the glass, the temperature reached in the furnace and the duration of that temperature were all additional factors affecting the colour of the finished product.⁴⁸ Consequently, the glass imported for the manufacture of tesserae is unlikely to have been simple raw or second-hand glass, as this would involve either that glass itself already being coloured appropriately or its being coloured during the melting-down process. Easier by far would be the acquisition of coloured glass, as cakes or sheets or even tesserae. Thus an intermediate stage in the manufacture of tesserae seems to have been necessary, one in which either raw glass was coloured or raw glass was made as deliberately coloured glass. Both options imply specialized factories for coloured glass and a specific export trade in

44 F.M.Beibel, 'The mosaics' in *Gerasa, City of the Decapolis*, ed. K.H. Kraeling (New Haven 1936) 297–354, esp. 514 for the glass dump and 517–18 for the 'glass court'; C. Mayer, 'Glass from the North Theater Byzantine church and surroundings at Jerash, Jordan 1983–83', in *Preliminary Reports of ASOR-sponsored Excavations 1982–85*, ed. W.E. Rast and M. Zeiger (Baltimore 1988) 175–222. For Petra, Z.T. Fiema *et al.*, *The Petra Church* (Amman 2001) esp. 96–8, 370, 379 (which also deals with the analysis of the tesserae).

45 A.N. Shugar, 'Byzantine opaque red mosaic glass tesserae from Beit Shean, Israel' *Archaeometry* 42 (2000) 375–84. My thanks to Ian Freestone for this reference.

46 Gasparetto, 'A proposito dell'officina vetraria torcellana'.

47 M. Verità, A. Renier and S. Zecchin, 'Chemical analyses of ancient glass findings excavated in the Venetian lagoon', *Journal of Cultural Heritage* 3 (2002) 261–71. I am grateful to Marco Verità for this reference.

48 See J. Henderson, *The Science and Archaeology of Materials: An Investigation of Inorganic Materials* (London 2000) 29–38. R.G. Newton, 'Recent views on ancient glasses', *Glass Technology* 21(1980) 173–83, makes the case that it is improbable that ancient glassmakers added small proportions of colorants, suggesting that they did not have the chemical knowledge necessary. I am very grateful to Ian Freestone for discussion on this point.

coloured glass and tesserae, as there seems to have been with marble fixtures and fittings for churches.

Analysing Byzantine mosaic glass

One way forward in exploring these issues is through analysis of the glass tesserae themselves. If a picture of where they came from could be built up, it might reveal patterns: it might show whether glass came from Constantinople or from Italy or from the Levant; whether it was local to each site; whether, say, all ninth-century mosaic glass was intrinsically the same and whether it differed from eleventh-century glass; whether colorants were localized or universal. Chemical analysis offers some assistance in answering these questions for, increasingly, it is proving possible to date and source glass by its constituent elements.⁴⁹

Roman and Late Antique glass and what is called ‘medieval’ or Islamic glass have been distinguished by their different chemical compositions. Roman and Late Antique glass was a soda-lime-silica glass, characterized by an increasing use of manganese oxide rather than antimony oxide as a decolorant. It also contained little potassium and magnesia. These characteristics reveal a use of naturally occurring sodium carbonate, or natron, as a source of flux for the glass. The materials for this glass have also been shown to come extensively from the Levant (lime and silica, that is sand, from the mouth of the River Belus) and from Egypt (natron from the Wadi el-Natrun, between Cairo and Alexandria).⁵⁰ This typical Roman glass contrasts with soda-lime-silica glass with a high magnesium content. Such glass, made from the second millennium BC onwards, continued

