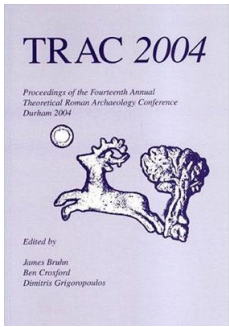

Paper Information:

Title: Social and Economic Aspects of Glass Recycling
Author: Daniel Keller
Pages: 65–78

DOI: http://doi.org/10.16995/TRAC2004_65_78
Publication Date: 31 March 2005

Volume Information:

Bruhn, J., Croxford, B., and Grigoropoulos, D. (eds.) (2005) *TRAC 2004: Proceedings of the Fourteenth Annual Theoretical Roman Archaeology Conference, Durham 2004.* Oxford: Oxbow Books.

Copyright and Hardcopy Editions:

Social and economic aspects of glass recycling

Daniel Keller

Introduction

The aim of this paper is twofold: firstly, the evidence for glass recycling has to be reconsidered and, secondly, it has to be placed into its social and economic context. The questions to be asked include the extent to which Roman glass was recycled? What was the reason behind this practice? What caused people in Roman towns to recycle broken glass rather than to discard it? What were the economic implications of glass recycling? To answer the first three questions, archaeological and textual evidence, mainly from the western provinces and the city of Rome, will be considered. A hypothesis for the practice of glass recycling in Roman towns will then be defined. For the wider economic aspects, a case study from a Byzantine province in the Near East will be presented.

Firstly, the nature of Roman and Byzantine glass production has to be considered. Roman glass production was apparently divided between primary workshops, where glass was prepared from the raw materials (sand, soda and lime), and secondary workshops, where glass was formed or blown into objects, vessels and windows (Price 1998: 331). The comparatively small number of known primary workshops, mainly in Palestine and Egypt (Gorin-Rosen 2000: 52–56; Foy and Nenna 2001: 35–39), but occasionally in the western provinces as well (for a singular case in Roman Britain: Cool, Jackson and Monaghan 1999; Price 1998: 338) and the large number of excavated glass workshops with small-scale furnaces for secondary production, especially in the western part of the Roman Empire (Price 2002: 83; Foy and Nenna 2001: 40–66) indicate that raw glass was primarily produced in the Near East and Egypt, where sand and soda of high quality was easily obtainable. It was subsequently traded by sea and on land to the secondary workshops all over the Roman Empire in the form of glass lumps, as shown by several shipwrecks with cargoes of raw glass (Foy and Nenna 2001: 106–112) or the reference to glass lumps transported on animals in Roman Palestine (Babylonian Talmud, *Shabbath* 154b). Besides imported raw glass the waste from glass forming and blowing could be used as raw material, as well as collected broken glass, which is called cullet. The use of cullet has a technological advantage as a certain amount of cullet mixed together with raw glass lowers the melting temperature (Vose 1980: 67). Furthermore, cullet is comparatively free of impurities usually found in the raw materials (Price 1976: 116).

Archaeological evidence for glass recycling

The problem in dealing with the archaeological record of glass recycling is the rather limited evidence. In the normal course of production, collected broken glass was melted down and recycled (Price 1998: 331–332. 338; Cool, Jackson and Monaghan 1999: 155). Only in rare cases, where glass factory sites were suddenly abandoned and deposits of cullet were left behind, does cullet enter the archaeological record, thus providing evidence for glass recycling.

Therefore, it is important to discuss the contexts of cullet deposits in order to understand how they were formed.

Deposits of cullet are known from military sites as well as from civilian settlements. Examples from civilian settlements are known from towns such as *Augusta Raurica* in Switzerland as well as from villas in the countryside such as at Pisanella near Boscoreale, Italy. The broken glass deposit from the villa at Pisanella was found in a basket which was in a basement storage room used for amphorae filled with wine and olive oil (Pasqui 1897: 518; Morel 1979: 256; Stern 1999: 451). Apparently, the broken glass was collected in this household, but before it could be recycled, the villa was destroyed by the eruption of Vesuvius in 79 AD. A levelling layer in a room in the eastern part of *Insula* 29 in *Augusta Raurica* contained a considerable amount of cullet, which was found together with glass waste. It is thought to be related to an as yet undiscovered glass workshop in the vicinity. The glass fragments belong to vessel types of the second half of the first century A.D. and the cullet and waste were redeposited at the end of the first/beginning of the second century A.D. in a part of the town which housed different industrial workshops (Rütti 1991: 152, 219).

Further to these discoveries from civilian sites, deposits of cullet come from industrial areas outside military camps such as Nijmegen (Isings 1980: 281, 341–344) and Guildhall Yard, London (Price 1998: 337–339; Cool, Jackson and Monaghan 1999: 157). The former comes from a *canabae legionis* and was deposited around 100 AD, the latter is close to the south-west corner of the Cripplegate fort and was deposited around 120 AD. While the finds from London are not yet published in detail, the context of the cullet from Nijmegen offers an explanation for its survival in the archaeological record: The glass fragments were found together with glass waste in three pits in the *canabae legionis*. While the largest pit contained almost 2,000 glass fragments, the two smaller ones produced a smaller quantity of 290 and 160 pieces, respectively. As all three pits are within a short distance of one another and belong to the same stratigraphical phase, the deposition of the three assemblages most likely took place at the same time, which can be dated to the transition of the first to the second century A.D. according to the latest glass finds, as well as to the associated pottery and coins (Isings 1980: 343–344 fig. 2–5). The dating offers the reason why the cullet and waste were not used for recycling since the *Legio X Gemina* departed in c. 104 A.D. and the fortress was not occupied by a whole legion thereafter. This most probably led to an end of the on-site local military glass production, as there was no longer any need for large amounts of glass vessels (Isings 1980: 281; Cool, Jackson and Monaghan 1999: 157).

