From Trash to Treasure

The Recycling of Glass in Roman and Early Medieval Period Britain

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For my father
who was unable to read this final thesis
but always believed it would appear.

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Abstract

The main aim of this thesis is twofold; first to asses the ability of material studies to identify and quantify recycling in ancient glass, and then to compare the nature and extent of recycling of glass in the first to fourth centuries in Britain, Roman Britain, to the following Early Medieval period, fifth to eighth centuries.

The first section of this thesis, the backbone, is a compilation of published values of glass analysed from English sites, and a comparative database from Europe. This also includes the expansion of the English database with the fresh analysis of glass from the sites of Dorchester-on-Thames, Oxfordshire, and Lyminge, Kent.

The next section is a theoretical discussion of recycling and particularly the recycling of ancient glass. This includes both the ramifications of different forms of recycling for artefacts, in terms of traditional archaeological concerns such as trade, deposition and object biography, but more importantly the material studies changes that one might expect to witness from such recycling.

This leads on to the chemistry of glass, and specifically how this can be used to demonstrate that recycling. Setting out and devising the material studies approaches to quantifying and qualifying ancient glass recycling, assessing which techniques are potentially of value. This synthesis and analysis includes both a large amount of legacy data, the database, as well as the small study of new glasses. In particular, the new glasses that will aim to increase the number of post-Roman glasses.

The final portion of the thesis uses the architecture of the previous sections to compare the patterns of recycling across time in Britain, specifically the geographical components. This demonstrates the relationship between geography and trade, and how this changes in England as Roman influence falls and a new power takes Britain.

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Chapter 1

Introduction

"Fortune is like glass; the brighter the sparkle,
the more easily broken."

Maxim 280, Publius Syrus

From simple glass jars to elaborate mosaics, Roman glass stands out from any archaeological assemblage, whether domestic, military or religious. For centuries it has fascinated scholars, glassmakers and the public alike, seen by resurgences such as the great renaissance that occurred after the late-eighteenth and early-nineteenth excavations at Pompeii and Herculaneum. A spectacular expression of this obsession was the 2007-2008 exhibition *'Reflecting Antiquity'* at the J. Paul Getty Museum, which showcased Roman vessels beside their related Modern period copies. The *Copy of the Disch Cantharus* (CMG 59.3.38) is a phenomenal piece, inspired by the height of Roman glass vessels, cage cups.

However, despite almost a century of material studies investigation on Roman glass, what were then considered the most basic of questions are still without answers. The early works, headed by Turner (1954b, 1956a,b,c), tended to be interested in linking glass compositions to the surviving literary accounts of glass production. However, 60 years later, details of how and where raw glass was produced and vessels formed are still hotly debated. Despite early optimism, provenance studies for glass have proven more complex than initially thought. Unlike single geological origin ma-

terials such as marble, glass is a mixture of raw materials from a variety of sources, and untangling this has not been simple.

There is, however, compelling evidence that almost all Roman glass seems to have the same or similar origin of the very clean sands of the Levant and Egypt, despite *glass-working* occurring across the Empire.[1] On top of this is a perhaps more complex problem to discuss archaeologically: recycling. This too is of increasing interest within heritage studies, exemplified by the Museum of London's 2017 *'Junk'* exhibition.

This thesis is aimed at understanding the chronological and geographic flow and recycling of glass throughout the first millennium in Britain, by considering chemistry. It is an attempt to synthesis all current compositional approaches used to infer chemistry, and combine them in a systematic way. For recycling to be apparent, both where and when was vital, thus a methodology was developed integrating chronology, chemistry and geography.

Traditionally, recycling is poorly defined and frequently dismissed in relation to almost every archaeological system. It is, however, becoming a legitimate research focus in historical metallurgy, as well as in glass studies.

It is not a single behaviour, but a wide range of social and technological practices that can be driven either by ideology, economy or a combination of both. What we currently lack is the understanding and terminology to discuss the wide range of practices under the wider label of 'recycling'. This complexity of recycling is beginning to be addressed (Degryse et al. 2006; Sainsbury et al. 2015), and is becoming the focus for copper alloys (Bray and Pollard 2012; Pollard et al. 2015; Swift 2012). However, the terminology used for recycling requires some consideration and adjustment for clear definitions to be applied to discussions of glass (Chapter 4.2).

With such linguistic steps made, it is clear that certain types of recycling are archaeologically visible and some more prevalent than others during the Roman and

[1]There is, of course, some disagreement about this (eg. Wedepohl et al. 2001), though the overwhelming majority of evidence seems to agree with this view, for the most part.

Late Antique periods. However, assessing this recycling and its importance to the industry is complex. It requires a way to discuss recycling relative to composition, something that is a matter of when and where the glass is found, as well as the visual characteristics (especially colour and opacity). The aim of this thesis is to assess the potential for material studies to qualify and quantify the recycling of glass and in so doing compare the changing quality of British glass from AD first to eighth century Britain, with particular attention paid to the relationship between geography and composition. As such, the suite of elements commonly analysed for in glass are discussed, with relation to their place in recycling studies (Chapter 5).

Roman Britain was chosen as the area to assess due to the wide range of site types, historically understood regionality, as well as the frontier nature of Britain. Traditionally Britain's trade with the wider Empire is thought to have become restricted from a very early period and, as such, the sourcing of glass is thought to have become problematic. It has been proposed that all glass in Britain prior to the tenth century AD is simply *"a gradually diminishing and degrading reservoir of cullet, ultimately derived from the prodigious industries* [of Roman Britain]*"*(Freestone and Hughes 2006, 128). In this work Freestone and Hughes are arguing against such a simplistic view, as such proclamations are often based more on suspicion, and rooted in modern European views of the necessity of Empire, than in scientific evidence.

This thesis is focused on the comparison of the Roman material to that of the following centuries. Traditionally, the Early Medieval period has not been a legitimate area of study. This 'dark' period between the height of Roman Britain and the coming drama of the Middle Ages has failed to fit into imposed narratives. Sometimes called 'sub-Roman' Britain or, more historically, the 'Dark Ages', there is much debate about how quickly Britain changes from a Roman province to High Medieval kingdoms, and what happens in between (Chapter 3.3).

Many of the terms used for this period tend to imply a grand inferiority of culture.

However, as is true of many such periods of change, recent scholarship has shown that it is far more complex and interesting than was once thought. For the sake of referring to this period, this paper will use 'Early Medieval' to avoid cultural terms in a period of shifting definitions.

One of the most apparent parts of this research is that there are notable and important holes in our understanding, which this work will be unable to fill. One of these is the comparative paucity of Early Medieval data from England. As this thesis relies heavily on previously analysed material, these preexisting issues are unavoidable.

When we consider glass, there is a clear bias in existing data and thus understanding. Considering this chronologically, firstly we have very little analysis from Britain's first half of the first millennium, except for the Roman period. It is known that glass was widely spread in Iron Age Britain, particularly in the form of jewellery and enamel, but only a small amount of chemical work has been done on this material (eg. Henderson 1991b). As we move through into the first millennium when glass became a common material, this bias remains. Areas outside direct Roman control, which still had access to materials, especially glass, are rarely subjected to the same concerted programmes of analytical study. One must only consider the work on Scottish Iron Age glass, which is limited and otften only typographic (Ingemark 2014). These biases, as well as our current holes in understanding, have led to the following study.

1.1 Scope of Study

This thesis covers glass found in England, excepting Cornwall, in the first millennium AD in Britain. Chronologically, the data collected begins at the start of the millennium, through to 800 AD. The choice of the beginning of this timeframe was to cover to the first Roman incursions into Britain, and the glass that both preceded and

followed them. The end of this period, which covers the rise of Mercian dominance, was chosen to cover the most disputed time of industry in Britain, the Early Medieval period. From this period onwards, significant changes in both the glass industry and historical recording means that the situation is vastly different.

Our understanding of glass moving into the tenth century and beyond is far clearer, with much glass work being tied into church production. The same is true of our understanding of the Romano-British glass industry, where glass was produced on a large scale in the Mediterranean, and shipped across Europe to be formed into artefacts. While both of these periods still have many questions to be answered, we have at least a basic outline of what is occurring with glass. The same is not true from 410 through to the end of the eighth century.

To assess this period, however, we need to compare the glass to both the earlier Roman material in Britain, and contemporaneous European material. This thesis is concerned with the flow of this material; where it is coming from, where it is going, and what happens to it along the way - specifically, recycling. All this needs comparative data, and thus a database of glass has been created (Chapter 2.3).

As for the 'British' glass of this thesis, the term is used to refer to Roman Britain, rather than its modern usage. The glass databases are separated into the main 'English' database and the supplementary 'European' one. Material from Roman sites that fall into the modern countries of Scotland or Wales are placed in the European database. The reasons for this are both modern and ancient. For modern considerations, the density and approach of analysis in England is far greater than the rest of the United Kingdom. The paucity of analysis beyond the borders means that no real geographical or temporal information can be drawn, as synthesis is not possible. For ancient justifications, the borders with both Wales and Scotland were not stable. Much of Scotland remained very much in the Iron Age for the entirety of the Roman period. While much of Wales had greater occupation, it is the modern research that

lets us down here. Similarly, Cornwall has been removed from the discussion here as, remote in terms of Roman Britain, no study of glass exists from the period.

The glasses in these two databases were collected both from published materials as well as the fresh analysis from two sites, Dorchester-on-Thames, Oxfordshire, and Lyminge, Kent. The fresh analysis was achieved by Electron Microprobe Analysis (EMPA) at the *Research Laboratory for Archaeology and the History of Art*, University of Oxford. These databases have then been analysed relative to their geographical and chronological status, to try and provide a broad-scale study of glass in the first millennium in Britain. Geography has been used to see if the composition of glasses can be related to location in Britain. In other words, did all parts of Britain have equal access to the same sources of glass. In particular, this glass has been assessed to highlight patterns of movement and recycling.

The first chapter, Chapter 2, deals with the methodology applied in this thesis; the over all approach, the history of glass studies in archaeometry that have led to such an approach, followed by the methodologies of further EMPA analysis, and the process of mapping. This chapter concludes with a discussion of the analytical strength and weakness of these methodologies.

Chapter 3 expands on the current understanding of the first 700 years AD in England, with a focus on glass. It covers the place of glass in Roman Britain, a tight timeline on typology and composition of glass, and a discussion of the political background or potential 'fall' of Britain. This concludes in a discussion about the acknowledged and assumed place of recycling in Britain, both during and after the height of the Roman period.

The history of recycling in archaeology as a whole is complex, and discussed in detail in Chapter 4. This, as well as material study, has informed the schema of recycling detailed.

Chapter 5 deals with the chemistry of glass making, as understood by relevant

past societies, as well as in modern chemical understandings. This work leads on to Glass Recycling in Archaeometry, Chapter 6, which is a synthesis of what chemical evidence may be useful in the identification of recycled glass.

The sites Dorchester on Thames and Lyminge, and the fresh EMPA results of glasses analysed for this study are dealt with in Chapter 7. These sites are considered individually and characterised, before being synthesised into the larger database.

Chapter 8 is a summary of the databases assembled, and their strengths and weakness before Chapter 9 uses this evidence to map recycling indicators across England. This shows that English glass is deeply reliant on recycling, across the Roman period and beyond. There is little difference between the two periods in many ways, with fresh influxes of glass being periodic across the whole first millennium.

The final chapter is a synthesis of all these geographic indications, by century, and a brief comparison to the European data. Due to the length of this thesis, European summaries are brief. The patterns of glass recycling in Britain are not unique, similarities are seen in glass across the northwest provinces, but also further south.

The mutability of materials like glass is not a simple problem for archaeology. It greatly affects the deposition of artefacts, and the apparent abundance of such materials. Many authors comment on the change in shard size in the fourth century and later, with larger shards becoming uncommon. The reason given is increased recycling, but this makes the judging of total numbers nearly impossible. As well as this, recycling can have a large range of social, economic and cultural factors contained within this practise. Untangling them all in present recycling practises is difficult enough, let alone millennia ago.

Despite the aforementioned limitations, it is hoped that by better understanding the recycling in Roman Britain, and especially Early Medieval Britain, a great deal more can be revealed about the industries of both periods, which in turn can inform

interpretations of glass on sites across the first millennium AD.

Chapter 2

Methodology

As iterated in the introduction, the aim of this thesis is to illuminate the flow of glass in the first 800 years AD in Britain, with particular emphasis on the flow of recycling. This thesis does so by the creation of an archaeological catalogue of scientific data, the expansion of it by fresh analysis, and the interrogation of said database by GIS and analytics. The methodologies applied to the each aspect will be considered separately, but first the over all approach must be discussed (Chapter 2.1.

After this, the existing framework of glass study shall be presented, and how this work has lead to the current question (2.2). Once this has been demonstrated, the database approach will be explained, and why such was chosen (2.3). This database approach is the backbone of this thesis and as such it is important to consider how the database was assembled and its strengths and limitations.

Following this, the method followed for fresh material analysis must be discussed, specifically the preparation and production of EMPA results and its detection limits (2.4). Finally, GIS mapping has been widely used to asses the geographic implications within this database and thus the methods applied and the geographic approaches used here will be elucidated (2.5).

As should be clear, these are all intrinsically linked but require unique considera-

tions. Together, the database, its expansion with the new analyses, and the GIS-based considerations of this databased encompasses the work as a whole, and begins to answer long held questions about the nature of industry in the fall of Roman Britain.

2.1 Overall Approach

The question of this thesis is the nature and extent of the recycling of glass in Roman Period Britain, as compared and contrasted to the Early Medieval Period. It relies off several principals, the validity of which will be discussed in greater detail as the thesis progresses. However, a few opening remarks are required.

Firstly, that there is significant variation or change that occurs in glass compositions from recycling (Chapter 6). While this has been shown to be true, it is a matter of a large suite of elements that must be considered together, and the amount of data needed to see such changes can be vast. To do this, such a thesis must rely on more analytical work than one person can produce in a few years. As such, this relies on a database of previously published work (Chapter 8).

Secondly, that we know what we mean when we discuss 'recycling'. A cursory glance at archaeological literature shows that this isn't necessarily the case. Because of this, this thesis has created a structure of 'types' of recycling possible, and discusses their likelihood to be archaeologically or archaeometrically visible (Chapter 4.1). During this thesis, it became clear that the type of recycling that is of the most use in looking for these long range patterns is 'cullet recycling'.

This approch using compositional evidence of glass, illustrates at least one sort of recycling in Britain. The next part of the question poses more of a problem, the 'nature and extent'.

To discuss nature and extent of glass at all in Britain, it is first worth considering the nature of societies in Britain prior, during and following the Roman Period. Pre-

Roman Britain, like many European regions of the period, eg. Gaul, was an area that contained a great many cultural groups who were disparate in nature. This regionality, as will be discussed in detail in Chapter 3, was maintained to different degrees throughout the first millennium. As such, it can be expected that the trade and use of materials and goods were not uniform across Britain. Glass, in this period a material dependent on trade, is thus not expected to be equally used or available in all parts of Britain at all times.

To discuss the nature and extent of glass, glass compositions and therefore recycling, and how this changes over time in Britain, it also matters how it changes geographically. As such, a mapping approach was also required, thus the use of GIS binning of data. This will be discussed in Chapter **??** and 9. By looking at how these indicators, which are proxies of recycling, shift in assemblage ubiquity across time, can show how much of the material in given parts of England were reliant on recycling, what kind of recycling, and what primary glasses are going into the mix. In turn, this can be related to the social geography of Britain at given points, the nature of the settlements, the likelihood of international connections. This has highlighted sites that are both more and less connected at different points than originally expected.

All of this work, however, is built on the chemical study of ancient glass, which has a long history.

2.2 The History of Glass in Archaeometry

Like many materials studied in archaeometry, the early applications of scientific analyses to Roman glass faced teething issues. Increasingly, across the discipline, it has become apparent that this was often because the answers available to archaeological science could not address the questions asked. This was for both scientific and

archaeological reasons. However, as increasing discourse within and between science and archaeology grew, this improved. Especially in the case of Roman glass, new questions are being formed by archaeologists and scientists together, exploiting the advantages and insights offered by both complex fields.

Unlike materials such as marble, which do not chemically alter during production, glass and metal undergo extreme alterations between raw sources and finished artefacts. Although certainly resultant and relatable to the origins of their raw ingredients, the relationship is far from simply linear. It is a combination of geochemical variation, thermochemical reactions, technical limitations and, most problematically, human choice. Despite this, there is a long history of glass studies in archaeometry, concerned primarily with provenance and, to some extent, production methods. Both archaeologically derived concepts, such as *chaîne opératoire*, and those reasoned by archaeological chemistry, such as glass 'primary' and 'secondary' productions, have allowed us to look beyond this. Specifically in this context, at the concept of recycling.

The first archaeometric work of consequence done on glass was the pioneering work of William Ernest Stephen Turner, beginning with a five part summary published across several years in the Journal of the Society of Glass Technology (Turner 1954a,b, 1956a,b,c). In his retirement Turner, a Fellow of the Royal Society and a Materials chemist, turned his attention to historical and archaeological glass. This work started to consider both the ingredients and the production behind early glass industries.

Particularly from Bronze Age evidence, it had become obvious to archaeologists that glass was a notable artefact of trade across the Mediterranean (such as the Amarna ingots and later confirmed by those in the Uluburun Shipwreck). Turner's works, as well as his contemporaries, were concerned with linking or disproving the connections between archaeological glass and surviving literary traditions, as well as filling in our very sizeable gaps with chemically reasoned evidence. The literary connection has remained of interest across the last fifty years (eg. Freestone 1992,

2008; Oppenheim et al. 1970 and elsewhere in this thesis), and is now deeply integrated into the scientific argument.

Turner's works precipitated a considerable amount of focus on chemical studies of ancient glass, such as those on the material sources by Sayre and Smith (1961), published in *Science*, and mass analyses of glasses from a huge range of ancient contexts.[1] The cumulative outcome of these many works was significant. They explained glass coloration and decoloration (eg. Sayre 1963), often with much input from modern industry chemists with an interest (eg. Weyl 1951), but finding a direct connection between particularly Roman glass and raw sources proved more problematic.

These early papers focused primarily on major and minor elements, and very clear groups appeared. However, these glasses seemed extremely uniform across Europe and the Mediterranean, and most variation having a stronger relationship to chronology than geology. Easily identified were three main periods of ancient glass, one of plant ash production, then of evaporite salt, then another of plant ash. Their chemical uniqueness will been discussed in Chapter 5. Particularly within the evaporite group, which covered Hellenistic to late first millennium glasses, there were groups defined by manganese and iron. As the evidence grew, it became apparent that even from an early period, Bronze Age glass was not being produced on the same sites as the objects and vessels being formed, now discussed as the split between primary and secondary production. Locating where this huge amount of glass came from remained the prime focus.

