ABSTRACT

JONES, ASHLEY GORDON. Motivation, Mechanics and Magnitude: A Study of Glass Recycling in the Roman Empire. (Under the direction of Dr. S. Thomas Parker).

The topic of Roman glass recycling is not often discussed in scholarly literature. Knowledge of this subject, however, is integral to our understanding of the Roman glass industry and the ancient economy more generally. Evidence for Roman glass recycling comes from three main sources: ancient literary references, archaeological remains, and chemical composition studies. All three types of evidence must be viewed in conjunction if we wish to understand the motivations for, as well as the mechanics and magnitude of glass recycling in antiquity. By examining these three categories of evidence together, this study will demonstrate that the Roman world recycled glass for at least three interrelated reasons: (1) technical improvements, (2) economic thrift, and (3) geographic concerns, such as the lack of access to raw materials or adequate fuel resources.

This study will focus much of its attention on case studies from the Roman Levant and Britain. By looking at provinces in both the east and northwest, this study will obtain a broader view of glass recycling practices as they pertain to different corners of the Empire. As will be revealed, there was no universal formula for glass recycling in Roman times. Procedures differed on account of the economic, political, and social landscape of a given region or site. Furthermore, glass-recycling procedures were not static but shifted in response to changing circumstances—be they faltering trade routes or the presence of new cultural groups. In this way, recycling allowed glassworkers to be both resilient and flexible when faced with hardships or new situations.
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Motivation, Mechanics and Magnitude: A Study of Glass Recycling in the Roman Empire

by
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DEDICATION

To my family and friends, who have been tremendously supportive.
BIOGRAPHY

Ashley Jones grew up in Edmonton, Canada. She completed her undergraduate degree at the University of British Columbia in Vancouver, where she majored in Classical and Near Eastern Archaeology and minored in Anthropology. She has a passion for material culture and has worked on three archaeological projects in Petra, Jordan. Since working in Jordan, Ashley has focused much of her studies on the Roman history of the Levant. In addition to studying the eastern Roman Empire, Ashley is also interested in Roman Britain and since coming to North Carolina State University, has had several opportunities to write papers on this subject. Her thesis is a culmination of these research interests.
ACKNOWLEDGMENTS

I would like to acknowledge Dr. Parker for encouraging me to study Roman glass and for editing the chapters of my thesis. I would also like to thank Dr. Dixon, for designing an independent study on ancient glass for me. This course first sparked my interest in glass recycling and Dr. Dixon’s encouragement allowed me to realize that this topic would be ideal for a Master’s thesis. I would also like to thank Dr. Heinen for helping me interpret and translate some of the ancient texts referred to in this thesis. Lastly, I would like to acknowledge both Dr. McGill and Dr. Mell who served on my thesis committee.
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GLOSSARY

Technical Terms

**annealing**: Gradually cooling a finished glass object to relieve stresses resulting from different rates of cooling of its various parts such as the body, handle, and foot of a vessel, or its surface or skin and its interior… Some ancient glass blowers may have simply covered finished pieces with hot ashes in order to slow down the cooling process, while others may have put their pieces in a specific area of the glass-working furnace or, possibly, in a separate oven built specifically for annealing, as is today the most common practice.

**blowpipe, blowing-iron**: A metal tube used for blowing glass.

**bubbles**: Air pockets accidentally trapped in glass during glass making, lass melting, glass working… Ancient glass usually has more bubbles than modern glass, perhaps because the glass has become too viscous for gaseous reaction products to escape or because the crucibles were made of clay.

**casting**: Filling a mold with amorphous glass. Most modern casting is done by pouring molten hot glass into a preheated mold and then annealing it. Before the introduction of hot glass in glass working, casting processes were variations of what is now commonly called chip casting.

**colorant**: Usually a metallic oxide added deliberately to the batch to color the glass. Frequently used colorants in antiquity were the oxides of copper, iron, cobalt and manganese. These produce different colors depending on the amount of oxygen in the atmosphere of the furnace. Such deliberately colored glasses are called “specialized glasses.” Glass that has not been decolorized or colored by deliberately introduced ingredients is called “natural bluish green” (or some alternative of this phrase). The natural bluish green color results from iron oxide, a common impurity in many sands.

**crucible**: A container or pot placed in the furnace for making or remelting glass. Throughout antiquity and the Middle Ages crucibles were small, made of fired clay.

**cullet**: …Broken objects or waste from glass working such as knock-offs, moils, etc.

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1 All technical terms, as well as those relating to vessel shapes, have been copied from Marianne Stern’s *Roman Mold-Blown Glass* 1995: 19-32, with the exception of *cullet dump*, *glass batch*, *goblet* and *sagging*, which I myself have defined. I have also defined all definitions in the section “Geographic and Historical Definitions,” unless otherwise cited.
cullet dump: Cullet that has been amassed and was intended to be used in the secondary production process, but was discarded or dumped prior to being recycled. Multiple factors could lead to the dumping.

decolorizer: An ingredient added to the batch to counteract the effect of impurities of iron oxide which give glass a yellowish or bluish-green color. In antiquity the most common decolorizing agents were antimony and manganese… Decolorized glass is “specialized glass.”

furnace: Throughout antiquity glass making and glass working required different technologies and different types of furnaces. This distinction is reflected in Greek and Latin terminology for the glass industry. The ancient Roman glass industry knew specialized furnaces for three different functions, one for each of the two steps of glass making and one for glass working.

glass batch: Used interchangeably to refer to the mixture of silica, alkali oxide and lime in secondary production, or the ingredients of raw glass which are melted down into a molten state during secondary production.

glass blowing: Inflating glass with air blown through a pipe to form a hollow object. Glass can be free blown, or it can be blown into various types of molds.

glass making: The process of making glass from basic raw materials. Throughout antiquity and the Middle Ages, glass making was a two-stage process requiring different furnace for each stage. First a solid-state reaction between silica and alkali (soda or potash) was required, but this reaction should not allow the mass to melt, because the released gases would be trapped in the molten glass. This process is also called fritting. After the reacted frit was cooled, ground up finely, and mixed with minor ingredients such as colorants, opacifiers, and others, the second phase consisted of melting the mixture… Ancient glass melted at approximately 1000-1100 degrees Celsius. The resulting raw glass was an article of trade; it was sold in ingots or chunks and transported to the workshops where glass working made it into objects and vessels.

glass melting: The preparation of molten glass by remelting fragments of cullet and/or raw glass for glass working. Glass melting requires only one heating operation. No knowledge of glass making is needed.

glass working: The forming of glass into objects. This can be done when glass is heated (hot working) or while it is cold (cold working). Hot working procedures used by the Romans included various casting techniques, fusing, mold-forming and sagging, core-forming and spinning, and blowing… In the Roman period, most hot working was done in a furnace built specifically for that purpose.
ingot: A mass of raw glass of a convenient shape for storage or transportation to be processed later. Glass ingots were usually shaped like a circular or segmental cake or square, depending on the shape of the crucible in which the glass was made.

kiln: See furnace.

knock-off: Glass remaining on a blowpipe or pontil after the vessel is removed.

marver: A flat surface of stone or metal on which a gather or paraison is rolled to smooth and shape.

moil: the unwanted part of the paraison—an inflated gob or gather of glass—which is removed from the blowpipe with the unfinished vessel. After the vessel is annealed, the moil is cracked off along a scoring line. Moils become cullet.

mold blowing: Blowing into a mold to give a vessel its final shape. The designs on the walls of the finished vessel appear in negative on the interior.

paraison: An inflated gob or gather of glass.

primary production: See glass making; the same definition applies.

pontil: A solid metal rod, to which vessels may be transferred from the blowpipe for further working. Also used for applying bits for handles and trails.

pontil technique: The technique of transferring a vessel to a pontil for further working after it has been cracked off the blowpipe. The technique did not become common before the end of the first century.

trail, trailing: A coil of glass applied hot to a vessel, either to form a handle or for decoration.

raw glass: See glass making.

sagging: A technique wherein glass is heated to a point at which it can no longer support itself, thus it sags. At this time, it can be formed into any shape. If allowed to cool slowly, the glass will retain the sagged shape.

secondary production: See glass working; the same definition applies.

viscosity, resistance to flow: Viscosity is the most important property of glass. All processes of glass working (blowing, trailing, marvering, pinching, etc.) depend upon it. The lower the
viscosity, the softer and less cohesive the glass. In its molten state glass loses cohesion. A high viscosity makes the glassy state possible. Viscosity is measured in poise. Depending on the temperature and composition of glass, viscosity changes. Different glass-working operations require different viscosities.

**waste:** Any refuse from glass working, including cullet, knock-offs, moils, and deformed or broken vessels.

**Descriptive Terms for Vessel Shapes**

**amphora:** Originally, a two-handled storage or transport vessel used by Greeks and Romans for both liquids and solids. The shape was imitated in reduced size in glass. Glass amphorae and amorphiskoi (miniature amphorae) were used predominantly for liquids and semi-liquids.

**beaker:** A straight-sided cup that could have been used for drinking, playing with dice, or other functions.

**bottle:** A storage container for liquids with a narrow mouth that could be closed with a stopper.

**cup:** A deep or shallow bowl used for drinking.

**flask:** A container of bottle shape that was not meant to be used for storage and therefore usually was not closed with a stopper.

**goblet:** A drinking vessel (without handles) that has a tall stem, supporting a deep bowl, and a round base.

**jug:** A container with one handle for pouring liquids; the mouth can be circular, spouted, or trefoil.

**Geographic and Historical Designations**

**Byzantine Period:** At its widest this term can be applied to the history of the eastern Mediterranean from 330 CE, when Constantine moved the capital of his Empire to Byzantium, until 1453 when the city was captured by the Ottoman Turks.

**Early Medieval Period:** The period of history in the northwestern parts of the empire from the fifth to tenth centuries.

**Eastern Empire:** The eastern part of the Roman Empire after its division in 395 CE.
**Hellenistic Period:** A term used to denote the history of the Greek world from 323 BCE, the death of Alexander the Great, through to 30 BCE, with Rome’s conquest of Ptolemaic Egypt.

**Levant:** A term designating the lands and islands of the eastern Mediterranean. These include modern Syria, Lebanon, Palestine, Israel and Jordan, as well as the island of Cyprus.

**Near East:** The region consisting of those countries lying adjacent to the eastern shores of the Mediterranean (i.e. the Levant) as well as Mesopotamia and Egypt.

**Roman Empire:** All territories under Roman rule from 27 BCE, when Augustus became Emperor, to the deposition of Romulus Augustus in 476 CE in the West, or the fall of Constantinople in 1453 in the East. The Empire was divided into eastern and western halves in 395 CE.

**Syro-Palestinian coast:** The term “Syro-Palestinian” is used by many scholars to designate all Palestinian, Phoenician, and Syrian lands of antiquity. “Palestine,” comprises roughly the area in Lebanon south of Tyre; Israel, including the Gaza Strip, and the western-half of Jordan. “Syria” correlates to the modern territory of the Arab Republic of Syria. “Phoenicia” refers to land on the coast of the eastern Mediterranean from Akko, in Israel, to Lattayka, in Syria (Stern 1995: 32). This term is particularly important for the history of glass, as this material is said to have had its origins there (Strabo, *Geography* 26.2.24-25; Pliny, *Natural History* 36.65). This is also the area in which Pliny claims glass blowing was invented (*Natural History* 36.193).

**Western Empire:** The western part of the Roman Empire after its division in 395 CE.
CHAPTER 1

Introduction

The “great Roman glass industry” developed under the guidance of Hellenistic glassmakers in the eastern Mediterranean during the first century BCE. While it initially relied on a host of Hellenistic procedures, glass production quickly developed into a strictly Roman enterprise and within two generations it attained maturity (Grose 1989: 241). This maturity was aided in large part by the advent of glassblowing, a revolutionary technique that forever changed the industry. Although Roman glassblowing is spoken about widely in scholarly literature, an equally momentous and closely related development—the introduction of glass recycling—receives comparatively little attention from academics.

Glass has the remarkable quality of being continuously recycled without losing much of its strength or original characteristics. While modern society is well aware of this property, it may be surprising to learn that glass recycling dates back to Roman times. Literary, archaeological, and chemical composition evidence attests to the prevalence of glass recycling from the first century CE onward. Despite this lengthy history, or perhaps because of it, modern glass recycling differs greatly from that which was carried out under the Romans. Nowhere is this more apparent than when one compares motivations for recycling in Roman times with our own intentions. “Going green” has become increasingly fashionable.

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2 Stern (1999: 444) refers to “the great Roman glass industry.” In this study the term “Roman glass” will apply to all glass from Roman areas of occupation from the first to seventh centuries CE. The term “Byzantine” will also be used to further qualify Roman glass from the Eastern Empire dating to the fourth through seventh centuries.

3 Hellenistic glass vessels were often made using the core-forming technique, which involved wrapping heated rods of colored glass around a sand or clay core (Markoe 2000: 157). Sagging for the creation of glass cups was also popular (Jones 2010: 304), while the casting method was used extensively for making glass bowls (Grose 1979: 54).
in recent decades. Society today champions recycling and encourages consumers to be environmentally conscious. This is in stark contrast to Roman times. By examining the literary, archaeological, and chemical composition evidence in conjunction, this paper will demonstrate that the Romans recycled glass, not out of care for the environment, but instead, for at least three interrelated reasons: (1) technical improvements, (2) economic thrift, and (3) geographic concerns, such as the lack of access to raw materials or fuel resources. In addition, this interdisciplinary analysis will provide information as to both the mechanics and actors involved in glass recycling, as well as the scale of this activity in varying corners of the Roman world.

**Early Glass: Origins, Development and Application**

Scholars believe that glass was first discovered in the Early Bronze Age Near East (ca. 2300), either from an evolutionary development in glazing technologies, or as a byproduct of metallurgy. As an industry, glass manufacturing developed slowly through a complex process of experimentation with chemical composition and techniques for production, manipulation, and application (Rasmussen 2012: 1). Artisans initially used glass as a less expensive substitute for precious stones. As such, the earliest extant glass remains are “small, fine objects, such as beads, inlays and cylinder seal” (Luckner 1994: 79). Glass vessels do not appear in the archaeological record until the Late Bronze Age, more specially...
the sixteenth century BCE. The systematic production of relatively large quantities of glass objects is generally believed to have begun in Mesopotamia (Reade 2012: 322). More specifically, since the earliest glass vessels have been found at sites controlled by the Hurrian kingdom of Mitanni, its people have been credited with this breakthrough (Luckner 1994: 79). A list of sites in the Mitanni region where early glass vessels appear can be found in Henderson’s work; he notes that these include: “Alalakh, Nuzi, Assur, Tell el-Rimah and Tell Brak” (2013: 135).

Glassworkers created these early vessels by way of the core-forming technique, which involved wrapping heated rods of colored glass around a sand or clay core (Maroke 2000: 157). Although laborious, the core-forming method would retain prominence for the next fifteen hundred years.

While glass products of the Late Bronze Age tend to be “granular or opaque,” by the Iron Age (ca. 1200 BCE) procedures such as dipping and hand molding helped to generate brightly colored glasses with homogenous textures (Humphrey et al. 1998: 375). During the Hellenistic period (323-30 BCE) this rather conservative industry began to see increased levels of experimentation. While certain types of glassware became more elaborate—such as molded monochrome wares and mosaic polychrome wares—others became significantly less expensive and more widely available (Jones 2010: 303). In addition, glass production greatly intensified during this period thanks to the introduction of new techniques such as sagging for the creation of glass cups. Jones remarks, “these cups came remarkably close to mass-production” (2010: 304). Glassworkers also employed the casting technique for the creation of open-form vessels, such as bowls. These bowls are thought to be the first commonly used glass vessels in antiquity (Grose 1979: 54). Although glass vessels were becoming more

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6 The systematic production of relatively large quantities of glass objects is generally believed to have begun in Mesopotamia (Reade 2012: 322). More specifically, since the earliest glass vessels have been found at sites controlled by the Hurrian kingdom of Mitanni, its people have been credited with this breakthrough (Luckner 1994: 79). A list of sites in the Mitanni region where early glass vessels appear can be found in Henderson’s work; he notes that these include: “Alalakh, Nuzi, Assur, Tell el-Rimah and Tell Brak” (2013: 135).

7 The Late Bronze Age phase of glass production is also associated with a number of technological advancements including: (1) the creation of the first furnace that could lodge a sizable crucible; (2) the intentional production of opaque glasses; and (3) the production of the first mosaic glass vessels made using molds (Henderson 2013: 156).

8 A good discussion on Hellenistic glass can be found in Jones (2010: 303-304).

9 See the Glossary above for the definition of technical terms such as *sagging* and many others.
popular thanks to these new techniques, it is not until the invention of glassblowing that the industry truly took off.

The Glassblowing Revolution

Glassblowing involves remelting raw glass so as to turn it into its molten (completely liquefied) state. As the molten glass cools it becomes plastic and shapeable, at which point it is placed on the end of a blowpipe and blown freely or into a mold (Stern 1995: 23). Scholars believe glassblowing originated with craftsmen on the Syro-Palestinian coast during the first century BCE. Pliny tells us that *flatu figurare*, or “shaping by breath” was a means of production for which Sidon had been famous in the past (*Natural History* 36.193 as cited in Stern 1999: 443). Interestingly, the earliest archaeological evidence for glassblowing comes from a workshop in Jerusalem, also in the Levant (Henderson 2013: 213). Although the craft had its origins in the eastern Mediterranean, glassblowing would come to be perfected in Italy.

With Rome’s increased presence in the eastern Mediterranean during the first century BCE, the Romans quickly noted glassblowing and appropriated it for their own benefit. During this time, Sidonian glassblowers commonly migrated to Italy and established businesses there. Stern argues that the interaction between Romans and Sidonians was responsible for many breakthroughs and advancements that led to the development of “the great Roman glass industry” (1999: 444). Over a century of experimentation divides the first trial inflation from the standardized glassblowing methods observable in the mid-first century

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10 Sidon was part of the “Phoenician homeland” during antiquity. It is located in modern-day Lebanon.
CE. By this time, many of the tools and techniques, which we still consider integral to the craft today, were firmly established: glassblowing furnaces with closed heat-chambers, the blowpipe, the use of molten glass, the pontil technique, and fire-finishing of a vessel’s rim (Stern 2008: 536).11

Glassblowing revolutionized the industry by greatly increasing the versatility of the material and in turn opening it up to a wide variety of potential uses. The entire nature of glass vessels changed: thin-walled transparent objects began to replace the thicker and heavier styles of earlier periods (Rasmussen 2012: 32; Stern 2001: 9). Furthermore, glassblowing increased the speed of production thereby allowing glass to become a relatively cheap commodity (Humphrey et al. 1998: 358).12 Glass was no longer simply a luxury material, but could be employed for the fabrication of a wide assortment of utilitarian vessels (Henderson 2013: 251). While the first blown vessels tended to be small and used to contain perfume oils, cosmetics or medicine, dining supplied a second function (Forbes 1996: 15). Metal dinner sets were often replaced by glass counterparts as the former were said to give off unpleasant odors, an advantage that Petronius commented on: “You will forgive me if I say that personally I prefer glass; glass at least does not smell. If it were not so breakable I should prefer it to gold; as it is, it is so cheap” (Satyricon 50, as translated by Heseltine 1951: 89). In addition, glass jugs, flasks and decanters were preferred to metal alternatives because they did not affect the taste of wine (Stern 2001: 39).

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11 The gap can perhaps be explained by the fact that ancient glassworkers were often specialized and did not communicate with one another. Beadmakers—the first artisans to discover that glass could be blown—had little use for inflation, while the glassworkers who made vessels had few opportunities to discover the new technique (Stern 2008:536).

12 The Roman poet Martial spoke about the advantages of cheap glassware in Epigrams 12.74.
Although glass vessels from the first century were distributed widely throughout the Empire, from the second century onward glassblowing followed two separate trajectories in the western and eastern Mediterranean. While the glass industry flourished in the west during the first century CE, the late Roman and early Byzantine periods were the most prominent eras for glassblowing in the east (Stern 1999: 480-481). This divergence will be explored further in subsequent chapters.

Glass Production: A Brief Overview of Organization and Scale

As early as the second millennia BCE glass production involved two distinct processes: primary (glassmaking) and secondary (glass working) production (Jones 2010: 302). These steps did not need to occur in the same locality. In fact, they were generally carried out “in separate locations by different specialists” (Jones 2010: 302). Primary production, the engineering stage, refers to the creation of raw glass from a mixture of three ingredients: silica (sand or crushed quartz); soda, (in the form of plant ashes or minerals, i.e. natron), which is used as a flux to lower the melting temperature of the silica; and lime, either present in the silica source or added separate as limestone or shell (Ganio et al. 2012: 743). When fused at high temperatures—more than 1000 degrees Celsius—these

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13 The division between primary and secondary glass production is evidenced by the Ulu Burun Shipwreck. Dated to the Late Bronze Age (more specifically the 14th century BCE) this wreck contained 175 glass ingots (Pulak 1988). It demonstrates that raw glass was being shipped to other areas of the Mediterranean where it could then be worked into vessels and other objects.

Although they generally occurred separately, there is evidence for both primary and secondary production occurring at the same locality at Apollonia-Arsuf, Israel during its Late Byzantine phase of occupation, i.e. sixth and seventh centuries (Freestone et al. 2008). This has also been suggested for the Romano-British site of Coppergate York, although the evidence from this site is not conclusive (Jackson et al. 2003; Price 2003).

14 “Natron is a naturally occurring evaporite that forms in evaporitic lakes of Egypt and Syria, most
ingredients form raw glass. Raw glass was then shaped into ingots or broken into chunks so as to be easily transportable (Jones 2010: 302).

While the steps involved in raw glass production are well known, scholars still debate the organization of this industry in Roman times. Presently, two competitive models for glassmaking exist: the “regional production” and the “localized production” models (Foster and Jackson 2009: 190; Gallo et al. 2014: 8). According to the “regional” model, primary glass production was a large-scale venture that took place in a small amount of centers, likely limited to areas with direct access to the essential materials—namely a particular type of silica source. Raw glass produced at these centers would then be shipped to secondary workshops throughout the Mediterranean (Foy et al. 2000, 2003; Freestone et al. 2000, 2002; Freestone 2003). In contrast, the “localized model” argues that a larger number of regional workshops produced raw glass on a relatively small-scale and then redistributed their product to nearby glass-working artisans (Wedepohl and Baumann 2000; Wedepohl et al. 2003). While both models are appealing, there seems to be more scholarly support for the former.

Excavations have identified very few primary production centers active in the Roman world. Of the raw materials necessary for glassmaking, sand and lime were widely available throughout the Roman world, however soda was harder to come by. Deposits of mineral soda (natron) are rare in Mediterranean but are known in Egypt and Syria (Price 2003: 81; Rasmussen 2012: 23). Therefore, it is not surprising that the Levantine coast and Egypt were important areas for primary production during antiquity. Recently, however, notably the Wadi Natrun, approximately 100 km west of Cairo” (Rasmussen 2012: 23).

Glassmaking furnaces have been found in Apollonia, Bet Shearim, and Bet Eli’ezer; all of which are in present-day Israel (Abd-Allah 2010: 1868).
scholars have conducted analytical studies in an attempt to prove that production occurred in other areas of the Empire as well. These studies were spurred on by literary testimony: Pliny the Elder (Natural History 36.194) remarks “that besides Egyptian and Levantine resources, also raw materials from Italy and the Gallic and Spanish provinces were used in glass making” (as cited in Degryse and Schneider 2008: 1993). Chemical composition analyses undertaken by Degryse and Schneider (2008) and Ganio et al. (2012) have confirmed Pliny’s insights. These studies reveal that the central and northwestern parts of the Empire (Italy, Gaul, and Spain) were in fact producing raw glass from the first through third centuries, but that from the fourth to eighth centuries, primary production was once again limited to the Near East.16

Secondary glass production, the artisanal stage, is the process by which raw glass is shaped into vessels and other objects. By the first century CE glassblowing had ousted the core-forming method as the most common secondary production technique. Evidence for secondary glass production is much more prevalent in the archaeological record than primary production; glassblowing workshops dating to the first to seventh centuries have been found throughout the Mediterranean (Price 2003: 83).17

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16 This is confirmed by the compositional signatures of glass and raw materials studied from these locales. It appears that during the Roman Imperial period, shell from the western Mediterranean was being used as raw material (more specifically as a source of lime) during primary production (Degryse et al. 2008; Ganio et al. 2012).

17 For example, glass-working installations have been found in the provinces of Britannia (Price and Cool 1991; Price and Cottam 1998), Gaul (Foy and Nenna 2001) and Germania (Follmann-Schulz 1991; Wedepohl et al. 2003), as well as in Turkey (Degryse et al. 2005; Lauwers et al. 2007), and multiple sites throughout the Near East, such as Jalame (Weinberg 1988), Beit She’an (Mazor and Bar-Nathan), Ramla (Tal et al. 2008), and Beit Ras (Abd-Allah 2010).
The Mechanics of Glass Recycling: Cullet and its technical advantages

The term “recycling” is rather ambiguous. Indeed it can be used broadly to refer to any practice that extends the life of material resources. This would include measures involved in the “maintenance, repair, exchange and the adaptation or reuse of material culture” (Werret 2013: 627). A more precise definition, however, will be used in this study:

Recycling is an activity whereby a secondary material is introduced as a raw material into an industrial process in which it is transformed into a new product in such a manner that its original identity is lost. Secondary materials are those that (1) have fulfilled their useful function and cannot be used further in their present form or composition and (2) materials that occur as waste from the manufacturing or conversion of products. (Darnay and Franklin 1972: 3 as cited in Degryse et al. 2006: 494).

In accordance with this definition, glass recycling—both ancient and modern—involves the introduction of cullet into the glass batch. The discovery that molten glass could be blown was intimately connected to the awareness that cullet could be recycled. As Stern states, “the realization that glass could be totally remelted led to the deliberate collection of broken glass vessels and recycling became synonymous with remelting” (1999: 451).