Further evidence for the habitual collection of broken glass during the occupation of military sites is provided by the deposition patterns of glass from other early Roman legionary sites, such as Usk in Wales in the early Flavian period and Inchtuthil in the late Flavian period (Price 1985: 304; Price 1998: 339). As only a few glass vessels survived from the period of the use of these fortresses, and in cases where they did, only in individual fragments, an organised system of glass collection is likely to have been in existence during the occupation of the respective camps. On the other hand, the deliberate abandonment of complete glass vessels in deposits belonging to the final phase of these camps, such as pits, culverts and latrines, as well as the deliberate deposition of re-usable cullet and waste in pits, suggests the end of the collection of broken glass when the troops moved on, and the material which was obviously not worth the effort of transporting was disposed of (Price 1995: 140; Cool, Jackson and Monaghan 1999: 157).

Due to all these finds of cullet in connection with military camps, it may be assumed that the Roman army was involved in collecting broken glass to be used as cullet in glass

production (Price 1998: 339). Furthermore, it appears that the Roman army did produce its own glass vessels and windows as the findspots of these pit deposits of cullet are usually connected with an industrial area outside the associated camp (Isings 1980: 344). By collecting broken glass, the Roman army could relatively easily obtain cheap raw material to be recycled locally, and consequently, was not dependent on long distance trade in raw glass nor was it necessary to produce raw glass from the raw materials on a large scale (for a singular case in York: Cool, Jackson and Monaghan 1999). The latter was important as the military camps were seldom close to sources of high quality sand and soda. That the Roman army was involved in the production of glass vessels and windows to a certain degree is also indicated by an epigraphic reference to an *immunis specularius*, a soldier being involved in making windows; he belonged to the *Legio XIV Gemina* at *Carnuntum*, Austria, in the first half of the third century A.D. (Bormann 1914: 338–339; Sternini 1995: 137–138; Price 1998: 339).

Textual evidence for glass recycling

The earliest archaeological evidence for glass recycling is a pit deposit from Watling House, London, which is dated to the Neronian/early Flavian period (Shepherd 1986: 141–143). Other finds from the early Flavian period, such as the previously mentioned glass finds from Usk or the basket filled with broken glass from Boscoreale, support the hypothesis that glass recycling began in the early Flavian period at the latest. At the same time, strongly coloured glass was falling out of fashion, since from the last quarter of the first century A.D. onwards, it was replaced by either naturally coloured bluish-green or colourless glass. Therefore, such cullet could be remelted in larger quantities without risking an undesirable muddy colour. This would be the case, if strongly coloured glass fragments were mixed together (Stern 1999: 451).

The discovery that broken glass could be totally remelted found its reflection in the literature of the Flavian period. Poets, such as Martial (*Epigr*. 1.41.3–5; 10.3.3–4), Statius (*Silv*. 1.6.73–74) and Juvenal (*Sat*. 5.48) refer to the collection of broken glass (Leon 1941: 233–236). This widespread literary response to a technical innovation related to Roman glass production is noteworthy and confirms the archaeological dating of the beginning of glass recycling in the Roman world (Stern 1999: 450–451). Here, the literary context of the written evidence for glass recycling is of importance: Statius describes the *Saturnalia* under the Emperor Domitian and Martial generally gives a picture of everyday life in Rome in the late Flavian period, while Juvenal's approach is a satirical one, which is nevertheless a reflection of reality. The fact that these three poets mention the collection of broken glass in the context of everyday life indicates that glass recycling was common in the last quarter of the first century A.D. in Rome.

Furthermore, these texts offer an explanation why people in Rome were collecting broken glass instead of throwing it away: All three poets tell us that the Romans exchanged broken glass for sulphur, most likely in the form of sulphur tipped pieces of wood, i.e. matches (Leon 1941: 233–234). As Martial refers to certain poems so worthless that a purchaser of broken glass would not pay a sulphur match for them, this indicates that the exchange of broken glass for sulphur matches was a common practice (Leon 1941: 234–235). While Statius and Juvenal provide us only with the information that broken glass was exchanged for sulphur, Martial offers a little more detailed insight into the matter by calling the person who barters sulphur for broken glass a peddler or hawker (*ambulator* or *circulatrix*). The aim of Martial's poem is to lambaste a certain Caecilius, who thinks of himself as a poet, but in Martial's eyes he is

nothing but a tramping hawker who collects broken glass or any other simple street-vendor. This strongly indicates that the hawkers collecting broken glass were regarded as part of the lowest level of the working force on the streets of Rome. Furthermore, Martial describes them using foul language, hence confirming their low social status.

A hypothetical reconstruction of glass recycling in a Roman town

Based on the evidence reviewed above, we can assume the following process for the collection of broken glass: Hawkers walked through the streets of Roman towns and called for broken glass to be exchanged for useful household goods such as sulphur matches. These are mentioned in the texts, but one can assume that they stand for any cheap and not too sophisticated household good. Statius is not just talking about broken glass like Martial and Juvenal (*vitra fracta* or *vitrum ruptum*) but rather about crushed glass (*vitra comminuta*), which implies that hawkers exchanged sulphured sticks even for small glass fragments, hence they collected any broken glass whatever its size (Leon 1941: 235). This exchange was practical for both sides; for the household to acquire something useful such as sulphur matches for broken glass vessels which would otherwise have been thrown away as worthless, as well as for the glass workshops to obtain cheap and comparatively good raw material by literally collecting it in the streets of their own town rather than completely depending on imported raw glass alone or getting involved in the long and complicated production of raw glass. In addition, hawkers could obviously make a profit out of bartering sulphur matches for broken glass, which was subsequently melted down completely, and finally blown into new glass vessels. That broken glass had indeed a real value is known from Cassius Dio's account (60.17.6) of the emperor Claudius granting Roman citizenship as cheap as the value of some bits of broken glass, hence indicating that broken glass was not worthless, but a cheap commodity to be obtained or sold (Morel 1979: 256). This practise continued until modern times, as shown by the use of broken glass in small 18th century glass workshops in France (Diderot and d'Alembert 1765: pl. 16) or even nowadays in Cairo and Damascus (Stern 1999: 451–452).