Trace elements were turned to as an attempt to better discriminate between these sources, but again there was far less variation than researchers had been expecting. While more groups were apparent within this confused dataset, these still seemed more strongly chronological. As such, it led authors to the now standard view of

[1]One only needs to consider the programme of analysis by Robert Brill, begun in the sixties and now comprising a multi-volume text (Brill 1999). As well, beyond the more traditionally considered regions, there was also a surge of interest in ancient glass in the USSR (Besborodov and Zadneprovsky 1962) and across Asia (Ritchie 1937).

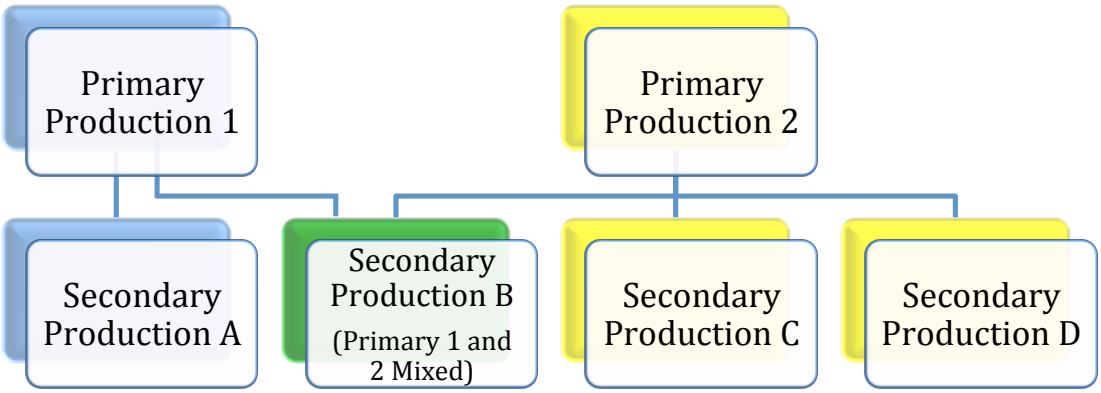

Figure 2.1: Primary and Secondary Production Models, after the work of Freestone.

Roman glass production. It describes a mass production of glass from raw materials (*primary production*) and then, usually, transportation of this raw glass, sometimes great distances. At another workshop this was turned into vessels etc (*secondary production*) (Foy et al. 2000; Freestone et al. 2000). This has been summarised in diagrammatic form [Fig. 2.1]. Estimating the number of primary sources is problematic, but it is clear that the scale of production in the first millennium was massive. For example, 17 furnaces capable of producing approximately 8 tonnes of glass each were found at the seventh to eighth century site of Bet Eli'ezer (Gorin-Rosen 2000, 55-56). It should be emphasised that there were still marginal productions of glass around the Empire, but current estimates of Western production account for only around 5% of all Roman glass (Degryse 2014).

As well as this primary and secondary production, however, glass continued to be confused by another issue of production, recycling. Much of the early studies of Western European glass failed to neatly match the glass produced in the large Mediterranean workshops. However, further research on this has shown that in fact much of the lack of matching is due to the problems of recycling (Freestone 2015, 31). Recycling has been integrated into the workshop diagram to show how complex this makes provenance [Fig. 2.2]. This has become the focus of a great amount

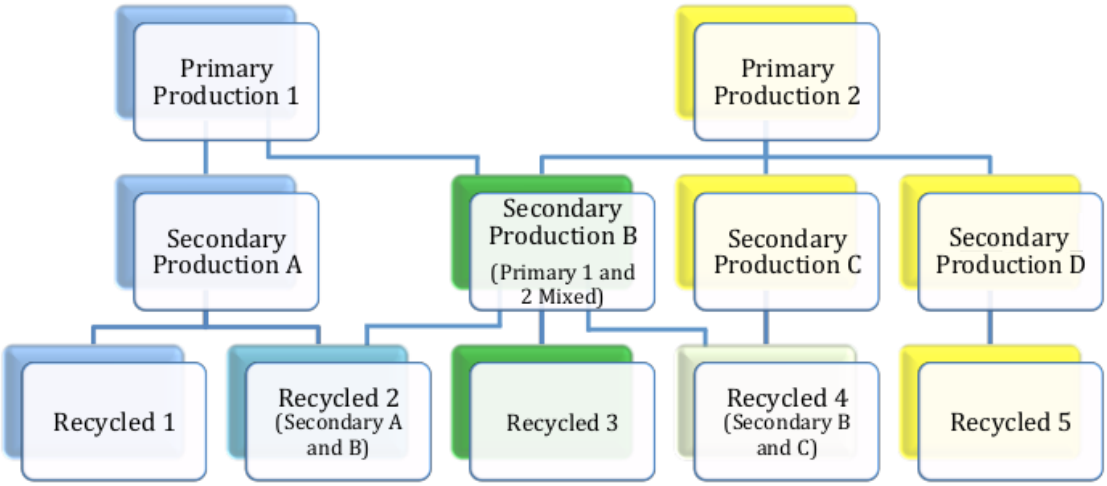

Figure 2.2: Primary and Secondary Production Models with recycling integrated, expanded from the work of Freestone.

of glass research now underway, such as the AHRC funded *Addressing the Invisible: Recycling, Glass and Technological Practice in the 1st Millennium AD* at the University of Leicester, and the ERC funded *GlassRoutes*, at the Centre National De La Recherche Scientifique.

A seemingly ever expanding suite of elements is analysed for in glass, and much of this has to do with the evolution of techniques used to consider archaeological materials. Almost all of the early analysis of glass involved solution chemistry and gravimetrics. Earle Caley 1962, for the Corning Museum of Glass, produced a survey of the very earliest analyses, *Analyses of Ancient Glasses 1790-1957; A comprehensive and critical survey.* All of the early analysts dissolved their glass; Klaproth's analyses of Roman glass (1801), Pettenkofer's (1857) and Claudet's (1862) consideration of the Pompeii glass. The latter two both also observed opaque glasses under magnification to try and asses how certain colours were achieved, for instance cuprite in red opaque glass. Despite a sudden explosion of analyses, usually of two or three shards at a time, during the first half of the twentieth century, there was little added sophistication in technique or use of standardisation. While Caley's book makes an effort to comment on which of these analyses are valid and which are not, none of these have been

deemed of reliable enough value to be used in this thesis.

The first spectrographic analysis of ancient glass was published as a brief note in Nature, and was the analysis of 32 specimens of Chinese glasses, later published in full (Ritchie 1937). These were, however, semi-qualitative, as were the further Chinese and Egyptian glasses published by the team and colleagues, though with some confirmation by gravimetric methods. A similar though more advanced pairing of methods was performed by Hahn-Weinheimer (1954) on Roman window glass. Much of the work done by this method, judged to be of good quality, was collated and tabulated by Turner (1954a,b, 1956a,b,c). This allowed a great deal of understanding of the patterns of glass making and colourant use to be understood.

Sayre and Smith (1961) used a combination of techniques, arc spectrography, flame photometry and colorimetry, the spectrographic plates being read quantitatively by means of a photoelectric densitometer. Further improvements on wet techniques came with the introductions of more sophisticated means, such as polarographic analysis (Hughes 1972). Few of these techniques were standardised, and different analysts had their own preference. However, with the late 50s and early 60s, Brill began an extensive series of work, analysing solid state glass by X-ray, as introduced in *Scientific American.*(Brill 1963). Such work eventually expanded from XRF, to the microprobe analysis of Velde and Gendron (1980). These analyses, despite their age, are of high accuracy. The ability to use solid state glass was instantly seized upon, and particularly ED-XRF (Energy Dispersive X-ray Fluorescence). These techniques were particularly embraced by the Ancient Monuments Laboratory (now Historic England) (Bayley 3635, 3701, 4183; Heyworth 1987, 1988a,b). However, such surface techniques are not without pitfalls, as had been earlier demonstrated by Cox and Pollard (1977). Sample preparation of abrasion and polishing was favoured by many analysts as a way around this, and were used for some of the larger scale analyses projects (Sanderson et al. 1984). However, the practicalities of working with ar-

chaeological material has meant that it was not always possible. Something which is still the case, as polishing is by its nature destructive. As it stands, XRF on glass is usually reserved for glass which must be measured in situ, or can not have any form of destructive analysis performed.

Concurrent with this, other techniques were being explored, notably flame atomic absorption spectroscopy (AAS) (Brill 1988; Tennent et al. 1984). While this was much more accurate than earlier wet chemical techniques, it still necessitated glass digestion and therefore greater sample destruction and complexity of preparation. Towards the end of the 80s, another movement within archaeological science led to a higher quality of data produced by glass scientists. Heyworth et al. (1988) wrote of the potentials of using inductively coupled plasma spectroscopy (ICPS) in archaeology, and Heyworth himself was a key analyst in this (Heyworth 1989). While early ICPS still required acid glass digestion, unlike flame AAS, the range of elements possible to measure was much greater. This meant that glass, with its complex relationships between major, minor and trace elements could be measured more fully.

ICPS of digested glass in solution became the standard through most of the nineties, accompanied by increasingly sophisticated applications of XRF, as well as increasingly the more accurate scanning electron microscope (SEM-EDS). There were also some novel applications of techniques used, such as the revival of neutron activation analysis (NAA) (Gratuze et al. 1992a). While an accurate technique, the dissolution of glass required makes ICPS a relatively expensive, as well as somewhat more hazardous, technique. The increased systematic errors involved in wet chemistry also make it less popular among some. However, improving spectroscopic techniques have led to better results.

The introduction of laser ablation sampling (LA) changed all this, allowing ICPS to be performed directly on samples as they were ablated. While such sampling was common in geology, it took some time for it to be routinely used in archaeological

materials, originally making the jump with materials such as obsidian Gratuze et al. (2001). Now LA-ICP-MS is among the standard techniques used in destructive glass study, along with electron microprobe analysis (EMPA), SEM and to some degree XRF and dissolution ICP-AES. For ancient glass, the five techniques commonly in use are thus EMPA, SEM-EDS, ED-XRF, ICPS (Either MS or AES) and LA-ICP-MS, all of which appear in this thesis. Of these, they are all comparable, however microprobe and LA-ICP-MS are the most accurate, followed by ICP-MS, ICP-AES, and then ED-XRF. Accuracy is not the only measure by which a technique is preferred, and there are other considerations of the appropriateness of technique, which have been summarised in table form (Table 4). As such, these five techniques all remain current and common, with occasional papers appearing using more novel approaches.

As well as using these techniques for compositional elemental study, mass spectrometry on digested ancient glass has been used for the isotopic study of glass. The considerations and uses of isotopes in glass will not be elaborated on in this thesis. Isotopic studies, while useful in discussions of recycling, require a suite of different techniques and considerations, and were thus not a part of this present thesis.

2.3 Assembling the Database

After centuries of archaeometric study, and over fifty years of rigorous scientific analysis of ancient glass, a huge amount of legacy scientific data now exists. Increasingly there has been an almost historiographic interest in locating, centralising and managing this data and finding creative ways of putting it to use. This is partly driven by academic interest, but also by necessity. Museum conservation, government policies and funding requirements all make the analysis of fresh glass, particularly destructive analysis, complex. The same is true for many other archaeological materials. In conjunction with this, due to the finite nature of the material we are dealing with,

one must weigh up the benefit of the information that can be gained through destructive analysis versus the preservation of the artefact, either for future posterity or particularly for improved analytical techniques to be developed.[2]

Instead, we turn to legacy data. While dealing with such data can be incredibly difficult, with unique considerations and requirements, similar studies so far implemented have demonstrated that the yield can be incredible. Great success has been seen in metal projects, particularly copper alloys in as diverse projects as the British Bronze Age, the Neolithic Alps and Iran and beyond (eg. Bray and Pollard 2012; Cuénod et al. 2015; Perucchetti et al. 2015; Pollard et al. 2015).

The use of large databases to answer broad-scale questions is becoming increasingly popular in archaeology, especially in Britain; Both those collating traditional archaeological reports, such as the *Roman Rural Settlement Project* [eg. Smith et al. 2016] and the *EngLaID Project* [eg. Cooper and Green 2016; Stansbie and Mallet 2015], as well as collating scientific information on a large scale, such as the *FLAME Project* [eg. Bray and Pollard 2012; Cuénod et al. 2015]. Britain has been an extensive focus of archaeological work for centuries, and what can be achieved by the synthesis of these many years of work is great.

Similarly, largescale data projects are becoming preferred for some glass approaches, such as Degryse's ARCHGLASS project and the newer *Addressing the Invisible*.[3] With funding increasingly insecure for post-excavation work, it is paramount that appropriate syntheses of existing material is carried out. Not just to make the best use out of this pre-existing material, but also to better direct ongoing work.

Drawing inspiration from such ongoing projects, especially FLAME, this thesis

[2]This was particularly pertinent in this study with the Lyminge glass, the significance of the assemblage being very great. The nature of this will be discussed in Chapter 7.2.

[3]Degryse's work has been published (Degryse 2014), and explores the use of isotopic systems to provenance glass. The other only recently funded by the British Academy, is being undertaken by Chloe Duckworth. This project uses experimental archaeology to reconstruct glass recycling in the 1st millennium AD Mediterranean, as well as creating a GIS database of Mediterranean glass. This database will be available online at the completion of her work, in conjunction with other concurrent work, including this current database.

was conceived as a compendium of published results of glass in Britain, spanning eight centuries. Somewhat like a corpus of traditional archaeological material, this thesis is an assemblage covering all the scientific work currently available on glass in Britain, from the first century until the end of the eighth century. This time range was chosen to best address the archaeological question at hand; glass was rare in Britain prior to the Roman invasions, became common throughout the Roman period, but in the early Medieval period, the story is less clear. This thesis therefore includes all the available data until the solidification of large, more clear Anglo-Saxon kingdoms in the eighth century, to assess how this relates to the earlier patterns of trade and recycling.

As this thesis is interested in the geography of glass trade and recycling in Roman Britain, as well as the potential change in glass industry and trade after 410, certain expansions were needed. It was instantly apparent that a British database would be insufficient to discuss trade, so a comparative though far less detailed European database was also collected. While there is a great deal of analysis of glass from the Levant and Near East, as the primary origin of most Roman glass, these were not added to the database. The reason is two fold; both the prosaic reason that this thesis is interested in the travel of glass on the far edges of Europe, so known averages of primary glass are sufficient, as well as the pragmatic reason that this would create a data collection and management project too unwieldy for a doctoral project.

While all British glass entered into this database has been catalogued by WGS84 (World Geodetic System 1984), the European glasses were instead merely categorised by regions.

However, papers containing data were collated in the same way.

The papers chosen for this database all had to be published after Turner 1956c, the last of Turner's series of papers on the chemistry of ancient glass. It was decided that any earlier papers, such as those cited in Caley 1962, were potentially too difficult to

integrate or understand in the context. The comparability of the authors used and their techniques will be discussed in relation to inclusion, below.

This thesis searched for any possible paper containing raw data, or with raw data available as supplementary material. The *Annales du le Congrès de l'Association International Pour l'Histoire du Verre*, *Archaeometry*, *Journal of Glass Studies* and *Historic England Reports* (formally English Heritage Reports and Ancient Monument Laboratory Reports) were all examined for any appropriate papers. From these papers, their authors and bibliographies, and consultation of several experts in the field, more papers were found. On top of this, the *Juliette K. and Leonard S. Rakow Research Library* of *The Corning Museum of Glass* was searched using the terms 'chemical analyses', 'Britain', 'England', 'scientific', and also 'Europe'. Any of these papers that contained data were also included.[4] It should be noted that there are many more papers with scientific analyses, even in these journals, but as the raw analytical data was not available, they could not be included. Many papers have only been published as a synthesis of results, which is clearly quite limiting in such an approach as taken here.

This collection of papers has created a database of over 2,500 analyses of British glasses, spanning 800 years and a comparative European database that contains more than 1,000 further glasses. Due to the variable nature of these papers, several general standardisations have been used. The most pertinent of which is that glasses, which in their original publications were assigned dates that spanned two centuries (ie. second-third century glass), were ascribed the date of the later century (ie. third century), except in cases such as second-early third century, which were then attributed to the earlier century. This is only relevant in simplified discussions and mapping. The choice of the later period was due to the recycling focus of this work as a whole. It

[4]A special thanks must be extended to Ian Freestone, Karl Wedepohl and Caroline Jackson for their assistance in gaining access to data, as well as the staff of the Rakow Library, particularly Jim Galbraith, for all his assistance with the Museum, and Gail Bardhan, whose encyclopaedic knowledge of the Rakow Library collection was invaluable.

was thought that if the glass analysed was primary glass it would allow the latest possible date. However, the problem with this is also that it may appear that glass was recycled due to a composition falling out of production. The potential problems with this decision were deemed acceptable to allow simpler graphing, particularly geographically, and it was standardised to keep potential skew manageable. It will be kept in mind for all analytical discussion. If the glass' context spanned a longer period, it was simply omitted from discussion of centuries, and was used for 'fuzzier' periods, such as either Roman or Early Medieval, or more correctly, pre- or post-fourth century. This simplification for the current study has not eclipsed the data that was originally present, as such, the database contains three fields: 'Date as Given', 'Date - Period' and 'Date - Century', of which only the second two have been transformed for this thesis. As much original information as possible has been retained within the database at all times.

As well as this, all data has been converted to weight percent (wt%). While many elements, such as those common as trace, are almost always recorded are ppm, the decision to do this for all elements uniformly was again about ensuring comparability. Similarly, any paper that did not analyse for any particular element was left out of discussions involving that element. For elements that were measured but fell 'below detection', they have been included as 'zero weight percent' in analyses, unless otherwise stated. Again, this can cause biases, as there are a range of different detection limits, but this will be discussed in relation to comparing analysis within the database. Due to the amount of data dealt with, a technique of 'binning' was required. Many of the lower compositional bins that will be discussed will be underpopulated, where as the lowest will likely be overpopulated, due to this problem of detection limits. As will be apparent, in nearly every case this means possibly recycled glass will *not* show as such. Thus, the bias is towards a lack of recycling indicators, and again, this will be discussed in the context of each map. The details of each paper in the database

will be discussed in summary in Chapter 8 and extensively in Appendix **??**, including which techniques were used for each individual element.

There are, of course, many other challenges with using legacy data, particularly in this dataset. How does one compensate for the large 'digital lacunae', the information missing due to inconsistencies in artefact identification, sampling, techniques of analysis, or simply the data hidden on index cards in desk draws, sometimes having outlived their creators. Of these, variation of technique is perhaps the major problem, particularly with such a vast database as has been assembled here. It is also the origin of most of the standardisation required, mentioned above. Different methods have different strengths and are hugely variable in terms of both accuracy and precision, as well as detection limit. In the case of copper alloys, a series of papers from Oxford have shown successful results using a threshold of presence/absence for a suite of elements deemed to be diagnostic (Bray and Pollard 2012; Cuénod et al. 2015; Perucchetti et al. 2015; Pollard et al. 2015). While this has proved useful for metals, the nature of glass manufacture and the results of previous attempts by the author mean that such a technique can not be easily applied.