49 For chemical fingerprinting, see J. Henderson, ‘The scientific analysis of ancient glass and its archaeological interpretation’ in *Scientific Analysis in Archaeology and its Interpretation*, ed. J. Henderson (Oxford 1989) 30–62; also M. Verità, ‘Tecniche di fabbricazione dei materiali musivi vetri: indagini chimiche e mineralogiche’, in *Medieval Mosaics: Light, Color, Materials*, ed. E. Borsook, F. Gioffredi Superbi and G. Pagliarulo (Florence 2000) 47–64. R.H. Brill, ‘Scientific investigations of the Jalame glasses and related finds’, in *Jalame*, ed. Davidson, 263, states that ‘glasses made in different factories, at different times, can be distinguished on the basis of their compositions.’ I.C. Freestone, ‘Compositions and affinities of glass from the furnaces on the island site, Tyre’, *Journal of Glass Studies* 44 (2002) 67–77, suggests that there is enough difference in the composition between the Serçe Limani glass and the glass from Baniyas to suggest that it might be possible to distinguish glasses from different primary production centres. Henderson, ‘Glass trade and chemical analysis’, is positive about the prospects for analysis. Also see the suggestions for future research made by R.H. Brill and P. Pongracz, ‘Stained glass from St-Jean-des-Vignes (Soissons) and comparisons with glass from other medieval sites’, *Journal of Glass Studies* 46 (2004), 131–2.

50 For the significance of the River Belus, see Pliny, *Natural History* 5.75 and Strabo, *Geography* 7.16,25. For other Classical references, see M.L. Trowbridge, *Philological Studies in Ancient Glass* (Urbana 1930). Although Cutler, ‘Industries of art’, 560, n. 20, suggested that since the raw materials for glass were universally abundant, there was no technical reason why tesserae could not have been produced anywhere, Freestone and Gorin-Rosen, ‘The great glass slab at Bet She’arim’ on sand, and Nenna, Picon and Vichy, ‘Ateliers primaires et secondaires’ on natron make it clear that specialized raw materials were required.

to be produced throughout the Roman and Islamic periods in Mesopotamia — hence its definition by some as medieval or Islamic. From the ninth century, its use spread to Northern and Western Europe, using plant ash rather than natron as a flux.⁵¹ In the East, after the Arab conquests of the seventh century, Egypt and the Levant continued to produce soda-lime glass but replaced the natron with a high magnesium plant-ash.⁵² Analyses of the glass from various sites in Israel, for example, have revealed this shift in the ninth century.⁵³

Analyses of Byzantine mosaic tesserae have shown that they match the production patterns apparent in vessel glass. A specific study comparing tesserae from Shikmona in the fifth century, Hosios Loukas (tenth century) and San Marco in Venice (eleventh–thirteenth centuries) indicated that, in each case, the glass was a contemporary product.⁵⁴ At Shikmona and Hosios Loukas, the tesserae were of the soda-lime-silica variety, but those from Shikmona were of the low-potassium, low-magnesium sort, whilst those from Hosios Loukas contained high levels of magnesium. The Shikmona tesserae were thus of the Roman/Late Antique type of glass and those from Hosios Loukas of the Islamic type. In contrast to both, tesserae from San Marco were made from potash glass, with a high lime and phosphate content, in other words, Western in composition. Other elements of the analysis offered interesting insights into the composition of the tesserae. Each site used manganese in different proportions as a colorant, but consistently within the group of tesserae as a whole. Tin was used as an opacifier at Shikmona and at San Marco, but not at Hosios Loukas. At each site, therefore, the chemical fingerprints of the glass indicated a single source for each group of tesserae.

Other studies have indicated similar patterns. Analyses of the tesserae from the sixth-century mosaics of San Vitale in Ravenna have indicated that the glass used there was derived from one source at one period.⁵⁵ A study of tesserae from between the fifth and the thirteenth centuries shows fifth- to ninth-century tesserae from archaeological sites and churches in Ravenna and Milan as low-magnesium, low-potassium glass, that is typically

51 E.V. Sayre and R.W. Smith, 'Compositional categories of ancient glass', *Science* 133 (1961) 1824–6. For a detailed account, Henderson, *Science and Archaeology of Materials*, 24–108.