Therefore, the practise of glass recycling as it is known from the archaeological and literary evidence provides a local economic cycle in which producer, consumer and middlemen profit without any kind of costly procedures by the simple means of barter. However, this does not mean that glass recycling was done exclusively on a small scale. On the contrary, the large pit deposit from Guildhall Yard, London, with more than 50kg of blowing and working waste and cullet, points to an organised collection of broken glass on a rather large scale (Price 1998: 337–338). Furthermore, in settlements glass finds of certain periods are often missing from the archaeological record because they were most likely collected and remelted on a regular basis (Rütti 1991: 19; Cool and Price 1995: 6).

The only evidence for long-distance trade in cullet comes from a shipwreck dated to the end of the second/beginning of the third century AD, found at Grado near Aquileia in northeastern Italy. Broken glass was found as part of the cargo of a Roman ship, which mainly transported wine and olive oil in Aegean and North African amphoras. As the glass fragments were found in the remains of a wooden barrel and thus transported in it, we are indeed dealing with a load of cullet transported together with wine and olive oil amphoras, as it is not possible to transport complete glass vessels in a big wooden barrel without breaking them. The destination of the ship and its consignment was most likely the Roman port of Aquileia, where the glass would have been recycled (Tortorici 1994; Foy and Nenna 2001: 111). However, as

this is so far the only known Roman shipwreck which had cullet as part of the shipment, while all the other shipwrecks of the Roman imperial period in the Mediterranean transported either raw glass or complete glass vessels (Foy and Nenna 2001: 106–112), it seems that cullet was only occasionally traded over longer distances. On the contrary, the deliberate disposal of cullet in pit deposits such as in the *canabae legionis* at Nijmegen, when the legion moved on, suggests that broken glass was not worth transporting, as it could have been obtained everywhere on a local basis. Certainly this was cheaper than trading broken glass over longer distances, as this would have increased the value of a cheap commodity.

Most of the evidence we have gathered so far, both from textual and archaeological records, points to a rather local phenomenon of glass recycling. Broken glass was collected within towns or military camps and was used as cheap and easily obtainable raw material in local secondary glass workshops rather than being traded to distant ones.

Glass recycling in Byzantine Southern Jordan: a socio-economic case study

In the Byzantine period, the area of Southern Jordan, from the Red Sea in the south to the Wadi Mujib in the north, together with the Negev and Sinai, formed the *Provincia Palaestina Salutaris/Tertia* (Fig. 1). Petra, the ancient capital of the former Nabataean kingdom, was the administrative as well as economic centre of this province (Fiema 2002).

About 5 km southwest of Petra lies Jabal an-Nabi Harun, the mountain of the Prophet Aaron. Since 1997, a Finnish team, directed by Jaakko Frösén and Zbigniew T. Fiema, has been investigating an architectural complex situated on a high plateau of the mountain (Fig. 2). This building complex includes a church and an adjacent chapel in the centre (trenches B, C, E, F, G, H, I, L and M), a western wing of separate rooms (trenches K and O), a series of rooms in the south (trenches A and P) and a large court surrounded on three sides by 14 rooms of substantial size (trenches D and N). Constructed in the mid-fifth century AD, the buildings remained in use, with some modifications, until the eighth or ninth century A.D. (Fiema and Holmgren 2002). The church and chapel clearly indicate the ecclesiastic character of the complex, while the rooms in the west and south were probably used in connection with storing and processing of food, and the northern part of the complex resembles a pilgrimage hostel. Based on these observations, the complex may be interpreted as a pilgrimage centre and monastery.

A large amount of broken glass was discovered in two adjacent rooms situated to the north of the western part of the church (Fig. 2). As the glass fragments were found close together in a narrow space, they most likely represent two piles of broken glass consisting of fragments of glass vessels, mainly glass lamps (Frösén and Fiema 2001: 364; Lindblom 2002: 222), as well as of parts of window panes. The fragments are rather large in size, and although there are many joining pieces, they never form a complete vessel because there are always small fragments missing. This leads to the conclusion that the broken glass was collected from a certain place, but only larger pieces were picked up, while smaller pieces were cleared away. As the glass finds consist almost entirely of lamps and windows with only very few fragments of other glass vessel shapes, the collected glass probably originated from the neighbouring church. The process of glass collection took place after the church of the pilgrimage/monastic complex was destroyed and cleared out. The stratigraphic analysis indicates that at this point the church was no longer an ecclesiastic structure, but the chapel was probably still in use and the occupation on the site continued in a limited or even casual way (for the different phases of