Instead, a new but related approach has been tried here, along with traditional glass compositional groups. Each element that has been included in this database has been individually considered for both its appearance in raw sources (what part of the glass recipe it comes from - sand, flux or additives) and its potential as a diagnostic for recycling [Table 1]. While this means a more complex arrangement than has been used for copper alloys, preliminary results proved fruitful. For glass, particularly in terms of recycling, what one is often looking at is a matter of correlation based on three different raw ingredients, silica, alkali and colourant, so it is worth considering a wider range of elements.

The advantage of this approach is that older papers, often with much smaller suites of elements analysed, are still of some use. As has been shown to work with

copper alloys, while not all data is suitable for all analyses, even the 'less reliable' papers can be integrated. This is because we are looking for long term, large scale trends, rather than being concerned with individual glasses and absolute values. For the most part, this thesis is focused on the flow of material and broad-scale trends, rather than whether or not a single glass is likely to be recycled. As such, as much previous work as possible has been integrated.

Form is also clearly a very important factor when considering archaeological glass. The relationship between form and composition has been commented on by several authors (eg. Baxter et al. 1995). Ethnographic evidence shows a preference for recycled material in beads and utilitarian vessels, rather than high end tablewares. However, the assumption that this is true at all times in the past is incredibly problematic. The drive and perception of 'recycling' is not a known factor. In subtle gradation of material related to form, however, can not really be commented upon in this thesis. Once again, the synthesis of such a large volume of data has led to a large variety of reporting techniques. While preference would be to have all vessel glass characterised by Isings number and beads under Guido or Brugmann's typologies, this was not possible. While some papers recorded this information, the majority did not. As such, all samples were divided into five main categories, and 12 subcategories, when possible.

- Manufacturing
  - Rods
  - Waste
  - Droplets
  - Wasters
  - Glass attached to clays
- Beads.
  - Monochrome
  - Polychrome
- Enamel
- Window glass
- Vessel glass
  - Cups
  - Bowls
  - Plates
  - Lamps

- Unknown

As well as this typological simplification, colours were simplified. Colours had often been recorded by eye, including simple terms, such as 'blue', more elaborate descriptions, like 'pale blue', to the simply lyrical, 'pale peacock blue with streaks of azure and sky blue'. While some papers took a more objective approach, with either wavelength recorded by colorimetry, or assessed by Munsell colour charts, the lack of comparability across works posed a problem. As such, colours were simply attributed to blue, green, red, purple, yellow, blue-green, naturally coloured and colourless. Oranges and pinks were categorised as red, unless clearly stated as a 'yellow orange', in which case, 'yellow'. The colours most relevant for most discussions were colourless, naturally coloured, green and blue, which are often less disputed.

Aside from the chemistry, the database records as many as possible of the following:

Category	**Options**
Sample	Either the find number or museum ascension number, as it is recorded in the original paper.
Thickness	In mm.
Dimensions	Length by breadth, in mm.
Collection	What collection the glass belongs to, if belonging to a museum or similar body.
Plant/Soda	If the paper records whether it is plant ash or soda glass.
Shortened Description or Form	Description of glass as in original publication.
Object Type	*Either* window, manufacture, vessel glass, enamel, beads
Colour	Recording of the colour as it is in the original publication.
Revised Colour	*Either* colourless, naturally coloured, blue-green, blue, green, yellow, red, purple, black, brown
Date as Given	Chronology, precisely as given in the paper.

Date - Period	*Either* Roman, Early Roman, Middle Roman, Late Roman, Saxon, Early Saxon, Middle Saxon, Late Saxon.[5]
Date - Century	Summarised single century.
Excess Strata or Site Information	Any locational data beyond site, such as grave number or actual excavation strata.
Location	Site name.
Region/County	The region of country, or in English examples, the county.
Analysis	*Either* ED-XRF, SEM-EDX (LA)-ICP-MS, ICP-AES, AAS, EMPA, WDS-EMPA, WDS-XRF, OAS, ICP-OES, AAS.
Standards Info	Whether or not standards were used, and which ones. The results are added to the database if analysed.
Laboratory	Where the analyses were performed.
Pretreatment	What pretreatments were used.

Not every paper or glass contains all this information, but this is the extent of the database, beyond chemistry. The hope of creating such a database is that such work as performed here will be repeatable and the database will be of use to other researchers. The author has contacted the ADS about hosting this.

While most analytical consideration will be discussed relative to individual analyses, there are several issues that are broadly relevant to all. As mentioned, all data has been recorded to as wt%, rather than ppm. However, there is also the problem of recorded oxide is notable. As papers often do not record the basis of assumption of oxide type, this thesis assumes that all papers are correct in their assertion. That is, if a paper records 0.03 wt% Sb_2O_5, then for analyses this is normalised to Sb 0.023 wt%.[6]

As well as this, there is the problem of 'binning' data, which is used for many of

[5]The term 'Saxon' has been used in this part of the database as as short hand for 'Early Medieval period', partly to avoid potential confusion between 'Early Medieval' and 'Early Early Medieval'.

[6]This is achieved by calculating what percentage of the atomic weight of the molecule corresponding to antimony, then calculating the percentage of the weight percent that this corresponds to.

the maps. The data is divided between compositional bins, relative to the weight of a certain element. Due to the range in detection limits in each technique and paper, this means that some of the lower bins, those dealing with values such as 0.005 wt% to 0.01 wt%, will be underpopulated, and the lowest bin, ie. less than 0.001 wt%, will be overpopulated. That is, if the detection limit is 0.01 wt%, glass with that element in 0.009 wt% would show up as below detection, and would be placed in the less than 0.001 wt% bin. This will cause the apparent 'lack' or certain elements. As will discussed later, such a technique is likely to bias against the recycling metrics that look for slowly decreasing trace elements. However, such an approach was deemed the most feasible for dealing with such a large amount of data, achieved by a variety of techniques.

2.4 EMPA Method

As well as the collection of published glasses, the decision was made to include fresh analyses. Originally, this included 156 shards from Dorchester-on-Thames and 36 from Lyminge, but due to machine failure and availability, this thesis only contains 104 and 35 respectively. All glasses, however, were sampled and prepared, with the hope that in the near future they will be analysed and published.

The glass was sampled by the removal of a small fragment, approximately 3mm square, using zinc-carbide cutters and a diamond-tipped scorer. The shards were then set in SpeciFix-20 resin. To assist with this, PVC packing tape was used to secure the glass shards on the newly exposed edge, with between 20 to 30 shards in each resin block [Fig 2.3]. This ensured that the analysed side of the block exposed a cross section of previously unexposed glass, meaning that deterioration could be viewed by SEM.

Once the shards had set, this exposed edge was polished with a Buehler MetaServ

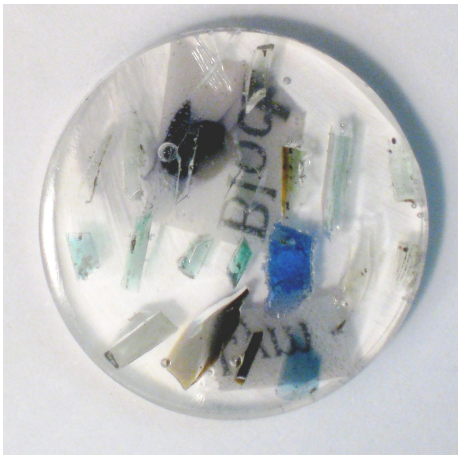

Figure 2.3: An example of one of the blocks of mounted glasses, polished and ready to be carbon-coated and analysed by EMPA.

Grinder-Polisher. Blocks were polished on cloths with Buehler MetaDi Monocrystaline diamond suspension at 9, 6 and then 1 μm. The final results were checked under optical microscope at 200x magnification to ensure no visually apparent scratches remained that would cause problems with the carbon-coating or EMPA analysis. Once the blocks were sufficiently polished, they were carbon-coated, to allow conductive contact with the microprobe.

The machine used for these analyses was a wavelength-dispersive Jeol 8600 electron microprobe (EMPA) at the Research Laboratory for Archaeology and the History of Art, University of Oxford. An accelerating voltage of 15 kV, low beam current of 7.5 nA and a take-off angle of 40° were used in these analyses. The first analyser crystal was thallium acid pthalate (TAP), which analysed silicon and aluminium at 30s peak counts. The second TAP crystal analysed Na for 12s, P for 60s and Mg for 30s. The third crystal was pentaerythritol (PET), and analysed K and Ca for 20s, Ti for 30s, Cl for 50s and Sb, Sn and Pb for 60s. The final crystal used was lithium fluoride (LIF), which analysed Fe for 30s, Mn for 40s and both Cu and Co for 60s. All lines analysed were k-lines, except Sb and Sn, which were l-lines, and Pb, m-line. K ratio was then analysed and the final results calibrated for each sample.[7]

[7]The author would like to thank Victoria Smith, the University of Oxford, for her invaluable help

Corning A, B, C and D were all analysed as reference standards, each 16 times. They were dispersed throughout the run to ensure there was not significant machine drift or error across the entirety of the analyses. As well as this, each sample was analysed a minimum of three times, and an average value used to try and better cope with the heterogeneity of glass samples and any possible segregation within the sample analysed. The final results are included in Appendix 1, both as raw data, used averages, and Corning standard results. The samples and context are discussed in Chapter 7, and Corning results in Chapter 8.3.1.

2.5 Mapping and GIS

Geography married to archaeological composition was one of the key elements of this work. As such, *ArcGIS* was used in the majority of the statistical work. Unlike other statistical software, geographic information systems (GIS) allow for the storage and interrogation of large amounts of data that include a spacial component. ArcGIS is used for the creation of maps, compiling of geographic data, and the querying thereof. Such interrogations can either reference only the dataset at hand, in this case, the glass database, or other informative datasets, such as road networks, rivers, harbours, or view-sheds. While the original conception of this thesis also included the interrogation of three other datasets, Roman roads, ancient harbours and rivers, time constraints curtailed this.

While not used for statistical studies, Roman roads have been retained on maps as a visual key to indicate the connectedness between different areas of Britain. Further work will allow statistical calculations about whether the distance of sites from major Roman nexus affected the composition. While both rivers that existed in the landscape at the same time are similarly vital, as are the locations of ancient harbours, they were not included. This was because, as the course of rivers is so varied

with the microprobe, particularly the calibration.

overtime, and the dating on known ancient harbours in Britain lacking[8], the inclusion would only increase confusion.

The Roman roads were added to the map as a shapefile (McCormick et al. 2013b), from the *Digital Atlas of Roman and Medieval Civilizations* (DARMC) (McCormick et al. 2013a). The *Roman Road Network*, last updated in 2008, is a shapefile compilation of the Roman roads identified in the Barrington Atlas of the Greek and Roman World (Talbert 2000). DARMC is a Harvard based project of collection and digitising Roman and Medieval geographic data, including hoard locations, roads, and settlements.

An effort was made to include rivers, however this proved far more problematic. England has undergone extensive hydro-engingeering, with the mass canalisation of the country in the eighteenth century fundamentally altering the riverine routes. However, such work began much earlier. The Romans themselves built connections between rivers, such as Foss Dyke, and work continued with various additions to almost every major river system in England. Locating any mapping of rivers that is accurate to the first millennium in Britain is thus incredibly difficult. As it was apparent that there would be insufficient time to interrogate the relationship between these rivers and composition, they were not included.

As well as this imported information, the geolocation of the glass within the created database was paramount. With the assistance of *GoogleEarth*, all sites were located, and their WGS84 coordinates used to plot them into the GIS system (Fig. 2.4). Due to the range of papers used, some coordinates are very accurate, referring to specific areas of sites material was found, often the recorded location was a single town, and thus the coordinates used are less accurate. The scale at which this thesis is working means this is unlikely to cause any significant change to the data.

[8]While the work of the DARMC database on Harbours is significant (de Graauw and all 2014), drawing mostly from the Barrington Atlas and the work by Cleere (1978), both the nature of the sites and the range of excavations has not allowed accurate dating.

Inside of Britain, a 'fishnet' has been created with this geolocated data. It is built of rectangles, polygons measuring approximately 25 breadth by 32 height kilometres, the extent of which was determined by the geographical limit of the data found, ensuring all data fell inside. The fishnet created included 20 rectangles, by 25, with each covering an area of 800 km^2, as seen in Fig. 2.5. This approach, rather than surveying individual excavations or sites, was chosen in an attempt to show the most comparable compositions geographically, instead of according to the density of finds, excavation or analysis, but with that information still at hand. Data can be analysed within each fishnet.

To make the fishnet easier to refer to, cells were given coordinates of 'αa'. As such, it can be easily seen which cells each location falls into, and therefore the group of sites.

Beyond Britain, coordinates of glass finds were not sought, as the the sources of data were in more varied. Instead, regional blocks were used, as given by the papers. The shapefiles for the regions used were taken from Natural Earth Data, Admin 2-states, provinces (Fig. 2.6).

The GIS system allows the analysis of the data, collected and generated in this thesis, to ascertain the patterns of trade and recycling in the first millennium glass in Britain.

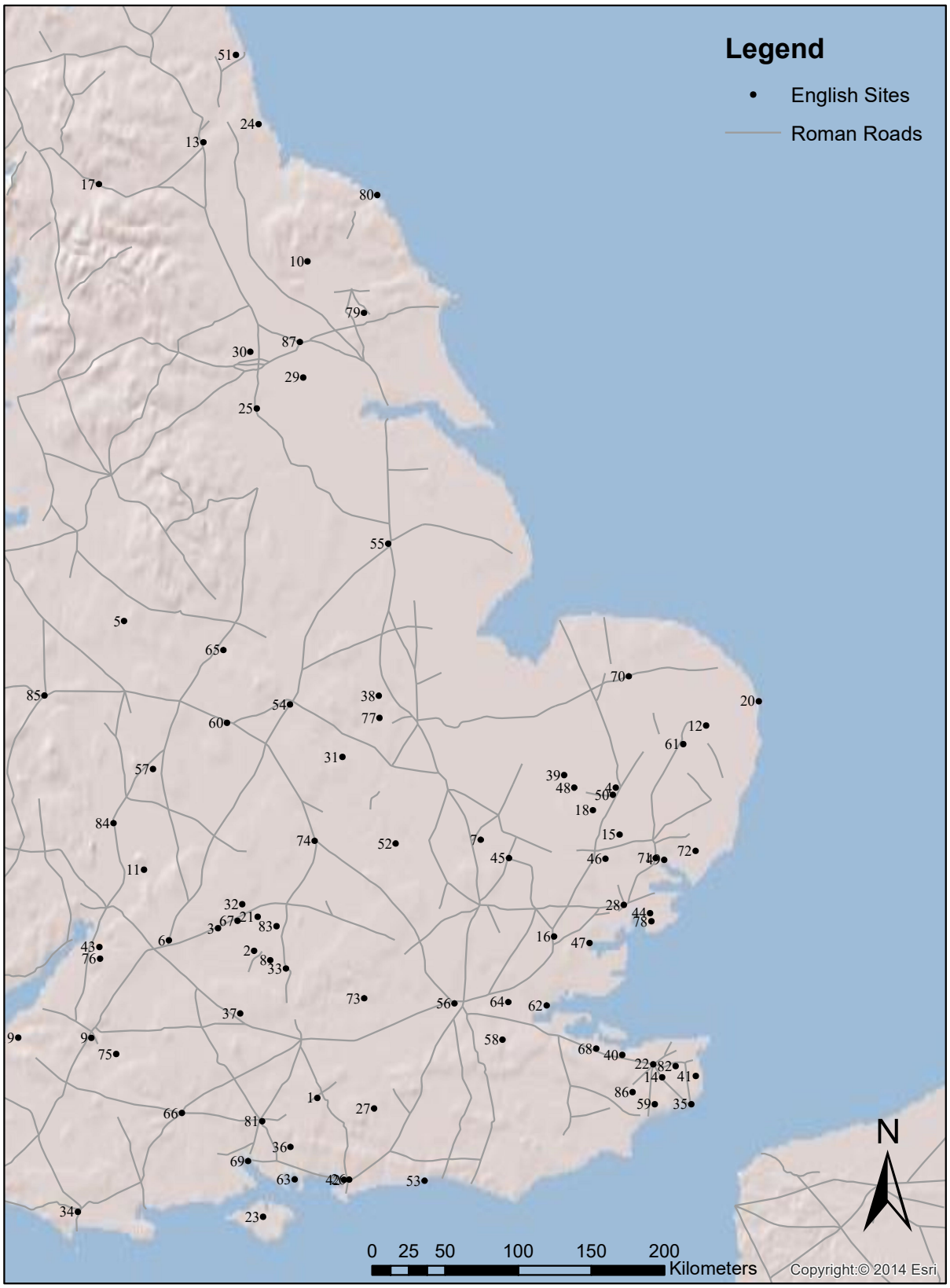

Figure 2.4: British sites with analysed glass (including Lyminge and Dorchester on Thames), against Roman Roads.