Cullet can be used in both the primary and secondary production process, although the latter seems to have been more common in the Roman World (Foy 2003: 273). The use of cullet allows for several technical improvements. Firstly, it is possible to fashion glass vessels solely out of cullet, a procedure which was carried out in Roman London (Perez-Sala and Shepherd 2008a: 143). The use of cullet on its own lowers the overall temperature needed to melt a glass batch. “Technologies requiring just a portion of cullet require temperatures of 1200 degrees Celsius whereas a furnace using cullet alone requires a maximum of 1200 degrees” (Perez-Sala and Shepherd 2008a: 143). Not only does this mean
less fuel will be expended, it also allows furnace technology and design to be simpler and more accessible to glassworkers.

On the other hand, cullet can also be added to a batch of raw materials. In this case, the use of cullet is advantageous as it promotes rapid melting and acts as a nucleus around which new glass forms (Stern 1995: 21). Cullet will melt long before a reaction occurs between the primary materials in the glass batch. The molten cullet thus provides a “continuous liquid phase” which easily absorbs heat, and when stirred, transmits that heat to the raw components of the batch—eventually causing them to react. As a result, new glass is produced more quickly and by using less fuel (Perez-Sala and Shepherd 2008a: 143). Lastly, when using cullet, more glass is produced per mass of crucible volume than when relying solely on raw materials. This is because “when using raw materials a percentage of the input is lost as waste gases, but when using cullet, there is no loss” (Perez-Sala and Shepherd 2008a: 143).

Although the addition of cullet has its advantages, one must be careful not to use it excessively. The introduction of too much cullet will increase the batch’s viscosity (Degryse et al. 2006: 494). Stern emphasizes the importance of maintaining the proper viscosity; as she argues, every aspect of glass working depends on it—such as blowing, trailing, and marvering (1995: 29). If a batch were too viscose, glass-working artisans would have a much more difficult time carrying out these steps. In addition, when vessels are made from cullet alone, they often end up having a bubbly texture (Price and Cottam 1998: 10; Keller 2005:}
Indeed cullet offered important technical benefits; however, the Romans needed to be selective with its usage or risk debasing their products.

The Advent of Glass Recycling

Despite the noticeable connection between glassblowing and the use of cullet, scholars are not certain when glass recycling first began. Pliny, writing around 70 CE, seems to have been unaware that glass fragments could be completely remelted (Natural History 36.199). In fact, the earliest literary reference to recycling comes from the Flavian poet Martial (Epigrams 1.41.1-5). On account of this, Stern suggests that glass recycling began sometime between 70 CE, when Pliny had finished writing most of his Natural History, and 86 CE, the date when Martial began to publish Epigrams (Stern 1999: 451). Conversely, Foy argues for an earlier date; glass recycling could have been taking place despite Pliny’s ignorance (2003: 272). It remains unclear whether the advent of recycling can be placed prior to or after 70 CE. Archaeological evidence from Pompeii, however, suggests that recycling may have been practiced as early as 79 CE. Here, excavators uncovered a basket full of broken glass that might have been a deliberate collection of fragments intended to be recycled (Morel 1979).

Regardless of the initial date, it is likely that by the late first century CE glass recycling was being practiced in the Roman world. At this time, strongly colored glasses, which had been popular in the Hellenistic period, were going out of fashion. Instead, the Romans opted for naturally colored bluish-green or colorless glassware (Stern 1999: 451; Paynter 2006: 18). This has to do with the fact that cullet lowers the overall temperature required to melt a glass batch. When glass is melted at high temperatures, imperfections, such as tiny bubbles, can be skimmed off the surface, while lower temperatures do not allow for this procedure (Price and Cottam 1998: 10).
These types of glasses were ideal for recycling. As Stern asserts, “[they] could be remelted without the risk of becoming an indistinct muddy color as would have been the result of remelting mixed fragments of colored glass” (Stern 1999: 451). While these two developments—the decline of brightly colored glass and the subsequent advent of glass recycling—may be coincidental, the increased popularity of naturally colored and colorless vessels probably augmented the rate at which Romans recycled glass. At the very least, it would have made their recycling ventures more successful.

**Previous Work on Glass Recycling**

As mentioned above, the topic of glass recycling has not received much attention from scholars. Only recently has this subject become of interest to the academic community. Marianne Stern’s article “Roman Glassblowing in a Cultural Context” (1999) has done much to promote this subject. Her article offers a brief but concise overview of glass recycling practices in the ancient world. She focuses primarily on the advent of glass recycling and the mechanics involved in this procedure. She begins by explaining that the reuse of broken glass fragments in mosaics and other artwork was a common feature during early periods of glass-making history. She then explains how the introduction of glassblowing and the use of molten glass led to the discovery that broken fragments could be remelted and thus recycled. Similarly, Danièle Foy’s “Recyclages et réemploys dans l’artisanat du verre. Quelques exemples antique et médiévaux” (2003), offers a short overview of the practice of recycling in ancient and medieval times. While she includes information on the literary, archaeological
and chemical evidence for this procedure, her work is brief and does not offer any in-depth analysis.

Daniel Keller has looked at this topic more thoroughly. In his article, “Social and Economic Aspects of Glass Recycling” (2005), Keller argues that the available evidence for this practice must be placed into its social and economic context; only this way can we begin to understand why glass recycling was practiced and what economic implications the practice had on Roman society. Keller focuses on both archaeological and textural evidence for his analysis. On the basis of this evidence Keller offers a hypothetical reconstruction of what glass recycling might have looked like in a Roman town: “a local economic cycle in which producer, consumer and middlemen profit without any kind of costly procedures by the simple means of barter” (2005: 68). He then offers an archaeological case study—southern Jordan during the Byzantine period—in order to demonstrate how complicated the interpretation of glass recycling is. He concludes by stating, “the practice of glass recycling is always strongly connected to the actual socio-economic situation” (2005: 76). In his view, economic hardships and/or a lack of resources can often account for why people recycled glass in the Roman world.

Keller’s approach to the study of Roman glass recycling is insightful and his work has done much to expand our knowledge of the subject. While he is right to stress the economic benefits of glass recycling, other factors, such as the technical improvements afforded by recycling, were also at play and must be equally considered. In addition, Keller’s study could

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19 Keller lists several civilian and military sites that yield material evidence for glass recycling (2005: 66) and then summarizes the literary evidence for this practice. Unfortunately Keller does not supply the ancient texts, nor does he critique them; he merely repeats what previous scholars have said on the subject.
benefit from more than one case study. Surely not all parts of the Roman Empire recycled glass for the same reasons or even to the same extent. Perhaps economic considerations are more significant in some parts and periods of the Roman Empire, while different concerns take precedent in other regions or times.

In a related article, titled “Deposition, Disposal and Re-use of Broken Glass in Early Byzantine Churches,” Keller stresses the importance of carefully analyzing glass finds from church contexts (2009). Churches present an interesting situation in regards to the study of the ancient glass industry. Glass remains feature prominently in these establishments and the manner in which glass was deposited can tell us much about the objects. By using case studies, Keller lists several reasons why an excavator might uncover large deposits of glass in church settings; one such reason may be that the church was collecting the material so as to recycle it. He claims, “broken glass from Early Byzantine churches could have been recycled, but this practice depended on the general economic situation” (2009: 287). It is not always appropriate to interpret glass remains as evidence for recycling. Instead, Keller cautions us against making such claims before the economic environment and other scenarios have been taken into account. This is an astute argument and one that will be revisited in Chapter 3.

Archaeological excavation reports also frequently mention Roman glass recycling. While the authors of these reports acknowledge that recycling occurred in the Roman Empire, they often fail to supply supplementary information about this practice and/or to connect their data to a wider historical context. Some recent publications, however, are
attempting to correct this inadequacy. For example, in an excavation report on London’s Roman Amphitheater, Perez-Sala and Shepherd present a short section, titled “The cullet dump and evidence of glass working” (2008a), in which they define cullet and its multiple uses in antiquity. They make mention of a few literary references to recycling and talk at length about the technical advantages of cullet. These authors also compare the evidence for glass recycling from the London amphitheater to other possible recycling sites in Roman Britain and the western Empire more generally. This report is a valuable tool for our understanding of glass recycling and thus will be explored in more depth in Chapter 3; archaeologists should consider similar approaches if evidence of this practice arises on their sites.

Chemical composition studies often deal indirectly with the topic of Roman glass recycling. Unfortunately these publications are laden with scientific jargon and are generally not accessible to a wide audience. Furthermore, since those conducting the studies are mostly scientists, instead of historians, their work tends not to focus on the context or historical significance of their results. A study by Schibille et al. (2012) does a good job of avoiding these pitfalls. These authors offer a comparative analysis of glass samples from two sites in Jordan, Petra and Khirbet et-Tannur. Their data reveals that, despite being situated relatively close to one another, the two sites engaged in very different glass recycling practices. In order to explain this difference the authors spend a good deal of time discussing the economic, social and political status of each site and how this may have affected glass consumption. This publication will be discussed further in Chapter 4.
With the exception of the work mentioned above, most references to glass recycling are made in passing. It is often a subsidiary subject and rarely an author’s main research interest. What is lacking is a holistic approach to the study of glass recycling in the Roman world. Indeed, evidence for this procedure comes from three main sources: (1) ancient literature, (2) archaeological remains, and (3) chemical composition studies. These sources, however, have yet to be comprehensively studied in conjunction. The current study will explore these three categories of evidence in order to rectify this situation. In addition, it will focus on two very different areas of the empire: the Levant, more specifically sites in modern Israel and Jordan, and Britain, a province in the northwestern Empire. It is often not appropriate to make generalizations about the Roman Empire as a whole. Despite the ideal of Romanitas, the Roman Empire was not a single entity and it is important to recognize regional differences.²⁰ By looking at provinces in both the east and west, this study will obtain a broader view of glass recycling practices as they pertain to different corners of the Empire. The hope is that this approach will provide a more nuanced understanding of the motivations for, as well as the mechanics and magnitude of this complex procedure.

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²⁰ Romanitas is a term denoting the spirit or ideal of ancient Rome. It is used to indicate a set of cultural, political and social concepts that can be applied generally to the entire Empire.
CHAPTER 2

Literary Evidence: Street Peddlers and Petty Crime

Glass recycling is not often discussed in Roman literature. Surprisingly, Pliny, our most significant source on the ancient glass industry, makes no reference to this practice. Although he mentions that fragments of broken glass can be bonded together using heat, Pliny seems to be unaware that these pieces can be remelted to form a new batch of glass:

fragmenta teporata adglutinatur tantum, rursus tota fundi non queunt praeterquam abruptas sibimet in guttas, veluti cum calculi fiunt quos quidam ab oculis appellant (Natural History 36.199).

“Pieces of broken glass can, when heated to a moderate temperature, be stuck together, but that is all. They can never again be completely melted except into globules separate from each other, as happens in the making of glass pebbles that are sometimes nicknamed eyeballs” (as translated by Eichholz 1989: 157).

As mentioned earlier, this misunderstanding led Stern to assert that the Romans began to recycle glass sometime after 70 CE—when Pliny had completed the majority of his Natural History (Stern 1999: 451). Conversely, Daniele Foy argues for an earlier date; glass recycling could have been taking place despite Pliny’s ignorance (2003: 272). Regardless of the initial date, the Romans appear to be recycling glass by the late first century CE (Stern 1999: 451).

While no ancient source deals directly with glass recycling, the purposeful collection of broken glass—or cullet—is mentioned by the Flavian poets Martial and Statius, the second century poet Juvenal, the third century historian Cassius Dio, and the early medieval historian Gregory of Tours. Unfortunately, these extant accounts are brief and often refer to the collection process in a derogatory manner. Glass recycling was a poetical topos used to refer to the vulgarity of a person or place. In addition, broken glass was occasionally
employed as a euphemism to indicate worthlessness. For example, in Petronius’ *Satyricon*, written during the reign of the Emperor Nero (54-68 CE), the character Ascyltos remarks:

Quid ego, homo stultissime, facere debui, cum fame morerer? An videlicet audirtem sententias, id est vitrea fracta et somniorum interpretamenta? (*Satyricon* 10.1)

“Well, you fool, what do you expect? I was perishing of hunger. Was I to go on listening to his views, all broken glass and interpretations of dreams?” (as translated by Heseltine 1951: 13).

As Perez-Sala and Shepherd argue, these literary techniques seem to be at odds with the value that artisans placed on broken glass (2008a: 143). Indeed ancient literature does little to clarify questions concerning the market value of cullet in Roman times. Yet, despite their shortcomings, these sources offer insight into both the scale of recycling and the social status of those engaging in this activity. As such, literary evidence is an integral component to the study of glass recycling in antiquity. In fact, Martial and Statius have become standard citations for scholars referring to Roman glass recycling; unfortunately the other sources mentioned above are often left out of the discussion. The following chapter will analyze, translate and discuss the aforementioned accounts to better understand the place of glass recycling in ancient society and its broader implications for the Roman economy.

**Early Accounts: The Flavian and Second Century Poets**

The works of three poets—Martial (ca. 41-104 CE), Statius (ca. 45-96 CE), and Juvenal (ca. 60-140 CE)—are often cited as evidence for ancient glass recycling (Leon 1941; 21

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21 It should be noted that in the Loeb translation, M. Heseltine translated *vitrea fracta* as “broken bottles” not “broken glass.” I have chosen the latter here, as I believe it to be the most accurate translation.
Stern 1999; Foy 2001; Price 2005). In all three accounts, the ancient authors mention broken glass in conjunction with some sort of “sulfur” item. Martial, who began to publish *Epigrams* in 86 CE, provides the earliest description:

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Urbanus tibi, Caecili videris
non es, crede mihi. quid ergo? verna es
hoc quod Transtiberinus ambulatory
qui pallentia sulphurata fractis
permutat viteris… (*Epigrams* I.41.1-5)
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“You fancy yourself a wit, Caecilius. Believe me, you are not. What then? You are a vulgar buffoon. What you are, the cheapjack from across Tiber is, who barters yellow sulphur for broken glass” (as translated by Shackelton Bailey 1993: 69).

Statius describes a similar scenario during a celebration of the Saturnalia:

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hoc plaudant grege Lydiae tumentes,
illic cymbal tinnulaeque Gades,
illic agmina confremunt Syrorum,
hic plebs scenia quique comminutes
permutat viteris gregale sulphur (Silvae I.6.70-74)
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“Here a crowd of buxom Lydian girls are clapping hands, here tinkle the cymbals of Cadiz, there troops of Syrians are making uproar, there are theatre-folk and they who barter common sulphur for broken glass” (as translated by Mozley 1982: 69).

Philologists have debated the meaning of these two passages since the early twentieth century. What is the connection between sulfured items and broken glass? In 1908, Edwin Post, referring specifically to Martial’s *Epigrams*, wrote, “it is uncertain whether the *sulphrata* was to be used as a cement or tinder, i.e. bits of wood tipped with sulfur” (1908: 21). Post preferred the former explanation; citing Pliny (*Natural History* 29.11.51,

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22 All translations provided in this chapter are from the Loeb Classical Library unless otherwise stated. Since many of these translations are written by British authors, they have used the British spelling for sulfur, i.e. sulphur.
36.67.199), he suggested that broken glass was mended with an adhesive made of sulfur in Roman times (Post 1908: 21). As both Leon (1941) and Smyth (1947) later argued, Post’s reading of Pliny was misguided. In fact, Pliny himself “does not suggest sulphur has any such [adhesive] property” (Harrison 1987: 203). Cato the Elder (ca. 234-149 BCE), however, mentions sulfur as an ingredient in a certain type of plaster:


“Make a cement for a wine-jar as follows: Take one pound of wax, one pound of resin, and two-thirds a pound of sulphur, and mix in a new vessel. Add pulverized gypsum sufficient to make it of consistency of a plaster, and mend the jar with it” (as translated by Hooper 1936: 57).

Yet this type of plaster seems only to have been effective on ceramic vessels and was probably not applied to glassware (Harrison 1987: 203). An alternative recipe for glue provided by Pliny—egg white plus lime—could possibly rejoin glass fragments, but, as Harrison explains, “the bonding would not have been strong enough to allow regular use, only display” (Harrison 1987: 203).23 Indeed, no adhesive known from ancient times could have restored a glass vessel to its original service (Harrison 1987: 204).

Post’s argument has since been rejected in favor of an idea proposed by Leon, who suggested that street peddlers acquired broken glass to recycle it (1941: 235-236). They would offer sulfur matches—a useful household commodity—in exchange for glass fragments that would otherwise have been thrown out (Leon 1941: 236). To support this

23 Although Harrison notes that this recipe is in Pliny’s work, he does not cite the passage where it can be found. I was unable to track down this citation.
conclusion, Leon draws our attention to another passage from Martial in which “the exchange of broken glass for sulphured sticks [sulphrato... ramento] is alluded to as a regular thing” (1941: 234):

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quae sulphurato nolit empta ramento
Vatiniorum proxeneta factorum (Epigrams 10.3.3-4)
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Referring to certain defamatory poems, Martial notes that they are so worthless that “the purchaser of broken Vatinian vessels wouldn’t pay a sulphur match for them” (Leon 1941: 234). Although this passage suggests that the phrase “as worthless as broken glass” was proverbial, it also seems to demonstrate that the exchange of glass fragments for sulfur matches was a “well-known practice” in Roman times (Leon 1941: 235). While other suggestions have been put forward since, Leon’s idea—that peddlers collected broken glass so that it could be recycled—still holds favor among scholars.24

Most recently, Harrison has refined Leon’s claim. According to Harrison, the items Martial’s peddlers hawked in exchange for broken glass were not sulfur matches, but a much more valuable commodity: vivum. As Harrison notes, “at face value, the context of [10.3.2-3] seems to parallel 1.41.2-5 so closely that *ramento*, there openly modified by *sulphurato*, almost demands to be supplied in 1.41” (1987: 206). However, he argues that the extra detail of *ramento* in 10.3 is an intentional mistake made by Martial.25 During the height of his career Martial was plagued by forgers and Epigrams 10.3, a passage in which Martial

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24 Such as that by Smyth (1947: 46-47) who argues that broken glass was repurposed by mosaicists. This claim has been dismissed on the grounds that mosaics were not popular during the 1st century CE (Harrison 1987: 204).

25 See Harrison (1987: 206) for a more detailed discussion. As he demonstrates, there are several other inaccuracies in 10.3 that expose Martial’s intent.
complains of a certain imposter, can be seen as his response to this epidemic. While the early
lines of Epigrams 10.3 lists several phrases that the imposter has taken directly from Martial,
Martial draws our attention to “slight changes in language” so as to “expose the limits of the
charlatan’s genius” (Harrison 1987: 206). Harrison suggests that *ramento* from 10.3 was not
only added because it was not intended in 1.41, but also “to show that it was wrongly
inferred by the plagiarist” (1987: 206). Furthermore, Harrison notes that sulfur matches did
not exist in antiquity; instead, by adding *ramento* the imposter may have been trying to
describe chemically treated fire logs (1987: 205).26

In his rush to embellish, Martial’s imposter overlooked the important adjective
*pallentia* in 1.41 (Harrison 1987: 206). *Pallens*, meaning pale or greenish, compliments
Pliny’s description of *vivum*, the purest grade of sulfur known to the ancient world (*Natural
History* 35.50.175).27 In its solid form, *vivum* served as both an internal and external
medicine; it was effective as a cough syrup, general pain reliever, wart remover, and laxative
(Harrison 1987: 207).28 Additionally, sulfur was, and still is, an integral ingredient in many
skin lotions and can also be used for personal hygiene purposes (Harrison 1987: 207).29 As
such, this product would have been a more enticing trading item than sulfured fire logs

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26 Percussion or friction matches were not invented until the nineteenth century. Evidence from Seneca
(*Natural Questions* 1.1.8), suggests that sulfured sticks were used to promote fire retention or expansion in
Roman times; these sticks, however, were not used to start fire (Harrison 1987: 205).
27 Pliny notes that *vivum*, in its solid form, was *tralucetque viret*, “translucent and green.”
28 As Harrison elaborates, Celsus comments on the use of *vivum* as a cough syrup (1.390), pain reliever
(1.348), and wart remover (2.10), while Pliny notes that sulfur-based mixtures can help to stop bleeding
(*Natural History* 34.50.167) and can also be used as a laxative (*Natural History* 35.54.79). Harrison does not
specify which work of Celsus these comments belong to. I can only assume Harrison is referencing *On
Medicine*, but I was unable to track down the specific references he cites.
29 Even Homer wrote about the use of sulfur for personal hygiene (*Iliad* 16.228; *Odyssey* 22.481, as
In addition, it would have resulted in a far greater impetus to recycle glass. In lieu of discarding fragments immediately upon breakage, people would have saved broken glass for recycling. In exchange, they would obtain a valuable and versatile product. This conclusion does not negate the possibility that fire logs were a marketable product in Roman times nor that they might have been exchanged for broken glass. In fact, Harrison concedes, “that may well be the activity in which the ‘drowsy-eyed salesman of sulphured merchandise’ is engaged in Martial 12.57.14” (Harrison 1987: 207). He maintains, however, that in the case of *Epigrams* 1.41, the hawker was certainly trading *vivum*. As such, we should consider that the broken glass obtained in exchange for *vivum* was considerably more valuable than has previously been posited.

In both Martial and Statius’ accounts, glass recycling seems to carry a negative connotation. Lowly peddlers were recycling glass directly on the streets; there seems to have been no formal organization. For these poets glass recycling was a way of hinting at the low and vulgar nature of a character or locale. In contrast, the second century poet, Juvenal, spoke about the exchange of sulfur for glass without these negative undertones. Juvenal’s writing describes an unfortunate client having a meal with his wealthy patron. The client is featured drinking out of a cheap goblet that is so badly broken it “calls for sulfur” (*poscentem sulphura*):

> tu Beneventani sutoris nomen habentem siccabis calicem nasorum quattuor ac iam quassatum et rupto poscentem sulphura vitro (*Satires* 5.48).

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30 *Sulphuratae lippus insitior mercis.*

31 This is not to say that recycling done by glassworkers would have been seen in a negative light. Only that those who acquired broken vessels on the streets were looked down upon—at least by these poets.
Unfortunately, Post’s flawed hypothesis seems to have led several authors to mistranslate this passage. An early translation in 1918 from G.G. Ramsay reads: “But you will drain dry a cracked cup with four nozzles that takes its name from a Beneventine cobbler, and calls for sulphur wherewith to repair its broken glass” ([1918] 1993: 73). In fact, some modern translations of Juvenal’s work, such as that of Peter Green, still display this error: “But the cup you drink from, the sort with four big nozzles—named after Nero’s long-nosed cobbler from Beneventum—will be shoddy and cracked, crying out for sulphur to mend it” (1998: 30).

The scholars mentioned above have all attempted the same solution for this problematic Latin phrasing. There is nothing in the original Latin passage, however, that explicitly states that sulfur would be used to mend the broken vessel. Instead, it seems plausible that early translators were influenced by Post’s argument and that this mistake has continued to be repeated. A better translation of Juvenal might read: “but you will drain dry a cracked cup with four nozzles that takes its name from a Beneventine cobbler, and is already demanding sulfur as a price for the shoddy and broken glass.”

While Juvenal’s account does little to help us define the agency of those who collected cullet, it nonetheless suggests that the exchange of broken glass for sulfur was a normative practice. When studied in combination with the works of Martial and Statius, it seems plausible that during the late first and early second century, street peddlers collected

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32 Lewis and Short cite Plautus (Mercator 2.4.22): *pro reliquis (libris) idem pretium poposcit*, as an example of *posco* denoting a cost (1907: 1402-1403).
broken glass on a relatively regular basis. If Roman poets referenced this practice in passing, it must have been relatively common.

**Later References: Cassius Dio and Gregory of Tours**

It appears that glass recycling became more frequent throughout the Roman Imperial period. The historian Cassius Dio (ca. 155-235 CE) states that the Emperor Claudius made Roman citizenship so widely available that one could attain it in return for a piece of broken glass:

> ὡνοῦντο καὶ διὰ τούτο μεγάλων τὸ πρῶτον χρημάτων πραθεῖσα, ἐπειθ᾽ οὕτως ὑπὸ τῆς εὐχερείας ἐπευωνίσθη ὅπε οὐκ ἔπειθ᾽ οὕτως ὑπὸ τῆς εὐχερείας ἐπευωνίσθη ὅπε καὶ λογοποιηθῆναι ὅτι κἀν υάλινα τις σκεύη συντετριμένα δῷ τινι (*Roman History* 60.17.6).

“For this reason, though the privilege was at first sold only for large sums, it later became so cheapened by the facility with which it could be obtained that it came to be a common saying, that a man could become a citizen by giving the right person some bits of broken glass” (as translated by Cary and Foster 1924: 411).

Marianne Stern cautions against assuming glass recycling was taking place during the reign of Claudius (41-54 CE). Instead, as she argues, this passage highlights how ordinary glass recycling had become by the time of Cassius Dio’s writing. According to Stern, the late second to early third centuries CE was a time “when recycling was so common that ‘broken glass’ had become an idiomatic expression for indicating cheapness” (Stern 1999: 451). In this light, broken glass must not have been too expensive for glassworkers to acquire, especially when compared to the price of raw glass.

Glass recycling was likely spurred on by this economic incentive. According to Diocletian’s *Price Edict* (16.1-9) of 301 CE, one pound of “Alexandrian glass” (raw glass
from Egypt) would have cost 24 denarii, whereas one pound of simple vessels fashioned out of this type of glass would cost 30 denarii—leaving a profit of 6 denarii, minus secondary production expenses such as fuel. This was by no means a large profit considering that the minimum daily wage of an unskilled laborer was 25 denarii, plus meals worth ca. 5-10 denarii (Price Edict 7.1-23 as cited in Stern 1999: 462). Substituting cullet for a portion of raw glass during the secondary production would have been both logical and thrifty. Glassworkers could have easily obtained cullet from a middleman, such as the peddlers described by Martial and Statius. In addition, artisans could have recycled waste glass and misfired vessels found within their own workshops. Both these actions would have been economical and were probably practiced by a majority of glass-working artisans.