52 For nuances and issues, D. Whitehouse, 'The transition from natron to plant ash in the Levant', *Journal of Glass Studies* 44 (2002) 193–6.

53 Freestone, Gorin-Rosen and Hughes, 'Primary glass', 65–83. Also, for the transition between Roman and Islamic glass, see O. Dussart, B. Velde, P.-M. Blanc and J.-P. Sodini, 'Glass from Qal'at Sem'an (Northern Syria): The reworking of glass during the transition from Roman to Islamic compositions', *Journal of Glass Studies* 46 (2004), 67–83.

54 I.C. Freestone, M. Bimson, D. Buckton, 'Compositional categories of Byzantine glass tesserae', *Annales du 11 congrès de l'association internationale pour l'histoire du verre 1988* (1988) 271–80. M. Verità, 'Analisi di tessere musive vitree del battistero della basilica di San Marco in Venezia', in *Scienza e tecnica del restauro della basilica di San Marco* (Venice 1999) 567–85 looks at fourteenth-century tesserae from San Marco. The glass is significantly different from that of the thirteenth-century tesserae. My thanks to Marco Verità for this reference.

55 C. Fiori, M. Vandini, V. Mazzotti, 'Colore e tecnologia degli 'smalti' musivi dei riquadri di Giustiniano e Teodora nella Basilica di San Vitale a Ravenna', *C+CA* 33 (2003) 1–20. My thanks to Cesare Fiori and Mariangela Vandini for this reference.

Late Roman, whilst tesserae from Daphni in the eleventh century and Santa Maria in Aracoeli in Rome in the thirteenth are both high in potassium and the glass from Sta Maria in Aracoeli is also high in magnesium.⁵⁶ Here again, the glass matches its period. The basic conclusion to be drawn is that Byzantine mosaic tesserae were produced by colouring and opacifying the glass typically in use at the time.

Interestingly, at Shikmona, Hosios Loukas and San Marco, small groups of tesserae did not fit these patterns: opaque reds at Shikmona; blue at Hosios Loukas; gold at San Marco. This suggests that whilst most colours were made together on site, perhaps some more technically demanding colours came from elsewhere.⁵⁷ As Freestone, Bimson and Buckton rightly conclude, it must be the case that the tesserae types used in the mosaics were in part determined by the ability of the mosaicists to obtain certain colours and that the availability of certain types of glass influenced the final appearance of a mosaic. Production and economics must therefore be seen as significant factors in the overall appearance of a mosaic.

Other elements within tesserae can offer crucial information for understanding the production of colours. The nature of opacifiers added to glass to make it more opaque changed over time. The earliest opacifiers were antimony compounds, but tin was gradually introduced, perhaps from the fourth century onwards, an early example being Centcelles.⁵⁸ Fifth- to seventh-century Byzantine glass tesserae from mosaics in Israel and Jordan appear to have been opacified solely with tin compounds; ninth- to eleventh-century tesserae from Greece used crushed quartz, perhaps because it was cheaper and more widely available.⁵⁹ Tesserae from Ravenna, including sixth-century tesserae from San Vitale, appear to be of glass of Roman composition, using antimony as an opacifier, something rare in Byzantine mosaic work. Colorants are another key area for distinguishing glasses. Coloration of mosaic glass was based on presence of four colouring elements, iron, copper, manganese and cobalt. By combining these in different proportions and in different glass matrices, and by adding opacifying agents such as antimony and tin, it was possible to obtain a very wide range of colours.⁶⁰

56 A. Ruffini, C. Fiori, M. Vandini, 'Caratterizzazione chimica di vetri musivi antichi. Parte 1: metodologie d'analisi e risultati; parte 2: elaborazione dei dati analitici', *Ceramurgia* 29, 4 (1999) 285–98 and 29, 5 (1999) 361–8. M. Verità, B. Profilo, M. Vallotto, 'I mosaici della basilica dei Santi Cosma e Damiano a Roma: studio analitico delle tessere vitree', *Studi Rivista della Stazione sperimentale del vetro* 5 (2002) 13–24 reveal the difference between sixth–seventh and seventeenth-century tesserae at the church of SS Cosmas and Damian in Rome and suggest that a comparison with tesserae from the Great Mosque in Damascus would be informative. My thanks to Cesare Fiori, Mariangela Vandini and Marco Verità for these references.