Alton, Hampshire 1
Appleton, Oxfordshire 2
Asthall, Oxfordshire 3
Bardwell, Suffolk 4
Barlaston, Staffordshire 5
Barnsley Park, Gloucestershire 6
Barrington, Cambridgeshire 7
Barton Court Farm, Oxfordshire 8
Bath, Somerset 9
Beadlam Villa, North Yorkshire 10
Beckford, Worcestershire 11
Bergh Apton, Norfolk 12
Binchester, Durham 13
Bishopsbourne , Kent 14
Brettenham, Suffolk 15
Broomfield, Essex 16
Brough, Cumbria 17
Bury-St.-Edmunds, Suffolk 18
Cadbury Congress, Bristol 19
Caister-on-Sea, Norfolk 20
Campsfield, Oxfordshire 21
Canterbury, Kent 22
Carisbrooke Castle, Isle of Wight 23
Castle Eden, Durham 24
Castleford, West Yorkshire 25
Chichester, West Sussex 26
Chiddingfold, Sussex 27
Colchester, Essex 28
Coppergate, North Yorkshire 29
Dalton Parlours, West Yorkshire 30
Desborough, Northamptonshire 31
Ditchley, Oxfordshire 32
Dorchester-on-Thames, Oxfordshire 33
Dorchester, Dorset 34
Dover, Kent 35
Droxford, Hampshire 36
East Shefford, Berkshire 37
Empingham, Leicestershire 38
Eriswell, Suffolk 39
Faversham and Howletts, Kent 40
Finglesham, Kent 41
Fishbourne Villa, West Sussex 42
Frocester Court, Gloucestershire 43
Great Bently, Essex 44
Great Chesterford, Essex 45
Great Waldingfield, Suffolk 46
Heybridge, Essex 47
Icklingham, Suffolk 48
Ipswich, Suffolk 49
Ixworth, Suffolk 50
Jarrow and Monkwearmouth, Tyne and Wear 51
Kempston, Bedfordshire 52
Lancing Down, Sussex 53
Leicester, Leicestershire 54
Lincoln, Lincolnshire 55
London *(incl. Maiden Lane, Watling House, Moorgate, Copthall Avenue, Norton Folgate, Tower of London, Bedfordbury, National Gallery, Westminster Abbey)*, Greater London 56
Longbridge, West Midlands 57
Lullingstone Villa, Kent 58
Lyminge 59
Mancetter, North Warwickshire 60
Morningthorpe, Norfolk 61
Mucking, Essex 62
Portchester Castle, Hampshire 63
Rainham, Greater London 64
Repton, Derbyshire 65
Salisbury (Old Sarum), Wiltshire 66
Shakenoak Villa, Oxfordshire 67
Sittingbourne, Kent 68
Southampton (Hamwih), Hampshire 69
Spong Hill, Norfolk 70
Sproughton, Suffolk 71
Sutton Hoo, East Anglia 72
Taplow, Buckinhamshire 73
Towcester, Northampton 74
Trowbridge, Wiltshire 75
Uley, Gloucestershire 76
Wakerley, Northamptonshire 77
West Clacton Reservoir, Essex 78
Wharram Percy, Yorkshire 79
Whitby, Yorkshire 80
Windchester, Hampshire 81
Wingham, Kent 82
Woodeaton, Oxforshire 83
Worcester, Worcestershire 84
Wroxeter, Shropshire 85
Wye Down, Kent 86
York *(incl. York Fortress, York Minster, Wellington Row, Fishergate)* 87
North Yorkshire

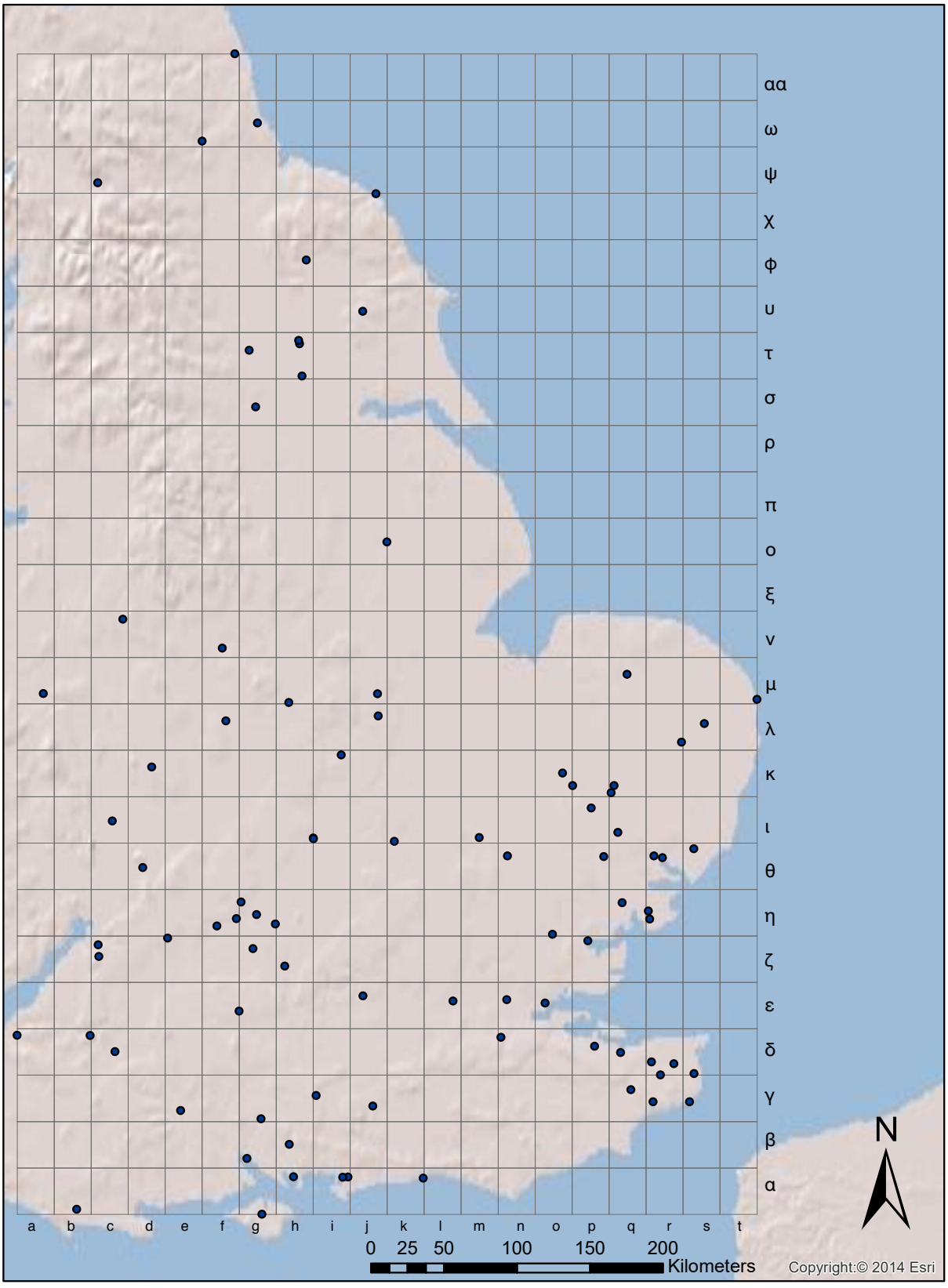

Figure 2.5: Extent of the Fishnet used to analyse the English data, dictated by the range of the data found, and the location of the sites.

αb	Dorchester, Dorset
αg	Carisbrooke Castle, Isle of Wight
αh	Portchester Castle, Hampshire
αi	Chichester, West Sussex
	Fishbourne Villa, West Sussex
αk	Lancing Down, Sussex
βg	Southampton (Hamwih), Hampshire
βh	Droxford, Hampshire
γe	Salisbury (Old Sarum), Wiltshire
γg	Windchester, Hampshire
γi	Alton, Hampshire
γj	Chiddingfold, Sussex
γq	Wye Down, Kent
γr	Lyminge, Kent
γs	Dover, Kent
δa	Cadbury Congress, Bristol
δb	Bath, Somerset
δc	Trowbridge, Wiltshire
δn	Lullingstone Villa, Kent
δp	Sittingbourne, Kent
δq	Faversham and Howletts, Kent
δr	Bishopsbourne , Kent
	Canterbury, Kent
	Wingham, Kent
δs	Finglesham, Kent
ϵf	East Shefford, Berkshire
ϵj	Taplow, Buckinhamshire
ϵl	London, Greater London
ϵn	Rainham, Greater London
ϵo	Mucking, Essex
ζc	Frocester Court, Gloucestershire
	Uley, Gloucestershire
ζe	Barnsley Park, Gloucestershire
ζg	Appleton, Oxfordshire
	Barton Court Farm, Oxfordshire
ζh	Dorchester-on-Thames, Oxfordshire
ζp	Heybridge, Essex
ηf	Asthall, Oxfordshire
	Shakenoak Villa, Oxfordshire
ηg	Campsfield, Oxfordshire
	Ditchley, Oxfordshire
	Woodeaton, Oxforshire
ηo	Broomfield, Essex
ηq	Colchester, Essex
ηr	Great Bently, Essex
	West Clacton Reservoir, Essex
θd	Beckford, Worcestershire
θn	Great Chesterford, Essex
θp	Great Waldingfield, Suffolk
θr	Ipswich, Suffolk
	Sproughton, Suffolk
θs	Sutton Hoo, East Anglia
ιc	Worcester, Worcestershire
ιh	Towcester, Northampton
ιk	Kempston, Bedfordshire
ιm	Barrington, Cambridgeshire
ιp	Bury-St.-Edmunds, Suffolk
ιq	Brettenham, Suffolk
κd	Longbridge, West Midlands
κi	Desborough, Northamptonshire
κo	Eriswell, Suffolk
κp	Icklingham, Suffolk
κq	Bardwell, Suffolk
	Ixworth, Suffolk
λf	Mancetter, North Warwickshire
λj	Wakerley, Northamptonshire
λr	Morningthorpe, Norfolk
λs	Bergh Apton, Norfolk
μa	Wroxeter, Shropshire
μh	Leicester, Leicestershire
μj	Empingham, Leicestershire
μq	Spong Hill, Norfolk
μt	Caister-on-Sea, Norfolk
νc	Barlaston, Staffordshire
νf	Repton, Derbyshire
oj	Lincoln, Lincolnshire
σg	Castleford, West Yorkshire
τg	Dalton Parlours, West Yorkshire
τh	Coppergate, North Yorkshire
	York, North Yorkshire
υj	Wharram Percy, Yorkshire
ϕh	Beadlam Villa, North Yorkshire
χj	Whitby, Yorkshire
ψc	Brough, Cumbria
ωf	Binchester, Durham
ωg	Castle Eden, Durham
$\alpha\alpha$f	Jarrow & Monkwearmouth, Tyne & Wear

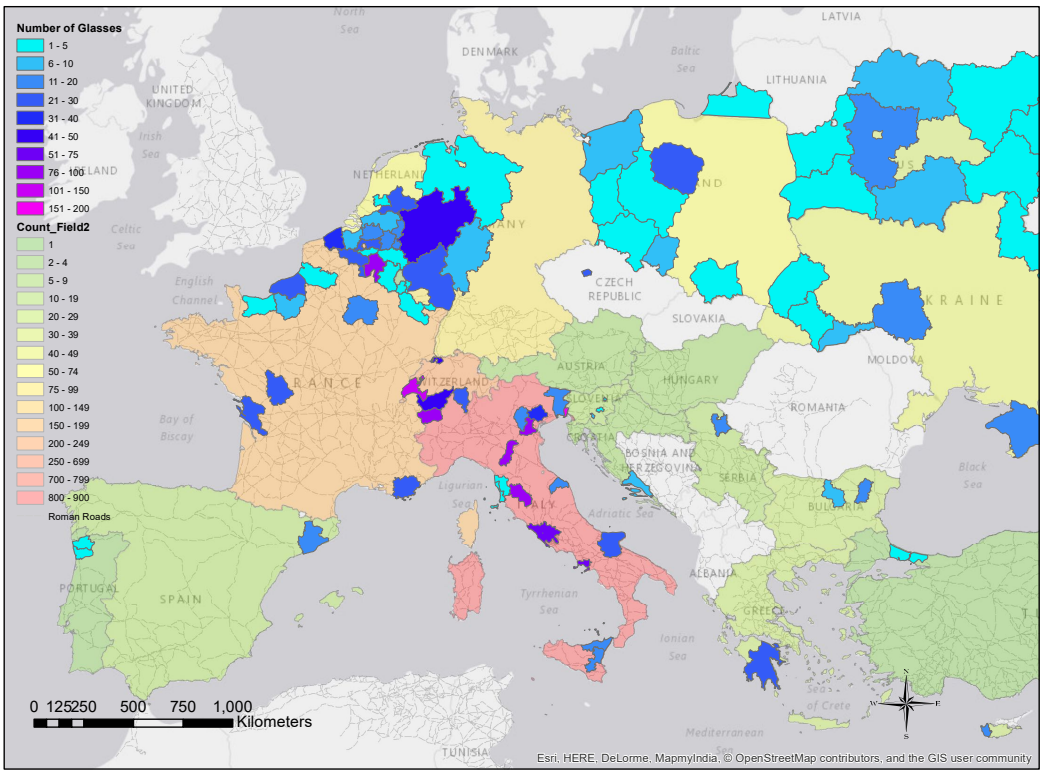

Figure 2.6: European Regions with glass analysed, colour indicating density of analysed data. The background colour shows the total number of glasses per country, and the foreground, the number of glasses per administrative region.

Chapter 3

Beyond Roman Britain

As discussed in Chapter 2.2, the Roman system of glass, on a large scale, is broadly understood. However, the Roman Empire is a large and unwieldily entity, with a huge degree of variation, as true in glass as any other material. As such, one must consider the place of glass as a material in Britain in the first millennium. This then needs to be understood in the larger schema of the nature of 'Roman' in Britain, and a possible of way of life that can be seen to 'fall' at the end of the fourth century. Finally, this chapter will look at our current understanding of recycling both before during and after the period known as 'Roman' Britain.

3.1 Timeline of Glass in Britain

3.1.1 Pre-Roman Glass

There was no native glass vessel industry in Iron Age Britain. There was, however, an extensive late enamel and bead industry and some importation of continental vessels. The glass working done in this period in Britain begins with low-technology beads and, towards the end of the Iron Age, elaborate enamelwork and some small items such as gaming counters. Although Strabo comments on extensive glass being

exported to Britain from Gaul during the Augustan period [*Geographica*, IV.5.3], the archaeological evidence seems to imply this was in fact rare.

In 1956, an Iron Age burial at Hertford Heath, Hertfordshire uncovered a stunning yellowish-green, ribbed glass bowl (Price 1996). It is one of a very small number of glass objects in Britain prior to Roman occupation, most of which were uncovered in burials. An Augustan burial in Welwyn Garden City, also in Hertfordshire, contained 24 glass gaming pieces and fragments of both beads and bangles (Stead 1967). In Hurstbourne Tarrant, Hampshire, yellowish brown vessel fragments were found (Hawkes and Dunning 1931), and a vessel, now lost but seemingly a blown flask, was also from Mount Bures, Essex (Stead 1967, 53).

Of the glass found actually in Iron Age settlements, both polychrome mosaic shards and a monochrome linear-cut bowl without ribs were found in the later levels at Braughing at Skeleton Green [79-84](Price and Cool 1988), a polychrome mosaic bowl in the Iron Age layers of Silchester (Boon 1969), two further fragments at Heybridge, Essex and two or three from the pre-conquest levels at Colchester (Harden 1947). As well as this, there are several other possible shards of ribbed bowls, notably from London, but none with secure provenance (Price 1996, 53). However, through all this, it is clear that at least some of the 'Roman' drinking culture and rituals seem to have made it to Britain (Cool 2006, 163).

As well as these imports, the local glass production produced a notable number of artefacts. Though, these are almost entirely beads and enamel, the later particularly are so striking that they are often used to typify the height of Late Iron Age British art. While the imported vessel glass had been consistent with other Roman glass of this period, produced in the Near East, this local glass is not. It is more usually a plant ash, rather than a soda glass, which had been the norm since the Bronze Age across Europe in glass.[1]

[1]Also in some enamels - certain forms and colours, such a mosaic cane and some red, are glasses, rather than true enamels (Hughes 1972; Leeds 1933).

This glass is chemically immediately apparent in studies of British glass due to this use of plant ash. While there are limited studies of Iron Age British material, it has all shown a relatively high sodium plant ash production. This is usually interpreted as a mixed composition of some natron material, and some plant ash glass. For example, the glass analysed by Henderson and Warren (1981), with the exception of beads of Guido's class 10, have sodium of 12.9 wt % (σ 5.4), magnesium of 0.7 wt% (σ 0.15) and potassium 0.71 wt% (σ 0.70).

With the invasion, however, came glass, in great variety and abundance, but with comparatively standardised composition.

3.1.2 First to Early-Third Century Glass

During the first to early third centuries, glass flooded into Britain in huge quantities, as it did across most of the Empire. The majority of it was vessel glass, though windows and beads were also common. While there was a wide range of tablewares, assemblages in this period are by far in a way dominated by household vessels, especially storage bottles (Price 2000b, 1). Unlike in the Iron Age, glass is not a just luxury in this period. While there are hugely elaborate pieces, such as the Portland Vase [Figure 3.1], it is also used for incredibly common vessels. Glass is found in almost every Roman context; burial, occupation (whether urban, military, or regional), and religious.

This thesis will not go into too much detail about the glass forms in Roman Britain as if has been extensively studied and commented upon, in such books as *Romano-British Glass Vessels: A Handbook* (Price and Cottam 1998). This book contains a detailed breakdown of vessels by periods [212-215]. As well as this, many volumes exist including the chemistry of these vessels (eg. *Glass of the Roman Empire* (Bayley et al. 2015)). A brief comment must be made, to understand the skilled nature of such work and variation across time.

Figure 3.1: The Portland Vase (British Museum, Registration No.: 1945,0927.1, Image No.: AN251751001 © The Trustees of the British Museum.)

Cast forms are still being produced in the mid-later first century, despite the fact that glass-blowing had been developed over a hundred years earlier. However, during the early years of Roman-Britain, mould and free-blown tablewares predominate, particularly blown storage bottles which are produced in huge numbers during first and second century. In fact in such quantities and with such standardised forms that some were even deliberately produced in an embossed mould by various producers of things like food stuffs.[2]

Hot decorative elements are often used in this period, including moulding, cased glass (particularly for cameo-cutting), blobs and trails (including highly modelled prunts), tooled points and folds. On cold glass, there is enamelled decoration, wheel-cutting and abrading, and a variety of deep-cutting (facets, cameo-cutting, relief-cutting, figured-cutting). The range of designs is far greater than in earlier and later periods, and the range of decorative elements used greatly depend on the sort of glass and intended market. Glass in this period runs from mass-produced, unfinished bottles, to incredibly detailed one-offs such as cage-cups, that required relentless, almost mindbending hours of finishing work after the initial production.

Quite a few early glasses in Britain are brightly coloured: dark blue, yellow/brown, yellow/green, dark green, purple and some opaque colours, such as pale blue, orange/red, green and white. However, these colours fall out of favour in the earlier Flavian period, except as decorative elements on other vessels. The vast majority of glass in this period is blue-green coloured, as this is the glass used for the majority of bottles and other household containers, as well as some higher quality tableware. This glass is likely a naturally coloured, caused by impurities of the Eastern Mediterranean sand. There is also a good deal of antimony colourless glass, as well as nearly-colourless glass.

In the first century, the decorative elements are predominately white trails and

[2]For a survey of this, see Foy and Nenna (2006a,b, 2011).

blobs, both marvered and unmarvered.[3] Then moving into the second and third century, this instead shifts to a preference for strongly coloured translucent dark blue, dark green and yellow/brown. This is also the period of enamelling on vessels in Britain, which after this does not return again for many centuries.

The blue-green glass across the empire has a fairly standardised composition (Jackson 2005, 2), and the rest of the glass from this century predominantly falls under Jackson (2005) Group 1a, 1b and 2a. Unlike the period beforehand, the glass of this period is natron glass, imported from the Roman networks which spread this glass across half the world. Roman blue green glass has typical values of sodium of 17.2 wt % (σ 0.53), magnesium of 0.61 wt% (σ 0.06) and potassium 0.80 wt% (σ 0.16). While the values differ, it is higher sodium and lower magnesium than Iron Age glass. Most notably, there is also very little variation across this glass type in terms of alkalis. [4]

Vessel production is clearly widely spread in Britain at the time (Price 1998, 331-348), though not the production of glass itself. However, recycling was a significant part of the Roman industry and it seems that in this period recycling was more intensive in cities. This is based only on archaeological evidence, as shards on urban sites are noticeably smaller (Price and Cottam 1998, 7). This is interesting as several large *civitates* in this study show heavy recycling.