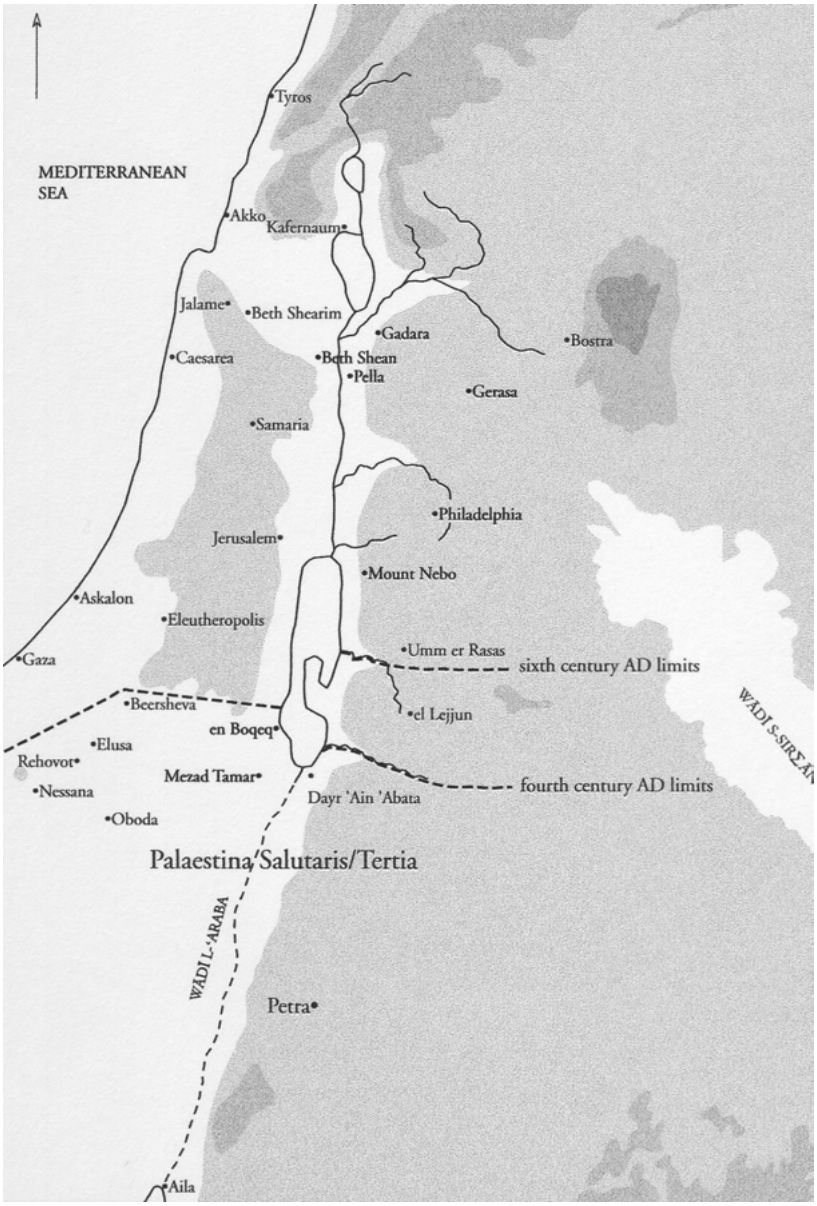

Figure 1: Map of the Byzantine province Palaestina Salutaris/Tertia.

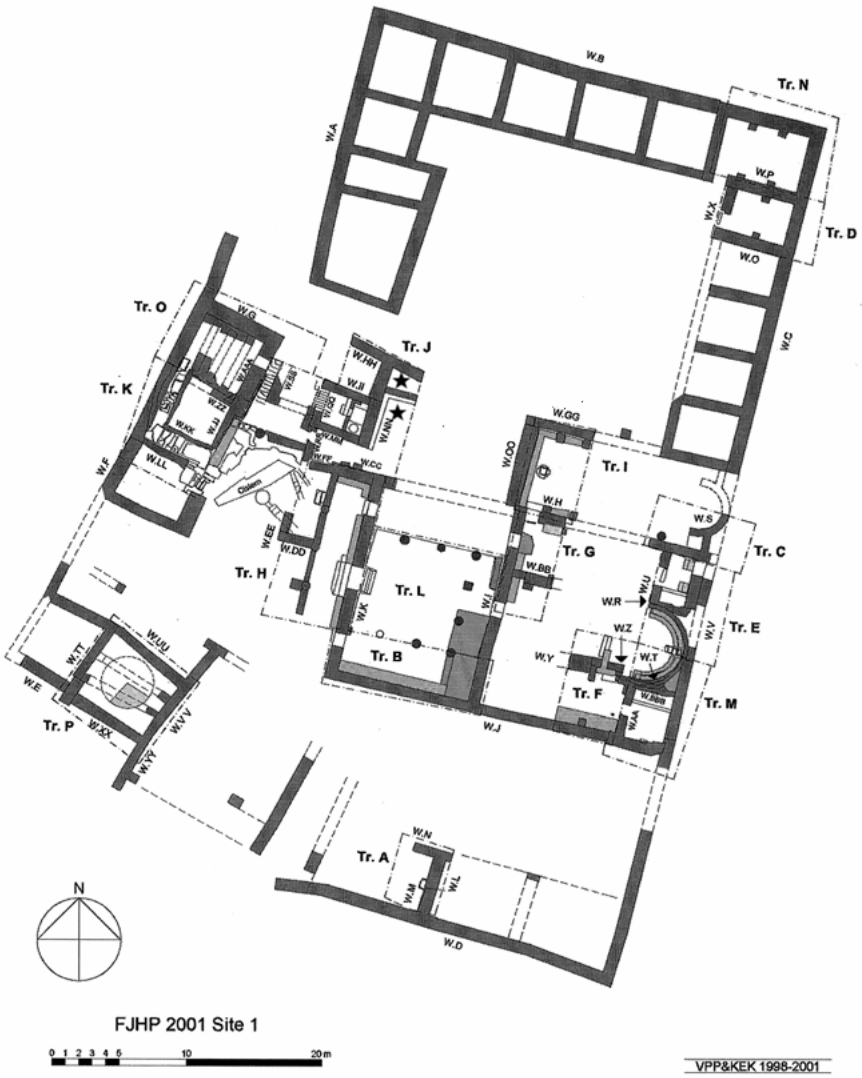

Figure 2: Plan of the pilgrimage/monastic complex on Jabal Harun. The stars indicate the location of the glass piles (after J. Frösén and Z. T. Fiema, Petra. A city forgotten and rediscovered. 2002. Helsinki: University of Helsinki Press. 264 map G).

the church see: Fiema and Holmgren 2002: 104–108). The collected glass was deposited in the two rooms adjacent to the church and stored there to be re-used at a later stage. As the glass from trench J can be dated to the late Byzantine/early Islamic transitional phase of the mid-seventh century A.D. (Lindblom 2002: 222; Keller forthcoming), and the later phases of the church on Jabal Harun show signs of temporary and casual occupation only (Fiema and Holmgren 2002: 108), it seems possible that the broken glass was not re-used, because of the decline of the entire complex. However, the fact that broken glass has been carefully collected and stored in two piles in rooms close to the church, points to an original intention to melt it down and recycle it.