57 Evidence about opaque red glass supports this proposition: R.H. Brill and N.D. Cahill, 'A red opaque glass from Sardis and some thoughts on red opaques in general', *Journal of Glass Studies* 30 (1988) 16–27.

58 For Centcelles, see H. Schlunk, *Die Mosaikkuppel von Centcelles* (Mainz 1988). The analysis of tesserae is on pp. 184–9. On opacifiers, Verità, 'Tecniche di fabbricazione'.

59 One tessera provides evidence for tin opacified glass at Nea Mone: I.C. Freestone, S.G.E. Bowman, D. Buckton, 'Recycling in the production of Byzantine enamel', unpublished research paper.

60 For an account, see C. Fiori, I. Roncuzzi-Fiorentini and M. Vandini, 'Colours and stories of the Italian mosaics', in *The Art of Ceramics: The Blend of Art and Science in Technology*, ed. N. Claussen (Techna 2001) 149–72. My thanks to Cesare Fiori and Mariangela Vandini for this reference.

Such analyses have revealed some interesting developments in glass production. Roman mosaic tesserae appear to have been a ready source of coloured glass in the Western medieval world. At San Vincenzo al Volturno in the ninth century, such mosaic tesserae were used to create coloured glass. Analysis of Byzantine enamel glass indicates surprisingly that the glass in Byzantine enamels was not obtained from Byzantine glass makers but was made from old Roman tesserae obtained from the West, implying a trade in such tesserae. The same technique occurred in Carolingian Rome. However, there is no evidence to suggest that the makers of Byzantine mosaic glass employed Roman tesserae as colorants.⁶¹ Nevertheless, such findings raise interesting issues about both artistic practices and trading networks.

By beginning to distinguish these sorts of differences, it becomes possible to say more about the changing nature of the manufacture of glass tesserae and to consider why these technical changes may have taken place. It will also become increasingly possible to draw conclusions about the diffusion of glass tesserae. How alike are the tesserae from Ravenna and Milan? How different are those from Hosios Loukas and Daphni? At present, this practical research on mosaic tesserae remains disparate and localized within each site or region. Few comparative studies have been made, and much remains to be done both to pull together these separate findings and to expand the range of tesserae tested.⁶²

The problems with these forms of analysis should not be overlooked, however. It is too easy to assume that glass was made locally or provincially, with each glasshouse or group of glasshouses having its own sand and thus its own distinctive composition that can be detected. Rather, because raw glass was manufactured in one location, exported to another to be manufactured into objects, and then, potentially, recycled, the link between form and fabric is far more tenuous.⁶³ Although the composition of glass on a site is likely to resemble that of the primary glass suppliers, recycling and mixing together glass from more than one primary source adds a layer of confusion. The presence of sixth-century Syrian glass in a seventh-century Byzantine context might indicate recycling or trade, rather than the export of raw glass or of finished products arriving at that site. Only gradually is a composite picture as to how and where glass was traded being built up. If tesserae could be compared across sites in terms of their manufacture and potential

61 Dell'Acqua, 'Ninth century window glass', 36 and n. 13; D. Buckton "Necessity the mother of invention" in early medieval enamels', *Transactions of the Canadian Conference of Art Historians* 3 1982 (1985) 1-6; Freestone, Bowman and Buckton, 'Recycling in the production of Byzantine enamel', unpublished research paper; I.C. Freestone, S.G.E. Bowman and C.P. Stapleton, 'Composition and origin of Byzantine and Early Medieval enamel glasses' in *Catalogue of Medieval Enamels in the British Museum*, ed. D.Buckton (London, forthcoming). My thanks to Ian Freestone for allowing me to see and cite both of these key articles well in advance of publication.