This passage from Cassius Dio, however, raises some important questions. As glass recycling became increasingly common, did the value of broken glass decline? Were hawkers (or perhaps other agents) of the second and third centuries exchanging different products for broken fragments than those of the first century? Unfortunately the literary record does not help to clarify this situation. What ancient sources do reveal, however, is that the practice of exchanging broken glass fragments for some sort of reward—be it monetary or material—continued over several centuries and was not simply a short-lived trend.

The literary discussion of glass recycling appears again in early medieval Gaul. Bishop Gregory of Tours, writing in the late sixth century CE, mentions recycling in the Glory of the Martyrs. He tells us of “a bold thief” who entered a church in Yzeures, in modern France, by night hoping to steal liturgical vessels. Upon realizing that custodians
were watching him, the thief resorted to stealing the church’s glass windowpanes in hopes of acquiring gold in exchange. Next, the thief:

Missumque vitrum in fornace per triduum decoquens, nullum exinde opus potuit expedire; vicitusque crimine, divinum super se iudicium intuens, nequaquam motus perdurat in malis. Ablatum autem a cacavo vitrum, quod in pilulis nescio quibus conversum fuerat, negotiatoribus venundedit (Glory of the Martyrs 58).

“put the glass in a furnace and heated it for three days, but he accomplished nothing. [Although] he was overwhelmed by his crime and [although] he realized that a divine judgment had been passed on him, he was not upset and persisted in his evil deeds. He took from the furnace, glass that had been changed into some sort of small strands and sold it to merchants who had arrived” (as translated by Van Dam 2004: 57).

Because of his sins, Gregory of Tours later notes, the thief came down with lepram perpetuam, i.e. “incurable leprosy” (Glory of the Martyrs 58). While this source differs significantly in format from those of the Flavian poets, glass recycling—or rather the collection of cullet—is depicted in a similar light. It is still being performed by someone of (presumably) low social standing and the process seems to be quite informal. This passage is useful as it indicates that scrap glass was still being purchased in early medieval Gaul.

Although glass appears to be less valuable than other commodities found within a church, nonetheless broken fragments were profitable. Indeed glass recycling was not limited to a few centuries, but rather it was an activity that continued to be practiced after Roman times.

Conclusion

Literary evidence for glass recycling is somewhat limited and problematic. No in-depth description of the recycling process seems to have survived and negative connotations prevail in most extant accounts. When viewed alone, the literary evidence seems to suggest
that glass recycling was an informal venture conducted by lower-class members of society. One gets the sense that recycling was not an esteemed pursuit in ancient times. We must remember, however, that in all the above instances, glass recycling was not the main focus of the narrative. Instead it seems only to have been mentioned in passing: as a way to insult someone, a way to evoke imagery, or even to teach a moral lesson. Although they do testify to the presence of glass recycling in Roman times, the way in which ancient authors present the collection process may not be entirely accurate.

Due to the paucity of literary sources and their lack of detail, it is hard to know exactly what value the Romans placed on broken glass. We are left wondering whether all peddlers hawked the same product in exchange for cullet and how much money Gregory’s thief received for the windowpanes he stole. Could the value of broken glass have shifted over time as recycling became more common? Stern seems to argue in favor of this, but the evidence is scant (1999: 451). Furthermore, the value of glass may have varied depending on its type or the location within which it was being recycled. Presumably naturally colored glasses would have been more desirable than brightly colored alternatives. It is also possible that in areas with less access to the raw materials required for glassmaking, the value of broken glass would have been higher. Indeed questions persist; yet they should not serve to undermine the importance of including ancient sources in our discussion of Roman glass recycling.

Literary evidence is useful in so far as it implies there was a market for broken glass and that these fragments were purposefully collected. At least three distinct parties seem to
have been involved in the recycling process: (1) the owner of the original glass vessel, (2) the itinerant peddler who collects its broken pieces, and (3) the artisan who remelts cullet in order to create new objects. In all cases, material rewards or economic incentives seem to have propelled the process. Glass recycling was performed because it was a logical, economically beneficial, and worthwhile activity for all participants. Literary evidence, however, raises the question of the scale of this operation. Did only a few peddlers and thieves make a business out of recycling glass? Or could it have been carried out on a much larger scale? Did there exist a community-wide initiative to recycle glass—as is the case in modern times? As will be discussed in the following chapter, archaeological evidence renders a much different account than that which ancient authors provide. It appears that glass recycling may also have been a formal and large-scale enterprise.
CHAPTER 3

Archaeological Evidence: The Multiple Practitioners of Roman Glass Recycling

While ancient authors testify to the low status of those who recycled glass in the Roman world, archaeological evidence seems to suggest that glass recycling was a rather sophisticated process in antiquity. Material evidence for glass recycling comes from a wide variety of geographical regions and archaeological contexts—most notably from Byzantine churches, urban settings, shipwrecks, and industrial areas throughout the Mediterranean. Despite the variety of evidence, there are many difficulties in identifying glass recycling using material remains. Excavators rarely find glass vessels intact; as with most artifacts, glass remains are normally fragmentary and in poor condition. Surely not all broken glass uncovered from archaeological sites can be interpreted as cullet meant for recycling. In order to establish the presence of glass recycling, archaeologists must instead demonstrate that an intentional collection of broken vessels and/or waste glass has been amassed. In order to do so, the excavator needs to notice subtle patterns in the archaeological record and be aware of the prominence of glass recycling in the Roman world.

The popularity of glass recycling in the Roman times has several implications for the archaeological record. While recycling may be environmentally advantageous, it is archaeologically disastrous. In other words, the recycling of glass prevents it from entering the archaeological record. As a result, the glass recovered from most archaeological sites should be considered only a small portion of the original assemblage. Perez-Sala and Shepherd say it well:

33 All dates in this chapter are CE unless otherwise stated.
The glass that is found in many domestic occupation deposits may well be the glass that has simply escaped recycling. This glass must be a much reduced sample of what was originally in circulation, but the level of collection cannot be deduced and the significance of these fragments cannot be calculated. To understand the use of glass in antiquity it is necessary to find the glass that has been collected for recycling (2008a: 144).

Studying collections of cullet is one of the best ways to understand the function of glass and the workings of its industry in Roman times. It is therefore important that excavators recognize these deposits and record them carefully.

This chapter will review the material evidence for ancient glass recycling in three parts. The focus will be on comparing case studies from both the eastern and western parts of the Roman Empire. The first section, titled “The Archaeology of Collection,” will examine large deposits of cullet found in both Byzantine churches of the East, particularly those from modern-day Jordan, and those found in urban settings of the northwestern province of Britain. These collections suggest that cullet was amassed in order to benefit local glass workshops. The second part of this chapter will focus on “The Archaeology of Transportation.” This section will review the glass remains from two shipwrecks and discuss the possibility that cullet was transported across the Mediterranean in antiquity. When shipwreck evidence is taken into account, glass recycling appears to be a rather sophisticated procedure that engaged a diverse range of practitioners. Lastly, “The Archaeology of Production” will discuss the evidence for glass recycling from two distant glass-working sites: one located in Israel and the other in Britain.

When viewed in conjunction, the archaeological evidence demonstrates that there was no universal formula for glass recycling in Roman times. Recycling had multiple
practitioners, methods, and benefits; yet, the degree to which people recycled glass and their motivations for doing so, often differed. Procedures varied on account of one’s geographical position and access to resources—be they the proper primary ingredients to create raw glass, or enough fuel to maintain high-temperature fires. Since one’s motivation for recycling was often dictated by location, this chapter will compare glass recycling as seen in both the eastern and western parts of the Roman world. This is a useful juxtaposition as it can help to elucidate the different agents involved in, and intentions behind, glass recycling as it relates to opposite corners of the Roman Empire.

Seeing as much of this chapter will compare the glass industry of the eastern Mediterranean to that of the northwestern province of Britain, a few preliminary remarks are necessary. Firstly, it should be noted that primary glass production was much more common in the east, and was virtually absent from Roman Britain.\textsuperscript{34} This phenomenon can, in large part, be explained by geographic circumstances. Britain’s glass industry lacked direct access to all the primary materials necessary for glassmaking. Therefore, Britain had to obtain raw glass through long-distance trade. While glassmaking occurred from the first to third centuries in the nearby provinces of Gaul, Spain and Italy, by the fourth century production in the west seems to have halted. From the fourth to eighth centuries, scholars believe that only centers in the Levant and Egypt were in operation (Degryse and Schneider 2008; Ganio

\textsuperscript{34} As mentioned earlier, only one site in Roman Britain, Coppergate York, is thought to have been involved in the production of raw glass (during the late second or early third century); yet the evidence from this site is not conclusive (Jackson et al. 2003; Price 2003). As Price mentions, the glassmaking that went on at Coppergate York was very different from that which we see in the eastern Mediterranean. In particular it was “small in scale” and pottery vessels, not tanks acted as crucibles (2003: 89). Even though York may have engaged in primary production, it is also obvious that the collection of cullet, and thus glass recycling, was also undertaken at the site (Price 2003: 89).
et al. 2012). This occurrence may have provided an impetus for glassworkers in Roman Britain to rely more heavily on cullet than their eastern counterparts, who retained reliable access to raw glass well into the Byzantine period. In Britain, substituting cullet for a portion of raw glass would have been both logical and economical.

In addition, political factors also influenced the divergent trajectory of the glass industry in these distant parts of the Empire. In the fourth and fifth centuries, as urban life in the northwestern provinces began to break down, glass workshops were often moved from marginal locations and reestablished within walled areas of cities or towns—either in the center of public buildings, or on major thoroughfares (Price 2005: 174). While the glass industry never fully ceased in Britain, it certainly fizzled out after the Roman occupation of the island ended in 410. The situation in the eastern provinces—where Roman cities continue to thrive until the early seventh century and in many cases well past this point—is quite different. Glass production and consumption remained a vital part of the Late Roman and Byzantine economy (Price 2005: 174). Indeed evidence for glass working between the fifth and seventh centuries is abundant in Israel. Several settlements including Sepphoris, Beit She’an, and Beit She’arim were manufacturing glass vessels during this period (Gorin-Rosen 2000). Similar evidence has been recorded in Turkey at the site of Sardis, where glass working was noted near the settlement’s synagogue and bath complex (von Saldern 1980: 95-97). In addition, at Pella in Jordan glass kilns and fragments of raw glass were uncovered

35 For example, in Leicester a glass furnace was built in the west colonnade of the city’s market (Wacher 1978: 30 as cited in Price 2005: 174).
from the site’s late Byzantine phase of occupation (Bourke 2014: 5). As such, the material remains from Britain reviewed in this chapter generally date to an earlier period than those of the East.

3.1 The Archaeology of Collection

Archaeological evidence for the collection of cullet comes from both the eastern and western halves of the Roman Empire. In the east, there is evidence from Byzantine churches in Jordan; whereas in the west, dense deposits of cullet have been identified in urban districts of Roman Britain. While the cullet collections from these case studies indicate that recycling was taking place in distant areas of the Empire, it should be noted that the finds differ in both the circumstances that lead to their accumulation and in their date. In several of Jordan’s Byzantine churches, excavators have uncovered “glass heaps” which may have been intentionally amassed by the church—perhaps as a way to raise funds for their establishment—or by later occupants of the building looking to make a profit. On the other hand, the deposits found in Britain are referred to as “cullet dumps” and appear to be refuse from nearby secondary production workshops. This debris was likely discarded when a particular workshop went out of business and/or changed locations. Two well-known cullet dumps from Roman Britain will be investigated in this section; both of these date to the second century. In contrast, the glass heaps from churches in Jordan are much later in date, i.e. fifth through seventh centuries.

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36 The set of workshops, which contained these glass kilns, was erected in the sixth century and was destroyed by an earthquake in 749 CE (Bourke 2014: 5).
Cullet Heaps from the Churches of the Eastern Mediterranean

Archaeological evidence suggests that in the eastern Mediterranean glass recycling was closely connected to the Church, which consumed an abundance of glass vessels and objects (most often lamps, tablewares, bottles, windowpanes and tesserae). While glass fragments are commonly found scattered throughout church complexes, archaeologists also occasionally encounter large piles of broken glass, heaped up in specific locations—normally in church courtyards and other related structures. Glass heaps from church contexts have been noted at sites such as Jerash (Baur 1938), Khirbet al-Kerak (Delougaz and Haines 1960), Petra (O’Hea 2001), and Jabal an-Nabi Harun (Keller 2005). In all cases, the glass remains are said to have been broken prior to being deposited, a fact which led excavators to conclude that the piles consisted of glass intended to be recycled (Baur 1938: 515; Delougaz and Haines 1960: 49; O’Hea 2001: 370; Keller 2005: 72).

While scholars frequently explain ecclesiastical glass heaps as evidence for intentional recycling programs, an opposing explanation exists: they may be ritually significant objects used by the church and then discarded upon breakage (Jones 2006: 412; Meyer 1988: 184). According to this theory, the sacredness of certain vessels prohibits them from being recycled and therefore, when broken, they are stored in an unused part of the church grounds (Meyer 1988: 184). Several types of glass vessels served specific religious and liturgical functions in the early Byzantine church (i.e. fourth – seventh centuries). These include, glass chalices; patens, plates to carry the Eucharist bread; and ampoullae, small lentoid and larger prismatic vials used to hold myrrh and holy water (Antonaras 2010: 391-
As Keller points out, the use of glass vessels for liturgical purposes and for storing holy oil is known from both literature (Jacob of Edessa Cannons, 28) and material remains (2009: 285). In this paper, the term “liturgical vessel” will refer specifically to those glass vessels that were used either during liturgy or for the storage of holy oils. This definition includes but is not limited to the chalices, patens and ampullae, referred to above.

In the Byzantine period, there were specific regulations for the disposal of sacred vessels (Keller 2009: 283). Broken vessels used in liturgy, or which had been sanctified by holy oil, were often buried in favissae (repositories for the discard of decommissioned sacred vessels). These favissae were generally underground reservoirs or cellars located near a church complex. The concept of a favissa (Greek bothros) dates back to Early Bronze Age Mesopotamia and appears to have survived in the Near East well into the Byzantine period (Fiema 2001: 75). Interestingly, textual evidence for the burying of holy glass during the early Byzantine period refers only to chalices and patens (vasa sacra, or sacred vessels) used for liturgical purposes (Jacob of Edessa, Canons 28, 30; Michael Damiette, Nomocanon 7, as cited in Keller 2005: 72) but not to lamps and other vasa non sacra (Keller 2005: 72).

Several sites in the Byzantine Near East show evidence for the burying of sacred glass vessels: Aswan/Seyene in Egypt, Jabal Harun near Petra in Jordan, and Nir Gallim, near Jerusalem (Keller 2009). At each site glass vessels were disposed of in some part of the

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37 Ampullae may also have been used to store and pour wine for the Eucharist (Woods 2004: 49).
38 In terms of archaeological evidence, a glass flask was discovered with a reliquary underneath an altar in the church of St. John at Samra, Jordan (Humbert and Desreumaux 1987: 332 as cited in Keller 2009: 285).
39 An early example of a favissa was uncovered in a Temple of Abu at Tell Asmar (ancient Eshnunna), Iraq. Here, a group of twelve votive statuettes, which can be dated to the Early Dynastic Period, i.e. the first half of the third millennium BCE, were found buried (Amiet 1980: 529 as cited in Fiema 2001: 130).
ecclesiastical complex and buried in the ground as per the suggested guidelines (Keller 2009: 283). This fact led Keller to conclude, “these vessels must have been used in the liturgy of their respective churches or were sanctified by Holy Oil either during baptism or for libations at the tomb of a saint or martyr” (2009: 283-285).

While it is clear that glass vessels that were considered sacred by the Church would have been disposed of carefully and kept from being recycled, the previously mentioned glass heaps—from Jerash, Khirbet al-Kerak, Petra and Jabal an-Nabi Harun—should not be seen as representative of this practice. The ways in which the glass fragments were amassed at these sites and the types of vessel found within the heaps differ significantly from what would be expected of a collection of decommissioned sacred vessels. I have chosen two case studies to elucidate this claim: the Church Complex at Jerash, in northern Jordan and the Petra Church, in southern Jordan.

The evidence from Jerash and Petra requires that close attention be paid to the kinds of glass vessels being collected and the way in which they were amassed. At both sites, collections of broken vessels were amassed outside the church proper but within or near its grounds. This fact may suggest that the heaps were destined to be recycled. By piling glass fragments in public spaces (such as courtyards) there is a risk that the glass will be taken by scavengers looking to make a profit. If the piles consisted of decommissioned sacred vessels, one would assume they would be disposed in a more secure location—perhaps a storage room within the church. In addition, few fragments of liturgical vessels were uncovered among the Jerash or Petra glass heaps; instead, the assemblages largely consist of fragments
from common and utilitarian types of glassware such as lamps, windowpanes, and bowls. This fact also suggests that the glass heaps were collections of cullet set to be recycled. If the heaps consisted of specialized liturgical or elaborately decorated vessels, the alternative explanation might be more likely.

Several explanations could account for the presence of glass recycling heaps in church contexts. It is possible that if there was a demand for broken glass, as the literary evidence suggests, the church, a public space used by a great number of people and a building that employed glass extensively, would have been an ideal location to amass broken vessels. One can even imagine that the church used money earned from the sale of glass fragments to help support itself. In addition, Tal et al. argue that in the Byzantine period, “the production of glass (both primary and secondary) was probably monitored by the central authority of that time, the church” (2008: 95). Therefore, if the church played a role in the production of glass, it might also have been involved in recycling said material.

This scenario could account for the glass heaps at Jerash; however, at Petra, a different explanation is necessary. The recycling heaps within the Petra Church postdate ecclesiastical occupation, signifying that the church did not organize this particular collection of cullet. As Keller explains, the numerous glass heaps at the Petra Church may be related to the lack of available raw glass in southern Jordan in the seventh century. As he states, “the decline of interregional trade meant that glass recycling became an economic necessity as there was no other option to obtain raw glass on a large scale” (2005: 74). Cullet was thus

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40 This claim is somewhat problematic; it seems to be more of an off-hand comment than a well thought-out argument. However, according to Tal et al. this was the case for the sites of Apollonia-Arsuf and Beth Shean (2008: 95).
used as a raw material for the production of glass vessels. This is evidenced by the poor quality of glass vessels in the eastern provinces during the late Byzantine phase: many pieces are poorly formed and their surfaces contain bubbles—an effect that can occur when only recycled materials are used to manufacture new glass vessels (Keller 2005: 74).

Jerash

Jerash, or ancient Gerasa, is a well-preserved ancient city situated in the valley of Chrysorhoas, ca. 48 kilometers north of Amman. The site enjoyed many natural advantages and thus was occupied at an early date. While archaeologists have scarcely excavated the remains of early periods, scholars assume that the town was officially founded during the Hellenistic period. Jerash was later incorporated into the newly fashioned Roman province of Syria in 64 BCE.41

The appearance of numerous churches defines Jerash’s later history. C. H. Kraeling describes the late fifth and sixth centuries as a “brilliant new epoch” for Jerash, in which the economy flourished and Christians built an elaborate series of churches (1938: 65-66). The effects of this program continued undisturbed until the early seventh century when Jerash underwent significant socio-political change. This was in part due to the Sasanian Persian occupation of the city from 614-628, and the Muslim conquest in ca. 635 (Kraeling 1938: 68). Recent excavations, however, reveal that Jerash continued to flourish in the Umayyad

41 For a brief and up-to-date discussion of the history of Jerash, see Meyer 1988. For information concerning Jerash’s incorporation into the Roman Empire see Kraeling 1938.
Period (661-747) and that many of its churches remained in use until a devastating earthquake in 746/7 (Meyer 1988).

Glass was abundant in the excavations at Jerash from the 1920s to 1930s (Baur 1938) and in excavations by various international teams in the early 1980s (Meyer 1988). Several of these projects recovered glass from church contexts, however, the earlier excavation seasons uncovered dense deposits of broken glass, up to 0.25 meters in depth, concentrated within what excavators call Jerash’s “Church Complex” (Baur 1938). The latter will be the subject of the following paragraphs.42

**The Church Complex at Jerash**

Researchers do not know when Christianity first appeared in Jerash. Excavators call the earliest church in the city “the Cathedral” (see Figure 1). This church was likely erected in the fourth century. It was constructed in front of a fountain, which eventually became the focal point of the largest and most elaborate network of ecclesiastical buildings in the entire city; excavators refer to this area the “Church Complex” (Crowfoot 1938). The large basilica of Saint Theodore, situated just west of the Fountain Court, was constructed later in 494-496 CE (see Figure 2). As Crowfoot explains, “the erection of this church led to the remodeling of the Fountain Court in front of the Cathedral” (1938: 172). The complex itself also contained a series of complementary secular buildings including baths, schools, and hospitals (Crowfoot 1938: 176).

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42 Much of the glass that recovered in the 1980s dates to what the excavators call Jerash’s “Late Byzantine/Early Umayyad phase” (ca. 630-670) and thus does not correlate well with the other sites under investigation here (Meyer 1980: 198-211).
The Glass from Jerash

Baur studied the glass remains of Jerash from the late 1920s and 1930s. While his report deals with all areas under excavation—including the Forum, Temple of Artemis and the west cemetery—he notes that the overwhelming majority of glass fragments came from churches. In particular, two contexts associated with the Church Complex proved to be especially rich in glass remains: (1) a passage north of Saint Theodore’s Church, and (2) a room under the north stairs leading up from the Fountain Court to the passage mentioned above. While neither context is situated within a church proper, Baur argues that both deposits consisted partially of glass that was used in the churches and then deposited upon breakage. Some of the other fragments, however, could have originally come from the secular buildings adjoining the complex (Baur 1938: 514-515).

There were few complete glass specimens among the Jerash assemblage, yet of those fragments that scholars could analyze, the majority were of “Syrian fabric” and either bluish or greenish in tone.43 All examples were of blown-glass, either blown-freely or into a multi-part mold and were broadly dated to the fourth and fifth centuries. Decoration was rare and generally confined to the necks of bottles (Baur 1938: 515). Due to the sheer volume of samples found, Baur notes that there is a “general impression that glass must have been plentiful in the city indeed” (1938: 513).

The glass heaps recovered from the passageway north of Saint Theodore’s consisted mainly of thick window glasses, many lamps, a large assortment of bottles, and a good

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43 Baur’s use of the term “Syrian fabric” likely comes from the fact that many of the glass vessels found in Jordan are assumed to have been fashioned out of raw glass from the Syro-Palestinian coast. Literary sources indicate that this region had the ideal type of sand for glassmaking. (Pliny Natural History 36.65).
number of wine glasses and plates. Similarly, the other assemblage found under the stairs was “unusually large” with tumbler and goblet-shaped lamps being by far the most common find (with 280 fragments total). Excavators also found dishes, bowls, wine glasses, bottles, and windowpanes in this collection (Baur 1938: 514). The types of glass fragments found within the Jerash glass heaps do not seem to be particularly valuable. Very few pieces were decorated, and most come from common vessel forms, which could be used in both religious and secular contexts.

Baur contends that the glass from the aforementioned heaps had been collected for a particular purpose, but that due to its condition (broken prior to being deposited) and the types of vessels found (miscellaneous mixture), this purpose could not have been storage. Instead, Baur argues that these fragments were “collected to be melted down into new glass” (1938: 515). Consequently, this glass was likely from the church and its surrounding buildings, hence both the preponderance of lamps, but also the presence of other vessels not always associated with churches. Carol Meyer offers an alternative explanation: “the glass, having been used in the church and broken, was still sanctified and could not be recycled,” thus it was simply deposited in some unused portion of the church grounds (1988: 184). This is an appealing hypothesis, however ancient literature seems to endorse Baur’s view: as mentioned in the previous chapter, the poets Martial, Statius and Juvenal all allude to the practice of collecting broken glass so that it could be remelted. These accounts corroborate

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44 As Baur notes, the minimum number of objects to which these fragments could have belonged is as follows: 200 tumbler-shaped lamps, 80 goblet-shaped lamps, 35 dishes, 30 bowls, 14 wine glasses, 6 vase-shaped lamps, a few bottles and plates and a little window glass (1983: 514).

45 Unfortunately Baur does not clarify how he knows that the glass fragments were broken prior to being deposited in these two locales.
Gregory of Tours’ story of a thief who stole glass from a church window in order to remelt it and sell it for profit.

As mentioned previously, the collection of cullet is closely associated with secondary glass production. Therefore, scholars often assume that if evidence for recycling is found at a site, the site probably contained a contemporary glass workshop. Unfortunately, the aforementioned collections from Jerash were not found in conjunction with glass-blowing implements, or a furnace; however, there is other evidence for glass working at the site. In an area northeast of the Fountain Court, which the excavators dubbed the Glass Court, “a number of cakes of glass in various colors were found heaped up... the total weight of the pile being over a hundredweight, [ca. 45 kilograms]” (Baur 1938: 517). Baur believes that someone manufactured these cakes with the intention of remelting them in order to make glass *tesserae* (Baur 1938: 518). Indeed, “mosaics form one of the most important elements of the internal decoration in the churches of Jerash” (Biebel 1938: 297). Although most *tesserae* found in the city were of local limestone, contemporary glass mosaics were present in the Cathedral chapel and Bishop Genesius’ church (Biebel 1938: 305). While this may be indirect evidence for glass working on site, it is probable that a city as prominent as Jerash would have contained at least one glass workshop. If so, recycling would have been a logical activity at the site as well. The glass heaps found in the Church Complex at Jerash may thus have been amassed in order to benefit a local glass workshop.

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46 As Crowfoot notes, the Bishop Genesis Church “lies on the north edge of the low ground which stretches from the group round St. John’s to the city walls.” While Crowfoot does not specify when the Bishop Genesis Church was constructed, it seems to have remained in use until the early seventh century, when a new inscribed mosaic was added (Crowfoot 1938: 249). St. John’s is one of three churches that lies approximately one hundred and fifty meters west-northwest of the atrium of St. Theodore’s (Crowfoot 1938: 241).
Discussion

The distribution of the Jerash glass remains—found in dense deposits, as thick as 0.25 meters—is particularly noteworthy. Were these intentional collections of glass? If so, perhaps the church was directly involved in glass recycling. Indeed the Church Complex would have been a logical and central location in which to amass broken glass fragments, especially if the recycled glass was then made into glass *tesserae* and reincorporated into these ecclesiastical buildings. One can even imagine that the church may have used the money from the sale of glass fragments to finance the elaborate complex. While the discovery of the two glass piles suggests that these particular collections of glass escaped recycling, it is likely that the process of collection happened more than once. Earlier collections could have been sold to glassworkers and recycled. The money made off of the sale of these fragments may have helped to fund the church. The finds from Jerash can be compared to those from the Petra Church. In this latter monumental establishment, excavators uncovered glass heaps in the church itself and its surrounding structures.