Further piles of glass were found in two other churches in the city centre of Petra: in the atrium and in one of the adjacent rooms to the south of the atrium of the Petra Church (Fiema 2001: 96–98), as well as in the atrium of the so-called Blue Chapel in the vicinity of the Petra Church (Bikai and Perry 2001: 9). In both cases, the glass piles belong to the latest phase of continuous occupation in the seventh century AD, before the respective churches were abandoned and only occasionally occupied for domestic purposes in later periods. Therefore, we have the same archaeological evidence as in the two rooms adjacent to the church on Jabal Harun, which means that there seems to be a regular pattern of collecting broken glass from churches and storing it in piles in rooms adjacent to the churches in order to keep it for recycling.

In the province *Palaestina Salutaris/Tertia*, other church sites with such glass piles are known (Fig. 3), for example, at Horvat Be'er Shema' in the Negev, where many fragments of glass lamps were found in rooms to the south of the church (Gazit and Lender 1991: 45) and at the legionary fortress of el Lejjun, south of Wadi Mujib, where a large amount of glass lamp and beaker fragments were found in the sacristy of the church in a sixth century A.D. context (Jones 1987: 627–628). These examples demonstrate that glass was not only collected for recycling in the churches in Petra, but in several church sites of the province.

Similar glass piles are also known from church sites in Northern Jordan, such as Jerash, or in Galilee, such as Khirbet el-Kerak (Fiema 2001: 97 notes 425–426). As in all these sites (Fig. 3) the glass piles were found in rooms next to the respective church, and as all these glass deposits were easily accessible, we can conclude that the broken glass was not dumped there, but rather stored in these places to be re-used at a later stage. It has been argued that these piles of broken glass represent broken holy vessels which could not have been reused again as they were still sanctified and thus needed to be buried (Meyer 1988: 184). If the broken glass would have been deliberately stored, one would expect it to be found in a *favissa* as in the Petra Church (Fiema 2001: 75) or in an abandoned baptismal font as in Nir Gallim near Jerusalem (Gorin-Rosen 2002) rather than piled up and stored in an accessible room such as on Jabal Harun and outside the other mentioned churches. Furthermore, the textual evidence for burying broken holy glass vessels does only refer to chalices and patens (*vasa sacra*) used in the liturgy (Jacob of Edessa, *Canons* 28, 30; Michael of Damiette, *Nomocanon* 7) but not to lamps and other *vasa non sacra*, which are forming those piles of broken glass. Therefore, we are indeed dealing with cullet and glass recycling and we may assume a regular pattern of broken glass collection for recycling connected to churches for the entire province in the later stage of the Byzantine period, i.e. in the sixth and seventh century's A.D. which needs to be explained.

In order to understand the practice of collecting broken glass in the context of churches in the province *Palaestina Salutaris/Tertia*, it is important to point out that there is a strongly regional glass corpus in Byzantine Southern Jordan and the Negev of the sixth and seventh

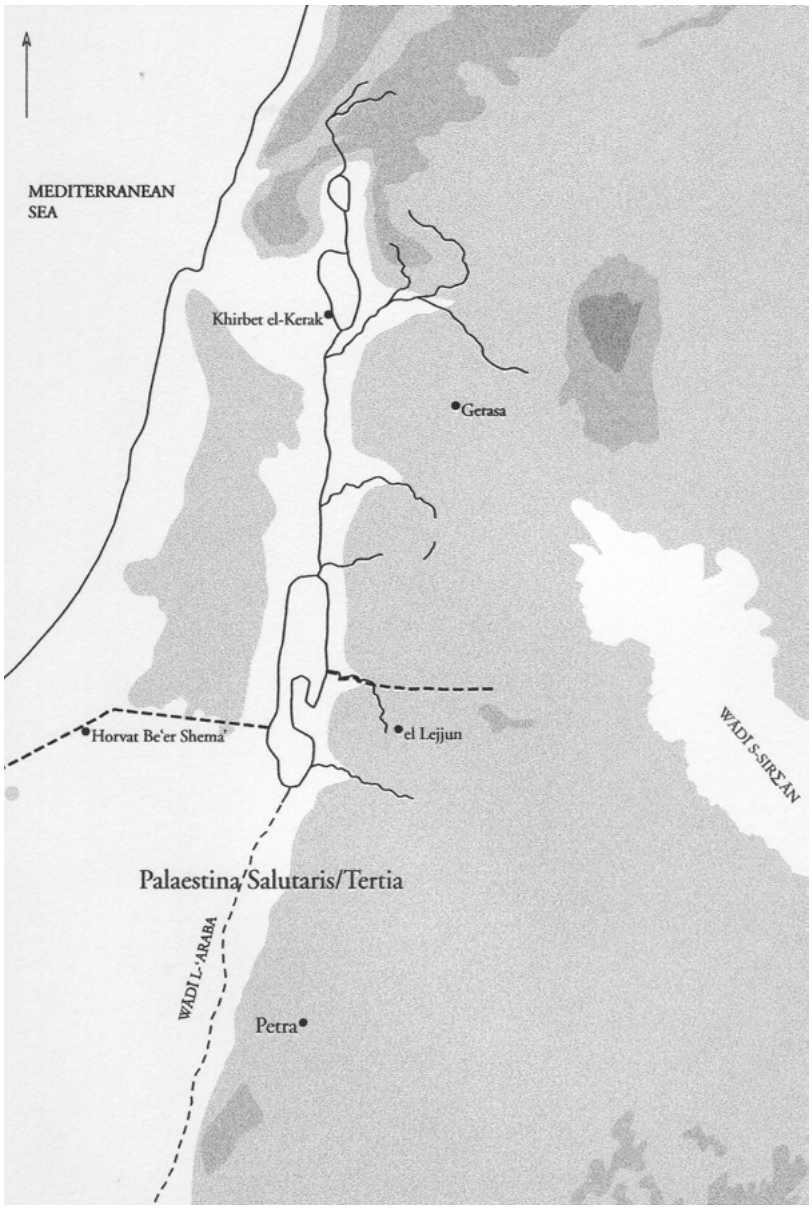

Figure 3: Sites with glass piles outside churches.