62 R.H. Brill, *Chemical Analyses of Early Glasses, vol. 1: The catalogue; vol. 2: The tables* (New York 1999) begins this by bringing together Brill's analyses (including Byzantine tesserae) in tabular form. A third volume of analysis is awaited.

63 See the discussion by Freestone, Ponting and Hughes, 'Glass from Maroni Petrera', and Henderson, 'Glass trade and chemical analysis'.

origins, then more could be said with conviction about the nature of mosaic production and its implications for our understanding of Byzantine manufacturing processes and trade patterns over time across the period of the empire.

Trading and pricing

One final aspect to consider in more detail is the location of this material within what is known of trading patterns and cost in the Byzantine world. How easy, and likely, is it that glass or tesserae were transported across the empire, and how much might it all have cost?

It is believed that mosaic decoration on a large scale involved huge financial investment and industrial organization. On the basis of Mango's suggestion that the mosaics at Monreale needed at least a million tesserae, and taking the average tessera to weigh five grams, François and Spieser calculated that five tons of glass were required there and that over 400 tons of glass were needed for the Justinianic mosaics in Hagia Sophia.⁶⁴ However, these are not impossible amounts of raw and recycled glass to produce or to transport. One furnace at Beth She'arim produced nine tons of glass in one (unsuccessful) firing. Five tons of glass was potentially a cargo that could be carried by one ship alone; the glass, serving as ballast, in the Serçe Limani ship weighed three tons.⁶⁵ Four hundred tons of glass is relatively little compared to the 160,000 metric tons of grain shipped from Alexandria to Constantinople every year under Justinian.⁶⁶

Written sources imply that the movement of tesserae around the Mediterranean was not unknown. In the eighth century, mosaic cubes and workmen appear to have been exported for the decoration of the Great Mosque in Damascus and the mosque at Medina.⁶⁷ When mosaics were added to the Great Mosque in Córdoba, these tesserae too were said to have come from Byzantium.⁶⁸ Eleventh-century evidence from Kiev records

64 Mango, cited by Mundell Mango and Henderson, 'Glass at medieval Constantinople' 339, n. 24; François and Spieser, 'Pottery and glass in Byzantium' 595. However, they do not explain from where the estimate of five grams is derived.

65 M. McCormick, *Origins of the European Economy: Communications and Commerce AD 300–900* (Cambridge 2001) 96.

66 *Ibid.*, 97.

67 The sources are all Muslim and all tenth century, referring back to eighth-century building activities. For arguments about their validity, see H.A.R. Gibb, 'Arab-Byzantine relations under the Umayyad Caliphate', *DOP* 12 (1958) 219–34, texts on 225, and A. Cutler, 'Gifts and gift exchange as aspects of the Byzantine, Arab and related economies', *DOP* 55 (2001) 247–782. For the mosaics, see H. Stern, 'Notes sur les mosaïques du Dôme du Rocher et de la mosquée de Damas à propos d'un livre de Mme Gautier Van Berchem', *Cahiers Archéologiques* 22 (1972) 201–36; R. Hillenbrand, *Islamic Architecture* (Edinburgh 1994) 73.

68 For the Great Mosque in Córdoba: H. Stern, *Les Mosaïques de la Grande Mosque de Cordoue* (Berlin 1976), and, for the relevant texts, see P.-A. Jaubert, *La Géographie d'Edrisi II* (Paris 1999: reprint of Paris 1836–40) 60 and J.D. Dodds, 'The great mosque of Córdoba', in *Al-Andalus: The Art of Islamic Spain*, ed. J.D. Dodds (New York 1992) 22.