Petra

The monumental site of ancient Petra lies in southern Jordan, about halfway between the southern tip of the Dead Sea and the head of the Gulf of Aqaba. It is most widely known as the capital of Nabataea, a state whose economy was based on long-distance trade of exotic goods—such as incense and spices—from Southern Arabia. Although the emperor Trajan annexed Nabataea in 106, Petra continued to thrive both politically and economically under Roman rule. In fact, Petra remained the “most prominent urban center” in southern Jordan
until the sixth century (Russell 2001: xi). Recent excavations at Petra, which have uncovered three elaborate churches, speak to the importance of this city in Byzantine times. The three churches—the Petra Church, Ridge Church, and the Blue Chapel—lie on a ridge north of the Colonnaded Street, Petra’s main road, originally built by the Nabataeans (see Figure 3). The following section will focus solely on the Petra Church; unfortunately, final excavation reports have not yet been published for the Ridge Church or Blue Chapel.47

*The Petra Church*

Christians were present in Petra in the early fourth century and by the mid-fourth century the city was the seat of both a local and a metropolitan bishop. Petra’s conversion to Christianity, however, was by no means complete by the end of fourth century. Literary evidence suggests that Christianity did not predominate in Petra until the later fifth/early sixth centuries. It is during this period that we see few literary references to pagans in Petra and much talk of the Christian nature of the site (Schick 2001: 1).48 After the Islamic conquest of the region in 636, it appears that Petra lost its importance as an ecclesiastical center. Around this time, the site of al-Rabba (ancient Areopolis, east of the Dead Sea) seems to have replaced Petra as the seat of the metropolitan bishop (Schick 2001: 2). It is thus unsurprising that the Petra Church thrived in the fifth and sixth centuries, the same period that Christianity flourished at the site.

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47 All three churches were constructed within a relatively short period of time, from the late fourth to mid-fifth century. For more information on the churches of Petra, see Perry and Bikai (2007: 435-443).
48 For instance, “Eusebius, while commenting on Isaiah 42:11, mentions that Petra is a city in Palestine filled with superstitious men, who have sunk in diabolical error, but that in his day churches were being founded at Petra” (Schick 2001: 1). For a more detailed discussion of the literary evidence for Christianity in Petra, see Schick (2001: 1-2).
An early Byzantine residential quarter predates the construction of the Petra Church. Architects of the church integrated much of the earlier domestic structures into the building, adding modifications where needed (Fiema 2001: 29). The transition from a domestic to sacral use of the site most likely occurred sometime in the mid-fifth century (Fiema 2001: 53). The complex of the Petra Church contains various elements: a courtyard, a triple-apse basilica, an atrium and multiple side rooms (see Figure 4). Excavation of the church focused on its basilica and the atrium, while more than half of the complex remains uncovered (Fiema 2001: 7). The church underwent several phases of construction and additions throughout its lifespan, the last of which included the installation of an elaborate floor mosaic.

Near the end of the sixth or perhaps the very beginning of the seventh century, a fire destroyed the Petra Church. The damage was restricted to the church proper and did not affect much of the surrounding complex. While a number of scenarios could account for the fire, Fiema prefers to see it as a repercussion of the socioeconomic conditions of Petra during the late sixth century; indeed this seems like the most plausible explanation. In this light, the fire may have been the result of “urban unrest—a phenomenon endemic in Byzantine cities, that was caused by economic or intra-Christian conflicts” (Fiema 2001: 94). Although it remained structurally sound, after the fire the Petra Church ceased to be used as an ecclesiastical structure. Fiema argues that this was likely due to economic considerations;

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49 The mid-fifth century date for the construction of the church is based on artifact analysis and architectural components (Fiema 2001: 53).
50 For a detailed explanation of the fire and its effects, see Fiema (2001: 91-94). The fire may also have been caused by lighting, carelessness, or a hostile takeover (perhaps by the Sasanian Persians or Muslims), although there is no direct evidence to support these hypotheses. Fiema favors the socio-economic explanation because the fire was accompanied by vandalism but not the wholesale destruction of the church complex.
building a new roof would have been a costly investment. Instead, the undamaged components of the complex were reoccupied by civilians (Fiema 2001: 94-95). The church was an attractive shelter for later occupants due to the availability of relatively undamaged space and the numerous compartments suitable for living (Fiema 2001: 104). In addition, during this period parts of the church were converted into workshops (Fiema 2001: 95) Later, two earthquakes in the mid-seventh century would ensure the abandonment of the church for good.

The Glass from the Petra Church

O’Hea, who examined the glass remains from the 1992 and 1993 excavation seasons, has produced the only in-depth analysis of glass from the Petra Church. Her report focuses on the glass found in the nave and aisles of the church itself. Although she did not include an analysis of the glassware found in the atrium and surrounding structures, she argues, “a preliminary look at this material suggests exactly the same range of material as found within the church” (2001: 370). She did, however, make note of an “apparently deliberate collection of broken glass” that was uncovered directly outside the church. O’Hea suggests this collection might have been a recycling heap (2001: 370).

While this is the only glass heap mentioned in O’Hea’s work, several other collections of broken glass were discovered in the church complex. These collections were recorded in Fiema’s chapter on the architectural phases and history of the Petra Church (2001: 75-76, 96-98). Unfortunately Fiema did not systematically quantify or describe the glass from these contexts. Nonetheless, a brief look at these finds will illustrate the practice of collecting glass
and how it unfolded at the Petra Church. Before discussing Fiema’s work, however, I will offer a brief summary of the glass remains from the church proper, as the material found within the Petra Church is said to have consisted of the same types of glasses uncovered elsewhere in the excavation.

*Glass Remains from inside the Petra Church*

Excavations of the church yielded two categories of glass: objects used when the church was occupied and those that date to the post-ecclesiastical use of the building. Glass from the lowest destruction levels consisted mostly of windowpanes and hanging lamps, which O’Hea dates from the fifth to seventh centuries. Other finds from this period include simple bowls and trail-decorated or plain flasks (O’Hea 2001: 370-371).

Based on her analysis of the lower destruction levels, O’Hea remarks that the Petra Church contained decolorized, blown window glass in both round form with folded rims, and square or rectangular panes.51 The square or rectangular panes were by far more common, while the rounded panes formed only one percent of the total weight of the glass assemblage (O’Hea 2001: 371). The glass used to make the Petra panes tended to be strongly greenish-blue, bluish, or translucent, and was relatively thin (measuring between 0.2-0.3 millimeters in thickness). Some of the rectangular panes, however, were olive green in color and must have come from a different glass batch (O’Hea 2001: 371).

Archaeological evidence also reveals that at the time of its destruction, the Petra

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51 Decolorized glass will be discussed in the next chapter. As the natural color of glass is green-blue colorless glass was made either by selecting refined raw materials or by the addition of a decolorizer.
Church utilized two types of hanging lamps: stemmed lamps and handled bowl-lamps. The church seems to have used these types in almost equal proportions (O’Hea 2001: 372). The Petra Church may also have employed wheel-incised bowls as lighting fixtures in the narthex and middle of the southern aisle. These bowls were made of “distinctively thick, faintly bluish-green or yellow-greenish fabric” (O’Hea 2001: 373). The best-preserved example of this vessel type was decorated with the image of tunic-clad male figure carrying a scroll.52

The Petra Church also boasted elaborate mosaics on its floors and interior walls. While the majority of the floor tesserae were cut from stone, those found on the walls were created, in large part, from glass. Excavators uncovered most of the glass tesserae in the eastern end of the church. They were concentrated in the main and north apses, in addition to the nave, and most likely fell after the abandonment of the church (Waliszewski 2001: 300). These tesserae varied immensely in color; they were found in 32 different shades. The subject matter of the wall mosaic remains unknown, although “a few sections of the mosaic fragments… show human figures against a backdrop of mosaic cubes with gold leaf” (Marii 2013: 14).

O’Hea identifies all other glass from within the destruction layers, as “common” or “domestic wares.” This glass may not necessarily have been used by the church, but rather by those who occupied it after the fire. Of these, O’Hea notes, “simple, undecorated bowl rims… predominate” (2001: 374-375). Decorated glass vessels, other than the wheel-incised bowls mentioned earlier, are rare at the Petra Church. Some fragments remain of mold-blown

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52 O’Hea does not specify how this decorative element was applied to the vessel; presumably this was a mold-made vessel.
honeycomb bowls, beakers and flasks. Archaeologists also recovered two fragments of goblet stems and a “simple” flask, which the church may have used to store holy water or which could have served a domestic purpose (2001: 375).

While the Petra Church must have used glass abundantly, the glass vessels found during the excavation seem only to have fulfilled a few functions. These include lighting, storage, and dining. Glass lamps and windows were prominent throughout the complex. With the exception of glass fragments from a goblet and a small flask, no other obvious liturgical vessels were uncovered in the destruction layers. As revealed below, their absence is likely due to the fact that while the church was used for ecclesiastical purposes, liturgical items were decommissioned through deposition in favissae, several of which were discovered at the Petra Church.

Location and Function of Glass Collections in the Petra Church

As Fiema notes, the collection of broken glass was a regular activity performed throughout the history of the Petra Church. While the church served an ecclesiastical function, broken liturgical items were collected and properly discarded “as a matter of religious propriety” (2001: 97). This is evidenced by the multiple favissae associated with the church complex. For instance, a drain leading into a cistern lost its primary function due to a renovation project in the early sixth century. After the abandonment of the cistern, the associated drain was transformed into a favissa. In this drain excavators uncovered a “substantial quantity of broken glass,” which was intentionally deposited and then sealed.
with a perforated capstone (Fiema 2001: 75). It is also possible that this installation was
used as a recycling cache by someone who was secretly collecting glass until they had
enough to sell it to a glassworker. The drain’s association with the church, however, and the
presence of other possible favissae at the site, suggest the former conclusion is most likely.
The other examples of favissae found at the Petra Church complex, like the favissa just
mentioned, are generally associated with the renovation of the church complex during Phase
V, which began in the early sixth century (Fiema 2001: 75-76). Fiema argues that this
remodeling provided an opportunity to bury all old, broken, and perhaps unfashionable
liturgical vessels (2001: 75).

Not all collections of broken glass from the Petra Church can be explained as favissae.
Fiema argues that after the destructive fire in the late sixth or early seventh century, glass
collection was performed with a different goal in mind. The glass collections belonging to
these later phases, when the building ceased to be used for religious purposes, can only be
explained through “purely economic considerations” (2001: 97). In other words, they can be
considered recycling heaps; the broken glass fragments in these deposits were collected so
that they could be sold to glassworkers and remelted to form new vessels.

Phase IX, the non-ecclesiastical phase of occupation, yielded abundant evidence for the
collection of broken glass vessels, windowpanes and tesserae fragments. Phase IX directly

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53 This perforated capstone would have allowed the installation to be easily accessible; it also reveals
that the interior of installation was likely accessed multiple times throughout its life span, otherwise it would
simply have been sealed with a non-perforated stone. Each time a vessel was decommissioned the capstone
would be lifted and the vessels would be placed inside for safekeeping (Fiema 2001: 75).
54 I would like to thank Dr. Dixon for bringing this possibility to my attention.
55 Fiema gives no end date for Phase V; as he explains, the division between Phases V and VI is
“somewhat artificial” and based solely on different architectural additions. Phase VI continues well into the late
sixth century, certainly after 582 CE (2001: 80).
followed the fire that destroyed the Petra Church (Phase VIII) and lasted from the end of the sixth century to well into the seventh century (Fiema 2001: 105). During this time, “the undamaged parts of the complex were reinhabited, and the gutted church subjected to systematic but selective exploitation for useful elements” (Fiema 2001: 94). As mentioned earlier, no steps were taken to restore or retain the ecclesiastical nature of the church; instead, the building was converted to accommodate dwellings and workshops. In addition to using the church for domestic purposes, the new inhabitants were interested in making a profit from the building’s remaining debris. Fiema explains that in Phase IX “people were interested in removing specific materials which either had a market or could be reused without costly and time-consuming modifications” (2001: 95). Glass vessel fragments and tesserae featured prominently among those objects considered of value to the new occupants.\(^{56}\) Interestingly, these exploitative measures seem to have stopped prematurely; some valuable materials, which could have been profitable for the latter occupants, were left untouched (2001: 95).\(^{57}\)

Room IX, on the western side of the complex, was among the rooms reinhabited after the fire. During Phase IX the room was altered and the layout changed somewhat. According to Fiema, however, “the most important discovery associated with this phase in Room IX was the presence of glass paste cakes; these are usually considered to be products of a glass remelting process” (2001: 96). In total, 50 glass cakes, or fragments thereof were found in the room, most of which “lay in concentrations, as if forming small heaps” (Fiema 2001: 96).

\(^{56}\) In addition, it appears that marble and shale paving stones were also targeted for removal (Fiema 2001: 95).

\(^{57}\) Some of the glass mosaics were left intact along with slightly damaged marble.
These “cakes” were mainly rectangular in shape, and had an average size of ca. 0.2 by 0.15 by 0.03 meters (Fiema 2001: 96). Glass cakes were considered ideal for transportation and were often transformed into mosaic tesserae (Fiema 2001: 97). The cakes from Petra have a much more limited range of colors than those from Jerash; they range from very pale, cream blue, to a deep navy blue.

In addition to these glass cakes, large quantities of glass vessel fragments, as well as glass and stone mosaic tesserae were found in Room IX. While this material appears to have been “indiscriminately collected,” Fiema suggests it was brought to Room IX in order to be further sorted. He goes on to argue that the heaps of broken glass found within this room ought to be regarded as “raw material ready for recycling” (2001: 97). During Phase IX, this room was a “glass collection and processing center,” used to store both cullet and raw glass (in the form of cakes). These products would then be remelted at a nearby glass-working furnace and formed into new vessels for use somewhere in Petra or the wider region (2001: 97). As with Jerash, however, there is no sign that a furnace or glass workshop existed at Petra, and thus no way to corroborate this conclusion (Marii 2013: 12).

Besides the finds from Room IX, broken glass was also found amassed in a stone cupboard on the western side of the church’s atrium. This cupboard had three shelves and was set into one of the walls of the church’s forecourt, the structure that was eventually transformed into the atrium in Phase V. Half a meter northeast of this cupboard, another collection of broken glass (including lamp, vessel, and window fragments) was found in a slightly ashy layer directly above the portico floor. Fiema suggests that the cupboard and
surrounding area had become another “collecting point” (2001: 97). The survival of these collections, however, indicates that the material never made it to nearby glassworkers for remelting. Indeed “considering the large quantities of glass found elsewhere in the complex, it is clear that the entire operation of glass collection was either not finished, or somewhat uneven in temporal intensity and efficiency of operation” (2001: 97).  

Discussion

Glass was collected on multiple occasions and amassed in various areas throughout the Petra Church. Archaeological evidence reveals that during its time as an ecclesiastical structure, the church disposed of ritually significant glass in private, relatively inaccessible, areas. This action was likely done with the view of preserving the sanctity of certain vessels. Such a procedure would ensure that none of the decommissioned vessels could be recycled. During the non-ecclesiastical phases of occupation, however, the church’s new inhabitants wished to profit from the debris. They scavenged the church for glass fragments and amassed them in large heaps throughout the complex. Excavators assume that these deposits are representative of some sort of recycling program, possibly connected to the production of glass tesserae.

Local interest in recycling broken glass from the church may have been spurred on by the decline of interregional trade in the east during the seventh century. Unfortunately southern Jordan lacked suitable raw materials to produce raw glass on a large scale (Keller

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58 It should also be noted that in later phases, such as Phase XI, the collection of useful material, including glass and stone, was still being carried out.
Without good access to primary producers in the central or northern Levantine coast and Egypt, it is likely that many of the glass vessels made in southern Jordan during this late period were fabricated from recycled materials (Keller 2005: 72-76). The Petra Church’s new inhabitants may have been aware of this fact and thus sought to capitalize on it.

Conclusion

At several different sites in Jordan, excavators uncovered large deposits of glass concentrated in specific areas on church grounds. This phenomenon may be indicative of some sort of recycling program. While certain scholars suggest these might be piles of decommissioned sacred vessels, the archaeological evidence seems to support the former conclusion. The assemblages from the Church Complex at Jerash and the Petra Church contained mundane glass vessels with few decorative features. Much of the glass found within the heaps seems to have fulfilled a practical role and could have come from both religious and secular contexts. Fragments of glass lamps and windowpanes were recovered in large numbers; other types of vessels include bottles, jugs, and plates. Interestingly, very few specialized liturgical vessels were unearthed from either of these churches. One would assume that if glass fragments were being carefully disposed of due to their sacred nature, we would find fragments of liturgical vessels within these glass heaps. Their absence, therefore, seems to point to the fact that the glass heaps were set to be recycled.

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59 Perhaps, as Gregory of Tours’ account suggests (see above, Chapter 2), these vessels were targets for looters.
In addition, one would assume that the church would not consider undecorated windowpanes sacred since they do not fulfill any specific ceremonial role. The fact both the assemblages from the Jerash complex and the Petra Church yielded large amounts of plain window fragments also suggests that these deposits were recycling piles. Indeed windowpanes, generally made from thick glass and already decolorized, are considered ideal for recycling (Shepherd and Wardle 2009: 37). Lastly, these glass heaps were found outside the churches, in open and public spaces, not within them. If these were sacred objects, highly valued by the Church—as Meyer would have us believe—it would be more appropriate for the Church to dispense of them in secure locations away from the public. Indeed, it is clear that at Petra, those objects considered sacred by the church were buried in *favissae.* All other glass collections not deposited in this fashion must be indicative of a different practice.

If we follow the assumption that upon breakage, non-liturgical glass was collected so that it could be remelted into new vessels, glass may have been even more prominent in these establishments than the archaeological record suggests. An economic incentive may explain the reoccurrence of glass recycling heaps found in ecclesiastical contexts; money earned from the sale of broken vessels could have benefited the Church or generated income for later inhabitants. Yet, despite the evidence for recycling programs, neither of the sites studied here yielded incontrovertible evidence for on-site manufacture of glass vessels. Artifact fabrication does not seem to have taken place on church grounds, but perhaps
nearby. At both sites, however, there is evidence of mosaic production, suggesting that a glass furnace or workshop was situated in the vicinity. If true, the cullet collection scheme organized by the churches at Jerash and the non-ecclesiastical inhabitants of the Petra Church would have benefited local glassworkers.

Cullet Dumps from Roman Britain

Glass heaps are not limited to churches of the eastern Mediterranean. Similar finds have been discovered in urban settings of Roman Britain. At a few sites in Britain excavators have noted the presence of “cullet dumps.” Two of the largest cullet dumps ever recorded were found in Roman London: at what is now 35 Basinghall Street and at Guildhall Yard, the site of a former Roman amphitheater. Note that the remains from both these sites appear to be refuse from glass workshops that went out of use sometime in the second century. In this light, the finds from Britain are much earlier than their eastern counterparts and they also differ in the circumstances that lead to their accumulation. After the supposed workshops were abandoned, the material within them seems to have been cleared out and discarded at nearby dumping grounds.

Archaeological evidence from London suggests that although the town had a long tradition of glass working, only one workshop or area was involved in secondary glass production at any given time (Shepherd and Heyworth 1991). In 2009 there were twenty-one glass working sites known in Roman London (Shepherd and Wardle 2009: 23). These sites

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60 In addition, since glass collection was often done by itinerant merchants, secondary production sites need not be extremely close to the area in which glass is being collected. These merchants could have transported the cullet to glass workshops.
can be clustered into eight distinct geographic areas (Figure 5). The earliest evidence for
glass working in London comes from a Flavian quayside workshop at Regis House (Brigham
et al. 1996: 38) and contemporary workshops uncovered in the Walbrook valley and further
west on Watling Street (Shepherd 1986). By the mid-second century, glass working is
attested in the upper Walbrook valley, as evidenced by excavations at Northgate House and
Coleman Street in Moorgate (Keily and Shepherd 2005). Here excavators uncovered glass
waste, furnace fragments and broken glass vessels. At the end of the second century,
however, the glass-working industry seems to have left this area in favor of sites in London’s
southeast end—as evidenced by several excavations in this corner of the city. Firstly,
excavations at the Tower of London in 1955 revealed the remains of a tank furnace and
associated glass debris (Bayley and Shepherd 1985). In addition, small quantities of glass
waste were also found at St. Dunstan’s Hill and Colchester House (Shepherd and Wardle
2009: 29). There are few later finds except for “residual dumping” among third and fourth
century deposits in the Norton Folgate region just north of the city (Perez-Sala and Shepherd
2008a: 145).61

A pattern can be detected here; at various stages of London’s early Roman history,
glass working shifted to new industrial zones on the periphery of the settlement. As Perez-
Sala and Shepherd argue, “this progression... suggests small-scale [secondary glass]
production, except perhaps for the second century… activity near the Guildhall and at the
nearby upper Walbrook sites,” such as 35 Basinghall Street (2008a: 145). The vast quantities

61 Occupation of Londonium ceased after Roman withdrawal from the region (ca. late fourth/early fifth
century) presumably because the city no longer filled the role of an imperial administrative and military center
(Cowie 2008: 50). By the 440s Anglo-Saxon material culture came to dominate the region (Cowie 2008: 53).
of glass uncovered from the cullet dumps at these two sites suggest that in second century London glass working was being performed on a relatively large scale. Yet, these workshops, like all others in London, only remained in use for a generation or two.

35 Basinghall Street

35 Basinghall Street is located on the western edge of the upper Walbrook valley. In Roman times, it was situated on “the fringes of a marginal area, away from the main focus of residential settlement” (Shepherd and Wardle 2009: 31). There was very little activity here prior to the second century. While the site yielded minimal evidence for permanent structures, most of the land was covered in pits, initially created to quarry brickearth. These pits were later reused for the disposal of both domestic and industrial garbage (Shepherd and Wardle 2009: 32). Shepherd and Wardle note that among these pits, in the southeastern corner of the site, more than 10,000 fragments of glass, weighing more than 70 kilograms in total, were recovered. While this debris was not found in conjunction with a contemporary glass furnace, excavators suggest that the material came from a nearby workshop and was discarded once the facility ceased to operate (Shepherd and Wardle 2009: 32).

Shepherd and Wardle argue that the glassworkers of Roman London were “peripatetic,” meaning they moved from one location to the next in pursuit of a new market. Having served the upper Walbrook market for some time, these glassworkers may have moved on to another area or town, leaving behind remnants of their last few days of production (Shepherd and Wardle 2009: 61). These authors, however, do not address why the cullet was discarded and not transported to the new location to be recycled. Instead, they
confidently state that the Basinghall dumps are evidence that glass recycling took place at a nearby workshop (Shepherd and Wardle 2009: 7). What the excavators do not consider is the possibility that this glass was intentionally hidden. Similarly to coin hoards, these glass fragments may have been buried by someone who intended to come back for them. Since cullet was a valuable product that could be sold to glassworkers, it is possible someone wished to capitalize on this but did not have the means or time to fulfill their goals. Shepherd and Wardle’s explanation, however, seems most appropriate given the size of the dump. Burying such a sizable quantity of glass would have required a lot of energy; energy that might be better served transporting these goods to another glass workshop still in operation. In addition, glass was not the only material to be found within the dump. Broken ceramic vessels, among other goods such as animal bones, were also located here. Since broken pottery is not often something that would be hoarded, its presence suggests that the other material found at the site has also been dumped, not hidden for safekeeping.

*The Cullet Dump at 35 Basinghall Street*

Shepherd and Wardle divided all the glass remains from 35 Basinghall Street into two broad categories: large lumps of glass and smaller pieces of cullet. Among the large fragments were several chunks of naturally colored raw glass, possibly imported from the Continent (Shepherd and Wardle 2009: 35). The other large pieces, designated as “tank metal” (i.e. glass from tank furnaces), probably came from a nearby glass workshops. As

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62 Thanks again to Dr. Dixon for bringing this possibility to my attention.
63 Of course, this operation would require that the collector have knowledge of the location of other glass workshops.
Shepherd and Wardle explain: “It is normal for the glass or tank metal that accumulated during the lifetime of a furnace to be broken up for recycling when the tank was dismantled, and its presence [at 35 Basinghall Street] suggests the cessation of the industry on this particular site” (2009: 35). One fragment weighed ca. 30 kilograms, however, most others were much smaller (Shepherd and Wardle 2009: 36).

In addition to raw glass and tank metal, cullet—consisting of broken glass vessels—was recovered from several of the Basinghall pits. One pit in particular contained 4 kilograms of cullet (Shepherd and Wardle 2009: 37). Most cullet recovered from the site was blue-green in color, but substantial amounts of colorless glass and some darker blue, amber and yellow fragments were also found. Many glass fragments were “extremely small,” which suggests they had already been prepared for remelting (Shepherd and Wardle 2009: 35). Shepherd and Wardle also note that the assemblage contained many body fragments from thick bottles and windowpanes, “a natural choice for cullet” as these objects contain much larger volumes of glass than thin-walled alternatives (2009: 37). The excavators also uncovered layers of melted window glass that had fused together to form one lump, as if it had already been partially processed (i.e. melted down) by the glass workshop. According to Shepherd and Wardle, “this is perfect evidence for the preparation of cullet on the site” (2009: 37).

In addition to the bottles and windowpanes, the excavation team identified at least 400 individual vessels by form. These mainly consisted of tablewares, such as bowls and jugs, or containers, such as jars and phials. Relatively few fragments of drinking vessels were
found. As Shepherd and Wardle conclude, “the general character of the group, with very few
fragments of 1st century forms, suggests that it dates from well into the 2nd century” (2009: 37). While the identification of these vessels helps to date the deposits, they also give us
information as to the types of glass being recycled. Domestic tablewares—likely coming from inhabitants of Roman London—appear to have been commonly collected for recycling.