century's AD. The glass lamps and beakers, the two main glass types of Byzantine Petra, have close typological parallels from Byzantine sites in the Negev, such as Nessana, Rehovot, Mezad Tamar and en Boqeq, as well as from Jordanian sites south of the Dead Sea or the Wadi Mujib, such as Dayr 'Ain 'Abata, el Lejjun and Khirbet Faris (Fig. 4). Glass from Byzantine sites to the north of the Wadi Mujib (province *Arabia*) and to the north of the Negev (province *Palaestina Prima*) may look similar, but they show distinctive manufacturing differences, while glass vessels from Galilee and northern Transjordan (province *Palaestina Secunda*) are clearly different from those from the south (Lindblom 2002: 220–221; Keller forthcoming). This suggests a regional or provincial organisation of the Byzantine glass production in Southern Jordan and the Negev.

Further evidence for a regional economic system, which was limited to the province *Palaestina Salutaris/Tertia* and its immediate neighbouring towns, can be found in the Byzantine papyri from Petra (Frösén 2002: 20) and Nessana (Kraemer 1958): in both archives, land possessions or trade relations between Petra or Nessana on the one hand and Aila, Elusa, Beersheva, Gaza or Eleutheropolis on the other are mentioned (Fig. 4). These trade relations and land possessions show not only the movement of people between these places, but suggest also an intense regional or provincial economy, which was more or less limited to the borders of the province and did not reach far beyond these limits.

As the glass production was obviously part of this provincial economy, where the raw material for the glass vessels, lamps and window panes could have been obtained from is an interesting question. As there is hardly any archaeological nor textual evidence for interregional trade beyond the provincial borders on a larger scale (Fiema 2002: 232–234), it must have been difficult to get sufficient raw glass from the large primary glass workshops in Judaea, Galilee and Egypt. As there was a considerable demand for glass, especially for lamps and windows in churches, as well as for cups in households, the recycling of broken glass became more than just an optional addition to the imported raw glass as it used to be the case in the western part of the Roman Empire in earlier times (as discussed above). On the contrary, the decline in interregional trade meant that glass recycling became an economic necessity as there was no other option to obtain raw glass on a large scale. That the Byzantine glass vessels, lamps and windows were indeed made of recycled broken glass, can be seen in the rather poor and bubbly quality of all of these pieces (Keller forthcoming), since glass made with only cullet as raw material often is of poor quality, as can still be observed in the modern glass workshops in Cairo and Damascus (Stern 1999: 451–452).

The socio-economic significance of glass recycling

The relationship between glass recycling and the church has to be considered from two aspects: on the one hand, we have to consider that churches are the best known structures of this region in Byzantine times, as very few other site types from Southern Jordan dating to that period have been fully excavated and published. On the other hand, there is no doubt of the important role the church played in the economy of Byzantine Petra and Southern Jordan (Fiema 2002: 217–219). Therefore, the glass piles outside of churches in the province *Palaestina Salutaris/Tertia* not only indicate that broken glass from the site could have been easily obtained in large quantities, due to the intensive use of glass lamps and windows in churches, but they also represent the economic power and status of the church, where broken glass was hoarded for reuse.

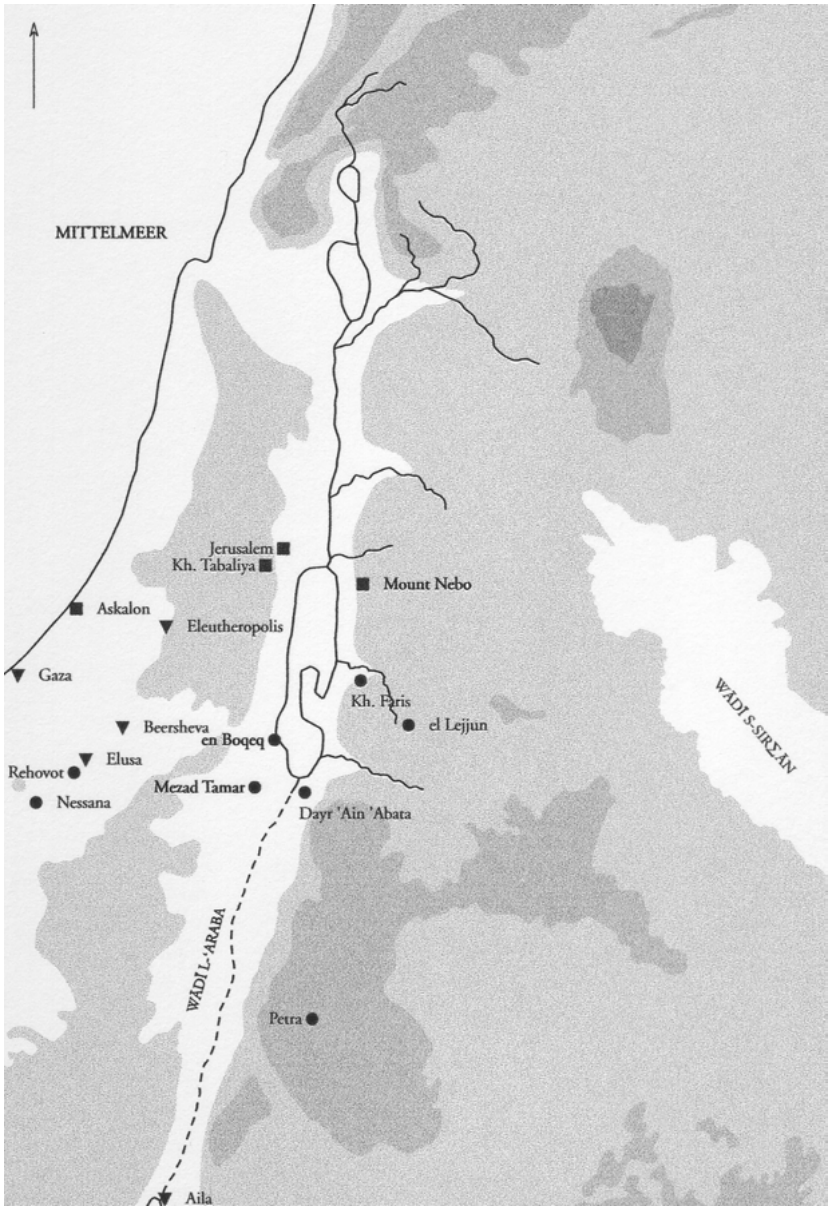

Figure 4: Sites with characteristic Byzantine glass vessels and sites mentioned in Byzantine papyri from Petra and Nessana.