This is the most heavily studied and well understood period for British glass, as is true of many materials. This period covers the height of Roman Britain, and thus many of the generalisation about the Roman period in Britain apply to this date range alone.

[3]'Marver' refers to the practise of rolling warm glass along a flat unreactive surface, or marver. This is used to shape the glass, flatten in designs and cause a change in working temperatures.

[4]Values taken from Foster and Jackson (2009, 192).

3.1.3 Late-Third to Fourth Century Glass

The third to fourth century in Britain saw a shift in the use of glass. Starting at the end of the second century, but steadily continuing, the quantity of bottles drops significantly, and the glass vessels that become the most common are those directly related with serving and consuming (Price 2000b, 1). As the period continues this becomes predominately drinking (Cool 2006, 224), meaning that by end of the third century, the only glass that remains in any quantities are drinking cups, and the smaller objects such as beads, enamel and tesserae. Most of these vessels are not found in graves, but in settlements; religious, civilian (both urban and rural) and military.[5] Some high status rural sites, such as Barnsley Park, have yielded a huge number of shards (in this case, approximately 2,100 (Price 1982)), and the ritual site at Uley had over 900 (Price 1993). However, it is common for rural sites of this period have around 100 shards, a much lower number than seen in earlier periods. Less glass has been recovered from sites along or near the Wall than elsewhere in Britain at this period, with the exception of the fort at Binchester (*Vinovium*).

As noted, in all of these cases, the diagnostic shards are overwhelmingly drinking vessels and bowls (Price 2000b, Fig. 2). While this is consistent with the drinking culture seen in other materials at this period, there is another interesting point to note; In this period shards are increasingly small, with apparently more care taken to curate large shards (Cool 1995). This means both that it is harder for us to be as certain about typology, but also that there must be an explanation of this. It is probably evidence of recycling, as one can ignore the 'nuance factor' of shard removal, as this would not have changed over time. This seems to be more true of urban sites,

[5]To give an indication of how rare glass is in burials, Colchester, a site with much glass found in its living site at this period, had only 11 vessels between 669 graves at the Butt Road Graveyard (Cool and Price 1995, 185). While this is an extreme case, this bias has held true on other sites. Of the glasses found in burials, it is not the high-quality luxury vessels seen in other North-Western provinces, but more utilitarian. Glass, despite its seeming commonness on urban British sites, is only found in comparatively rich burials (Price 2000b, 4).

potentially because of the ease of getting shards to a skilled or semi-skilled glassworker to be used as cullet.

Despite the shrinking of forms noted above, new vessel forms, or variations on existing ones, do continue to be produced in this late Roman period, despite Britain's instability. Very few of the forms that become common in Britain in the fourth century are seen at all in the Mediterranean and some, such at Isings 129, have specific British variations (in this case, the bottle has a rolled rim and a constriction at the base of the neck not seen elsewhere). Many forms are simply unknown elsewhere.

By the fourth century, drinking tablewares are the only real production; cups, beakers, bowls and jugs. Very few closed forms remain at all, such that by the end of this period, they are essentially non-existent. Utilitarian containers, with the exception of small flasks, or unguent bottles (Isings 83), are gone. The vessels produced are, on average, very thin-walled and small. They are predominately free-blown, as opposed to mould-blown which was favoured in the previous centuries, but optic-blowing remains moderately popular.[6]

For the most part fourth century assemblages are convex cups and conical beakers, both usually with cracked off rims and concave bases (Price 2000b, 5-8). Isings 96 and 106 are the most common forms, but there is a huge degree of variation; Rims are curved or straight, unworked or smooth, nearly hemispherical or conical with concave or straight sides. The walls, while usually very thin, range to the very thick, with bases variable: flat, concave or sometimes with a tubular base edge.

Some of the rarer forms, beginning around mid-fourth century, lack parallels outside Britain, supporting the now considerable evidence for late indigenous forms and production (Cool 1995, 14).[7] The three most frequently occurring of such forms in

[6]Optic-blowing refers to a technique where the vessel is partly blown into a mould, to impress the design, then removed and free blown. The result is that the mould design remains, but is inflated and stretched. This is often used to create a rib-type pattern on bottles.

[7]For a summary of less common forms also in use in this period, see Price 2000b, Bowls, Fig. 5;

this period are a two-handled flask, a handled cup with a tubular rim and a small globular jug with stout one rod handle (Cool 1995, Fig 3.11, 4.3 and 3.8). The last of which is not just British but strongly concentrated in the South East, the most northern example in Lincoln (Price 2000b, 21).

Both hot and cold decorations are both still used in this period. The most common techniques are horizontal abraded or wheel-cut lines, facet cut geometric designs, freehand wheel cutting, or incised figural. More rarely, there are cameo or cage-cup style deep-cuttings.

It is worth a brief discussion of the most common decorations on cups and beakers, particularly moving into the fourth century.[8] Abraded lines, being the most common design, appear just before the third century, and by the fourth century they are exceptionally common, particularly on glass found in settlements. A handful of glasses found at Dorchester-on-Thames have abraded lines. The cups decorated with abraded lines are mostly of fine glass, but vary, and they do tend to curve toward the rim, becoming straighter over time.[9] Beakers with abraded lines also begin to appear around the first-half of the fourth century, and again these are mostly thin-walled. This is the only cold-working that remains into the Early Medieval period, though it is not particularly common (Price 2000b).

The next most common form of decoration in this period is applied trails. Unlike in the main Roman period, they tend to be self-coloured and proud, however, when they were of a second colour, they were marvered as before. It is a common decoration on cups but beakers with self-coloured trails are uncommon. This is in direct contrast to the early Anglo-Saxon period, where beakers are very commonly adorned with self-coloured trails (Price 2000b).

Jugs, Fig. 6; Bottles, Fig. 7, and also Cool (1995).

[8]For a summary of forms of cups and beakers, see: Price (2000b, Fig. 3 and 4).

[9]With the late exception in Grave 81 at Lankhills Windchester, AD 350-370 (Harden 1979, 211-213).

By the end of the fourth century, the main decorations that remain are hot-working, such as indented decorations, trails, claw-shaped bosses, and optic and mould blown patterns. The only cold-working remaining is horizontal abrading. This would probably significantly simplify the manufacturing process, no finishing being required post annealing beyond washing (Price 2000b, 21). However, rather than a completely simplified industry, it is worth noting there are as many forms at AD 410 as there were at AD 350. There certainly seems to be less glass in circulation, and less settlements have yielded glass, so arguments for increased recycling are credible. The problem, if this is true, is estimating true numbers of vessels in use at any one time.

There is also less of a range of quality, the particularly high-status vessels in high-quality glass dropping out of manufacture. It has been suggested that this might be sociological, caused by the failure of the systems such as patronage, *clientela*, that demanded *largitio*. It is likely such vessels (ie. Cage cups) were never available or produced for a common market.

Materially, most glass in this period is 'naturally' coloured, a range of pale greens to yellows, with a very small amount of bluish glass also present. The blue-green glass that had been the predominant glass of the earlier period has mostly disappeared. This is linked to larger patterns of glass manufacture. There is some stronger coloured glass (blues, dark green, yellowish brown or purple) but it mostly features as decorative trails or blobs. Very few whole vessels seem to be produced in strong colours.

The fourth century sees a marked shift in glass composition right across the Empire. The blue-green glass that was by and far and a way the most common glass of the Roman period was superseded by the introduction of 'the HIMT glasses' and Levantine 1. HIMT (high iron manganese titanium) glass was first identified by Freestone (1994) at Carthage. Since then its distribution has spread out, with various

related compositions (HIMT London (Freestone et al. 2005), Group 1 (Foy et al. 2001), HIMT 1 and 2 (Foster and Jackson 2009)).[10] These glasses all appear in the late-third to fourth century, and become one of the major glass group in Britain in this period.

As well as these glasses another type, Levantine 1, appeared in this period (Foster and Jackson 2009; Freestone et al. 2000; Jackson 1994). This glass, similar to the earlier Levantine glasses, is shown to be consistent with the primary glass tanks at Apollonia (Foy et al. 2001; Tal et al. 2004). However, while this glass is common throughout the Empire, it is fairly rare in Britain.

While variations of 'HIMT' glass cover a large proportion of fourth century glass in Britain, there are several intermediary glass compositions, likely related to recycling. In general, glass in this period shows a marked rise in iron, titanium, magnesium, as well as colourants in naturally-coloured glasses. However, this study will show that this glass in fact has specific geographical patterns.

3.1.4 Anglo-Saxon Period I Glass

For a long time it was assumed that for glass in the Early Medieval period, Britain had only a handful of shards from a handful of sites, and no vessel manufacture (Harden 1956, 1978). This was particularly seen as true for Anglo-Saxon Period II, the late sixth to seventh century. It was thought that many of the shards found in Britain were brought to the West as cullet, broken long before they ever entered Britain, intended to be remelted into beads and other small low-technology artefacts. However, the last fifty years work, particularly by Evison and more recently Campbell, has shown this not the case. Glass was widely distributed throughout the Early Medieval period, with the shards representing hundreds of vessels, with importation actually peaking

[10]During recent discussions at a joint conference between the *Association for the History of Glass* and UCL, *"Things that Travelled"*, it was evident that 'HIMT' was likely more than one glass type, variations such as HIT (High Iron Titanium glass), common across the Empire and likely numerous enough to posit a different, if related, manufacture.

in the later of the two periods discussed here, with many vessels being produced on the Continent (Campbell 1995, 2007). In terms of pottery trade parallels, in Period I the majority of the trade seems to be with the Mediterranean, and Period II, with the continent, probably western France, however this may not be true for glass.[11]

Early Anglo-Saxon glass has been separated into two periods, as defined by Vera Evison (2000, 47-50). The first of these runs from AD 400 - AD 550. This period is characterised, historically, by huge influxes of Germanic peoples and a significant change in glass usage. While it used to be seen likely that the glass of this period was disconnected to earlier production (Cool 1995, 15), increasingly work on both vessels and foodways argues instead for more continuity, especially in the South East (Cool 2006, 226). The move toward only using glass for tablewares, that began in the preceding century, continued and intensified. By the fifth century, drinking vessels appear to be the only glass vessels produced (Evison 2000, 47). It has been postulated that this is related to Germanic drinking rituals. The reason it begins earlier is linked to the movements of peoples into the Gallic and British provinces, known from many other sources. Evison comically points out, however that in some ways the vessels of Anglo-Saxon England can *'hardly be classified as tableware'* as they are either without flat bases, or with feet so small that they would be incredibly unstable when filled, completely unable to adorn a table. It is likely that the drinking was done standing, and related to similar traditions as Germanic drinking horns, which inspired some forms.

Whereas in the third and fourth century, the majority of glass has come from settlements rather than graves, the opposite has been seen to be true in the fifth to sixth century (Evison 2000, 47). There are several potential reasons. The historical argument is that glasses were strongly connected to individuals, thus were buried

[11]For evidence of this trade, and the shift between Period I and II, see Campbell (2007).

with them, rather than being discarded on sites. More pragmatically, there is also the fact that many more graveyards than settlements have been excavated for this period.

The assumption of poor shard numbers mostly comes from the excavations at Mucking and West Stow [Evison 1985; Evison 2000, 48], and has not been mirrored in recently excavated sites such as Lyminge, discussed in this thesis. However, the shards found at these sites, while in significant numbers, are often quite small. It is potentially the case that the glass at this stage is not so much rarer in circulation, but the total amount of glass is less, so it is more frequently recycled. As mentioned in reference to fourth century glass, this would cause a decrease in the number of shards residual in sites, and the size of those shards.

What is interesting to note is the fact that this rarity of shards in settlements is not true of sites in the Atlantic facade of Britain. Here, glass is still more commonly found in remaining settlement sites rather than burials (Campbell 1995, 36). More than 40 'celtic' sites have produced glass between Periods I and II. Both Cadbury Hill Congresbury (contemporaneous with Anglo-Saxon Period I) (Rahtz et al. 1992) and Whithorn (contemporaneous with Anglo-Saxon Period II) (Campbell 1995, 37) also show evidence of remelting on the sites and there is a considerably deal of evidence of that a more 'Roman-style' dining and drinking remained in the 'Celtic' areas of Britain. While a similar preference for beakers is seen, conical beakers account for 77% of the assemblage, they are occasionally accompanied by shallow bowls, a further 14%. These bowls have become uncommon in Anglo-Saxon sites (Campbell 1995, 36). The vessel glass here remains of high quality, pale yellow or green-yellow, very thin (0.1-0.5mm), with few impurities and over 60% are decorated with opaque white trails, marvered into the surface. The designs tend to be in a vertical chevron pattern, but not the feathered pattern seen in Anglo-Saxon vessels. Their manufacture does not seem to be the same as the Anglo-Saxon vessels, and they are thought to be

produced outside Britain, potentially Bordeaux. Analysis at Longbury Bank, Dyfed, showed the white trails are not antimony but tin oxide, which is generally consistent with the changing history of colourants (Henderson 1993, 45). Some blue vessels are also found on this site. The majority of glass contemporaneous with both Anglo-Saxon periods on Western sites is found down the Welsh coast, leading up into the Severn, and along the southern coast of Dumfries and Galloway. These sites seem to be looking to sea trade, rather than across into Anglo-Saxon England.

In Anglo-Saxon England, in Period I, there is a notable contraction of forms in use. The most common forms are hemispherical cups and conical beakers with cracked off rims (Cool 1995, Fig. 5.1-2). In the large late-fourth to fifth century dumps at York and Wroxeter, these forms clearly predominate, though there are still forms such as bowls with cracked off rims and indented bowls. In Anglo-Saxon Period I, unguent bottles finally disappear and the only closed forms that still occur are funnel-mouthed jugs (Cool 1995, Fig. 5.8-9), and possibly a conical form of Isings 123, and even those are exceptionally rare. Typologically Evison (2000) settled on 41 groups, divided between bowls, cone beakers, and more rarely, claw, bell and stemmed beakers. Some of these forms, particularly cone beakers of the Kempston type, are clearly English made.

As had started to occur in the fourth century, less techniques are used in manufacture. These glasses have cracked-off, unfinished rims, and the decorative elements left are self-coloured trails, left proud, or occasionally opaque white, which is sometimes marvered. These techniques are all done on hot vessels (Evison 2000, 49-50). This is consistent with the trend beginning in the previous century, cold working completely disappears, which potentially implies some connection or continuation of industry.

Very little of this Anglo-Saxon glass has been analysed. The exception of published work is a collection of 29 vessels in the British Museum, analysed by Freestone et al.

(2008a), 14 from Period I and 15 from Period II. Of the five approximate major known European and Mediterranean production groups of the period, the 'Period I' glass chemically only bears vague resemblance to HIMT, but the glasses analysed were close enough in spread to suggest that they may represent a single discrete compositional group, which Freestone called Anglo-Saxon Period I. This group is potentially a combination of the first century to fourth century glasses, but the trace elements do not imply this. It bears a close resemblance to Merovingian Vicq glass and analysis implies that both of these are using a fresh Southern Levantine or Egyptian glass, with a minimal level of recycling. This means that comparatively fresh glass is still reaching Britain. The discovery of raw glass at Lyminge (SF 697), which on visual examination shows a striking resemblance to a chunk of Levantine 1 from Apollonia is suggestive but will be discussed later.

As well as Freestone and Hughes work, there is an unpublished theses on glass from this period, by James Peake, 2013. It is focused on beads, rather than vessel glass. While it is an extensive study, it is physically restricted to East Anglia.

3.1.5 Anglo-Saxon Period II Glass

The next Anglo-Saxon Period, defined by Evison, runs from AD 550 - 700, and sees another change in glass vessels. At this period, we clearly start to have true Anglo-Saxon kings that are in direct trade with Frankia. However, this does not mean that the glass in Britain was necessary Frankish. Evision has identified 36 vessel groups of this period. Claw beakers, the standout of the previous century, fall out of fashion, and instead of conical beakers, and globular beakers are the most common forms. In Kent, likely at Faversham, there was a large British production of these vessels, and a Kentish manufacture is also suggested for pouch bottles. (With 13 finds, all save one, solidly in Kent, Evison even posits they are potentially the work of a particular blower based there). Bag beakers, too, have at least one Kentish variant. It seems that a

significant amount of the glass in this period was blown in Anglo-Saxon England, if not solely in Kent. There is even some evidence of British forms, on a very small scale, being exported to Europe.

At the Atlantic Facade, unlike in the previous century, there is clearly trade with Anglo-Saxon sites at this period. Some distinctly Anglo-Saxon vessels such as a blue squat jar, claw beakers and a palm cup have been found at Dinas Powys and sub-Roman Whithorn (Campbell 1995, 37). Due to their rarity, they are potentially diplomatic gifts or brought by individuals, rather than evidence of larger, market trade.

Despite these new connections, the only real technological improvement that occurs in this period in Anglo-Saxon sites is the flame-rounding of rims, often folded all the way over to leave a looped rim. Colours once again return, first a deep blue, but also a small amount of other colours, such as an emerald green. There are also several polychrome elements such as white trails with red or blue streaks, or yellow-brown swirled with green.

At the 'Celtic' levels of the Whithorn, Dumfries and Galloway, one sixth-century phase contains a large amount of glass. It is in large fragments, in context with large lumps of melted glass vessels. The vessels are a unique variant of cone beakers, with a higher level of impurities than in the other glass, a pale amber, occasionally dichroic pink. There is also a large quantity of apparent wasters too. It seems they made these vessels here.

In term of composition, this period is again is lacking in published values. However, the Freestone et al. (2008a) study showed that once again the deep blue is being produced by cobalt with high lead, which is consistent with Roman blue glass. Freestone posits this is potentially derived from cullet. In terms of base glass for the rest, there are two or three distinct compositional groups. The largest group is very like Anglo-Saxon Period I of the previous century but with the addition of a small

proportion of plant ash. This is potentially added as a plant glass 'glass extender', rather than as a blowable glass, which would imply that glass sourcing is potentially problematic. This is also supported by the fact that the rest of the glass is a Levantine glass with significant enrichment in Co, Cu and Zn. These enrichments imply it is likely at least partly recycled.

What existing compositional studies seem to imply is that the times when glass is in stress in Britain is not so much at 410, but it rather occurs both in the fourth century, then again in the mid-sixth. By contrast, the fifth century seems to have some access to either fresh glass or vessels made from it. However, this has not been considered together, but rather as individual sites, points of illumination, with this thesis connects to understand the 'flow' of glass across time.