Production waste was yet another category of glass found in the dumps at Basinghall Street (Shepherd and Wardle 2009: 39). The most common form of waste glass was the moil (i.e. waste from the end of the blowing iron)—over 6,000 fragments were found, 1,500 of these being complete or nearly complete. Moils, as Shepherd and Wardle explain, are “diagnostic evidence for the manufacture of [blown] glass vessels and suggest that, although we have no evidence for the structure of the furnace itself, the workshop was nearby” (Shepherd and Wardle 2009: 39). While the lack of furnace remnants make it hard to assess the scale of secondary glass production at Basinghall, Shepherd and Wardle state, “this glass workshop was not a small scale manufacturing site, but was responsible for the production of a considerable quantity of glass for use in London, and, perhaps beyond” (Shepherd and Wardle 2009: 55).

Discussion

From this analysis of the Basinghall cullet dump, several conclusions can be drawn. It appears that the glassworkers of second century London were producing large quantities of glass vessels by relying heavily upon cullet. The types of glass being recycled included broken glass vessels (bottles and tablewares), other objects (such as windowpanes), and
waste glass. As mentioned above, Shepherd and Wardle do not discuss why the cullet from Basinghall Street—if it were so valuable—did not accompany the glassworkers when they departed the upper Walbrook Valley, but was instead discarded. A very similar scenario seems to have unfolded at Guildhall Yard. Excavators from this site give multiple explanations for why the cullet was dumped and not reused. As such, a discussion of this phenomenon will be left until after the Guildhall Yard material has been presented.

**Guildhall Yard**

Guildhall Yard is in the northwestern part of Roman London, 500 meters north of the Thames and just 200 meters west of the Walbrook stream (Bateman et al. 2008: 1). This area was initially used for quarrying and was not subject to any significant development until 70 CE. At this time, London seems to have grown rapidly and a public building program was implemented. This is evidenced by a wooden amphitheater constructed at Guildhall Yard in the late first century. In the early second century London continued to expand and new public facilities were established to meet the town’s growing needs (Bateman et al. 2008: 4).

A fire in 125 interrupted this expansion. While there is nothing to suggest that the fire directly affected the Guildhall amphitheater, the structure was either robbed out or dismantled around this same time. The site was then cleared and a stone amphitheater was erected in its place (Bateman et al. 2008: 39). The stone amphitheater was updated in the third century but by the mid-fourth century it fell out of use and was abandoned—like most other public buildings in Roman London (Bateman et al. 2008: 4).
Excavators are unsure how much time elapsed between the demolition of the timber amphitheater and the erection of its stone counterpart. However, it appears that for a short while the site was used for other purposes:

There may have been a short hiatus in occupation between the demolition of the timber amphitheater and its replacement, and during this time various external activities took place, including quarrying and dumping. A large assemblage of artifacts was recovered from deposits associated with this time (Bateman et al. 2008: 39).

A timber-lined drain that ran eastward through the original amphitheater’s entranceway was also removed and robbed of its timber during the destruction phase. The robbing created a “low lying area” that was then used for the disposal of large amounts of trash, including “a substantial dump of glass cullet” (Bateman et al. 2008: 39).  

The Cullet Dump at Guildhall Yard

Perez-Sala and Shepherd examined the glass from Guildhall Yard and divided the assemblage into two broad categories: (1) glass vessel fragments and other objects, such as windowpanes, and (2) glass waste and non-glass material relating to the secondary production process (Perez-Sala and Shepherd 2008a: 142). They describe the glass working debris on site as physical evidence of secondary glass production nearby. The cullet, on the other hand, originally came from elsewhere and was likely transported to the workshop so as to be recycled (Perez-Sala and Shepherd 2008a: 144). Two divergent scenarios could account for the presence of cullet among the Guildhall assemblage:

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64 Other materials, such as burnt, crushed lumps of clay and pottery fragments were also found in the leveling dumps (Bateman et al. 2008: 42).
If the cullet brought into [the] workshop is formed of specific types of containers, it could be suggested that the glass workshop had close affinities with the users or purveyors of those vessels, the traders who used the containers being responsible for taking the broken glass to the workshop to be used as cullet (Perez-Sala and Shepherd 2008a: 145).

Alternatively, if a glass workshop from antiquity supplied a consumer market, the collection and delivery of cullet to the workshop could have been done by “scavengers” or “rag-and-bone” men who pick up “whatever was useful” and sold it back to the glass artisans (Perez-Sala 2008a: 145). This scenario recalls the literary evidence. The Guildhall Yard assemblage consisted of fragments from a large variety of vessel forms and objects such as windowpanes and tesserae (Bateman et al. 2008: 42). This seems to suggest that the latter model of cullet collection was used at the workshop near Guildhall Yard—although both methods may have been used simultaneously.

The bulk of the cullet deposited at Guildhall Yard consists of naturally colored greenish blue glass (over 50,000 fragments). As Perez-Sala and Shepherd remark, “[the] general chromatic homogeneity suggests that the fragments were selected by color, though a small proportion is formed of monochrome, polychrome and colorless glass” (2008: 208). Of the colored glass, eighty-nine fragments of dark blue glass, seventy-seven fragments of emerald green glass, and forty-two amber or brown fragments were recovered. Given these relatively low numbers, it is possible that the brightly colored and colorless glass was deposited with the remainder of the assemblage by mistake (Perez-Sala and Shepherd 2008b: 208). This would make sense as naturally colored wares would make for better cullet. Unlike vibrantly colored fragments, naturally colored glass does not run the risk of muddying a glass
batch; it can be added to most batches without the fear that its hue will affect the appearance
of the final product (Stern 1999: 451).

As mentioned above, a wide variety of vessel forms was uncovered from Guildhall Yard. These range from the pillar-molded bowls (112 fragments) to the ubiquitous and
versatile cylindrical and prismatic bottles and windowpanes. Most vessel fragments were
quite small with very few joins, suggesting that the assemblage that survives is only a small
portion of a much larger cullet supply. In addition, the small size of the fragments indicates
that the cullet had already been prepared for remelting (Perez-Sala and Shepherd 2008: 208).

Like at Basingall Street, moils, numbering 2936 in total, were by far the most
common type of glass waste found at Guildhall. Excavators also identified 307 droplets of
waste glass; most of them have “a flat, corroded surface” as a result of contact with the floor
when they were dropped (Perez-Sala and Shepherd 2008b: 203). This type of waste at
Guildhall suggests that the dump received debris from the clearing out of the workshop
(Perez-Sala and Shepherd 2008b: 204). Other notable finds include 166 fragments of fired
clay, many with a glassy material adhering to their surface, presumably fragments of the
glass-working furnace itself. Due to the small size of these fragments, however, Perez-Sala
and Shepherd were unable to identify the type of superstructure of the furnace (2008b: 202).

A total of 715 chunks of tank metal were also noted in the Guildhall Yard
assemblage. These were not found in association with a crucible. All pieces of tank metal
were natural greenish blue, with the exception of 14 pale green fragments. Hardly any of the

65 In fact, only one crucible has been found in Roman London, and it seems to have been redeposited in
a third or fourth century dump (Perez-Sala and Shepherd 2008b: 202).
fragments had smooth surfaces; instead, most fragments had turned into an opaque white bubbly material. “These imperfections might be the reason for the glass being discarded” (Perez-Sala and Shepherd 2008: 202). Thus it seems that some refuse in the Guildhall Yard dump was waste deemed unfit to be recycled.

Discussion

While the Guildhall cullet dump provides good evidence for the practice of glass recycling in early Roman Britain, one question remains: if the broken vessel fragments were valuable, why were they discarded? “It would appear that a great deal of care had been taken and possibly some expenditure made, to gather the glass and retain it for some time, only for it then to be abandoned” (Perez-Sala and Shepherd 2008a: 146). Perez-Sala and Shepherd offer several explanations. Perhaps the cullet collection scheme had become so productive that it led to a surplus of broken glass. As more and more glass was collected to be recycled, glass workers became increasingly selective and thus used only the best cullet, discarding the rest (Perez-Sala and Shepherd 2008a: 146). Alternatively, the cullet may have been of suitable quality, but perhaps the demand for glass vessels had diminished or production had declined at the nearby workshop on account of the loss of employees (Perez-Sala and Shepherd 2008a: 146). In both these scenarios, artisans would have been dumping glass over a long period of time, throughout the workshop’s existence.

On the other hand, it may be possible that most of the material in the dump was discarded simultaneously when the workshop went out of business. In the growing town of London, space was limited and fire-based industries were continuously uprooted and pushed
out into more marginal industrial zones as the site expanded (Shepherd and Wardle 2009; Perez-Sala and Shepherd 2008a: 145). “A workshop in the way of important development might be compulsorily purchased or confiscated, a possibility in the rebuilding of the amphitheater and development of the surrounding area” (Perez-Sala and Shepherd 2008a: 146). If this were the case, the glassworkers of the Guildhall area would have had to leave quickly, and may have been unable to transport their cullet to a new location. It is also possible that the workshop was cleared out and its refuse was deposited in the pits at Guildhall Yard as fill, to level out the surface to the east of the new stone amphitheater, which became a refurbished entranceway (Bateman et al. 2008: 39).

The systematic clearance of workshop debris is known to have been a requirement for potteries in Oxyrhychus, Egypt during the Roman period. Papyrological evidence from this site demonstrates that potters had short-term leases on workshops and that provisions were established in order to ensure that once the lease expired, the equipment and materials were cleared away and the facility was returned to the lessor “free from ash and sherds” (Cockle 1981 as cited in Price 2005: 172). As Price states, “whether site clearance on exit was a general condition in leases for other craft and industrial activity is unknown, but such a requirement in leases for urban glass workshops might provide a context for the large deposits of glass waste and cullet buried in pits, as at... Guildhall Yard,” and other sites (2005: 172).

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66 A similar scenario has been proposed for a glass factory in Avenches, Switzerland. Excavators there observed that the premises may have been abandoned during the Flavian period because of the expansion of the adjacent settlement (Morel et al. 1992: 3 as cited in Perez-Sala and Shepherd 2008a: 146). This may have also occurred in the Canabae Legionis at Nijmegen (Isings 1980).
Conclusion

At both 35 Basinghall Street and Guildhall Yard large cullet dumps consisting of a variety of glass remains—both broken vessels and waste glass—were unearthed from strata dating to second century. These dumps appear to have contained the refuse from nearby glass workshops. Much of the material found within the dumps could have been deposited after the workshops ceased to function. It may not have been possible for the glassworkers to transport all valuable items with them upon departure and therefore much of the material and debris from their workshops may have been disposed of at dumping grounds in the vicinity. If this interpretation is accurate, the finds from these cullet dumps can be taken as examples of the types of material used during the secondary production process in London. Cullet—found in abundance at the dumps—can therefore be considered an important component of this process. It seems as though broken vessels were being carefully collected by the glass workshops of London in order to supplement raw glass supplies.

As seen below, cullet played a prominent role in the manufacturing of glass vessels in Roman Britain. This was in part due to Britain’s lack of access to the primary resources necessary to make raw glass. Throughout the first through fourth centuries, Britain imported raw glass from elsewhere in the Empire—a costly and sometimes unreliable venture. A heavy reliance on cullet was a good substitute for long-distance trade.

Conclusion: The Archaeology of Collection

The collection of broken and waste glass appears to have been a procedure undertaken in the southeastern and northwestern provinces of the Roman Empire. It appears
that naturally colored and colorless glass was deemed most fit to be recycled. Fragments of
tablewares, bottles and windowpanes, as well as moils and other production debris, were
often collected. The way in which the collection process unfolded, however, is hard to
ascertain. Several scenarios exist: (1) the Church could have organized recycling programs in
certain regions, (2) those who sold or produced glass vessels could have been responsible for
amassing broken fragments, and/or (3) street peddlers could have performed this activity. In
all cases, it is likely that glass was collected in order to be remelted at local glass workshops.
In the following section, “The Archaeology of Transportation,” it will become apparent that
this was not always the case; occasionally cullet could be amassed and shipped to workshops
located far from their original point of collection.

3.2 The Archaeology of Transportation

While it appears that the collection of broken vessel and waste glass was often a local
endeavor, benefitting the glass workshops of the town or city in which it was being carried
out, underwater investigations reveal that glass recycling may have also been a much more
complicated venture, taking place over large distances. Although Stern argues that long-
distance glass trade was primarily concerned with fine tablewares and raw glass in the form
of ingots or chunks (Stern 1999: 472), recent investigations demonstrate that broken and
waste glass was also transported by sea in Roman times. From both a third century ship,
known as the *Iulia Felix*, and an eleventh century vessel found near Serçe Limani, excavators
uncovered cargoes of cullet. Excavators of both ships suggest that these materials were
transported to be recycled at their final destination(s) (Toniolo 2005; Bass 2009).
Indeed, it was often more economical to ship glass over water than by land. As DeLaine calculates, it would have cost 0.52 KM per ton per Roman mile to transport commodities by ox-carts, but only 0.012 KM per ton per mile to ship goods via the sea (1997: 210-211 as cited in Stern 1999: 473). In addition, since whole Roman glass vessels were quite fragile, transporting them by boat would have been an attractive option (Stern 1999: 473). Despite these advantages, glass was probably not often a major item of cargo on ships in the Mediterranean (Stern 1999: 472-473). In his seminal catalogue of ancient shipwrecks, Parker identified over a thousand wrecks dating to the Classical and Byzantine periods. Most of these were Roman, i.e. they dated from the third century BCE to the fourth century CE (Figure 6; Parker 1992: 1). Of the Roman wrecks catalogued, only nine contained cargoes of glass—five date to the first century, three from the second and third centuries, while two are of uncertain date (Parker 1992: 19 as cited in Stern 1999: 473). As Stern remarks, these dates complement the overall pattern of sea trade, demonstrating that it was “most intense” in the late Republican and early Roman Imperial periods (1999: 473). In the eastern Mediterranean, maritime trade was most popular during the Byzantine period,

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67 The unit KM refers to kastrensis modius, or “army modius,” Diocletian’s Price Edict’s favored capacity unit. As Arnaud tell us, maximum fares for sea transportation were “expressed in denarii [a Roman silver coin] per single volume unit, expressed in modii kastrenses, equal to [one and a half] Italic modii,” or 12.9 litres (2007: 322).
68 At the time of Parker’s study, Roman shipwrecks made up over 75 percent of all wrecks in Mediterranean earlier than 1500 CE (Parker 1992: 8). It should be noted that Roman wrecks are much more common in the western Mediterranean, but less so in the East, where they make up less than half of the total shipwrecks (Parker 1992: 9).
69 In total, Parker recorded twelve cargoes of glass vessels with an additional seven cargoes containing “other” types of glass, such as ingots or cakes.
with 222 shipwrecks dating from the fourth to twelfth centuries (Kingsley 2009: 31). Glass has been recorded on two such ships, Miljet A, a sixteenth century merchant vessel wrecked off the coast of Croatia, and the Serçe Limani wreck mentioned above (Kingsley 2009: 34).

The following section will investigate the cullet from the *Iulia Felix* and Serçe Limani ships. Although the two wrecks are divided by several centuries, they demonstrate that transportation of cullet by sea was an economically viable procedure both during and well after Roman times.

**The *Iulia Felix* Wreck**

The *Iulia Felix* wrecked off the northern coast of Italy near the town of Grado in the first half of the third century. The ship’s measurements (15-18 meters long by 5-6 meters wide) correspond to a type of small cargo vessel, called a “*corbita*” in antiquity (Dell’ Amico 2001, as cited in Silvestri et al. 2008: 331). Its cargo consisted mainly of amphorae, a minimum of 560 in number—these containers, along with the ship’s equipment, were used to date the ship. Also onboard, near the bow, was a large wooden barrel, about 1.4 meters high, filled with more than 11,000 fragments of glass (weighing 145 kilograms). The fragments once belonged to a wide assortment of glass vessels: goblets, cups, trays, plates, bottles, small jars and containers of varying size and decoration (Silvestri et al. 2008: 331).

According to A. Toniolo, all fragments represent broken glass, which may have been purposefully collected and destined to be recycled (2005: 161-164). “It is probable that this

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70 The largest portion of wrecks in the eastern Mediterranean date to the sixth and seventh centuries (Kingsley 2009: 34).
broken glass was stacked in special depots, from which it was taken up and loaded on ships in spadefuls, according to the weight required by orders” (Silversti et al. 2008: 331).

Excavators also note that this cullet was carefully selected for color and type (Silvestri 2008:1489). The majority of the fragments (6,000 of the 11,000) were pale green, pale blue, green or blue-green; yellow or dark green fragments were rare (Silvestri 2008: 1492). This is not surprising as darkly colored glasses might muddy a glass batch, whereas pale green-blue alternatives are better suited for recycling. In addition, a good amount of colorless shards were also recovered from the *Iulia Felix* (3,000 total), although these are far less abundant than their pale-colored counterparts (Silvestri 2008: 1492). It should be noted that of the colored fragments, most came from a specific type of glassware, i.e. thick-walled bottles. As Silvestri notes, Roman glass bottles can be thought of as “low-status” items in comparison to high-quality vessels such as plates and cups. Contrastingly, the colorless glass found on the *Iulia Felix* was more likely to consist of fragments from these types of valuable tablewares (2008: 1499).  

As Silvestri concludes, the evidence from the shipwreck reveals that the practice of glass recycling was common in the Roman imperial period, especially for low status, naturally colored vessels (Silvestri 2008: 1489). This observation corresponds nicely with the evidence reviewed in the last section, “The Archaeology of Collection.” The heaps of cullet from both the Byzantine churches in Jordan and the urban dumps found in Londonium contained mostly naturally colored glasses.

The cullet aboard the *Iulia Felix* was subjected to chemical composition analysis. All samples studied, both colorless and colored alternatives, displayed “strong evidence of

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71 More ordinary vessels, such as bottles, were also made out of colorless glass.
compositional variability” (Silvestri 2008: 1489). While more will be said concerning these analytical studies of glass in Chapter 4, it should be noted that compositional variability is one of the markers for glass recycling. Indeed this means that much of the cullet aboard the *Iulia Felix* was already made from recycled materials. While these glasses were intended to be recycled again, they never reached their final destination. This demonstrates that recycling was a relatively frequent procedure and that fragments could be recycled multiple times throughout their lifespan.

The *Iulia Felix* finds seem to contrast the aforementioned literary accounts in intriguing ways. While ancient authors portray glass recycling as a small-scale job reserved for lowly hawkers, this shipwreck gives the impression that it could sometimes be a more complex venture. A significant amount of organization must have gone into amassing, storing, and finally shipping the cullet. Silvestri et al. note, “It is not surprising that recycling engaged merchants, from the most modest peddler to large-scale enterprises involving shipments of tons of cullet” (2008: 332). Roman glass recycling was apparently popular and profitable enough to attract a wide assortment of practitioners.

**The Serçe Limani Wreck**

While the *Iulia Felix* is the only maritime excavation to offer conclusive evidence that cullet was transported by sea in Roman times, an eleventh century shipwreck, known as the Serçe Limani wreck, provides similar evidence for the continuation of this practice. The ship was sailing from the Fatimid Syrian coast to Constantinople in the third quarter of the eleventh century. It sought anchorage off the southern coast of Anatolia, near Serçe Limani,
but instead met its demise (Figure 7). Scholars identified the ship as a two-masted lateener with an overall length of 15.6 meters and a breadth one-third of its length (van Doornick 2009: 3). The ship’s home port was likely located somewhere along the northern shore of the Sea of Marmara, more specifically in the area of Rhaidestos—an important supplier of grain, wine, and oil to Constantinople (van Doornick 2009: 3). According to van Doornick, the ship’s crew seems to have been participating in a “rather marginal level of maritime commerce” (2009: 4). Only a small number of “substantial sized cargoes” were associated with the wreck; alongside these, however, excavators discovered many smaller “seemingly personal cargoes” (van Doornick 2009: 4).

Among the ship’s larger cargoes was an impressive load of glass, three metric tons in total: two thirds was raw glass chunks while the remaining ton consisted mostly of broken glass vessels and some waste glass (van Doornick 2003: 4). Excavators believe that the broken condition of the glass was “not the result of the ship’s violent end;” instead, they suggest that these glass fragments were originally part of the cargo and “designed to be recycled” (Bass 2009: 18). Several observations led Bass to this conclusion. Firstly, after nearly a decade of joining glass shards together, those studying the Serçe Limanı remains realized that “the joins did not depend on provenience;” shards that joined together came from excavation areas far removed from one another—both horizontally and vertically (Bass 2009: 18). If a glass vessel broke because of the shipwreck, one would expect to find its

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72 Excavators note that this was a relatively modest-sized vessel (van Doornick 2009: 3).
73 van Doornick does not specify what he means by “personal cargoes.” I assume he uses this language to denote the size and perhaps contents of various cargoes. It seems as though an individual’s personal cargo would be much smaller than a commercial-sized cargo, and perhaps it would consist of small trinkets that could be sold at a market.
various fragments grouped near one another. Finding fragments from the same vessel scattered throughout the excavation area, however, suggests that the vessel broke prior to being placed abroad and that its various fragments were shipped in different containers.

In addition, it was extremely rare that all pieces of a particular glass vessel were recovered during the excavation. As Bass clarifies, the missing fragments were not “overlooked on the seabed... [they] simply were not on the ship at the time it sank” (2009: 18). This fact also implies that the vessel fragments were already broken prior to being placed aboard and that certain pieces escaped collection. Lastly, cullet from Syria is known to have been imported by the famed glassworkers of Venice during late medieval times (fourteenth and fifteenth centuries, Jacoby 1993). Given the evidence from the Serçe Limani wreck, van Doornick suggests that a similar practice was also common during the Fatimid period, 909-1171 (2009: 4).

Bass claims that the Serçe Limani cullet was collected into woven baskets prior to being placed aboard the ship. “During the course of excavation we had noted faint oval outlines that suggested thin gaps in the large masses of broken glass concreted together. These suggested spaces once filled by a perishable material such as wicker” (Bass 2009: 18). The seabed outlines revealed that the wicker baskets were at least 40 centimeters wide and perhaps a meter high (Bass 2009: 18). With one exception, the glass cullet seemed to have been randomly placed into these baskets; moils, on the other hand, were grouped separately into their own baskets (Bass 2009: 18). While it seems odd that moils would be segregated from the rest of the glass fragments, their separation may indicate that they were collected
from a different source. Perhaps the waste glass came from secondary production workshops while the broken vessel fragments were amassed by peddlers in the streets. In addition, raw glass was positioned strategically above broken vessel and waste glass inside the wicker baskets. This fact led Bass to conclude that chunks of raw glass may have acted as lids keeping the rest of the cullet from spilling out (2009: 18). The presence of raw glass also lends extra support for the hypothesis that this cullet was meant to be recycled. It is possible that both the raw glass and cullet was being shipped to the same workshop or series of workshops in order to be remelted together and fashioned into new vessels.

These baskets full of cullet could have replaced stone ballasts and acted as counterweights on the ship (van Doornick 2009: 4). The use of stone ballasts is attested as early as the Bronze Age, as evidenced by the Middle Bronze Age wreck at Sheytan Deresi (Bass 1976) and the Late Bronze Age Ulu Burun ship (Bass 1986). Generally this role was filled by boulders, pebbles, beachrock or clay, and even sometimes sand (Parker 1992: 28). The evidence of glass ballast from Serçe Limani stands out as exceptional, but could easily be seen as a logical alternative. As van Doornick explains, “Shipping glass cullet cheaply as ballast often made economic and technical good sense, since melting glass requires a much lower temperature (2000° F) than making glass (2600° F), and a desired kind of glass cannot always be made from locally available raw materials” (2009: 4). Being able to sell this ballast at a port, however cheaply, could have supplied yet another source of revenue to these nautical merchants. Many people benefitted from this scheme, including the ship’s owner and the glassworkers who eventually received these products.
While the date of the Serçe Limani glass does not correspond to the period under investigation here, the wreck nonetheless demonstrates that glass recycling was so economical that ships continued to transport cullet far beyond Roman times. It also underscores the varying possible reasons for recycling glass, be they monetary, technical, or induced by geographic concerns (i.e. lack of access to raw materials).

Conclusion: The Archaeology of Transportation

The evidence from both the Iulia Felix and Serçe Limani wrecks seems to contrast with the picture of glass recycling painted by the literary sources investigated in the previous chapter. On both ships it appears that cullet was intentionally collected, placed in containers, and transported to another location to be recycled there. Presumably much energy and organization would have gone into this operation. In this scenario glass recycling appears to be a more structured and orderly venture, not only a menial task performed wholly by low-status individuals. While the peddlers described by Martial and Statius likely played a role in this scheme, it is apparent that other practitioners were also involved. These may have included glass-working artisans who ordered cullet from afar, workmen who transported cullet from its point of collection to the ship, people who sorted and weighed the glass according to orders, those responsible for loading the cullet onto the ship, and the ship’s owner—to name a few. Therefore, while the archaeological record seems to contradict our literary sources, it does not actually discredit them. Instead, it would appear that glass recycling was a complex affair in Roman times performed on a variety of scales.
The shipwreck evidence suggests that glass recycling was a prominent part of the Roman economy and was at least occasionally practiced on a large scale. Cullet must have had some value if it were shipped across the sea. These shipwrecks, however, do raise some questions. Which areas of the Roman Empire could afford to lose their broken and waste glass to foreign markets and which regions had a need for cullet? The following section, “The Archaeology of Production,” will help to answer these questions. As will become apparent, those areas that had direct access to raw glass seem to have engaged in more selective recycling, while those areas lacking easy access were forced to rely more heavily upon cullet.