- ● *same glass vessels as found in Petra and on Jabal Harun*
- ■ *different glass vessels than those from Petra*
- ▼ *sites mentioned in the papyri from Petra and Nessana*

However, to a certain degree it may even have been a socio-cultural necessity to hoard broken glass within the structural boundaries of the church. Lamps and vessels used in an ecclesiastical context could have been confined to use within the church itself. Consequently, even when these objects were broken, they could not have been removed from the area of the church. While the glass chalices and patens used in the liturgy had to buried once they were broken, the lamps which were not holy vessels could have been recycled, but it is likely that this process must have been carried-out within the boundaries of the church. This may imply itinerant glassblowers moving from one church to the other, blowing glassware and window panes using the collected broken glass from the earlier stages of these churches as raw material. The regional characteristics of the Byzantine glass vessels and lamps from the province *Palaestina Salutaris/Tertia*, as well as the known movement of people within this province and the regionality of the trade and economy correspond well with this hypothesis. Furthermore, it was not possible to purchase raw glass from outside the province due to the cessation of interregional trade, nor were there any suitable raw materials within the province to produce raw glass on a large scale. Therefore, the economic situation forced the church to implement glass recycling in order to maintain the necessary furnishing of their large buildings with glass lamps and glass windows.

This study demonstrates how complicated the interpretation of glass recycling is and how important the archaeological and the historical context of such finds is in order to fully understand their economic and socio-cultural meaning. It may well be that the Roman army faced similar socio-economic difficulties which forced them to use cullet on a large scale to guarantee the supply of glass vessels demanded by their officers and soldiers in places far away from the centre of the Roman empire. Furthermore, the collection of broken glass by hawkers in the streets of Rome may have been an economic necessity for the owner of the glass workshops to purchase enough glass as cheap as possible in order to fulfill the increased demand on glass vessels in the capital from the later first century A.D. onwards. However, each case needs to be regarded in its own historical and socio-economic context, but the practice of glass recycling is always strongly connected to the actual socio-economic situation. One can therefore assume that glass recycling became necessary when a large demand needed to be fulfilled in a rather difficult economic situation, while on the other hand hawkers could have been forced to barter a cheap commodity like sulphur matches for broken glass because of their personal socio-economic situation on a more regular basis.

Acknowledgements

I am grateful to Jaakko Frösén and Zbigniew T. Fiema (University of Helsinki, Finland) for allowing me to study and present glass finds from the Finnish Jabal Harun Project (FJHP) in Petra, Jordan, a project which is supported by the University of Helsinki and the Academy of Finland. I also have to thank Jeanette Lindblom (University of Helsinki, Finland) for all her help related to the study of these finds. Thanks are due to James Bruhn and Dimitris Grigoropoulos (University of Durham) for inviting me to present a paper on glass recycling at TRAC 2004. I am grateful to both of them for editing my paper together with Ben Croxford (University of Cambridge) and for providing me with many useful comments and suggestions. For the latter, I wish to thank the anonymous reviewer sincerely. I would like to thank Jenny

Price (University of Durham) for discussing aspects of this paper, as well as Tina Jakob (University of Durham) for checking and correcting my English.

Bibliography

Ancient Sources

Babylonian Talmud (Translated by H. Freedman 1938). *Shabbath* vol. II. London: Soncino Press.

Cassius Dio (Translated by E. Cary 1961). *Dio's Roman History*. London: William Heinemann.

Jacob of Edessa (Translated by C. Kayser 1886). *Canones Jacob's von Edessa*. Leipzig: J.C. Hinrichs'sche Buchhandlung.

Juvenal (Translated by G.G. Ramsay 1961). *The Satires of Juvenal*. London: William Heinemann.

Martial (Translated by W.C.A. Ker 1961). *Epigrams* vol. I. London: William Heinemann.

Martial (Translated by W.C.A. Ker 1950). *Epigrams* vol. II. London: William Heinemann.

Michael of Damiette (Translated by W. Riedel 1900). Der Nomocanon des Metropoliten 'Anba Michael von Damiette. In W. Riedel, *Die Kirchenrechtsquellen des Patriarchats Alexandrien*. Leipzig: A. Deichert'sche Verlagsbuchhandlung. 89–115.

Statius (Translated by J.H. Mozley 1961). *Silvae*. London: William Heinemann.

Modern Sources

Bikai, P.M. and Perry, M. 2001. Petra: North Ridge project. *ACOR newsletter* 13.1. Amman: American Center of Oriental Research. 8–9.

Bormann, E. 1914. Epigraphischer Anhang. In E. Nowotny (ed.) *Der römische Limes in Österreich* 12. Vienna and Leipzig: Kaiserliche Akademie der Wissenschaften. 317–342.

Cool, H.E.M., Jackson, C.M. and Monaghan, J. 1999. Glass-making and the Sixth Legion at York. In *Britannia* 30. 147–161.

Cool, H.E.M. and Price, J. 1995. *Roman vessel glass from excavations in Colchester, 1971–85*. Colchester Archaeological Report 8. Colchester: Colchester Archaeological Trust.

Diderot, D. and d'Alembert, J. le R. 1765. *Encyclopédie ou dictionnaire raisonné des sciences, des arts et des métiers, "Verrerie" vol. 17*. Neufchastel: chez Samuel Faulche.