3.2 Recycling During and After Roman Britain

As well as the usual patterns of glass trade, the patterns of recycling are vital, as has been touched on above. Many Roman artefacts are reused or recycled, either for their value as material or for apotropaic uses, both throughout the Roman period and beyond. This recycling is far more complex than is often discussed, as will become apparent in Chapter 4.1. It is a function of more than just availability or cost. Explored by Swift (2012, 202) in reference to Late Roman and early Medieval bracelets, "In each case, the decision to maintain, discard, deposit or transform the object would be made in relation to the perceived value and meaning of that particular object at that specific time". Swift notes that while there is seemingly an intensification of recycling in the late Roman period, recycling was always a part of the Roman supply (Swift 2012, 190).

Separating out the recycling which was part of the large-scale Roman economy from what happened afterwards is crucial. While parallels with Samian ware are

often chosen for discussing glass, perhaps a better comparison is metal. Mining and metallurgy were massive drivers of the Roman economy, as well as large-scale trade. Both in sourcing and manufacturing, metal has more in common with glass. However, unlike iron, which Britain produced around 2,250 tons (Davies 1936), glass was not produced in notable quantities here.

The story of recycling metal in the Roman economy is better understood than glass, or metal in other periods (Pollard et al. 2015). By the fourth century, there is a clear increase in systematic scavenging, stockpiling and reworking of both iron and bronze (Fleming 2012, 130-134). This is consistent with the assumption of what is happening with glass, however Britain would still have better access to some natural sources of ores.

As well as the complication of recycling for pure material values, there is also the complication that Roman material is common in Anglo-Saxon graves and contexts, such as Samian Ware and clipped coins (Caple 2010; Cool 2000). 25% of Anglo-Saxon graves are also in association with earlier graves, such as Bronze Age barrows (Caple 2010, 306). Much of this Roman material is used to perpetuate a concept of the Roman past, but often in a different, talismanic way. Even artefacts from the Iron Age are found in Roman contexts so it is perhaps not surprising to see this continuing. Swift (2012, 198) argues that much of this material is probably rediscovered, rather than simply curated.

Understanding this recycling requires not just a way to archaeometrically track it (Chapter 2), but also a better understanding of what we mean by recycling (Chapter 4.1).

3.3 Does Britain Fall?

Roman Britain, like all Roman provinces, is not wholly 'Roman' in character. In each region, province, *civitas* or single farmstead, being Roman meant something slightly different. The occupation brought huge changes, but rather than bringing what was traditionally thought of as the social, economic and political package of 'Romanization', the common view now is that the ethnically-diverse flood of new people and ideas *built* a *new* culture; taking, discarding and creating from multiple indigenous and introduced traditions. As such, this Romano-British culture was not what one would term 'Roman' in Gaul, Syria or indeed Rome itself, but was specific to the period of occupation in Britain. Roman life and culture was created *with* the Empire, meaning completely different things wherever it was found (Woolf 1997, 1998).[12] This was not, especially by 410, necessarily an imposed culture, which also means that the removal of armies and Roman structure does not necessarily mean the end of Romano-British culture. Perhaps one of the best materials to discuss this through is glass.

Prior to Roman invasion, in AD 43, approximately 23 major, independent and highly regional tribes existed in the comparatively small island of Great Britain (Salway 2001, 254). Some already had a great deal of interaction with Rome, and others, essentially none. For those who did interact, this ranged from near client kingdom status (Creighton 2006, 14-34), to extreme resistance. Roman vessel glass is a rare but present material in Late Iron Age Britain, popular within Gallia Belgica as well. This glass is chemically and technological distinct from the pre-existing native industry (Henderson 1991b, 122-125).

[12]Such theories of the nature of 'Roman' and *'Romanitas'* in Britain are not uniformly accepted but this theory is the most consistent with what is observed. Beginning with the works of Haverfield (1912), the terms *"Briton and Roman were not mutually exclusive terms"*(Rivet 1964, 29) Millet (1990), followed by others (Mattingly and Alcock 1997; Webster and Cooper 1996), argue for a fusion of native and Roman. Others, such as Barrett (1997) emphasises that a 'creolisation', that is not uniform but varied. Others, such as Creighton (2006, 12-13) not that by the point of conquest these were not binaries. For the most part, this thesis follows Woolf and Creighton's interpretation.

The 'conquest' itself was long, often politically complex, with explosions of violence of varying degrees at different places and times. Despite interest stemming from successes in Gaul, and Britain's advantages, especially tin, formal annexation of Britain, only beginning in the reign of Caligula, took hold under his successor, Claudius. Caesar's early ventures were short-lived- remaining influence maintained not by Roman establishment but by kingly friendships. As stated, for some areas of Britain the 'conquest' was an extension of existing relationships, for others, a brief bloody clash. Uprisings remained fairly constant in Britain throughout the Roman period and the northern frontier always proved problematic, as can still be seen by the remains of Hadrian's and the Antonine Walls. Throughout Rome's occupation, this Northern region always remained comparatively militarised, although this does not mean trade of seemingly deeply Roman goods, specifically of glass, did not go beyond its borders.[13] Before 43 AD, a great many Britons were 'Roman' in style and this only intensified.

While I am using both the terms borders and frontiers, the nature of the 'edges' of Roman Britain are far from simple. While this was, for many periods, a military frontier, evidence seems to indicate that is was rather a boundary, an extent of clear administrative control. As these military centres spawned veteran settlement, the nature of these settled areas changed (Feuer 2016, 95-100). These zones are unique, and change again as pressures of resources pull at the edges of the Empire (Whittaker 1983, Chapter 5-6).

Even during the height of Roman Britain, discussing the Province as a uniform, single entity is problematic. Despite the small landmass of this island, four (or potentially five) provinces split up Britain during its Roman period (Mattingly 2008, 228). Regionality can be seen in everything from brooches (Eckardt 2005) to buildings

[13]Roman period glass has been found at Traprain Law (i.e. National Museums Scotland X.GV 534) and other sites, near the Water of Leith. The work of Mary Davis of the Museum of Wales [pers. comm.], Dominique Ingemark (2014) and Birgitta Hoffmann (Hoffmann and Woolliscroft 2017) has brought significantly more glass to light than was previously known.

(Burnham and Wacher 1990; Perring 2002).

The importance of understanding the regional diversity of artefacts, markets and manufacture in Roman Britain is paramount in discussions of recycling and repurposing, as these directly affect artefact production, use, trade and value. While in some places the assumption of 'Roman' artefacts can be seen as comparatively straightforward, an extension of existing markets, in other places it can also be exceedingly complex. It is a balance of availability, cost, as well as cultural markets and personal choice, and recycling is a feature of all of these. This is also not uniform across time; one only needs to consider the shift of distribution of glass, from an Iron Age high-status burial good to everyday storage and tableware, to a common Late Roman burial goods, found at sites of occupation. This is a pattern which is driven by a large number of social, economic and technological factors.

Throughout the Empire, both the assumption and the eventual relinquishing of a 'Roman' culture is a *"process in which new cultural items are obtained by means of attributing new functions to previously existing ones"*, rather than simply an adoption of 'Roman' material culture in a 'Roman' way (Terrenato 1998, 23). In fact, people may not even see their adoption as Roman (Gosden 2005, 198).[14] This ambiguity of 'Roman' is just as relevant, if not more so, for the end of Roman Britain as the start.

While the date for the start of Roman Britain can be fixed, if somewhat naively, with the year a conquering force successfully took any hold in Britain, AD 43, the 'end' is more problematic, particularly culturally. It runs the gamut from essentially a constant culture until the establishment of christianised Anglo-Saxon kingdoms in the eighth century, to an instant collapse of life as it was known in AD 410. There are three events usually indicated as turning points in traditional historical literature: Honorius' refusal to assist, the Battle of Badon Hill, and Mercian Supremacy. The

[14]One can see similar parallels in the English assumption of particularly food goods as its own empire expanded, these stuffs moving from exotica to the mundane.

justification of each will be briefly summarised, to show the complexity of defining the fall of Roman Britain.

Britain was never a particularly easy member of the Roman Empire. The first century of Roman rule was marked by several notable revolts of native tribes. After this, the fluctuation in Rome's influence, particularly the effectiveness of the current Emperor, led to several attempts of secession, usually led by Roman military commanders who had been stationed in Britain.

The term post-Roman is often applied to any date after the removal of Roman troops to Gaul by Constantine III (AD 407), and then the refusal of imperial aid by Emperor Honorius (AD 410). In 383, a Roman General stationed in Britain, Magnus Maximus, usurped control and proclaimed himself emperor, leading the remaining British forces in an unsuccessful attempt to annex Gaul. This was not the first time this had occurred. After this was quelled, it was decided that maintaining an army in Britain was too costly and dangerous, but instead, a force would be available whenever Britain called. However, with what is believed to be increasing incursions from beyond the Empire at many frontiers, landings of a huge number of different peoples on Britain's shores and increasing piracy in the Channel, these calls became too frequent and other demands on Rome more pressing. And so, in AD 410, the Emperor Honorius refused one of these calls to send troops, essentially allowing Britain to slip out of the Empire's control. It should be immediately apparent that the assumption a single letter, even from the Emperor, caused immediate extreme changes to anyone living in Britain is problematic.

The traditional end of this Romano-British 'culture' is then the Battle of Badon Hill, which is recorded in a mass of semi-mythical, semi-historical accounts, but seems to have likely occurred prior to 455 AD.[15] However, Gildas, a British cleric living in the

[15]And without a King Arthur who struck down 960 men in a single day, which is one of the highlights in our major source [*Historia Brittonum*, IV.56], which was written some four-hundred years after the fact and heavily relies on the work of Gildas.

early sixth century, still records, in Latin, a life not dissimilar to that of the second to third century Romano-British peoples [*De Excidio et Conquestu Britanniae*]. Despite the fact that he is 'lamenting' what he saw, somewhat inaccurately, as having been lost, he is clearly speaking to an audience whose *Roman*-style education equipped them to understand his heavily classically influenced work of metaphor and prose (Higham 1994, 10).

The final point of transformation is Mercian Supremacy, which does not have an agreed date, but falls between the late-seventh and eighth centuries. The Anglo-Saxon Kingdom of Mercia, by AD 800, dominated over most of what had been Roman Britain, and the Kingdom of Northumbria essentially covered the rest. The fledgling kingdoms of the seventh century were at this point properly established, and 'Christianisation', at least at the upper levels of society, seems complete. It is at this point we can clearly point to an Anglo-Saxon England, with all of the trappings expected of the period. However, even here we see, in laws and accounts, a people referred to as Britons (ie. Ine's *wealh*)(Grimmer 2002, 5). While England is Anglo-Saxon, there is still a notable 'indigenous' ethnic group.

As should be clear, there is a reason for imbuing each of these dates with significance, but in reality it depends on what we see the 'fall' of Roman Britain to mean; political, social, cultural, industrial, population? Archaeologically, none of these are clear or definitive. Many of the changes began before AD 410 and continued to change long after. There are, for the most part, two major theories of life in Britain between AD 400-600, before one can really refer to an Anglo-Saxon England. Either that essentially life continued in much the same way it always had, or civilisation, as the Romans saw it, collapsed.

The first is supported by Dark and Dark (1997a), Cool (2000), Myres (1986), Hărke (2003) and others. These authors suggest that, while the grand-scale political

and economic organisation between towns and cities collapsed without imperial monitoring, industries remain somewhat profitable, becoming more localised and regional in both output and design. On a political level, very local power structures remain as do Romano-British tyrants, assuming the reins of power that the Empire had left. Change is slow and identity is fairly 'stable'.

The other view is that the collapse of Roman administration and withdrawal of the military hierarchy caused a fundamental identity crisis and change. The 'invisible majority', who had never been as 'Romanized' as the elite, experienced an ideological collapse which fundamentally changed their existence (Esmonde Cleary 2000, 92). Essentially the elite disappeared and the majority did their best to return to their Iron Age ways, modified by the brutal swathes of Germanic peoples, as cataclysmic change occurred on a larger scale.

Esmonde Cleary, among others (Loseby and Ripoll 2000; Reece 1980; Ward-Perkins 2005), argues for this immediate collapse. Esmonde Cleary believes that the persisting Roman material culture, into the fifth century, was 'terminally residual'. Nothing new was being created in anything like a Roman style as those left behind eschewed this externally motivated way of life. The material that once expressed and reinforced the elite was now active in forming a new culture, rejecting the social organisation that made it, but new 'Roman' forms ceased. Many of these authors rely very heavily on pottery for this narrative.

Considering this in the sense of glass, it is clear that whatever the political or social identification of their creators, glass of this period did not suddenly return to an Iron Age process. The continued common use of vessel glass, a distinctly Roman material, and the longevity of forms, argue against a real return to pre-Roman sensibilities. While glass is present in Iron Age Britain, it is chemically distinct and does not extend to blown forms.

Centuries of being part of the Empire had altered peoples life-ways such that even

if they strove to return to a 'pre-Roman' way of life, it is very likely that they had no more real idea of what that was than Gildas did of Britain's apparently golden Roman period. How quickly the people and their life altered again depends on both the society at the time, what they still had access to, and what came in to replace it. For the Britons, the main incoming was Germanic peoples, who had started to migrate in large numbers during the Roman period (Jones 1998, 1-4).

Much of the argument about when and how Britain stopped being Roman actually comes back to the first and most problematic comment about Britain, something that one could argue is still crucial to modern British cultural construction - it is a strongly regionally place.[16] Often seen as the biggest division is one that has long been highlighted as a metaphorical divide in England, the central Jurassic Ridge. For the Roman period, this is often summarised as the divide of the Fosse way, the 'civilian' South and the 'militarised' North.

The North was heavily occupied, with a periodically active frontier border, the division between 'Celtic' and 'Roman' seen as more overt and confrontational. This is not to say that all life in the North was not fundamentally altered in a Romano-British way. In the South, particularly the South East,[17] the tensions during the Roman period seem to have been more politicised, played out in very Roman ways. Life in the Romano-British cities was analogous with other provincial centres. However, Roman objects could have many uses, and many meanings, relative to time, place and perception of the users (Gosden 2005, 208-209).

Despite this tempting split of Roman Britain into the calm southern land, which was as Roman as Gaul, and the militarised North, a fiercely barbarian frontier, this is grossly simplified. Not only does it remove the very important temporal component from this discussion, but also ignores the fact that the Roman elements that made

[16]The regionality of Roman and Early Medieval Britain has proven crucial in discussion of architecture, religion, pottery and small finds, e.g. (Eckardt 2005).

[17]Cornwall remained, for one reason or another, resistant to the waves of Roman influence or invasion.

Calleva Atrebatum (Silchester) a Romano-British city, were not identical to those which made *Londinum* (London), or even *Eboracum* (York), one. As stated, even in the North, Roman influence is rife, with villas appearing by AD 200 as far North as the Tees (Quarry Farm, Ingle Barwick (Willis and Carne 2013)) and some are still under expansion in the fourth century, a period of waning Roman control. In terms of this thesis, there is a clear difference between the forms of glass across Britain in the Roman period but vessel and other glass is omnipresent.

The 'fall' of Roman Britain becomes markedly more complex when we begin to consider regionality. If there was notable variation between these cities, and the same people remained, even with the large influxes of migrants in this transition period, changes must take time and are varied. As Dark and Dark (1997a, 136) point out, at AD 500, only one of the five British provinces, Flavia Caesariensis, was Anglo-Saxon. It took a further two centuries for this to be 'complete', yet even these Early Medieval Kingdoms are not exclusively disconnected from the Roman Britain of the preceding centuries.[18]

All of this large scale history has incredible potential to affect artefacts, particularly glass. Both the market for the glass and the ability to actually source it is related to the connection to the world outside Britain. Where the desire for material remains but sourcing becomes difficult, this drives us to a crisis.

As has been eluded to, the political dislocation does not mean that Romano-British culture, particularly material culture, suddenly ended, but it does immediately introduce at least logistical problems. This is a particular problem with glass, whether raw or artefacts, which was a product of distance trade. Trade problems started early in Britain, in fact while still under Roman control. Ammanius Macellenius, writing in 367 AD, records the increasing levels of piracy and problems of trade across the

[18]A prime example is the kingdom of the Hwicce, the name of which is thought to derive from Britonnic term (Coates 2013, 1).

Channel,[19] meaning glass originally coming from the Eastern Mediterranean would be harder to source.

The evidence from many post-Roman, or Early Medieval, sites in Britain show that people did not start being 'non-Roman' as soon as the Emperor turned his back, nor did they suddenly abandon their belongings. More importantly for this discussion, they do not seem to have abandoned their desire for certain objects and materials, whether or not they viewed them as Roman. For instance, the site of Tubney Woods, had been assumed as Late Roman on a typological and stylistic basis, but absolute dating has given a date in the fifth to sixth centuries. As was discussed in the start of this chapter, desire for glass continued for the most part following patterns that begun in the centuries before.

Turning to broad geography, in the North it is true that the withdrawal of troops probably caused greater social disruption, many of the Roman settlements there being military. However, in the South, the end of direct Roman control seems as if it should be more viewed as a quiet petering out, with social organisation and individuals maintaining some level of both control and continental connection. Many sites, including both Dorchester-on-Thames and Lyminge, show at least some level of continuity between Roman and the early Anglo-Saxons. Particularly interesting is the case of the female burials at Dorchester-on-Thames, which retain a Roman-style burial, despite the associated males having Saxon burials (Booth et al. 2012; Dark and Dark 1997a). However, even in the North, it was not the end of the people, nor the things they used in their daily lives. While Esmonde Cleary argues that the Roman artefacts found here were used in a deliberately counter-culture way, one has to wonder how 'Roman' some of these things really were perceived after centuries of occupation.

[19]Though a Syrian, writing in Latin, he was concerned with Britain's trade with the Empire. He wrote extensively about Britain in his *Res Geste* [Books XVIII, XX, XXVI, XXVII, XXVIII]. He sees these trade problems as part of a a wider conspiracy, and idea now discarded.

Roman-style glass, particularly drinking ware, is a perfect example of this - once seen as the height of *Roman* fashion, by the third century, its ubiquity suggests it is merely the standard drinking ware. In fact, the prevalence of glass for drinking rather than storage-ware might more rightly be seen as a Germanic rather than Roman influence (Price 2000b, 1). Glass is mass produced and common by the fourth century and its use clearly persists into this period.[20] It seems this drinking culture, requiring extensive glassware, remained right through.

There were, of course, significant changes in Britain too, as well as the influx of people, such as an increase in agricultural production on the fringes of and inside cities. While this indicates a more subsistence lifestyle, Roman food supply was complex and relied heavily on national and international trade (Cool 2006, Chapter 16), and this could be adjustment, a sign of robusticity rather than collapse. Surplus was no longer as great or traded as far.

Similarly, as will be discussed in Chapter 4.1, recycling can be seen as an adaptive technique rather than, as is always suggested for the fourth and fifth centuries, scavenging.