### 3.3 The Archaeology of Production

Evidence for glass recycling comes directly from the secondary workshops that used cullet in Roman times. Secondary glass workshops, however, are often hard to identify in the archaeological record (Price 2003: 81). The discovery of *in situ* glassblowing furnaces and other installations associated with production is rare (Cool 2003: 141). In comparison to contemporary ceramic kilns, glassblowing furnaces are quite small and were often in operation for only a short period of time. Most known secondary production workshops functioned for a generation or two; after only a couple of decades, glassworkers might move to new locations (Perez-Sala and Shepherd 2008a: 145; Price 2005: 178). Multiple factors encouraged this itinerant lifestyle; for example, access to fuel resources. When fuel within an “economic radius” was used up, glassworkers would often leave a site in search of new vegetation (S. Weinberg 1988: 19). In addition, factors such as urban development also
affected glassworkers. Because glass working involved high-temperature fires it was considered a dangerous activity and a nuisance to residential and public development (Price 2005: 172). As such, when settlements expanded, glass working was often pushed out into more peripheral areas of a town or city (Perez Sala and Shepherd 2008a: 145). It should be noted that upon departure, glassworkers usually took their tools, such as their blowing iron and crucibles, with them. In addition, any tools left behind might also have been scavenged for raw metals. As such, these items are rarely found within glass workshops—making the identification of these facilities even harder for archaeologists (Price and Cool 1991: 25).

The following section will review evidence for recycling from two Roman glass workshops, also from both eastern and western portions of the Empire: one in Israel (Jalame) and another in Britain (Mancetter). Comparative analysis reveals that the workshop at Mancetter relied much more heavily upon cullet than did Jalame. The reasons for this divergence will be discussed below.

A Fourth Century Glass Factory at Jalame

Jalame lies ten kilometers southeast of Haifa in the foothills near Mount Carmel. The site is located on a small and sloping ridge that juts out from one of the foothills. The excavators, Gladys and Saul Weinberg, relied primarily on coins and lamps to date the site.\footnote{Recently, Kathleen Slane and Jodi Magness have questioned this method of dating (2005). They prefer to use ceramic fine wares to date the site. More will be said of their work in later paragraphs.} They dated the first period of occupation to 75-125 CE, when the top of the ridge was used as a cemetery and a series of buildings was erected on the western slope (1988: 2). Following
this phase, there was a gap in the occupation of the site from ca. 125 to 275. Yet “both lamps and coins indicate renewed occupation by the latter date, again on the west slope, where the glass factory was later built” (Weinberg and Weinberg 1988: 2). From 275-350 the settlement spread to the top of the ridge. Accompanying this expansion, a large villa—referred to as a “country house” by the excavators—was built atop the ridge. Later, wine and olive presses were added to the complex (Weinberg and Weinberg 1988: 3). As S. Weinberg states, “by the middle of the fourth century, this country establishment had become a large architectural complex that, to judge by the size of the villa and the [olive] presses, reflected prosperity and tranquility” (1998: 16).

Period 3 (ca. 351-378) at Jalame shows evidence of bustling commercial activity, likely associated with construction of a glass factory, built shortly after 351 (S. Weinberg 1988: 16). This factory was only in use for three decades, having been abandoned sometime before 383, and its closure was followed by the last significant period of occupation at Jalame, Period 4. Period 4 was characterized by an extensive rebuilding program, which utilized a different style of masonry than the previous phases (S. Weinberg 1988: 19). Originally, occupation at Jalame was thought to have extended into the fifth century, but excavators were uncertain about how long this persisted (Weinberg and Weinberg 1988: 4). S. Weinberg explains, “because of the shallow fill over the remains of Period 4 it is difficult to say when occupation ended” (1988: 21). He suggested that the site was abandoned sometime in the early fifth century and that Jalame’s buildings had all collapsed by ca. 425.75

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75 The cause of this abandonment is unknown, but S. Weinberg asserts that it had nothing to do with natural disasters such as an earthquake (1988: 21).
More recently, however, Slane and Magness have re-evaluated the evidence from Jalame. Upon reviewing the ceramic fine wares found on site, they concluded that occupation at Jalame extended well into the late sixth century. “Far from being a short-lived phase, Period 4... extends from ca. 450-ca. 575 or 600” (Slane and Magness 2005: 261). Unfortunately Period 3—the period when the glass factory was in use—contained virtually no fine wares. On account of this, Slane and Magness have not yet reevaluated these deposits, although they do mention, “it is theoretically possible that they could be associated with the fifth century material identified [in their own study]” (2005: 261).

The Jalame Glass Factory and Evidence of Recycling

Excavations at Jalame yielded a particularly large amount of glass (G. Weinberg 1988: 24). As G. Weinberg notes, “The existence of a [secondary] glass factory at Jalame has been established beyond a doubt by masses of raw glass and cullet, heaps of waste accumulated during the manufacturing, and thousands of vessel fragments” (1988: 24). Evidence for the glass workshop at Jalame can be classified into three categories: the furnace and a series of working floors surrounding the installation, sorting floors found within eight to sixteen meters south of the furnace, and lastly, a large area of “dumped debris” deposited near the factory (S. Weinberg 1988: 16).

G. Weinberg argues that the workshop produced mainly domestic and utilitarian glassware destined for local consumption. There were likely many other glass factories in the region manufacturing similar products (G. Weinberg 1988: 24). Indeed Jalame was by no

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76 This area extends twenty meters east-west, to the lowest limit of the slope that has been excavated.
means a “pioneering establishment;” its artisans had likely worked at other sites before moving there and their successors probably found employment at other locations after leaving Jalame. While the origin of Jalame’s glassblowers is unknown, they probably remained in the same region throughout their career (G. Weinberg 1988: 24). “It appears that the whole region was once wooded and that glassblowers moved their operations once they had exhausted the economically available fuel” (G. Weinberg 1988: 25). For this reason, the factory at Jalame was only in use for about three decades.

What is unique about Jalame, however, is the large quantity of glass found on the site. Excavators claim that the material uncovered from Jalame greatly exceeds that found at any other secondary production center from antiquity. This led G. Weinberg to claim that “here glass was obviously cheap, and relatively little of it seems to have been collected for remelting” (1988: 24). The glass recycling performed at Jalame was a highly calculated process and only specific types of glass were chosen for remelting. I will touch more on recycling at Jalame below, but now it is necessary to discuss the archaeological evidence for the glass workshop.

The Glass-working Furnace at Jalame

Reconstruction of Jalame’s glass furnace proved to be a difficult task because of the proximity of the remains to the modern surface (Figure 8). In addition, a structure was built over the workshop area during Period 4—a fact which also complicated interpretation of the furnace’s remains. G. Weinberg does, however, make some “tentative” statements about its design. She claims that the furnace’s foundation “occupied a rectangular space measuring ca.
2.40 meters east-west by ca. 3.60 meters north-south (not including the walls)” (1988: 28). The foundation was made mostly of stone, but the occasional baked brick was included. Inside the furnace excavators uncovered the remains of a siege—i.e. a bench on which crucibles would rest (1988: 31). No glass-working tools, however, were found at Jalame, presumably because the glassworkers took them when they abandoned the facility (G. Weinberg 1988: 33).

Little is known about the superstructure of the furnace, but G. Weinberg suggests that the roof was a “barrel vault, built of unbaked bricks” and plastered with clay or mud (1998: 33). In addition, there was no evidence for a separate annealing oven, but the “southern third of the furnace” might have been used for this purpose (G. Weinberg 1988: 33). Molten glass appears to have been worked outside the furnace itself. Hard clay floors immediately north and south of the furnace contained “masses of glass drippings and other glass waste embedded into them” (G. Weinberg 1988: 31).

**Jalame’s Sorting Floors and Evidence for Recycling**

While the furnace was the main component of glass working at Jalame, activities associated with the production process spread much further beyond its boundaries (Weinberg and Weinberg 1988: 16-17). As previously mentioned, a series of “sorting floors” was discovered within eight to sixteen meters of the furnace itself. Four superimposed floors (designated Floors 3-6 by the excavators) were rich in glass remains and contained many

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77 The north-south measurement is uncertain since not many of the original stones remained *in situ* (G. Weinberg 1988: 28).

78 “When the furnace was first fired, the roof would have become a sturdy vault providing a reverberatory effect” (G. Weinberg 1988: 33).
“minute” glass fragments, seemingly collected in order to be remelted.79 As S. Weinberg explains:

Here would have been brought the glass chunks, to be broken up and then melted down for making vessels. [Added] to these would be carefully sorted vessel fragments, to be remelted. Some of these were certainly brought from elsewhere, but there were also vessels from the Jalame factory that had been poorly formed, or cracked during annealing etc. (1988: 18)

These sorting floors provide a wealth of information as to the manufacturing process at Jalame. This evidence reveals that the Jalame factory both recycled vessels not fit for consumption and obtained broken fragments from other sources—probably the inhabitants of the site. It also provides physical evidence that cullet was combined with raw glass during secondary production. All remaining glass, which was found to be unsuitable for recycling, seems to have been disposed of at the nearby dump (S. Weinberg 1988: 18).

**Jalame’s Glass Dump**

The area that produced the largest amount of glass, from all stages of manufacture, was the dump for the workshop’s refuse. The dump occupied a sizable area—the excavated portion alone measured 150 square meters (S. Weinberg 1988: 18).80 This area was ideal for dumping as it was dominated by large rocky outcroppings; over time, as more debris was deposited, the ground became level with these outcroppings. S. Weinberg points out that the most notable feature of the dump was “lenses [or thin layers] of whitish limey conglomerate that occur throughout it;” these layers were positioned one above the other with “softer fills

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79 Floors 1 and 2 were devoid of glass and belong to a period before the presence of the factory.  
80 The dump was located in the southwestern corner of the excavated area. Therefore, it could have extended beyond these parameters.
separating them” (1998: 18). Within the whitish substance excavators uncovered a large amount of glass—including both vessel fragments and waste from the production process—but they also uncovered brick fragments, pot sherds, coins and other refuse (S. Weinberg 1988: 19).

The dump did not appear to serve any other purpose prior to the opening of the glass workshop (S. Weinberg 1988: 18). Coins within the dump, however, demonstrate that it was used almost immediately after the factory began manufacturing vessels and that it continued to function for all three decades of the factory’s existence (S. Weinberg 1988: 19). This fact reveals that, unlike the “cullet dumps” from London, the dump at Jalame was used continuously throughout the life of the workshop and did not consist solely of garbage discarded after the factory went out of use. The dump also demonstrates that the workshop at Jalame discarded a lot of glass, which could otherwise have been recycled. Recycling did not seem to be as intense at Jalame as elsewhere in the Empire, such as in Britain. Instead Jalame’s glassworkers seem to have been relatively selective, possibly as a matter of quality control or even prestige. Perhaps glass vessels were thought of as more valuable if made up of mostly raw glass, rather than recycled fragments from old vessels? As will be revealed in the following chapter, luxury glass vessels tended to be made with a smaller portion of recycled materials than utilitarian or more common glass products.

Based on chemical analysis of the Jalame glass, Brill argues that Beit She’arim, located only a few kilometers southwest, may have been the primary production center

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81 While S. Weinberg does not address why coins were found within the dump, their presence is likely accidental.
supplying raw glass to Jalame (1988: 284).\footnote{For information about the raw glass industry at Beit She’arim, see Gorin-Rosen (2000: 55-56).} Since Jalame had reliable access to raw glass, perhaps they did not see a need to recycle old fragments or waste glass. But if that were the case, why recycle at all? Two interrelated reasons could explain this phenomenon: recycling is economical, as it cuts down on the amount of fuel required to form vessels. By promoting rapid melting and lowering the temperature required to melt a glass batch, the use of cullet would have helped to extend the life of Jalame’s workshop. A small portion of carefully selected cullet could cut down on fuel costs, without being a primary ingredient for the fabrication of new vessels. Using a small amount of cullet would have allowed for better control of both the color and quality of the final product. Recall from the introductory chapter that the use of large amounts of cullet increases the viscosity of a glass batch, making it hard to shape and form vessels. In addition, the use of too much cullet can result in bubbly glass. Being selective with one’s use of cullet would have been a way to avoid these hazards. This, coupled with other obvious economic incentives, such as the lower cost of cullet versus raw glass, were probably the reasons why evidence for recycling was found on Jalame’s “sorting floors.”

A Secondary Production Site in Mancetter, Britain

While in the Eastern Empire cullet seems to have been used alongside raw glass during secondary production, Price and Cool argue that in Britain and elsewhere in the northwestern Empire, cullet was more heavily relied upon—maybe even acting as the main ingredient in a glass-working batch. Indeed, “it is likely that much of the glass worked in
Roman Britain was made from recycled vessel fragments” (Price and Cool 1991: 23-24) because the island did not have direct access to the primary materials, such as natron, required to create raw glass. As mention earlier, only the eastern Empire, as well as sites in Italy, Gaul, and Spain, are known to have engaged in this industry (Degryse and Schneider 2008; Ganio et al. 2012). Large quantities of broken vessel fragments and waste glass have been found at several secondary production sites throughout Britain (Price and Cool 1991: 24; see Figure 9), one of which, the site of Mancetter, will be discussed here.

Mancetter lies southeast of the River Anker in the West Midlands of Britain. The site seems to have had a long history of Roman military occupation. While earlier camps and forts are known, in the pre-Flavian period a “two-phase vexillation fortress” was constructed at the site (Burnham and Wacher 1990: 255). In addition, Mancetter was one of five fourth-century 


burgi (i.e. fortified settlements) on Watling Street (Burnham and Wacher 1990: 255). In terms of the non-military population, not much is known. While excavators have uncovered pottery from the “pre-Flavian period,” the first domestic structures at Mancetter seem to date to the Flavian period (69-96 CE). As Burnham and Wacher argue, these early inhabitants must have been attracted to the settlement by the presence of Mancetter’s large and prosperous garrison (1990: 259).

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**83** Only one site in Roman Britain, Coppergate York, is thought to have been involved in the production of raw glass (during the late second or early third century); yet the evidence from this site is not conclusive (Jackson et al. 2003; Price 2003). As Price mentions, the glassmaking that went on at Coppergate York appears to be very different from that which we see in the eastern Mediterranean. In particular it was “small in scale” and pottery vessels, not tanks acted as crucibles (2003: 89). Even though York may have engaged in primary production, it is also obvious that the collection of cullet, and thus glass recycling, was also undertaken at the site (Price 2003: 89).

**84** Other notable sites in Britain where excavators have noted evidence of secondary glass production include Caistor by Norwich, Castor (Water Newton), Clochester, Leicester, London, Silchester, Worcester, Wilderspool, and Wroxeter (Price and Cool 1991).
During the Roman period, Mancetter became part of a large and important industrial region, which extended several kilometers southward to Hartshill, near Nuneaton. Industrial production began with pottery in the early second century. At this time, Mancetter was best known for its production of mortaria—a specific type of conical grinding bowl (Price and Cool 1991: 24; Burnham and Wacher 1990: 259). These vessels were distributed widely throughout the northern half of Britain, up to and beyond the Antonine Wall, into north Wales and the south Midlands (Burnham and Wacher 1990: 259). Mancetter’s pottery kilns lie almost entirely in the southwestern part of the settlement. Alongside these kilns, excavators uncovered a glass-working furnace in operation in the mid second century or slightly later (Price and Cool 1991: 24).

*The Mancetter Glass Furnace and Associated Finds*

The glass furnace at Mancetter was circular in shape and contained a flue on one side. Made of clay, the furnace was relined three times, suggesting multiple phases of use. During its final phase, the installation contained floor tiles and was oval internally (Price and Cool 1991: 24). The most striking feature about the Mancetter furnace was its small size: “in Phase I it had an internal diameter of 0.8 meters but by Phase III it had been reduced to 0.51 by 0.34 meters” (Price and Cool 1991: 24). It should be noted that no annealing oven or glass-working tools were found in the vicinity; however, other evidence strongly suggests that the furnace was used to make glass vessels. For instance, a dribble of glass was found adhering to the final lining of the furnace.
Multiple glass wasters, moils and broken vessel fragments were found nearby the furnace (Price and Cool 1991: 24). The waste glass found at Mancetter had a total weight of about 1.2 kilograms and consisted mainly of moils. According to Price and Cool, the small amount of waste found on site is an indicator that most of this material was recycled during the secondary production process (1991: 26). When compared to the large amount of glass waste found in the dump at Jerash, it seems plausible that Mancetter’s glassworkers were recycling most of the glass they had access to, and that they did not have the liberty to be as selective. It is also possible that some of the glass waste was thrown out in a dump, but that said dump has yet to be found. Alternatively, perhaps the Mancetter glassworkers left a larger amount of cullet behind than was recovered during excavation. It is possible that later inhabitants, recognizing the value of cullet, may have collected this material so as to resell it. If this were the case, however, one would assume the collectors would have amassed all possible waste instead of leaving a small portion behind. While these explanations are plausible, given Britain’s lack of access to primary materials necessary for glassmaking, it would have been logical for glassworkers at Mancetter to recycle most of their waste glass. This material was already directly at their fingertips and would not have cost anything extra.

In addition to glass waste, the broken glass fragments were recovered from Mancetter; these came from an assortment of vessels such as collared jars, small jars, jugs and bowls. Most vessels were made of naturally greenish-blue glass but some fragments of colorless and yellowish glass were also present (Price and Cool 1991: 26). This distribution seems to follow the pattern found at Jalame and at the cullet dumps in London. Naturally
colored glasses were by far the most common whereas colored fragments are rarely present. This fact suggests that the former were more likely to be collected and recycled.

As Price and Cool remark, the “large numbers of vessel fragments found in the glass working assemblage at Mancetter suggests that cullet was the raw material for the industry there” (1991: 24). Instead of purchasing expensive raw glass that would have been imported from distant primary production centers, such as those in Near East or on the Continent, the glassworkers at Mancetter seem to have utilized cullet to a great extent as an economical alternative. The traders and peddlers responsible for selling the manufactured vessels may also have been involved in the collection of cullet (Price and Cool 1991: 27). If this site relied heavily on cullet there must have been a relatively systematic means of amassing it, in order to ensure steady supply and output.

Conclusion: The Archaeology of Production

Glass recycling was performed at secondary production sites in both the eastern and northwestern parts of the Roman Empire. Yet the manner in which these regions engaged in recycling differed. Jalame’s glassworkers appear to have participated in a minimal level of glass recycling and were rather particular about the kinds of glass they remelted. Contrastingly, the glassworkers of Mancetter relied extensively on cullet. While recycling at Jalame was likely done to minimize the factory’s level of fuel consumption, the workshop at Mancetter would have had additional reasons for utilizing cullet. Located much further from any primary production center, Mancetter did not have good access to raw glass. To acquire raw glass, Mancetter would have to depend on long-distance trade, an often unreliable
venture. Cullet would not only have been a logical alternative for Mancetter’s workshop, it would also have been quite economical. By using cullet, the craftsmen at Mancetter could avoid the costs of transportation and ensure a more dependable supply of glass, which could be remelted.

3.4 Conclusion

Based on the archaeological evidence reviewed above, glass recycling seems to have been a common endeavor performed in various regions of the Empire and by a variety of different parties throughout Roman times. Archaeology both complements and contrasts with the data from ancient literary sources. While there is a place in the glass recycling scheme for Martial and Statius’ street peddlers, the industry itself is much more complicated and diverse than these authors suggest. Although literary evidence portrays glass recycling in a negative light, as if it were a crude business, the archaeological record suggests recycling was a premeditated and intricate process performed both locally and over large distances. Cullet was collected in Byzantine ecclesiastical structures, perhaps to raise funds for the Church; it was shipped by sea, likely to benefit those areas with little access to raw materials or fuel resources; it also seems to have been an integral component of secondary glass production. Indeed there was much to gain for everyone involved in the process of glass recycling. A number of factors—economic, technical, and geographic—encouraged the Romans to recycle.

Unfortunately, much of the archaeological evidence for glass recycling is ambiguous. Material remains, while useful, cannot definitively prove the existence of glass recycling in
particular times, or places. Furthermore, the archaeological record makes it difficult to assess the extent to which the Romans recycled. Presumably most physical evidence for glass recycling does not survive. Recently, scholars have begun to perform chemical composition studies in hopes of better understanding Roman glass recycling. This analytical research seems to provide reliable methods of both confirming that the Romans recycled glass and of gauging the magnitude of this activity in various parts of the Empire.
CHAPTER 4

Compositional Analysis: The Extent of Glass Recycling in Opposite Corners of the Empire

Compositional studies of glass remains often focus on questions concerning primary production and glass-making technology. This is because the chemical composition of glass is diagnostic of the raw materials and additives—such as colorants or decolorizers—used to produce it (Paynter 2006: 1037; Schibille et al. 2012: 998). Furthermore, concentrations of certain trace elements in archaeological glass can be attributed to the geochemistry of various production areas from antiquity (Paynter 2006: 1038). These facts allow scholars to identify what ingredients were used in the ancient glass-making process and where certain types of raw glasses were produced in the Roman world.

More recently, however, scholars have demonstrated that chemical composition studies can also indicate the degree to which glass recycling occurred in the past. The introduction of cullet into the glass batch alters the chemical composition of glass remains and therefore, recycling can be detected through analytical means. Glass recycling can be recognized chemically by identifying whether certain levels of trace elements are present in a given glass composition. If trace elements, which cannot be explained as naturally occurring impurities or intentional additives are found in glass, these elements likely represent accidental additions that occurred by the introduction of cullet into the glass batch. In colorless and naturally

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85 Glass can be classified into compositional groups based on (1) its major constituents, which specify what type of glass it is; (2) its minor metallic constituents, which determine its color; and (3) its alkaline to oxide ratio, which indicates its source (Mari 2001: 377).

86 Trace elements can be found in all three of the main ingredients of raw glass: sand, modifiers, and colorants (Mari 2001: 377).
colored glasses, high levels of transition metals (e.g. cobalt, copper, zinc, and lead) are seen as evidence for recycling. This is true of glass from both the western and eastern Mediterranean (Jackson and Foster 2014; Schibille et al. 2012).

The transition metals mentioned above were common colorants in the Roman world and were added to glass batches in order to create brightly colored products. The presence of trace amounts of these metals in Roman glass that is not brightly colored, however, is assumed to be accidental and the product of somewhat careless recycling practices. For example, when trace amounts of cobalt—a colorant used to create glass with a strong blue hue—is found in colorless or naturally colored glass compositions, researchers often assume that small fragments of blue glass or highly decorated cullet has been added to the glass batch and thus recycled.

Specialists refer to these trace elements as “markers” for recycling and their presence can be measured as a percentage of the total glass composition. In order to determine the percentage of recycled material present in a glass batch, the levels of trace elements are measured against known compositions of raw glasses—products of primary production and thus glasses that have not been recycled. In a seminal study, Foy et al. (2003) provided a detail analysis of the chemical compositions of raw glasses from Roman times. “From this material it is possible to see at what levels any potential recycling ‘markers’ would be present as naturally occurring impurities” (Jackson and Foster 2014: 10). The presence of markers above these known levels, but not in sufficient amounts to indicate intentional addition, is suggestive of recycling.
Furthermore, if the mixing of more than one glass composition is found, this is often said to be the result of recycling. While a homogenous composition indicates that one type of raw glass was used to make a vessel, the discovery of vessel fragments with heterogeneous compositions points to the mixing of different types of glass, that were created using different raw materials and/or additives—a phenomenon that is often explained as the result of recycling.\textsuperscript{87} For example, the combination of high amounts of antimony and manganese in colorless glasses is often viewed as evidence of recycling. The natural color of Roman glass is blue-green due to the iron impurities in most sands. The Romans created colorless glass either by selecting raw materials low in elements such as iron, or by the addition of a decolorizer—either antimony or manganese (Degryse et al 2012: 998).\textsuperscript{88} Both manganese and antimony were common decolorizers in Roman times and the use of one would suffice to remove the natural blue/green tint of glass.\textsuperscript{89} As such, the presence of both elements in one composition (from the Roman and Byzantine periods) can indicate the mixing of different technologies and thus the addition of different kinds of cullet into one glass batch (Foster and Jackson 2010).

\textsuperscript{87} Indeed, a heterogeneous composition can also suggest the mixing of different types of raw glass during secondary production, not necessarily the recycling of broken vessels or waste glass. In most cases, however, the recycling explanation makes more sense given its technical and economic advantages.

\textsuperscript{88} For example, Pliny tells us sand from the River Volturno, in south-central Italy, was used to produce colorless glass \textit{(Natural History} 36.192-195). It is therefore assumed that sand from this region was of high quality and naturally low in impurities (Schibille et al. 2012: 998).

On the other hand, the use of decolorizers varied depending on time period and geographic location (Schibille et al. 2012: 998). While colorless glass is known from early periods of glass-making history (Bimson and Freestone 1988), it became increasingly popular in Roman times. From the late first century CE onward colorless glass was material of choice for high-quality tablewares, and it remained as such until the late third century (Paynter 2006: 1037; Silvestri et al. 2008: 331).

\textsuperscript{89} The use of decolorizers varied depending on time period and geographic location (Schibille et al. 2012: 998). Sayre and Smith were the first to propose a model and chronological sequence for the use of decolorizers in Roman glass making (Sayre and Smith 1961, 1967; Sayre 1963; Smith 1971 as cited in Schibille et al. 2012: 998).
Analytical methods have been used to determine the scale of glass recycling at several Roman sites throughout the Mediterranean such as Sagalassos, Turkey (Degryse et al. 2006), Britain (Foster and Jackson 2009, 2010), as well as Petra and Khirbet et-Tannur, both in modern Jordan (Schibille et al. 2012). The following section will compare the results from Britain to those from the two sites in Jordan. This comparison will allow fruitful conclusions to be drawn as to the extent of glass recycling in different corners of the Empire.