merchants selling tesserae in that city.⁶⁹ Nevertheless, the accounts of tesserae being sent to Muslim rulers present several problems. It is difficult to imagine that the Umayyads, who were involved in almost constant war with the Byzantines, could request and receive tesserae at least twice. Does this mean, as Gibb suggested, that trade between the two states continued? Should these texts, perhaps, be seen rather as propaganda pieces demonstrating the power of the caliphs over the Christian empire of Byzantium?⁷⁰ The inference of the written sources is that the Islamic world lacked either the necessary skills to make tesserae or the skills needed to put up mosaics themselves, yet this was a time when the Byzantines themselves seem to have been importing raw and worked glass from the Islamic Levant. Indeed, there is ninth- to twelfth-century evidence for Syrian gold sandwich glass, produced, in technical terms, in the same way as Byzantine gold mosaic.⁷¹ This is a clear case where analysis of the tesserae themselves might offer some answers.

How much it might cost to transport mosaic glass is unknown; no written source mentions glass and its value in this context, except in a very general fashion and with respect to luxury glassware.⁷² However, Cutler suggests that a reciprocal relationship between high price and high desirability might also mean that tesserae, durable and capable of being shipped at any weight, were commodities that naturally recommended themselves to overseas merchants.⁷³ If they could be shipped as ballast, so much the better. Glass itself was not an expensive medium; glass vessels and window glass are fairly common on Roman and Late Antique archaeological sites. Byzantine glassware is apparently less widespread, though excavations at Amorium and at Saraçhane indicate a considerable amount of this everyday glassware. Mosaic glass, made from such 'ordinary' glass, need not have been significantly more expensive in terms of the raw materials and colorants, though almost certainly so in terms of the technical skills needed to colour it appropriately. However, the quantity of mosaic glass and its dispersal throughout the Mediterranean world suggests that it was not overwhelmingly difficult to manufacture. Expenditure might well be influenced by quantity, but the major expense in terms of its manufacture must have lain in acquiring either difficult colours or metallic (gold and silver) glass.

However, the cost of gold glass may also be less than has been thought. Marlia Mundell Mango assumed a two-micron width of gold on the tesserae of Hagia Sophia and

69 In this case, inspired by fear to give away the tesserae. Text in C. Mango, *Art of the Byzantine Empire* (Toronto, 1974) 221–2; also Cutler, 'Industries of art', 561.

70 As is suggested by Cutler, 'Gifts and gift exchange', esp. 253–4.

71 M. Wenzel, 'Islamic gold sandwich glass: Some fragments in the David Collection', *Journal of the Royal Asiatic Society of GB and Ireland 1988* (1988) 45–72; P. Filippini, 'Blown gold-sandwich glasses with gilt-glass trailed inscriptions', *Annales du 13e congrès international de l'association internationale pour l'histoire du verre 1995* (1995) 113–28.

72 M. Mundell Mango, 'Beyond the amphora: Non-ceramic evidence for Late Antique industry and trade', in *Economy and Exchange in the East Mediterranean during Late Antiquity*, ed. S. Kingsley and M. Decker (Oxford 2001) 87–107, esp. table 5.1.

73 Cutler, 'Industries of art' 560.

thus estimated that 1,089 Roman pounds of gold were needed for the gold backgrounds in that church.⁷⁴ Using her formula, Cutler and Nesbitt calculated that, in the ninth century, the apse mosaic alone took some thirteen pounds of gold.⁷⁵ These figures imply that gold-glass mosaic was highly expensive. However, Marco Verità says that 20 grams of gold (a cubic centimetre) yields about six square metres of mosaic slab.⁷⁶ In this instance, the gold is less than one micron deep — about 172 nanomicros. Using Mundell Mango's figure of 9,925 m² as the area of Hagia Sophia covered by gold mosaic, then approximately 146 Roman pounds of gold would be required in all. This may go some way to explaining the presence of gold tesserae in smaller churches across the empire.