This potential break down of long-range trade becomes crucial in the story of glass, and similarly changing compositions of glass in Britain might help understand trade in this period. Unlike pottery, agriculture, and even metalwork, the raw ingredients and technology required for primary glass production in this period were incredibly restricted. If we expect to find this same 'robusticity' in glass, it will be displayed differently, and probably related to recycling processes.

While there are several examples and possible examples of secondary production

[20]Diocletian's *Edictum De Pretiis Rerum Venalium* lists several types of glass, both in pounds of glass (Alexandrian, 24 denarii; Judaean greenish, 13 denarii) and vessels (Alexandrian, 30 denarii; Judaean, 20 denarii) and then two qualities of window glass (best, 8 denarii; second, 6 denarii). It has been posited that this 'second' quality might refer to recycled glass [Freestone, *pers. comm.*]. A Roman pound is 328.9g, and an average vessel 20-40g, meaning that for 30 denarii one could purchase 10 vessels. Considering that the wage Diocletian gives his lowest wageworkers (labourers, muleteer and sewer cleaner) as 25 denarii, glass is clearly very affordable (Whitehouse 2004).

in Britain,[21] raw glass production does not seem to occur here in the Roman period.[22] Fresh glass required Mediterranean and continental trade which was now exceedingly costly, problematic and dangerous.

In summary, Primary Roman glass is, at least predominately, manufactured in the Near East (Freestone 2001). It is thought to come through mainland Europe to Britain, and these political events clearly constrict possible trade. As well as this, there tends to be the assumption that this caused production of vessels to become more regional, as seen in other matter, such as ceramic. In terms of raw glass, this means that one of four things must happen, summed up by Hilary Cool.

- Glass must disappear.
- Be sourced from new, closer locations (preferably British).
- The existing glass must be reused or recycled.
- A combination of these.

To understand which of these occurs, both the place of glass in Britain from the Conquest to Anglo-Saxon Britain we must consider, and the movement of glass within Britain. The first can be done with traditional archaeology, but increasingly the second draws on scientific analysis, integrated with this archaeological understanding.

[21]Secondary workshops, or potential workshops, are found all over Britain, for a brief list: London, Camelon, York, Caelron, Carlisle, Wilderspool, Wroxeter, Wall, Leicester, Castor, Worcester, Mancetter, Colchester, Verulaminum, Silchester.

[22]There are some Tank Furnaces in Britain, such as the one at Caistor by Norwich, 1.33 by 0.36 m (Price and Cool 1991, 24), but evidence elsewhere implies such could be used to melt cullet or chunks of raw glass, rather than fresh glass productions.

Chapter 4

Defining and Refining Recycling

4.1 Recycling and *Object Biographies*

Fifty years ago, archaeologists began to consider artefacts as much more than static indicators of production, but rather as integral parts of a cultural system. Works such as Binford and Binford (1968) and Binford (1983) pushed our understanding of the material world. While much of Binford's work was controversial and heavily debated, he was instrumental in bringing this sort of theoretical approach into archaeology, creating a whole generation of archaeologists and material anthropologists, both supporters and dissenters, who spawned many new approaches. The concept of *materiality* and particularly 'Object Biographies' is one such theoretical approach born from this. With a long history beginning with Kopytoff (1986), the potential of object biographies took many years to come to the fore. Materiality was heavily influenced by arguments in philosophy and anthropology (eg. Hegel 1977, Bourdieu 1972, Appadurai 1986 and Gell 1998) and arguably popularised in archaeology by a dedicated issue of *World Archaeology*, particularly an article by Gosden and Marshall (1999). Many of these authors were inspired by the work of Clarke (1968) and saw the 'social power of objects'; Objects are not only an integral part of human action, but

they are shaped by the actions they participate in, the objects themselves changing, and in turn have their own biography (Gosden and Marshall 1999). Although some change is gradual, with definitions shifting over time, there are also sharp moments of transformation, both for people and their material cultures. As Joy (2009, 543) argues, moments of transformation are deeply illustrative, and for artefacts, recycling is a key moment of change.

Only a handful of authors have seriously considered recycling as a part of an object's history. The first of these was Schiffer (1972). Heavily influenced by Binford, Schiffer was concerned about how simplified archaeologists' conceptions of deposition and end of 'use-life' were. He expanded upon earlier life-cycles of artefacts which considered 'production' as a series of linear steps away from raw material extraction/-collection, and towards artefact destruction and/or deposition (ie. Taylor 1948), his work particularly highlighted the concept of 'reuse'. Schiffer, surprisingly ahead of his time, comments that the reuse of an artefact is not necessarily something that can be dealt with simply, as it can mean a complex set of differing behaviours. He even went so far as to separately define 'recycling' from 'lateral cycling', the latter being used to refer to any assumption of a new 'use-life' with only basic maintenance, storage or transport intervening, rather than a true 'reforming' event. In his two definitions, a 'recycling' process requires the artefact to either undergo another manufacturing or preparation step. Although lateral cycling is noted as potentially very problematic for archaeologists as it can be extremely difficult to identify, understanding it is crucial both in understanding the formation of the archaeological record and the biography of the object. As he puts it rather succinctly, *"Differential refuse disposal patterns* [sic] *affect artefact location and association"* (Schiffer 1972, 156).

After this, reuse and recycling was rarely given any focussed attention, despite the contribution of such behaviours to the archaeological record being well acknowledged. However, in the past ten years reuse/recycling is increasingly drawing attention [Caple

2010; Swift 2012].

Certain elements are particularly vital in understanding recycling/reuse. Change can be ideological or physical; an artefact can be reused in its original or a modified form, or even as a raw material. The past of the object can decrease or increase the value of an artefact, caused by a multitude of factors such as previous owners, changing commodity values and even simply age. Swift (2012, 205) highlights time as central to understanding recycling. Indeed, whether we see an article as simply undergoing a secondary trade or being 'reclaimed', with new or additional social meanings, is often seen as a function of time. Age does not necessarily mean an object carries less value in its cultural world, in fact there are many cases that are the opposite. As Gosden and Marshall (1999, 171) note, one only has to think of our own obsession with patinas on antique furniture as a mark of value. The very fact that an object was once something else, or merely owned by someone else, can increase its value markedly (Swift 2012, 193), even if that previous life is mythological such as natural tors venerated as tombs (Bradley 1998). The earliest reuse in this sense seems to be Neolithic megaliths. There is reuse seen across this period, such as is seen a Locmariaquer in Brittany. A decorated menhir, after being split, formed the roof of two seemingly unrelated chamber tombs (Bradley 2002, 36-37).

These 'ancestor artefacts' can carry with them further weight as the product of an earlier, sometimes idealised world. This perceived, sometimes deliberately manufactured, continuity within societies can be seen in many periods across Britain. For example, 25% of Late Anglo-Saxon graves in England are in clear association with Roman graves (Caple 2010, 307). More bizarrely, they are commonly linked to even earlier structures, such as megaliths (Williams 1997).

As Swift (2012, 202) notes, relative to personal objects, *"In each case, the decision to maintain, discard, deposit or transform the object would be made in relation to the*

perceived value and meaning of that particular object at that specific time." As such, the decision to recycle can be less ideologically charged, the value being a matter of production and material consideration. For instance, the specialised uses of recycled copper alloys in post-Roman Britain is usually attributed to an increasing scarcity and a lack of knowledge of manufacture (Swift 2012, 191-192). They recycle old material as a source, implying it is more difficult or impossible to locate it otherwise. One can not, though, discount the potential ideological significance in even this sort of recycling, as Caple (2010, 310-315) notes relative to fifth to seventh century Saxon brooches.

The recycling of glass in the periods being discussed here seems to cover both highly ideologically charged reuse, as well as simple practical sourcing, and everything on a continuum in between. As such it is worth considering what we really mean by 'recycling' and related terms, especially in this current work.

4.2 Defining Recycling

One of the first problems that arises when trying to disentangle the complications of 'recycling' in archaeometry is that term itself is vague. As has briefly been mentioned, it does not refer to one behaviour, but a myriad of them, driven by social factors as frequently as economic ones. As recycling is beginning to come to the forefront of archaeometry for both studies of metal (Bray and Pollard 2012; Swift 2012) and glass (Foster and Jackson 2010; Freestone 2005; Ganio et al. 2012), it becomes increasingly more important for authors to be specific about forms of reuse.

'Recycling' of glass and metal can be split into three very broad categories: Re-use, repair and remelting. The first encompasses no physical changes beyond minor maintenance or decoration, and would result from a change of purpose, place, owner or cultural significance. The next, repair, sees minor physical alterations, either so

the object can continue in its previous function or assume a new one. This repair can apply to the object as a whole, or small parts of it. The final form, remelting, encompasses what most people consider to be 'recycling', and requires the object(s) to return to a liquid phase. Obviously, only materials such as metal, glass and plastics, which can return to a near preformed state, can be remelted. This can occur either with the loss or addition of material. These categories are, at minimum, the level of description needed when discussing recycling, in any context.

For this particular study, however, the forms of glass recycling must be discussed with a little more care. For this reason, nine categories have been created to discuss ancient glass recycling, though only minor alterations are required to consider metal in a similar schematic. Under reuse, there is finishing and reclamation. The former was included because of the potential time delay between original production and finishing techniques, as well as the potential chemical changes this causes. Repair includes reassembly, reworking and finally remelting covers reforming, consolidation, division, cullet and incorporation. These are all physical forms of recycling but there is of course also the recycling of stylistic forms or ideas, renaissance, but that will not be addressed here. Each of these can be summarised by what physical and/or chemical changes can be seen, represented in Table 11, but each type requires separate appreciation. While these categories might seem overly specific, this allows us to look more closely for predictable chemical changes across different recycling types.

4.2.1 Reuse

Finishing *Use of secondary physical or chemical processes after the main production of an artefact.*

Finishing, though less common in glass than metal, is relevant to recycling due to the changes it can potentially cause in the material and the fact that an artefact

can be finished more than once, reviving it for further use. This can either be for the same or a different function or owner. Finishing, as opposed to the simple mould-casting or blowing of glass, has long been known to cause significant change within the materials structure. As well as the purely physical change that finishing causes, the aesthetic changes are such that finishing can greatly alter the significance of the artefact within a social sphere. What is also particularly relevant is that there can be a great disconnect between the formation of the object and further work, which can be as little as engraving inscriptions on a long existing piece (Caple 2010, 305).

The most basic type of finishing on glass, which occurs on almost all glass, is annealing, without which glass is prone to breaking under thermal or mechanical shock. Decorative finishing on glass is traditionally done by a range of lapidary techniques and enamelling, both of which alter the style and sociocultural significance of an artefact (O'Hea 2011). Grinding and abrading create design by removal, whereas enamelling adds additional powdered glass to the vessel, which is then heated and fuzed to the surface of the vessel. Both of these techniques alter the internal structures of the glass.

The lattice structure of glass is very susceptible to temperature changes, and abrading and drilling creates pinpoints of intense heat. In the original production, slow cooling of glass, annealing, is paramount to the long-term survival of a glass under even minor pressure or temperature changes. It allows a more stable structure, with fewer stress points. As lapidary work causes points of heat, changing the internal stresses within the glass, it potentially increases the fragility of the glass. It is also a difficult task to perform, as glass fractures both easily and conchoidally, so it is easy to remove far more glass than intended. Such work is extremely skilled and time-consuming and increases labour, if not the final value of the artefact. Cold-working glass is likely to cause inadvertent chips, as seen on a kohl pot in the British Museum (EA24391), where the rim is obscured with with gold sheet to hide this. A shard from

Dorchester-on-Thames which was being shaped into what appears to be an intaglio was also similarly chipped in production, then discarded.

Pilosi and Wypyski (2002) have shown that the degree of cold-working performed has potential to be assessed through the studying of weathering patterns. Sometimes there are large areas of the surface that be been abraded, which is evidenced by the 'velvet finish' of sculpture, rather than the shine of unfinished or polished glass.

Cold-worked glasses are particularly well known from Egypt, such as the aforementioned kohl pot. Always associated with luxury objects, cold worked glass containers are used for unguents and perfumes, and this material was even used for a funeral headrest found in the tomb of Tutankhamen (Nicholson 2011). Enamelling on the other hand, is common on Byzantine glass, but is certainly not unheard of on Roman glass, even found in Britain. Similarly to cut glass, this seems more common on high quality glass vessels, such as a shard from Catterick, enamelled with the figure of Bacchus (Price and Cottam 1998, Plate 2.6).

Reclamation *The use of an artefact for their intended or new uses, socially and/or temporally removed from the original production*

This is exceptionally common in glass, and a good number of high status ancient glass vessels that were reclaimed have in fact remained above ground as a part of church or aristocratic collections. Two very obvious examples of this are the Lycurgus cup (1958,1202.1) and the Portland vase (1945,0927.1), both now in the British Museum's collections. Western glass produced from second-half of the first millennium was made with plant ash, so called 'forest glass', high in potassium and magnesium, leading to a lower quality glass whose colour it was difficult to alter. As such, it is often thought that reclaimed glass would have been seen as a status symbol, which certainly is true of the two exceptional examples given. The Portland vase was first recorded in 1601, in a collection belong to Cardinal del Monte in Italy, from whence

it passed to a noble medieval Italian family, the Barberini (Walker 2004).

This high value of reclaimed Roman glass also seems true in Early Medieval period in Britain. These pieces, often just shards, more often than not seem to be not curated, but rediscovered and repurposed, with a knowledge that they are the product of 'ancestors', despite the artefacts belonging to a Romano-British tradition that was not actually the cultural or ethnic predecessor of most Anglo-Saxon society (Swift 2012, 198). They are often seen used in a more talismanic way, rather than as the original purposes, particularly beads (Swift 2012, 202). This is interesting when there is also much evidence of such material being remelted in this same period.

At Orpington, where there was a gap between the end of Roman and beginning of Anglo-Saxon occupation, the later period burials contain a huge amount of earlier Roman materials, some clearly traded or sourced from other areas, rather than simply scavenged (Swift 2012, 199). Grave 2 contained an early to mid-fifth-century continental Roman glass bracelet, while the rest of the assemblage suggests a *terminus post quem* in the second-half of the fifth century.

As well as the sort of reclamation that has a clear heritage aspect, there is also another form that can be viewed perhaps more practically. The heritage of the object seems less important than its usefulness as much as such can be judged from archaeological records. For instance, drinking vessels with rim damage are sometimes repurposed as hanging lamps, such as the examples seen at Camulodunum (Harden 1947). Domestic bottles and jars also often end up in a variety of non-standard depositions. One particular example is their reuse in the late-first to early-second century in the North Western provinces as cinerary urns, many examples of which were discovered during the nineteenth century excavations at Poitou, France (Simon-Hiernard et al. 2000).

While reclamation does not change the chemical composition of an artefact, it can still be highlighted by archaeometry. Glass compositions in the ancient world have

distinct spatial-temporal relationships. As such, an object with a composition that is notably varied from those in which it is found in association with might be the result of a different, earlier production, reclaimed. While this is often apparent through typology, glass is notoriously fragile and sometimes all that remains is shards. In such cases, archaeometry can contribute.

4.2.2 Repair

Reassembly *The repairing of an object, to its original form, with or without the addition of further material.*

While not hugely common in glass, as reassembling glass vessels to their original functionality is problematic, the creation of vessels by reassembly is not impossible. In fact, it is common in one particular area of glass, medieval windows. Sometimes by the remelting of the pieces to reform broken windows, which in this schematic comes under 'reforming', but also by 'patching' the glass back together with mortar or metal, sometimes retaining the original pattern, other times not. A great many cathedrals have such reassembled glass. As well as the repair with existing glass, sometimes new glass is added.

Vessels can also be reassembled, clamped together with metal, like pottery, but this is rare. It severely limits functionality in vessels.

One rather strange potential example of reassembly is the cut-down cast-glass bowls of Egypt, one example being the 'Amman Citadel bowl (O'Hea 2011). These bowls are constructed of plaques of different colours, from bowls of the same size, re-assembled into the form with brass. Ideologically, it is interesting to consider whether or not these bowls were made to be broken down, or were a clever use of broken glass within a production centre. Unfortunately, there is no evidence within the archaological record one way or the other. Either way, it shows the reforming of a like object into the same form.

Once again, this is unlikely to change the composition, except for the possibility of leaching from any mortars used for repair. Reassembly of glass is usually immediately apparent as it requires the addition of other materials, metals, mortar etc, to bind the pieces together.

Reworking *The reuse of an object, creating a new form, with or without the loss or addition of further material.*

Reworking is not uncommon in glass, driven by cost, availability, social significance or a combination of these factors. An example that can be used for all three is *emblemata*, the decorative plates in mosaics. The earliest Roman wall mosaics were made out of shell, but then quickly a preference developed for bright colours in private homes. When coloured pieces first appear in mosaics, they are not *tesserae*, deliberately made glass tiles, but pieces clipped from broken glass vessels, as is clear from their shape. Examples of this can be seen in mosaics from Casa del Torello and Casa dello Scheletro, Italy (Stern 1977). Old glass could also be included in other decorative forms that required panels, such as decorative windows seen at the Petra church, Jordan (Schibille et al. 2008, 638).

As well as this, some reworking is as simple as the addition of extra elements. Some of the drinking vessels made into lamps mentioned as examples of reclamation are rather reworked, with lips or handles added allowing them to hang more easily. This is normally highlighted by form.

The creation of amulets from shards of vessel glass is also seen in many places, as far flung as Ancient Egypt and Anglo-Saxon England. In both cases, broken glass artefacts have been pierced and used as beads (Nicholson 2011; Swift 2012). It is interesting to consider the place and abundance of glass in these two societies. The Egyptian amulets are interpreted as low-status, whereas the Late Antique amulets made out of similar scavenged material are never found in poor graves (Heck and

Hoffman 2000). It is interesting to consider at any point whether the driving force was economics, status, or a combination. Was it a matter of the saving on the expensive material of glass or, in the cases of medieval beads in wealthy burials, was it ideologically or socially significant to own glass?

As with reassembly, reworking is unlikely to change composition, but can be highlighted, as is the case with the Petra church shard PCP-92-002, by archaeometry (Schibille et al. 2008). The composition of this shard, which was set into a multiple piece window, was of a much 'older' composition than the rest of the glass, implying that it was a piece of earlier Roman glass. Again, whether such a choice of reworking was ideological or pragmatic is another question.