Chemical Composition Evidence for Recycling in Late Roman Britain

While the archaeological record yields good evidence for the presence of recycling in second century Britain, analytical methods have recently been used to detect recycling in glass assemblages from late Roman Britain. In two recent studies, Foster and Jackson evaluated 517 glass fragments from nineteen sites of varying functions throughout Roman Britain (2009; 2010). All glass selected for analysis dated from the third to fifth centuries CE. Samples were taken from a wide variety of vessel forms and from both naturally colored and colorless glasses (see Tables 1 and 2). Jackson and Foster explain that this strategy allowed them to obtain “a full cross-section of glass types from potentially different status groups in late Roman society” (2014: 7). Using inductively coupled plasma atomic

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90 Samples were taken from domestic and military contexts, as well as urban and rural sites. The nineteen sites include: Barton Court Farm (Oxfordshire); Barnsley Park (Glouchester), Beadlam Villa (North Yorkshire); Marloe car park, Cantebury (Kent); Intra & Extra-mural sites, Cantebury (Kent); Casitor-on-Sea (Norfolk); Dalton Parlous (West Yorkshire); Dorchester (Dorset); Dorchester-on-Thames (Oxfordshire); Frocester Court (Glouchester), Pudding Lane, Swan Lane, Billingsgate Bath House (London); Lullingstone Villa (Kent), Portchester Castle (Hampshire); Shakenoak Villa (Oxfordshire); Temple of Sulis Minerva, Bath; Alchester Road Suburb, Towcester (Northampton); York Fortress (North Yorkshire), York Minster (North Yorkshire), Wellington Row, York (North Yorkshire; Foster and Jackson 2009: 196).

91 Colorless glasses are generally thought to be of higher status and would have been consumed mostly by the elite. Brightly colored and naturally colored glasses, on the other hand, were more widely available.
emission spectrometry (ICP-AES) Foster and Jackson were able to identify six distinct compositional groups based on the presence of varying decolorizers and trace elements.\textsuperscript{92} Of these groups, three in particular, HIMT 1, HIMT 2 (both naturally colored glasses) and Colorless Group 3 displayed markers of extensive recycling. As can be seen in Tables 1 and 2, these groups make up a large majority of the samples studied (almost 80%); this fact suggests that glassworkers in late Roman Britain were relying heavily upon cullet.

The following paragraphs will give a brief overview of late Roman Britain and the state of the glass industry during this period. This will be followed by a discussion of the evidence for recycling as seen in both naturally colored and colorless glasses from that time.

\textit{The Glass Industry of Late Roman Britain}

The late Roman period (third through fifth centuries) is seen as a transitional episode in the history of the northwestern Roman provinces. The material record indicates that this was a time of great political and economic change (Foster and Jackson 2009: 189). Britain itself underwent a dramatic cultural transformation—what was once Romano-British would become early Saxon (Jackson and Foster 2014: 6). Scholars, however, dispute the nature and pace of this transformation. Since the late 1970s, there has been much debate about the nature and timing of the end of Roman Britain. Two main perspectives exist: “the short chronology” view, first developed by Haverfield (1912), in which all Roman influence is

\textsuperscript{92} ICP-AES is an analytical technique used for the detection of trace metals in variety of substances, including glass. As Foster and Jackson explain, “this technique was chosen for its multi-element approach which is particularly advantageous with large datasets, and because it is comparable to other large analytical programmes on Roman glass” (2009, 191).
thought to have vanished from Britain by 410 CE,\textsuperscript{93} and the “long chronology” view, the dominant perspective in the 1960s and 1970s, which sees the continuation or survival of Roman culture in Britain long after military withdrawal (Faulkner 2002: 59-62).\textsuperscript{94} While scholars have not yet reached a consensus, recent archaeological evidence favors the former perspective (Faulkner 2002; Jackson and Foster 2014). The material record suggests that there was a long process of decline beginning in the third century and that this decline increased in pace in the mid-fourth century. It would appear that Roman Britain ended soon after 400 and that Romanitas failed to flourish in the fifth century (Faulkner 2002: 59).

The decline of Roman Britain can be observed through the stylistic and compositional study of Romano-British glass vessels. During the third century, the range of functions that Romano-British glass served began to diminish; drinking vessels (beakers, cups, goblets, etc.) remained popular but other types of vessels, such as bottles and flasks, slowly lost their appeal (Cool 2003: 142; Jackson and Foster 2014: 6). This process continued to gather momentum throughout the fourth century. According to scholars, fourth century glass from Britain differs greatly from that which came before it (Price 1978; Jackson and Foster 2014). The color and type of vessels change, while the quality of the glass itself declines. In addition, these vessels seem to be made with less care and skill. Yet perhaps the most interesting trend of the late Roman period in Britain is a heavy reliance on cullet during the secondary production process. In other words, glass recycling became increasingly common in Britain during the last century of Roman rule.

\textsuperscript{93} 410 CE is the traditional date marking the end of any formal Roman Imperial control of Britain. 
\textsuperscript{94} This view can be seen in the work of Frere 1972, 1974, as cited in Faulkner 2002.
By the middle of the fourth century British glassworkers had formed a “self-sufficient” model of production (Jackson and Foster 2014: 12-13). This self-sufficiency was possible thanks, in large part, to the practice of glass recycling. Indeed there is no evidence that raw glass production continued in the western provinces of Italy, Gaul and Spain after the third century (Degryse and Schneider 2008; Ganio et al. 2012). Therefore, from the fourth century onward, Britain’s glassworkers would have had to obtain raw glass from primary production centers of the eastern Mediterranean. Using local cullet would have been a good way to avoid or lessen one’s reliance on long-distance imports. In addition, by the fourth century it appears that British glassworkers had developed their own glass repertoire. During this time, the forms of glass vessels present in Britain began to diverge from those on the continent (Cool 2003: 142). For example, globular bodied jugs, a common vessel type from fourth century British sites, are rarely found outside Britain (Price and Cottam 1998: 165-168). The transition to a more independent model of secondary glass production in late Roman Britain may have been caused by a decline in trade, cultural changes, increasing isolation from the continent, or a combination thereof. These possibilities will be explored in the concluding paragraphs of this section.

*The Glass Sampled from Late Roman Britain*

Foster and Jackson separated their data into two groups: naturally colored glass (2009) and colorless glass (2010). This division was chosen in light of recent evidence suggesting that in the Roman world the production technology, provenance, and consumption
of naturally colored and colorless glass may have differed (Foster and Jackson 2010: 3068). It is possible that colorless glasses had a more specialized and centralized model of production than naturally colored alternatives (Jackson 2005: 765). Because of this, the following sections will discuss the naturally colored and colorless glasses separately.

*Naturally Colored Glass*

The majority of the glass studied by Foster and Jackson was classified as naturally colored glass. Three distinct compositional groups were identified among this dataset: Levantine 1, Blue Green, and HIMT glass. All three groups were discovered in a full range of vessel forms: such as cups, beakers, bowls, jugs and flasks (Jackson and Foster 2014: 7). While two of three groups show little signs of recycling, HIMT glass (i.e. “high iron, high manganese, high titanium”)—by far the largest compositional group—yielded evidence for extensive recycling.

*Levantine 1 and Blue-green Glass*

It is worth noting that of the naturally colored compositional groups identified by Foster and Jackson, two did not display markers for recycling: Levantine 1 and Blue-green glass types. Levantine 1 is thought to come from the Syro-Palestinian coast, likely at a site

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95 For more information on the varying production procedures, provenance and consumption of colored versus colorless glasses see Baxter et al. 2005; Jackson 2005; Paynter 2006; Degryse and Schneider 2008.  
96 The term “Levantine 1” has been used to refer to glasses from fourth century Jalame as well as later Byzantine sites in Israel (Brill 1988; Foy et al. 2003). Among the Romano-British assemblage, two subgroups, Levantine 1a and Levantine 1b, were discovered. These subgroups were distinguished on the basis of differing levels of manganese among their compositions (Foster and Jackson 2009: 193).
near the Belus River, in Israel (Foster and Jackson 2009: 189). Levantine 1’s distinctive features include low levels of iron oxide and soda, but high levels of lime. Jackson and Foster relied on well-known typologies of glass vessel forms in order to date the different glass compositions they found. As they explain, “compositional groups can be dated very broadly based upon the types of vessels sampled [be they specific types of bowls, beakers, cups, jugs etc.] and their known periods of circulation” (2014: 7). All Levantine 1 samples can be broadly dated to the fourth century, while certain forms were more closely dated to the mid and late fourth century. It should also be noted that no samples of pre-fourth century date had this compositional signature (Foster and Jackson 2009: 193).

Blue-green glass, on the other hand, can be dated to the first through third centuries. This was the smallest compositional group found in Foster and Jackson’s study—with only eight samples. As the authors note, Blue-green glass has a compositional signature that is “typically Roman” (2009: 194). The provenance of this Blue-green glass has not yet been discerned. Some reports suggest it was made of sands from the Levantine coast (Freestone 2000: 73), others have noted that the composition appears to be made from a combination of Egyptian natron and Levantine sands (Foy et al. 2000). It has also been argued that this

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97 Pliny mentions the Belus River, which has been identified as the modern Na’aman River, as the site where glass was first discovered (Natural History 36.65). The mouth of this river is located immediately south of the city of Akko, modern Acre in Israel (Rasmussen 2012: 12). Indeed this region was heavily involved in glass making in the early Imperial period when Pliny was writing. In a recent chemical composition study, Degeryse et al. (2008) verified that sand from the Belus River was used to make glass in Roman times.

98 Levantine 1a contains much higher levels of manganese, while Levantine 1b only had trace amounts of this element.

99 While this type of glass was produced prior to the fourth century, it remained in use throughout the late Roman period.

100 As mentioned earlier in Chapter 1, natron is a naturally occurring evaporite common to lakes of Syria and Egypt, most notably the Wadi Natrun, approximately 100 km west of Cairo (Rasmussen 2012: 23).
type of glass was made somewhere in the western Empire (Brill 1999; Leslie et al. 2006: 265; Degryse and Schneider 2008).

**HIMT 1 and 2**

The largest compositional group identified by Jackson and Foster was HIMT glass (Jackson and Foster 2014: 7). Recall from earlier in this chapter that HIMT stands for “high iron, manganese, and titanium glass.” Based on chemical analyses, scholars suggest this type of glass was made in the eastern Mediterranean, perhaps Egypt or north Sinai (Freestone et al. 2005, 155-156; Leslie et al. 2006, 261). All HIMT glass studied by Foster and Jackson was divided into two subgroups: HIMT 1 and HIMT 2. The difference between these subgroups was that HIMT 1 glass, on average, consisted of twice the proportion of oxides of iron, manganese and titanium than that found in HIMT 2 samples. In other words, subgroup 1 had a “stronger” HIMT compositional signature than subgroup 2 (Foster and Jackson 2009: 192). These two subgroups were dated to slightly different time periods, although there was some overlap. On the basis of glass typologies, the majority of HIMT 1 glass was dated to the mid fourth to fifth century, whereas the HIMT 2 glass seems to have been more popular prior to 350 CE (Foster and Jackson 2009: 193).

All HIMT glasses displayed evidence for recycling “to some extent” (Jackson and Foster 2014: 10). The HIMT 1 composition appeared to contain about 20% recycled materials; whereas in HIMT 2 glasses, Jackson and Foster were able to identify a much

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101 HIMT glass is not specific to British contexts, but has been found on archaeological sites throughout the Roman Empire (Jackson and Foster 2014, 8).
higher portion of recycled materials—between 40% and 60% (2014: 10). This data, however, is somewhat misleading; it seems to suggest that recycling was more common in the earlier periods—when HIMT 2 dominated the archaeological record—and that the use of cullet diminished over time as HIMT 1 became more widely available. A better explanation, however, would be that as HIMT glass became more popular in the mid-fourth century, the elemental patterns (or markers) that are indicative of recycling weakened, making it hard to accurately identify how much glass was being recycled. As Jackson and Foster clarify:

It is more difficult to distinguish recycled glass when HIMT started to dominate the market. Initially the composition was ‘watered down’ through recycling with non-HIMT compositions as there were more glass compositions in circulation and HIMT was not so widespread. This produced a composition which showed heavy recycling, but which was a ‘weaker HIMT’ composition; this is HIMT 2... In this scenario it may be possible that recycling increased through the period rather than decreased, but it is not possible to detect chemically (2014: 10).

As more Romano-British vessels were made out of HIMT glass, more of that type of glass became available for recycling and thus other types of cullet would have been relied upon less. As more HIMT glass was recycled, the chemical markers of recycling, found easily in HIMT 2, would begin to disappear and the HIMT signature of the glass would become stronger. This is why the chemical composition of HIMT 1 (dominant from the mid-fourth to fifth centuries) has a stronger HIMT signature but weaker markers for recycling. All of this is to say that the analytical evidence uncovered by Foster and Jackson must be read with caution. Most likely glass recycling became even more popular in Britain from the mid-fourth century onward, but we are unable to detect this increase through chemical analysis of HIMT glass types.
**Colorless Glass**

Although they were collected from the same range of Romano-British sites, the colorless glasses studied by Foster and Jackson tended to be earlier in date than their naturally colored counterparts. Most colorless samples dated to the late third and fourth centuries (2010: 3070). In addition to their earlier date, far fewer colorless examples were retrieved from the British sites—128 samples (25% of the total). Foster and Jackson claim, “this proportion of colorless vessels is thought to be representative of other late Roman assemblages from Britain” (2010: 3070). In other words, colorless glasses, known to have been luxury wares and of higher status, were less common in late Roman Britain than naturally colored alternatives. ¹⁰² This scenario may be a reflection of the economic status of those in Britain during the late Roman period, and/or of the ability of British glassworkers to obtain high-quality raw glass. One must, however, keep in mind that a similar pattern is witnessed throughout the Roman Empire; colorless glass was the material of choice for tablewares from the first to third century, but thereafter diminished in popularity (Paynter 2006: 1037). As such, the smaller proportion of colorless glasses in the later Roman period may simply have been a matter of taste.

Foster and Jackson go on to explain that the samples they chose to analyze were not selected “wholly for their colourless characteristics. Although many are ‘water clear,’ some

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¹⁰² Of those fragments that are deemed colorless by Foster and Jackson, most came from fine tablewares, rather than storage and transport vessels. Most sample were either from fine drinking wares, bottles or bowls.
are not truly colourless when viewed closely” (2010: 3070). Instead, the samples deemed “Colorless” in their study were named so because of the presence of high amounts of decolorizing agents in their compositional signatures. Foster and Jackson uncovered three distinct groups of colorless glass: Colorless Group 1, 2, and 3. These groups were distinguished by the presence of different amounts of antimony and/or manganese decolorizers in their compositions (2010: 3070). As mentioned above, only Colorless Group 3 displayed markers for recycling, while Colorless Groups 1 and 2 were produced without the addition of recycled materials into the glass batch.

**Colorless Groups 1 and 2**

In comparison to naturally colored vessels, colorless glasses are “less likely to show evidence for recycling... as the aim was to produce a glass which was water-clear and allowed light to pass through with the least resistance” (Jackson and Foster 2014: 8). This circumstance explains why both Colorless Groups 1 and 2 were not produced with the addition of recycled materials. Colorless Group 1 was designated as an “antimony decolorized glass,” and found to have low concentrations of aluminum oxide, iron and titanium (Jackson and Foster 2014: 9). These facts suggest that Colorless Group 1 glass was not only decolorized with antimony, but was also made from low-impurity, refined sands. Such a combination of techniques would produce high quality luxury glass. The majority of

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103 As Foster and Jackson put it, the “colorless” glasses they have investigated, range from water clear samples to those having a “slight green tinge” (2010: 3070).

104 It should be noted that in the original publication, these compositional groups are labeled as “Colourless Groups 1, 2, and 3,” since the authors use British spellings. I have called them “Colorless Groups 1, 2, and 3” to remain consistent with the American spelling that I use throughout the paper.
samples belonging to Colorless Group 1 date to the third century and earlier, while a few date to the fourth century.

In comparison, Colorless Group 2 was decolorized using manganese and had higher traces of aluminum oxide, iron and titanium (Jackson and Foster 2014: 9). The glasses from this group belong mainly to the fourth century. What makes Colorless Group 2 particularly distinctive is that the samples belonging to this group came from a “limited number of findspots” (Foster and Jackson 2010: 3072). All glasses with this signature were retrieved from high-status Roman villas located in southern England. As Foster and Jackson explain, “given the context that they are tablewares this is perhaps not surprising” (2010: 3072). Colorless tablewares are often recovered from domestic context and the upper strata of Romano-British society were most likely to consume these types of luxury vessels.

As we will see in the following section, high quality colorless glasses from the eastern Mediterranean are also unlikely to show signs of recycling. Several explanations may account for this pattern. These will be discussed later in the chapter after the evidence from Petra and Khirbet et-Tannur is taken into account.

**Colorless Group 3**

Despite the tendency against using cullet in the production of colorless glass, Colorless Group 3 displayed evidence for this procedure. Colorless Group 3 is dated to both the third and fourth centuries, although fourth century vessel types predominate, such as the

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105 Glass belonging to Colorless Group 2 was found at the sites of Barnsley Park, Shakenoak, Lullingstone and Frocester.
shallow convex bowl (Foster and Jackson 2010: 3073). This compositional group contained a mixture of decolorizers in the form of antimony and manganese. As Foster and Jackson explain, “the reason for the presence of both antimony and manganese may most plausibly be accounted for through recycling; either the mixing of colourless broken vessel glass (cullet) or cullet with new glass” (2010: 3072). In addition, Colorless Group 3 also contained traces of copper and lead, which are known to be indicators of “less careful recycling” (Jackson and Foster 2014: 10). The presence of these trace elements indicates that small amounts of blue/green cullet or pieces of a highly decorated glass vessels may have been added to the glass batch (Foster and Jackson 2010: 3073).

It is interesting to note that the combined use of antimony and manganese as decolorizers is a phenomenon thought to be limited to the western provinces. Indeed this occurrence is rarely observed in the East (Foster and Jackson 2010: 3074), except at Khirbet et-Tannur, which will be discussed below. This pattern suggests that the recycling of colorless glass was much more predominant in the West. In addition, Colorless Group 3 was the largest colorless group (54 percent of the total colorless samples) analyzed by Foster and Jackson, a fact which demonstrates that “by the [fourth] century, there was an increased reliance on recycled glass in the NW provinces” (2010: 3074). As Rome’s influence on Britain diminished, British glassworkers relied more heavily on (probably) local cullet as opposed to importing raw glass from elsewhere in the Empire.
Discussion

Foster and Jackson’s studies demonstrate the high degree to which recycling was taking place during the last centuries of Roman rule in Britain. In total, almost one third (30 percent) of all glass studied by Jackson and Foster showed signs of recycling, although this number could be as high as 46 percent (Jackson and Foster 2014: 11).\textsuperscript{106} HIMT 1, HIMT 2 and Colorless Group 3, the most common glass compositions from the third century onward, display markers for extensive recycling (Jackson and Foster 2014: 10-11). The popularity of recycling in late Roman Britain may have been due to the disruption of trade networks. Glassworkers in late Roman Britain may have been forced to rely on cullet due to a temporary hiatus in the supply of raw glass or because of a transitional period wherein different glassmakers—perhaps those in the eastern Mediterranean—were vying to supply the British market (Foster and Jackson 2010: 3074).\textsuperscript{107} Indeed Britain’s lack of local access to raw materials for glassmaking, such as the proper kind of silica, meant that any change in sources of supply would have greatly impacted its glass industry. Relying more heavily on cullet during a time when trade routes were shifting and/or faltering would have been a logical solution.

While disruption to trade networks undoubtedly had an impact on British glassworking procedures, we must also consider how cultural changes may have affected the

\textsuperscript{106} This 46 percent estimate takes into account that the whole of Colorless Group 3 may represent recycled material and also the more “generous” estimate for recycling that could be assigned to HIMT 2 glass (Jackson and Foster 2014: 11).

\textsuperscript{107} It is likely that there was a gap in the supply of raw glass to Britain. As was revealed earlier, known glassmaking centers in nearby western provinces (Italy, Gaul and Spain) ceased to function after the third century (Degryse and Schneider 2008; Gario et al. 2012). From the fourth to seventh centuries, only sites in the Levant and Egypt were in operation. Thus, if glassworkers in Britain were hoping to obtain raw glass, they would have had to rely on imports from the eastern Mediterranean.
industry. As Jackson and Foster note, “in the fourth century the migration of many Germanic people from beyond the ‘limes’ would have affected the ‘identity’ of societies in the north-west provinces; with the absorption of new cultures comes new ideas” (2014: 13). The presence of these newcomers may have incited a desire among British glassworkers to become independent from Rome.

It is clear that recycling was not a new practice in late Roman Britain, developed solely to combat contemporary issues; instead, glass recycling had a long history in the region. The archaeological evidence discussed in the previous chapter demonstrates that the glassworkers of Roman-Britain made use of cullet as early as the second century. Recycling was beneficial to early glassworkers as it was a thrifty alternative to relying wholly on raw materials and it also would have cut down on fuel costs. Analytical evidence confirms that this trend continued and possibly increased in the third and fourth centuries—as trade routes disappeared and socio-political changes disrupted local industries. While the breakdown of the western Empire had an impact on secondary glass production, recycling—an activity already undertaken by British glassworkers—could have easily compensated for the lack of “fresh” raw glass when trade routes faltered. The escalating dependency on (what was probably) locally recycled glass would have made the British glass industry more self-sufficient and can help to explain why fourth century vessel differ greatly in terms of form and quality from earlier examples. British glassworkers in this period shifted their procedures and began to develop their own style.

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108 *Limes* is a Latin word that is used to refer to the frontiers or boarders of the Empire.
Although the Romans first introduced glass to Britain, Rome’s retreat from the island did not mean that the glass industry ceased to exist. Glass production continued in Britain despite Rome’s waning influence. In fact, the absence of Rome coupled with the presence of newcomers provided an impetus for British glassworkers to develop their own supply mechanisms and to become independent from their neighbors. Glass recycling was a technique that helped British glassworkers to achieve this independence; no longer were artisans relying on shipments of raw glass from the Continent or further East. Instead, they had their own supply of material in the form of cullet. But how do these results compare to sites in the eastern Mediterranean, where access to raw materials and trade networks remained more consistent (especially in the Roman period)? Did the East not need to rely on recycling to the same extent as Britain? Or, perhaps there were different motivations for recycling among glassworkers in the eastern provinces?

Chemical Composition Evidence for Recycling in the Eastern Empire

While glass recycling has been frequently observed in the northwestern provinces of the Roman Empire, far less recycling is thought to have taken place in the East (Sayre 1963; Freestone and Jackson 2010). Recent analytical research has become integral to our understanding of this disparity. In a 2012 study, Schibille et al. performed a comparative analysis of late Roman glass vessels and windowpanes from the “Great Temple” at Petra, Jordan and the Nabataean temple at Khirbet et-Tannur, 70 kilometers to the north. While the samples chosen from Petra date to the first/second and fourth centuries, those from Khirbet
et-Tannur date from the third to early fourth century.\textsuperscript{109} Both of these sites are located along trade routes that connect Arabia to Syria (see Figure 10). As such, Schibille et al. remark, “it would be expected that neither [site] suffered any shortages in the supply of [raw] glass from the Levantine coast and/or Egypt”—at least during the period under investigation (2012: 999). Unlike the situation in Britain, these sites would not seem to have needed cullet as a substitute for raw glass in the Roman period.

Using electron microbe analysis (EPMA) and laser ablation inductive coupled plasma mass spectrometry (LA-ICP-MS), Schibille et al. identified six compositional groups in total between the two assemblages. The majority of the glass studied came, in its raw form, from the Levantine coast, and “most of the groups show evidence for highly selective recycling” (Schibille 2012: 997).\textsuperscript{110} As such, Schibille et al.’s study demonstrates that recycling was not restricted to the northwestern provinces, but also continued in consumer sites in the eastern Mediterranean (2012: 1019).

\textit{Petra Great Temple’s Lower Temenos}

The Great Temple at Petra was built in multiple phases and had several different layouts throughout its lifespan. The earliest Nabataean Temple was a distyle \textit{in antis}, later converted into tetrastyle \textit{in antis} (see Figures 11 and 12). Since all the glass remains studied

\textsuperscript{109} This chronological discrepancy is due to archaeological limitations.
\textsuperscript{110} The area in which the raw glass was produced can be detected by comparing the Petra glass finds to known compositions of raw glass. For example, Petra glasses 1-3 show a similar compositional pattern to the silica sources known from the Levantine coast (Freestone and Huges 2006, as cited in Schibille et al. 2012: 1011).
by Schibille et al. were found in an area of the Temple Complex known as the Lower Temenos, the following discussion will focus on the history of this structure.

The Lower Temenos has been described as the “formal introduction” to the Great Temple Complex (Joukowsky 2007: 89). This structure is situated immediately south of the Propylaeum—the monumental gateway leading from the Roman street up to the complex. The Lower Temenos was built 8.5 meters above the street and is covered in hexagonal stone pavers (Joukowsky 2007: 89). Joukowsky reports that fifteen “stages of activity” are noticeable in the Lower Temenos stratigraphy, the earliest of which dates to the first century BCE (2007: 96). During this preparatory phase of construction, a subterranean canalization system was built in the area of the Lower Temenos (Joukowsky 2007: 23). In the following phase (Phase II) this space was used to “bridge the great expanse between the temple proper and the lower eight treads of the Propylaeum Central Staircase” (Joukowsky 2006: 98).

It was not until Phase IV, sometime between the first century BCE and the first century CE, that the Lower Temenos was built up to the level seen today (Joukowsky 2007: 98). During this phase the Nabataeans undertook a monumental rebuilding and renewal plan, which included additions to all areas of the Temple Complex (Joukowsky 2007: 24). Site Phases V and VI (first through mid-second centuries) also show evidence of “Nabataean redesign and repair” (Joukowsky 2007: 27); these phases were immediately followed by the Roman annexation of Petra in 106, resulting in “localized destruction” of some structures in the complex (Joukowsky 2007: 31).\footnote{In addition to evidence of “localized destruction,” a large number of ballista balls, other weapons and different types of armor were found to be associated with this phase (Joukowsky 2007: 31).} Despite this destruction, the Great Temple did not
come to a catastrophic end at the hands of the Romans. In fact, during the Roman occupation of Petra, the Lower Temenos underwent yet another series of renovations and repairs (Joukowsky 2007: 100).