A further area linked to both cost and production is the availability of materials. In several churches, including the Eufrasiana at Poreč, the church at Dereāğzi and Hagia Sophia in Istanbul, stone and glass tesserae dipped in paint were employed.⁷⁷ The reasons for this are unclear. They may relate to a shortage of glass in the relevant hues. If so, the implication may be that certain coloured tesserae were brought to each site and ran out before the mosaic was completed rather than that the patron could not afford enough of the right materials. However, they may also reflect problems in making certain colours of glass, red in particular. Consequently, one issue that needs further consideration in this context is whether it was always the same colours that had to be produced through paint.

The real cost of mosaic lay perhaps in its workforce. Mosaic was simply far more labour-intensive than any other form of monumental art, especially when the complication of making the actual glass tesserae was added in.⁷⁸ In this context, Basil I's re-use of mosaic tesserae may not indicate a 'perennial shortage of tesserae' as much as a short-cut in manufacture.⁷⁹ Re-use of tesserae would certainly serve to economize on the labour

74 M. Mundell Mango, 'The monetary value of silver revetments and objects belonging to churches, AD 300–700', in *Ecclesiastical Silver Plate in Sixth-century Byzantium*, eds S.A. Boyd and M. Mundell Mango (Washington 1992) 125–6.

75 A. Cutler and J. Nesbitt, *L'arte bizantina e il suo pubblico* (Turin 1986) 106.

76 M. Verità, 'Technology and deterioration of vitreous mosaic tesserae', *Reviews in Conservation* 1 (2000) 68. My thanks to Marco Verità for this reference. Supporting evidence for the thinness of the gold is found in D. Bomford, J. Dunkerton, D. Gordon and A. Roy, *Art in the Making: Italian Painting before 1400* (London 1990) 22, discussing Cennino Cennini's claim that over 100 sheets of gold leaf could be made from one florin (weight anything between 3.55 g and 3.34 g). I am very grateful to Michelle O'Malley and Christopher Poke for debate on this.

77 Eufrasiana: A. Terry and H. Maguire, 'The wall mosaics of the cathedral of Eufrasius in Poreč: third preliminary report', *Hortus Artium Medievalium* 7 (2001) 131–66 and A. Terry and H. Maguire, *Dynamic Splendor: The Wall Mosaics in the Cathedral at Porec* (Penn State, forthcoming); Dereazi: Morganstern, *Byzantine Church at Dereāğzi* 103–5; Hagia Sophia: E.J.W. Hawkins, 'Further observations on the narthex mosaic in St Sophia at Istanbul', *DOP* 22 (1968) 151–66.

78 C. Harding, 'Economic dimensions in art: Mosaic versus wall-painting in Trecento Orvieto' in *Florence and Italy: Renaissance Studies in Honour of Nikolai Rubinstein*, ed. P. Denley and C. Elam (London 1988) 503–11.

79 C. Mango and E.J.W. Hawkins, 'The mosaics of St Sophia at Istanbul: The Church Fathers in the north tympanum', *DOP* 26 (1972) 22, and the further conclusions drawn by Cutler, 'Industries of art' 560.

force or the materials needed, rather than reflecting any technical lack or shortage. It was the manpower and manual skills needed for mosaics rather than the price of the raw materials that represented the principal cost for the patron. The case for mosaic as an expensive medium is not certain; the case for it as a costly one to install is clearer.

By collating evidence, this paper has sought to begin to build up a pattern of Byzantine mosaic manufacture within the Mediterranean throughout the Middle Ages. Considerations about mosaic glass have been linked to broader perspectives about trade, economics and production. The material presented has suggested several things: that mosaics were far more widespread than has previously been recognized; that raw glass, and so, potentially, glass for mosaics, was made on one site and exported to other sites to be worked; that chemical analyses offer the potential for tracing these patterns of glass-working and trade and can suggest working practices at different mosaic sites; and that, in terms of their materials, mosaics were less costly than has been previously assumed. More work remains to be done on the extent of glass mosaics within the empire, the comparison of tesserae across monuments and, indeed, a study of the other materials used for the making of tesserae. This material needs, in turn, to be linked with what Byzantine written sources tell us about mosaics. Taken together, these are all considerations that can place Byzantine mosaics in a different light.