Fiema, Z.T. 2001. Reconstructing the history of the Petra Church – data and phasing. In P. M. Bikai (ed.) *The Petra Church*. Amman: American Center of Oriental Research. 7–137.

Fiema, Z.T. 2002. Late-antique Petra and its hinterland: recent research and new interpretations. In J. H. Humphrey (ed.) *The Roman and Byzantine Near East* 3. Journal of Roman Archaeology Supplement 49. Portsmouth: Journal of Roman Archaeology. 191–252.

Fiema, Z.T. and Holmgren, R. 2002. The Byzantine monastic/pilgrimage center of St. Aaron near Petra. In J. Frösén and Z.T. Fiema (eds.) *Petra. A city forgotten and rediscovered*. Helsinki: Helsinki University Press. 99–110.

Foy, D. and Nenna, M.-D. 2001. *Tout feu tout sable. Mille ans de verre antique dans le Midi de la France.* Aix-en-Provence: Musées de Marseille/Editions Edisud.

Frösén, J. 2002. The Petra papyri. In J. Frösén and Z. T. Fiema (eds.) *Petra. A city forgotten and rediscovered*. Helsinki: Helsinki University Press. 18–24.

Frösén, J. and Fiema Z.T. 2001. The 2000 Finnish Harun project: Preliminary report. In *Annual of the Department of Antiquities of Jordan* 45. Amman: Department of Antiquities of Jordan. 359–376.

Gazit, D. and Lender, Y. 1991. Horvat Be'er Shema'. In *Excavations and Surveys in Israel* 10. Jerusalem: Israel Antiquities Authority. 43–45.

Gorin-Rosen, Y. 2000. The ancient glass industry in Israel. Summary of the finds and new discoveries. In M.-D. Nenna (ed.) *La route du verre. Ateliers primaires et secondaires du second millénaire av. J.-C. au Moyen Âge.* Lyon: Maison de l'Orient Méditerranéen-Jean Pouilloux. 49–63.

Gorin-Rosen, Y. 2002. A Group of Glass Vessels from Nir Gallim. In *'Atiqot* 43. Jerusalem: Israel Antiquities Authority. 119–126.

Isings, C. 1980. Glass from the *Canabae Legionis* at Nijmegen. In *Berichten van de Rijksdienst voor het Oudheidkundige Bodemonderzoek* 30. Amsterdam: State Service for Archaeological Investigations in the Netherlands. 281–346.

Jones, J.D. 1987. The glass. In S. T. Parker (ed*.) The Roman frontier in central Jordan. Interim Report on the Limes Arabicus Project, 1980-1985*. British Archaeological Reports International Series 340. Oxford: British Archaeological Reports. 621–653.

Keller, D. forthcoming. *Die Gläser aus Petra*. Petra ez Zantur 3. Terra Archaeologica 4. Mainz: Verlag Philipp von Zabern.

Kraemer, C.P. 1958. *Excavations at Nessana 3. Non literary papyri*. Princeton: Princeton University Press.

Leon, H.J. 1941. Sulphur for broken glass. In *Transactions and Proceedings of the American Philological Association* 72. Hartford: American Philological Association. 233–236.

Lindblom, J. 2002. Glass objects. In J. Frösén and Z. T. Fiema (eds.) *Petra. A city forgotten and rediscovered*. Helsinki: Helsinki University Press. 217–223.

Meyer, C. 1988. Glass from the North Theater Byzantine Church, and soundings at Jerash, Jordan, 1982-1983. In W. E. Rast (ed.) *Preliminary reports of ASOR-sponsored excavations: 1982-1985*. Bulletin of the American Schools of Oriental Research Supplement 25. Baltimore: Johns Hopkins University Press. 175–222.

Morel, J.-P. 1979. La ceramica e il vetro. In F. Zevi (ed.) *Pompei 79*. Naples: Gaetano Macchiaroli Editore. 241–264.

Pasqui, A. 1897. La villa pompeiana della Pisanella presso Boscoreale. In *Monumenti Antichi* 7. Milano: Reale Accademia dei Lincei. 398–554.

Price, J. 1976. Glass. In D. Strong and D. Brown (eds.) *Roman crafts*. London: Duckworth. 111–125.

Price, J. 1985. The Roman glass. In L. F. Pitts and J. K. St. Joseph (eds.) *Inchtuthil, the Roman legionary fortress*. Britannia Monograph Series 6. London: Society for the Promotion of Roman Studies. 303–312.

Price, J. 1995. Glass vessels. In W. H. Manning (ed.) *The Roman small finds. Report on the excavations at Usk 19965-1976*. Cardiff: University of Wales Press. 139–191.

Price, J. 1998. The social context of glass production in Roman Britain. In P. McCray and W. D. Kingery (eds.) *The prehistory and history of glassmaking technology*. Ceramics and Civilization 8. Westerville: American Ceramic Society. 331–348.

Price, J. 2002. Broken bottles and quartz-sand: Glass production in Yorkshire and the north in the Roman period. In P. Wilson and J. Price (eds.) *Aspects of industry in Roman Yorkshire and the north*. Oxford: Oxbow. 81–93.

Rütti, B. 1991. *Die römischen Gläser aus Augst und Kaiseraugst*. Forschungen in Augst 13. Augst: Römermuseum.

Shepherd, J. 1986. The Roman features at Gateway House and Watling House, Watling St, City of London. In *Transactions of the London and Middlesex Archaeological Society* 37. London: Parker 125–144.

Stern, E.M. 1999. Roman glassblowing in a cultural context. *American Journal of Archaeology* 103, 441–484.

Sternini, M. 1995. *La fenice di sabbia. Storia e tecnologia del vetro antico*. Bari: Edipuglia.

Tortorici, E. 1994. Il carico. In Babbini, L. et al. *Operazione Iulia Felix. Lo scavo subacqueo della nave romana rinvenuta al largo di Grado*. Edizioni della Laguna. 45–53.

Vose, R.H. 1980. *Glass*. London: Collins.