During Site Phase VIII (which predates the late second and third centuries), the Lower Temenos was abandoned and some stone elements were robbed out, such as the colonnade stylobates. Excavators, however, blame the earthquake of 363 for the collapse of most major elements of the structure (Joukowsky 2007: 100). Joukowsky notes that during this phase, “the Lower Temenos is enveloped by the accumulation of architectural fragments mixed with fill” (2007: 33). Although the site never fully recovered from this cataclysmic event, the Lower Temenos was reused during the Byzantine period, i.e. fourth and fifth centuries. This is evidenced by the appearance of new stone masonry elements and “industrial installations” for the manufacture of lime and other products (Joukowsky 2007: 35). “In the years following these installations the site undergoes further collapse with the collection of debris, possibly the result of the earthquake of 512 CE” (Joukowsky 2007: 101). All subsequent phases of activity in the Lower Temenos area display evidence of further destruction and looting.

*The Glass Sampled from Petra*

The glass analyzed from the Great Temple at Petra was retrieved during the 2004 campaign (Joukowsky 2007). In total, 47 samples of vessel and window fragments were studied using EPMA. In addition, 29 samples were also subjected to LA-ICP-MS. As Schibille et al. explain, this last step aimed “to determine the trace elemental patterns” of
Petra glassware (2012: 999). As mentioned above, all examples chosen for analysis were either from naturally colored, or colorless glass retrieved from the temple’s large forecourt, or Lower Temenos. Four distinct compositional groups were identified among the Petra samples (Schibille et al. 2012: 1005). Of these groups, two show markers of recycling: Petra 2 and Petra HIMT. Contrastingly, the compositional groups known as Petra 1 and Petra 3 showed little to no signs of recycling. All groups will be discussed below and will then be compared to those compositions from the Khirbet et-Tannur samples (see Tables 3 and 4). The following paragraphs will discuss those samples from Petra that lack markers for recycling and will then compare these to samples that show evidence for recycling.

**Petra 1 and 3: Compositions Without Markers of Recycling**

Petra 1 glass was classified as an “antimony decolorized glass” and was dated to the first to second centuries. This is the smallest compositional group identified by Schibille et al. with only 5 samples, all from luxury vessels. Petra 1 glass differs significantly from the other groups identified in their study as it was made from “refined sands” with low levels of calcium, aluminum, and potassium (Schibille et al. 2012: 1014). Nothing in the compositional makeup of Petra 1 glasses suggests recycling.

In comparison, Petra 3 glass—a naturally colored composition—also displayed little evidence for glass recycling. This composition is characterized by a lack of both antimony and manganese, and therefore the glasses from this group have a “greenish or bluish tinge” (Schibille et al. 2012: 1010). Petra 3 glass is much later in date to Petra 1; the samples belong to the fourth century. Schibille et al. also note that this group is “relatively heterogeneous,” as
the Petra 3 glasses do not all display the exact same compositional signature. While differing subgroups may be present among Petra 3 glass, Schibille et al.’s sample is too small to make further classifications or conclusions (2012: 1010).

Of these two groups, Schibille et al. note that it “seems likely that high-purity sands low in mineral impurities were deliberately selected for the production of the Petra 1 and most of the Petra 3 glasses” (2012: 1011). In addition, neither composition showed signs of contamination from transition metals (i.e. cobalt, copper, zinc, and lead). This lack of evidence for contamination led Schibille et al. to conclude that, “it is unlikely that these glasses contain any considerable amount of recycled material” (2012: 1011). These groups can instead be qualified as high quality glasses produced without the use of cullet.

This evidence suggests that in the production of high quality glasses and vessels, the use of recycled materials was considered inappropriate. It is likely that a combination of factors could explain this phenomenon. This may be a taste issue; perhaps there was an expectation among consumers of luxury glassware that the product be “pure.” There could also be an economic explanation. There would be no need to lower the price of glass by using cullet, if the consumer was able and willing to pay for a better product. Lastly, it is possible that glassmakers feared that the use of cullet would debase their material. It is true that when too much cullet is introduced into a glass batch, the final product can turn out bubbly instead of smooth. Glass artisans would not want to risk spoiling their merchandise if they could avoid it. These same principles can also be applied to the luxury glass (Colorless Groups 1 and 2) found in Britain.
Petra 2 and Petra HIMT: Recycled Glass

While some of the samples from the Great Temple in Petra showed no markers for recycling, two glass compositions, Petra 2 and Petra HIMT, displayed signs of highly selective recycling. Petra 2 glass was classified as a “manganese-decolorized glass” and most samples date to the fourth century.\textsuperscript{112} Both vessels and windowpanes were made from this type of glass. As Schibille et al. remark, “the spread of the major and minor elements [in this composition] suggest that Petra 2 is not a homogenous group, but that more than one raw glass (i.e. silica source) was used for the manufacture of these… glasses” (2012: 1010).

On the other hand, Petra HIMT glass was deemed “very distinct” from the other compositions among the Petra assemblage. While Petra 1-3 seems to have been produced from silica sources from the Levantine coast, the HIMT glass has a different geochemical signature and was likely made of Egyptian sources (Schibille et al. 2012:1016).\textsuperscript{113} All samples that had an HIMT signature came from fourth century vessel types.

In contrast to the Petra 1 and 3 groups, Petra 2 and HIMT glasses display a “very different element curve” (Schibille et al. 2012: 1011). More specifically, their copper content exceeds the typical levels and thus cannot be explained as naturally occurring impurities. Indeed, “this strongly suggests the contamination of these glasses through colourants, probably the result of recycling that would have inevitably introduced some coloured cullet” (Schibille et al. 2012: 1011-1014). While the levels of trace elements in glasses from Petra

\textsuperscript{112} Schibille et al. note that perhaps two or three of the samples could have been from the Flavian period (2012: 1010).
\textsuperscript{113} Admittedly the term Levantine coast is vague, but Schibille et al. do not supply any more specific information.
and Britain indicate that glass recycling occurred in both areas, the extent to which cullet was used differs significantly between these two regions. The compositional groups in Britain show evidence of “extensive” recycling, while those in Petra indicate “highly selective” recycling procedures. The reasons for this divergence will be explained below. First, it is necessary to review the evidence for recycling at Khirbet et-Tannur.

The Temple at Khirbet et-Tannur

Located on the secluded mountaintop of Jabal et-Tannur, the site of Khirbet et-Tannur consists of a Nabataean temple complex in use from the second century BCE to mid-fourth century CE (see Figure 13). The mountain’s peak shows no other signs of significant occupation and the nearest village in antiquity, Khirbet edh-Dharih, was seven kilometers to its south (see Figure 14). This village had a longer lifespan than Khirbet et-Tannur and contained “extensive facilities for pilgrims as well as agricultural installations” (McKenzie 2013a: 1).\(^{114}\) It is also important to note that Khirbet edh-Dharih was a caravan stop three days north of Petra on the traditional north-south route that ran from the port of Aqaba through Petra to Bostra and Damascus. According to McKenzie, Khirbet et-Tannur should be seen as a “satellite” of this main settlement, whose development during the Nabataean,

\(^{114}\) Khirbet edh-Dharih has a long history, however, the site was not continuously occupied throughout antiquity. It was first inhabited in the Early Bronze Age and shows signs of occupation in Edomite times (seventh and sixth centuries BCE). While there is no evidence for Nabataean occupation of the site prior to the first century CE, given that the earliest structures at Khirbet et-Tannur were built in the second century BCE, it is likely that earlier remain have simply not been found yet. The Nabataean settlement at Khirbet edh-Dahir continued until the 363 CE earthquake. For more information about this site, including later phases of occupation, see McKenzie 2013b: 39-45.
Roman, and Byzantine periods was closely linked to the activities at Khirbet edh-Dharih (2013b: 41).

Because it lacked a “perennial water source” Khirbet et-Tannur was never permanently settled (McKenzie 2013b: 39). It was instead a Nabataean center of religious pilgrimage, but lacked any domestic or commercial installations. In addition, Khirbet et-Tannur displays no signs of conversion to Christianity. As such, it should be considered a relatively unique site whose activities were limited to the religious sphere, a site whose material culture was not contaminated by a neighboring settlement or destroyed by people with opposing religious associations (McKenzie 2013b: 39).

The earliest structures at Khirbet et-Tannur date to the second and first centuries BCE; these include a simple altar, a court and series of surrounding rooms, some of which were used for ritual banqueting (McKenzie 2013b: 39-50). Ceramic evidence suggests increased activity at Khirbet et-Tannur in the first century CE (McKenzie 2013b: 50).\(^{115}\) During this period, some repairs were made to the altar and rooms were added on the southern side of the Court to accommodate the new needs. The repaired altar was in use for about two centuries prior to the “main construction phase” at Khirbet et-Tannur, which the excavators designated as “Period 2” (McKenzie 2013b: 53). The Period 1 structures were eventually destroyed by an earthquake, which ushered in this new phase of construction.

During Period 2, the entire temple complex was elaborately re-built and a new altar was erected (see Figure 15). While the date of Period 2 is uncertain, the construction techniques used during this phase are comparable to those found at the Nabataean temple in

\(^{115}\) This is evidenced by an increase in the total quantity Nabataean painted pottery sherds.
Khirbet edh-Dharih. On account of the similarities, excavators conclude that the Period 2 sanctuary dated to the early second century CE (McKenzie 2013b: 61). An earthquake, sometime in the second century, lead to another stage of repairs and ornate additions beginning in ca. 200—known as Period 3. This latest phase of the complex continued through the third century, when yet another earthquake struck (McKenzie 2013b: 137). The Period 3 structures were themselves repaired before the main destruction of the site around the mid-fourth century (McKenzie 2013b: 164). While the site was visited in the fifth or perhaps sixth century, it was never again reoccupied (McKenzie 2013b: 173).

*The Glass: Tannur 1 and 2*

All glass samples studied from Khirbet et-Tannur were retrieved from within the Nabataean Temple Complex. Only two different compositions were noted among the Khirbet et-Tannur samples, designated Tannur 1 and 2. Tannur 1 glass is very similar in composition to Petra 2. Like its counterpart, Tannur 1 was decolorized by the addition of manganese. Yet the samples from this group are distinctive in that they contain high levels of iron, titanium and magnesium as well as several transition metals. Schibille et al. explain that this difference suggests that Tannur 1 glasses were made with a “lower-quality sand source” than Petra 2. In addition, the high levels of contamination from trace metals indicate that a greater proportion of recycled materials were added to the Tannur 1 glass batch (2012: 1015).

Tannur 2, a mixed antimony/manganese colorless glass, was also identified among the assemblage. The concentrations of antimony and manganese in Tannur 2 glass exceed the amounts that would be expected as contaminants. Therefore, both elements must have been
intentionally added to the glass batch as decolorants. As with the glass samples from Britain, the presence of both antimony and manganese in one composition is likely the result of the “mixing of two glass types” (Schibille et al. 2012: 1016). This evidence, coupled with the elevated content of transition metals in Tannur 2 glasses, signifies that this composition was made up of a significant proportion of recycled materials.

Note that none of the Petra compositions are similar to Tannur 2. The absence of mixed antimony/manganese glass from Petra can be explained in a number of ways. This phenomenon may indicate that there was a difference in the availability of raw glass between the two sites (Schibille et al. 2012: 1016). Alternatively, it could be related to chronological differences of the glass corpora from the two sites. While the Khirbet et-Tannur glass mostly dates from the third to mid-fourth centuries, none of the Petra samples can be assigned to the third century. As Schibille et al. argue, it is possible that “the production of mixed manganese/antimony glasses was largely restricted to the third century” (2012: 1016). If we are to accept this as fact, then the lack of this signature at Petra does not necessarily indicate a lesser degree of recycling was happening there, but simply that the Great Temple was not consuming glass during the period in which the mixed antimony/manganese composition was most widely produced.

Discussion

Despite the proximity of these two sites, the glass samples retrieved from the Great Temple at Petra and the Nabataean sanctuary of Khirbet et-Tannur differ significantly in their chemical signatures. For example, no mixed manganese-antimony decolorized glass was
found among the Petra samples, whereas no typical HIMT glass, the largest composition from Petra, was identified in the Tannur assemblage (Schibille et al. 2012: 1014). In addition, while manganese decolorized glasses (Petra 2 and Tannur 1) were found at both sites, these compositional groups differ in terms of their iron-aluminum ratios and therefore different base ingredients must have been used to create these two glass types (Schibille et al. 2012: 1014). These facts suggest that Petra and Khirbet et-Tannur were not consuming the same types of glass and that they were being supplied by different primary producers.

In general, the samples from Petra fit into a wider variety of compositional groups than did those from Khirbet et-Tannur. Furthermore, glass from Petra, with the exception of Petra HIMT, was made from higher-quality sands that contained lower impurities. Tannur glasses, in contrast, appear to have been made from lower quality sands, and/or with a greater proportion of recycled materials. It is possible, however, that the high-quality glass was present at Tannur, but was recycled and therefore is no longer present in the archaeological record (Schibille et al. 2012: 1015). Schibille et al. explain these fundamental differences as the result of the varying “economic situations” of the two sites (2012: 1014). According to the authors, the luxury glasswares found at Petra should be seen as a reflection of the “thriving international trade” that the city engaged in during the Nabataean and early Roman periods (2012: 1014). Khirbet et-Tannur participated in trade to a much lesser extent than Petra, and thus did not have the same degree of access to luxury products. Another factor to take into consideration is that the function of both sites differed. While the glass found at Khirbet et-Tannur would have been used wholly for religious purposes, that from the Great
Temple came from an urban setting and may have served a larger variety of purposes (Schibille et al. 2012: 1019). Perhaps the temple complex at Khibret-et Tannur did not have a need or a desire for luxury glasswares and were instead content with lower quality alternatives.

In addition, it appear that Khirbet et-Tannur engaged more heavily and regularly in glass recycling, whereas a large portion of the Petra Great Temple glassware was made with non-recycled materials. This may suggest that there was an economic incentive to recycle during the Roman period. If a glassworker were to make a vessel using a portion of cullet he could charge a lower price for his product. A site like Khirbet et-Tannur, which lacked the resources and wealth seen at Petra, may have generated more demand for this cheaper vessel.

Differences aside, glasses from both Petra and Khirbet et-Tannur displayed evidence for “limited and highly selective recycling” (Schibille et al. 2012: 1019). This is likely due to the fact that both sites are located near primary glass production centers on the Levantine coast. As such, they would have had relatively reliable access to raw glass—at least during the Roman period. This access to raw glass would have diminished the need for cullet. Unlike British glassworkers who were forced to rely on cullet as a primary ingredient, glassworkers in this region could be selective about the amount of cullet they used. Note, however, that later in the Byzantine period (sixth and seventh centuries) sites in southern Jordan—such as the Petra Church, discussed in Chapter 3—no longer had this luxury. Similarly to what we see in Britain, when the Empire’s influence began to waver (on account of foreign intrusions) and interregional trade networks faltered, sites in the east may also
have been forced to change their glass recycling practices. Indeed if glass recycling was already a known practice in Jordan, further reliance on this procedure would have been a relatively simple solution to a daunting problem. Glass recycling, therefore, allowed glassworkers, both in the east and west, to be more flexible in the face of changing circumstances.

**Conclusion**

Schibille et al.'s study indicates that glass recycling was not limited to specific areas of the Empire. While motivations for recycling possibly varied from place to place, sites throughout the Mediterranean were engaging in this activity. Despite being situated along trade routes and near primary glass production centers in the Levant and Egypt, both Petra and Khirbet et-Tannur practiced glass recycling in the Roman period—although perhaps not to the same degree as can been seen in assemblages from late Roman Britain. In other words, the favorable location of these sites did not entirely eliminate the need or desire to engage in recycling practices.

Substituting cullet for a portion of raw glass would have been cheaper than relying solely on raw materials. Apart from the economic explanation, however, there must also have been other reasons to recycle if even sites such as Petra, which consumed large quantities of luxury goods in the Roman period, were involved. Access to raw glass was not a problem here, but there were comparatively less fuel resources, i.e. vegetation, in Jordan than in
Recycling in the East may not have been done out of necessity, but rather it may have been conducted selectively with a goal of more easily melting the glass batch. Perhaps glassworkers in the eastern provinces recycled because of the technical improvements that cullet offered. As mentioned earlier in Chapter 3, at the glass factory in Jalame fuel resources were scarce and a lack of appropriate materials could often affect the lifespan of a particular workshop. This worry could have spurred an incentive to recycle in the eastern Empire during the Roman period.

\footnote{Indeed animal dung could have been used as fuel in Jordan, however this resource does not burn as hotly as wood or shrubs and therefore would have been less ideal for glass working.}
CHAPTER 5

Conclusion

This study examined literary, archaeological, and chemical composition evidence in conjunction in order to obtain a clearer understanding of Roman glass recycling—a topic that remains poorly studied. From the examination of these three sources, several conclusions can be drawn as to the motivations for, as well as the mechanics and magnitude of glass recycling in Roman times. It appears that glass recycling was a relatively ubiquitous activity practiced in distant corners of the Roman Empire. Likely beginning in the first century CE, glass recycling became increasingly popular throughout the Imperial period and continued to be performed in Byzantine times in the eastern Mediterranean. Less is known about the continuation of this practice in the west after the end of Roman rule, but Gregory of Tours’ anecdote suggests glass recycling may have also been performed in early medieval Europe (Glory of the Martyrs 58).

Literary evidence suggests that itinerant peddlers were involved in collecting cullet and that they carried out this activity informally on the streets. Peddlers would barter common household goods in exchange for broken glass and then sell these fragments to glassworkers, who would recycle them. At least three distinct parties seem to have been involved in this process: (1) the owner of the original glass vessel, (2) the itinerant peddler who collects its broken pieces, and (3) the artisan who remelts cullet in order to create new objects. In all cases, material rewards or economic incentives seem to have propelled the
process. Glass recycling was performed because it was a logical and economically viable option for all parties.

Conversely, archaeological evidence seems to suggest that more diverse and/or complex recycling schemes also existed in antiquity. The material record demonstrates that cullet was collected in Byzantine ecclesiastical structures, perhaps to raise funds for the Church (as seen at Jerash), or to generate extra income for its later inhabitants (as seen at Petra); shipped by sea, likely to benefit those areas with little access to raw materials; and was an integral component of secondary glass production at sites in both the Levant (Jalame) and Britain (London and Mancetter). While the itinerant peddler had a role to play in these various schemes, other agents, not mentioned by our ancient authors, were sometimes involved—such as nautical merchants. Indeed, the archaeological evidence reveals that there was no singular formula for glass recycling in Roman times. Rather, it seems that glass recycling was both a small-scale venture and a large-scale business; a local endeavor and an activity that crossed provincial boundaries; a lowly job and a sophisticated enterprise; an act done out of necessity and a calculated process. These procedures varied on account of one’s geographic position, economic circumstance and socio-political situation.

Chemical composition analysis both confirms that glass recycling was being carried out in the Roman world and helps us to more accurately judge the scale of this activity in antiquity. While glassworkers of late Roman Britain relied heavily on cullet as a substitute for raw glass, artisans in Roman Petra and Khirbet et-Tannur could be more selective with their use of recycled materials. Interestingly, when comparing evidence from the
archaeological record to the chemical composition studies reviewed in Chapter 4, it becomes apparent that glass-recycling practices were not static in antiquity, but could shift in response to a multitude of factors. For example, while Roman Petra, with its preference for luxury vessels, seems only to have recycled a small portion of glass, in its Byzantine phase (sixth and seventh centuries), the site no longer had this ability. As interregional trade declined, Petra’s late Byzantine glassworkers may have been forced to rely heavily upon local cullet in order to make up for a lack of raw glass.

When these three categories of evidence are view in conjunction, it is clear that the Romans did not recycle glass out of concern for the environment; rather they were encouraged to do so for a number of other reasons. Using cullet was one way for glassworkers to save funds. Relying solely on raw glass would have been much more expensive than incorporating cullet into the secondary production process. This economic incentive would have been attractive to most glassworkers, with the possible exception of artisans who specialized in luxury wares. As was revealed earlier, the chemical signatures of these products tend not to contain recycled materials. This may be an issue of quality control, or simply a matter of taste.

On the other hand, the introduction of cullet also provided technical improvements. When added to a batch of glass during secondary production, cullet induces rapid melting and lowers the temperature required to melt a glass batch. These benefits would have been particularly useful for areas of the Empire that lacked substantial fuel resources, such as the
Levant. Other geographic concerns, such as a lack of reliable access to raw materials, turned cullet into a necessary commodity for certain glassworkers, such as those in Roman Britain.

Knowledge of Roman glass recycling practices refines our understanding of the glass industry and how it functioned in antiquity. Recycling gave glass-working artisans a degree of independence from the producers of raw glass. Even when trade routes faltered, areas of the Empire that did not have reliable access to raw materials could still have produced and consumed glass products locally. Glass recycling procedures thus allowed glassworkers to persist in the face of changing circumstances, even when those circumstances appeared to be detrimental.

Furthermore, the vast and diverse range of evidence for glass recycling in the Roman world suggests that the importance and prominence of the glass industry has been underestimated in the past. Scholars have previously posited that Roman glass was a low-end luxury product due to its frequent but not overwhelming presence in the archaeological record; yet the recycling of glass removes it from the archaeological record. Using solely material remains to assess the scale and significance of this industry can therefore lead to erroneous conclusions. If we take the evidence for glass recycling into account, however, it appears that glass was a much more prevalent and widespread commodity in antiquity.

This thesis contributes to the debate surrounding the Roman economy. Some scholars believe that the Roman world was host to a “primitive” style economy based largely on agriculture (e.g. Finley 1999). From this perspective, it is assumed that most Romans lived a near-subsistence lifestyle and that long distance trade was limited to luxury products. These
products are thought to have been consumed only by a small class of elite landowners. Other scholars, however, believe that the Roman system was similar to early modern European economies. These so-called “modernist” scholars suggest that the Roman world had a thriving market economy wherein a variety of products were traded throughout the Empire (e.g. Greene 1986). Glass, if seen not as a luxury product, but rather a common commodity consumed by the majority of Romans, lends support for the latter of these two models.

In conclusion, future research should try to address the topic of glass recycling from a holistic perspective. Much more can be known about this practice if we continue to examine the literary, archaeological and chemical composition evidence in conjunction. In addition, comparing case studies from various parts of the Empire can be a fruitful endeavor and should continue to be pursued.
REFERENCES


### Tables

**Table 1. Naturally Colored Glasses Sampled from Britain (Foster and Jackson 2009)**

<table>
<thead>
<tr>
<th>Compositional Group</th>
<th>Date (based on glass typologies)</th>
<th>Number of Samples</th>
<th>Makers of Recycling (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIMT 1</td>
<td>mid 4&lt;sup&gt;th&lt;/sup&gt; and early 5&lt;sup&gt;th&lt;/sup&gt; centuries</td>
<td>123</td>
<td>Yes—high levels of trace elements (20% but may be much higher)</td>
</tr>
<tr>
<td>HIMT 2</td>
<td>4&lt;sup&gt;th&lt;/sup&gt; century</td>
<td>221</td>
<td>Yes—high levels of trace elements (40-60%)</td>
</tr>
<tr>
<td>Levantine 1</td>
<td>mid-late 4&lt;sup&gt;th&lt;/sup&gt; century</td>
<td>24</td>
<td>None</td>
</tr>
<tr>
<td>Blue-green</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt; and 3&lt;sup&gt;rd&lt;/sup&gt; centuries</td>
<td>8</td>
<td>Some evidence, but no conclusions can be made—sample is too small</td>
</tr>
</tbody>
</table>

**Table 2. Colorless Glass Sampled from Britain (Foster and Jackson 2010)**

<table>
<thead>
<tr>
<th>Compositional Group</th>
<th>Date (based on glass typologies)</th>
<th>Number of Samples</th>
<th>Markers of Recycling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colorless Group 1 (antimony decolorized glass)</td>
<td>3&lt;sup&gt;rd&lt;/sup&gt; to mid-4&lt;sup&gt;th&lt;/sup&gt; century</td>
<td>46</td>
<td>None</td>
</tr>
<tr>
<td>Colorless Group 2 (manganese decolorized glass)</td>
<td>4&lt;sup&gt;th&lt;/sup&gt; century</td>
<td>13</td>
<td>None</td>
</tr>
<tr>
<td>Colourless Group 3 (mixed manganese/antimony glass)</td>
<td>3&lt;sup&gt;rd&lt;/sup&gt; to 4&lt;sup&gt;th&lt;/sup&gt; centuries</td>
<td>69</td>
<td>Yes—not a homogenous composition</td>
</tr>
</tbody>
</table>
Table 3. Glass Sampled from Petra (Schibille et al. 2012)

<table>
<thead>
<tr>
<th>Compositional Group</th>
<th>Date (based on glass typologies)</th>
<th>Number of Samples</th>
<th>Markers of Recycling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petra 1 (antimony decolorized glass)</td>
<td>1\textsuperscript{st} to 2\textsuperscript{nd} centuries</td>
<td>5</td>
<td>None</td>
</tr>
<tr>
<td>Petra 2 (manganese decolorized glass)</td>
<td>4\textsuperscript{th} century (two or three fragments that might be of Flavian date)</td>
<td>18</td>
<td>Yes—none a homogenous composition; high levels of transition metals</td>
</tr>
<tr>
<td>Petra 3 (naturally colored glass)</td>
<td>4\textsuperscript{th} century</td>
<td>15</td>
<td>Scant evidence</td>
</tr>
<tr>
<td>Petra HIMT</td>
<td>4\textsuperscript{th} century</td>
<td>9</td>
<td>Yes—high levels of transition metals</td>
</tr>
</tbody>
</table>

Table 4. Glass Sampled from Khirbet et-Tannur (Schibille et al. 2012)

<table>
<thead>
<tr>
<th>Compositional Group</th>
<th>Date (based on glass typologies)</th>
<th>Number of Samples</th>
<th>Markers of Recycling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tannur 1 (manganese decolorized glass)</td>
<td>3\textsuperscript{rd} century to mid 4\textsuperscript{th} century</td>
<td>9</td>
<td>Yes—high levels of transition metals</td>
</tr>
<tr>
<td>Tannur 2 (mixed antimony/manganese glass)</td>
<td>3\textsuperscript{rd} century</td>
<td>12</td>
<td>Yes—not a homogenous composition</td>
</tr>
</tbody>
</table>
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