4.2.3 Remelting

Reforming *The forming of one type of object into the same or another type of object, through a liquid state.*

Reforming can be as direct as collecting up the shattered pieces of one object and remelting them, to reform the same object. While this is not easily observable, it is possible some medieval windows were fixed this way. However, reforming can also cause quite drastic change, such as the reworking to create some Late Antique beads. In some cases, a single tessera (e.g. Cavalieri and Giumlia-Mair 2009). This is very apparent in such cases due to the distinctive chemistry of mosaic tiles. It should be noted that while they have been separated from beads formed without melting, which in this schematic are termed 'reworking', there is clearly an association. While the difference in manufacture may or may not have been significant for the society at the time, it is significant in this appraisal as, when trying to identify recycling, there is a notable difference between a reformed bead, chemically identified, and a visually apparent reworked shard. The example given, of Cavalieri and Giumlia-Mair's tesserae beads, shows the potential for archaeometry to highlight different

types of recycling.

Recycling - Consolidation *The collection of a large amount of scrap to form a single object.*

This particular form of recycling, thought to be common in Anglo-Saxon metalwork, seems to be uncommon for glass. However, in reality it would be exceptionally difficult to identify this as distinct from cullet recycling, discussed below, in which much collated scrap is formed into multiple objects. However, during the Late Antique and medieval periods, when glass was harder to source, it is indeed possible some windows were made this way. In glass, this form of recycling is usually seen being used to create a specific object, but it is probably impossible to separate from cullet recycling in any way apart from historical record.

Recycling - Division *The division of a single artefact into multiple artefacts.*

Unlike in metal, this form of recycling also seems to be uncommon in glass, in the sense of an artefact being purposefully divided to make many smaller artefacts. However, an interesting ontological problem occurs when considering Roman glass vessel-making, as a whole. As has been discussed in detail, Roman glass is generally thought to be made first as large ingots, then exported across the Empire to local vessel-making factories where the ingot is then broken down and manufactured into objects. Ideologically, this is very different from dividing, for example, a large glass bowl into multiple beads. This ideological gulf is such that the term 'division' recycling should not be used for ingots. However, if one was looking for predicable losses from remelting, the losses caused from ingot manufacture would have to be taken into account.

As has been mentioned in reference to both reworking and reforming, beads are a common product of glass recycling and some may have been made by division. It seems unlikely that pieces were directly broken down for this purpose, but rather such

artefacts were a way to use up broken objects, without much skill. Some Late Antique tesserae are also made this way, as are gaming tokens, which are often thought to be shards gently melted until they liquify into little drops (Lierke 2002).

In the post-Roman period in Britain, instead of vessels and other glass jewellery, comparatively low-quality glass beads are found in high-status burials (Cool 2000, 49-50). Similarly, examples are common along the Rhone and in Northern Italy, such as those seen in Aiano-Torraccia di Chiusi in Tuscany (Cavalieri and Giumlia-Mair 2009), as well as in Merovingian burials (Heck and Hoffman 2000).

Recycling - Cullet *The collection of large amounts of cullet material, melted down and reformed into multiple objects.*

This is the term used to cover what most people generally consider as 'recycling' and is thought to be the standard production of recycled glass throughout most of the ancient period, particularly during the Roman Empire. The collection of large amounts of cullet is well documented and evidenced in the Roman period,[1] and it has long been acknowledged as a problematic consideration in glass studies. It is clear that the huge stores of Roman glass, coloured, decoloured and naturally coloured, were partly produced from cullet. However, there are several elements of this which are perhaps less considered but should be of equal concern to archaeologists discussing glass trade. What proportion of glass is produced this way? What is the shifting social significance of this cullet and glass into the Anglo-Saxon period? Is recycling evidence of an ideological connection to an earlier occupation, cf. Saxon brooches (Caple 2010), or simply an exploitation of a useful material.

There is a lot of potential for identifying and perhaps even quantifying cullet recycling using archaeometry, with many studies focusing on trace elements or isotopes. While many of the examples of this are discussed in Chapter 6, a few notable papers

[1] Archaeologically, Silvestri 2008, and historically, Statius, *Silvae*; 1.6.73-74, trans. Shackleton Bailey, Harrison 1987; Leon 1941. See discussion in Chapter 5.1.

are Foster and Jackson (2010) as well as Silvestri (2008) use of decolourants/opacificers, based on the assumption that any levels that are too high for natural contaminants but too low for decolourised glass, indicate mixed cullet recycling. Isotope studies, looking at the origin of sands in glass, are mostly based at the University of Leuven, under the direction of Patrick Degryse (ie. Brems et al. 2012a,b; Degryse et al. 2006). These studies have highlighted many glasses that are a combination of sands from more than one source, indicating a glass produced from the recycling of material from more than one primary source.

It can be debated as to whether such recycling related to shortages when exploited at the height of the Roman Empire, the assumption which is made for the Late Antique period. It is, after all, a more economically advantageous production. Cullet recycling is economically preferable, not just as a way to reduce the need for raw material exploitation, but also technologically. The initial production of glass from sands requires far higher temperatures than any remelting events. The introduction of even a small amount of cullet in a fresh silica mix lessens the overall duration of melt required to form a successful glass (Bingham and Jackson 2008, p. 305).[2] However, heading into the Early Medieval period, the pressures are assumed more than simply trying to limit production costs. Trade networks, thought to be restricted from the fourth century onwards, were vital to the spread of Roman glass. As discussed frequently in this thesis, the majority of Roman glass is thought to be produced in the Levant then reworked across the Empire.[3]

This means two things in terms of recycling. Firstly, that the production from cullet would have been much less labour intensive, due to decreased transportation costs as well as requiring less production energy. Secondly, as trade slowed across the Empire, the sourcing of large amounts of fresh Mediterranean glass very likely

[2]In this schematic, a predominately fresh melt with a small amount of cullet would fall under Incorporation of Recycled Material.

[3]For more debate, see Brems et al. 2012a,b; Freestone 2001; Picon and Vichy 2003 etc.

encountered difficulties. In the Roman period there is evidence of cullet being transported notable distances, such as the sunken Grado shipwreck, *Iulia Felix* (Silvestri 2008), so transport costs are demonstrably not the only consideration in recycled production.

An aspect worth consideration is whether people or not were aware of this sort of cullet recycling, and what was produced this way. Is recycling really only to be expected in plain domestic vessels such as jars and bottles, or was it simply a matter of how one made glass in the Roman world? How does this change into the Early Medieval period, where the quality of glass has long been perceived as lesser, with forms being only simple and uncomplicated, and colours limited (Evison 2000, p. 1)?

Identifying such cullet recycling can be extremely problematic, and several approaches will be discussed in detail later in the text.

Incorporation of Recycled Material *The inclusion of a small amount of recycled material in either a fresh, cullet or mixed glass batch, for a specific finish or purpose.*

The last form of recycling that needs to be mentioned is a rather odd, deliberate form of recycling. This is thought to be particularly common in Late Antiquity, as a solution to trade shortages (Campbell 2007, 24). Ingredients related to colouring/decolouring were likely the hardest to source, and the most expensive. However, a decent range of colours and affects could be achieved by the addition of small pieces of very brightly coloured glass or even old metal.

The range of possible colours is one of glass' true advantages, whether to form imitation gem stones, as part of a larger social language of colour, or simply to increase the attractiveness of the glass. Ancient glass can achieve colours from pale blues, though purples, yellows, vibrant reds and even almost black, many of which that can exist in an opaque or translucent form (Weyl 1951). One only need consider

Figure 4.1: Thomas Panel, late Roman *opus sectile* wall decoration, (Corning Museum of Glass, Registration No.: 86.1.1, Image © Corning Museum of Glass.)

Roman works such as the Thomas Panel to see this [Figure 4.1]. Each of these colours have an associated cost, due to the range and availability of colour sources, and direct addition is not the only option.

The most well-known method is the incorporation of heavily coloured mosaic tesserae into a fresh or cullet melt of 'naturally coloured' soda-silica-lime glass. In this sense, the tesserae act almost as a dye pack, imparting a less vibrant but still notable colour to the whole batch. This technique has been known for quite a long time, with partly melted tesserae archaeologically attesting to this scavenging, *e.g.* Cavalieri and Giumlia-Mair 2009. Chemically, this is extremely apparent due to the fact that tesserae, when manufactured on a large scale, are predominately opaque. To achieve this, a significant quantity of an opacifier such as antimony oxide or tin oxide is required. The identification of these, also used as decolourants, in a strongly coloured glass that is not opaque, is a clear sign of recycling. It has been seen in many glasses, such as from Torcello in Venice (James 2006) and Sion in Switzerland (Wolf et al. 2005). It has been shown that to achieve the very brightest colours seen at Sion, the ration of the weight of the tesserae added to naturally coloured glass would

only need to be 4:10, and the chemistry of the glass is consistent with this addition (Wolf et al. 2005, p. 369).

Chapter 5

Chemistry of Glass

5.1 Ancient Instructions for Glass-Making

Before considering our current understanding of glass as a material, it is prudent to consider how people in antiquity understood it. The production and distribution of glass has been of great interest to Roman scholars for some time, and much of the original study was based in classical philology. Although there is a limited number of ancient sources that deal with glasses or glassmaking, they are significant. The three most relevant groups of sources, in terms of this present study, are Pliny the Elder's *Naturalis Historia*, the Roman satirists, and Medieval 'alchemists'. A brief list of other authors dealing with the earliest glasses and the period following that of study will also be discussed. This is due to the fact that very few written sources on glass exist, and they have often been used to draw conclusions about later and earlier glasses, often erroneously. Unfortunately, no sources exist from the early medieval period, none that are focused on Britain, and only one that makes any direct mention of recycling, which is a medieval source.

5.1.1 Pliny and *Comminutus Vitrus*

Pliny's *Natural History* mentions glass-making in several places throughout its 37 books. The largest discussion takes place in Book 36, but Book 31 also goes into much detail on soda, specifically natron, one of the major components of glass. What should be remembered about Pliny as a source is that he was a collator, collecting what he summarised as 20,000 facts gathered from 2,000 books written by 100 selected 'reputable' authors [Book 1]. Although these figures are to be taken with a grain of salt, it is true that his work is a collection of information from a great number of other sources - extant and lost, oral and recorded - for the general interest of a learned public. They are not an explanation for or by an experienced glassmaker, a glass-workers technical notes or recipe, or of any use to anyone trying to produce their own Roman tableware. His *Natural History* is an encyclopaedia, collated for general education, rather than specific accuracy on any one field.[1] While a fantastic and broad source, Pliny is often not accurate in technical details, as has been shown in reference to animals, metals and much more.

For those working on analytical studies of Roman glass, the sources of glass-making materials noted in Pliny can be problematic. While most modern authors are happy with his statement that the best soda for glassmaking is that from Egypt [Pliny, *Naturalis Historia*; 36.193], his Italian silica source, the mouth of the Volturno, a mere 25 miles from his home town of Naples, is often doubted (Freestone 2008, 87). This apparent error is particularly interesting, given his personal proximity to the location, Pliny being based for much of his adult life at Miseno on the bay of Naples. It is possible that Pliny had confused glass-making and glass-working, in modern parlance, primary and secondary production. However, the Greek geographer Strabo also claims that sand from Volturno was used in glass production [16.2.25]. Pliny

[1]For a brief discussion on the rise encyclopedism in Latin literature and Pliny the Elder, see Conte (1999, 499-503).

does not tend to record the sources of his information, so both authors could be drawing from the same incorrect Latin sources, or a combination of this and personal experience.

Modern scepticism of this source was originally due to early experimentation, which has shown the existing sand at Volturno is a poor glass-making sand, being predominately volcanic (Turner 1956a). Two of the earliest specialists in glass compositions, Turner and Brill, both suggest that in the two intervening millennium, the sand has been modified, or perhaps even quarried out, an idea still held by many (Freestone 2008, 86). Current Neodymium isotopic studies seem to indicate potential western sources, but specifically not the Bay of Naples, and in fact non-Eastern sources account for a very small proportion of all Roman production (Brems et al. 2012a,b).

Despite this confusion in relation to Italy, it does seem that the majority of Roman period glass sand seems to come from the area surrounding Pliny's allegorical origin of glass-making, the River Belus in Syria. It is clear Pliny recognises the significance of the Syro-Palestinian coast in the story of glass.

Pliny's two Egyptian sources for natron are also less controversial; Memphis, now identified specifically as Wadi Natron, and Naucratis, likely the Barnugi Lakes. Pliny also states you can evaporate the salts from Nile water, but it is not advised, something which has been born out by modern experimentation (Turner 1956c). It seems unlikely that any significant amount of glass was produced this way.

Natron is often seen as the limiting factor in soda glass production, specifically manufacturing locations, and thus where it is found is important to the locating glass-making sites, notably the Levant and Egypt. Natron, which is difficult to transport, didn't have to travel far. A significantly sized glass tank furnace has been excavated in the Wadi Natron by Nenna (2015), showing just how little that distance sometime

was.

The limitation of where glass is produced is directly relevant to recycling, especially in reference to post-Roman Britain. Partly because raw material contamination is key in terms of understanding glass composition, and thus identifying recycling. Also because as trade expands and contracts, the ease of sourcing glass in any place could change, but not necessarily the demand, making recycling potentially more necessary.

As well as locations, the other problematic area of Pliny's writing is the various additions to the basic silica and soda mix. He discusses, *"lustrous stones of many kinds came to be burnt with the melt and, then again, shells and quarry sands"* [Pliny, *Naturalis Historia*; 36.193, trans. Eichholz, 1962]. It has been suggested by Freestone (2008, 92) that what he means by this is not precious stones such as previously thought (ie. azurite and malachite, though these can be used to create the range of copper-based colours), but rather less versatile minerals. These copper ores have value of their own, predominately as semi-precious stones or exceptional metal sources, and there are less expensive and less contaminated ways to incorporate copper into a glass melt. Freestone instead suggests Pliny is referring to minerals such as stibnite, a striking black/silver crystalline structure, which is thought to be the main way in which the decolourant antimony was added. This crystal, Sb_2S_3, is crucial in much of the argument about recycling, as antimony is a key indicator.[2]

There is also the problematic term *'magnum lapis'*, or 'magnetic stone'. What Pliny means by this is term is unknown, and a great many possible explanations have been both suggested and ruled out. It may have been that Pliny himself wasn't entirely sure, as he was not a technical man by trade, but as we can't be sure what additives he is concerned with, this is less problematic for recycling studies. We must

[2]This will be discussed further ahead, see Chapter 5.4.2.

assume it is one of the range of colourants and decolourants known from analytical work to be added to glass.

Given Pliny's lack of personal experience in glassmaking, it is possible that oversights were from lack of understanding; however, this is also a problematic assumption. For instance, archaeologists originally noted that Pliny does not mention the process of fritting, often seen as the first process of much early glass manufacture. In this step, silica and soda are lightly fused, before being ground into a powder again, and then remelted. This is done to ensure good mixing and thus full vitrification, so the glass does not crack or disintegrate on cooling, or form a faience like sand core. However, although this process is known to be used in some cases, such as Medieval Spain (Govantes-Edwards et al. 2016), it has been shown to be unnecessary for successful glass production (Freestone 2008, 82). It seems likely that this was not an omission by Pliny, but merely not a feature of Roman production, where glass was produced on such a large scale that the process of fritting would have been near impossible.

What is most relevant to this work is that Pliny does not mention the production of glass from cullet. This is interesting, given, as will be discussed further on, there was a very definite and know trade in broken glass in the Roman Empire, and the inclusion of cullet in glass-making in this period is not disputed. What was the cause of this omission?

One of the potentially fascinating parts of recycling is a question of understanding, ideology and value. Did glassmakers deliberately obscure cullet recycling? If this is the case, how did the trade in broken glass feature in people's understanding. Was it simply not understood, or perhaps too obvious and known for Pliny to bother mentioning, a part of glass-working not glass-making? Did people trade cullet directly for vessels? The answer to these questions surely hangs in how significant, in terms of scale, recycling was in the Roman production of glass. but will likely never really be

understandable. This is part of the aim of this work, to both understand how much Roman glass in Britain was recycled and in what way it moved and transformed, as well as how this changes, both during the Roman period and beyond.

5.1.2 Roman Satirists

The recycling of glass in a social context is perhaps eluded to by several Roman authors. Most of these authors are, in fact, satirists, and only refer in passing to a well-known trade in broken glass. Almost uniformly they mention it in relation to those *"who barter common sulphur for broken glass"* (Statius, *Silvae*; 1.6.73-74, trans. Shackleton Bailey). There has been considerable debate about what was meant by this, particularly in Martial 1.41.[3] Firstly, neither what is meant by 'broken glass' (*fractis vitreis*) or by 'sulphur' (*sulphurata*) in the poem are completely agreed by commentators. *Vitrea fracta* is used as a metaphor in Petronius (10.1) as a synonym for worthless junk. However, as Martial refers to this specific trade in more than one place (1.41 and 10.3) as does Statius (*comminutus vitreis* - *Silvae*, 1.6.73-74) and Juvenal (*rupto vitro* - I.5.47-48), one must assume the trope is based on some sort of real and well-known trade in broken glass by vagrants beyond the Tiber (Leon 1941).

For most of the last century, many scholars and translators, such as Post (1908), believed that such traders *"repaired with sulphur and sold again"* the vessels. This still appears in some of the heavily philological study on glass, despite apt refutes by Leon (1941) and Harrison (1987). Firstly, despite sulphur's incendiary properties, it would not produce sufficient heat to fuse the two broken pieces together, and secondly, if it was rather a component of glue or cement, it would not produce a glass that would be sufficiently bonded for any use beyond display (Harrison 1987, 203), nor, it should be noted, are examples of such repaired glass common. One must assume,

[3] *"Transtiberinus ambulator qui pallentia sulphurata fractis permutat vitreis"*

as well, that the owner of the original vessel could do such repairs himself and would not be required to relinquish a glass of enough value to be worth patching. This assumes as well that the sulphur traded was in form useful for fusing, disputed by both Leon (1941) who argues it was rather a kind of match for transporting fire, and Harrison (1987), who claims it was *vivum*, a very high grade sort of medical sulphur. Unfortunately, the Latin makes it unclear, but whichever the case, it simply isn't 'on the spot' repairs.

The third problem brings us to the most likely explanation of what is happening, at least on the glass side of things. The philologist Leon (1941) noted that in Statius' *Silvae* he wrote "*comminutis permutant vitreis*" [4]. Unlike Martial's *'fractus'*, a participle from the verb 'to break', simply meaning broken, shattered or vanquished, *comminutis* can mean both crushed, broken and/or pulverised, a term which implies smaller fragments. Such fragments are particularly likely be difficult to simply patch together. Instead, it seems this is broken glass for trade, of value because it can be returned to glass workshops for remelting. Archaeological evidence such as the *Iulia Felix* (The Grado Shipwreck) confirms this large scale trade in broken glass, with over 11,000 fragments in barrels sorted by colour (Silvestri 2008, 1489), and on other sites glass shards are clearly separated in pits ready for remelting, sometimes accompanied by glass furnaces. These cullet collections are found throughout Britain, dating from both the Roman period (eg. Basinghall Street (Shepherd et al. 2009)) and into the Early Medieval period (eg. Lyminge (Thomas and Knox 2013), Chapter 7.2).

Although these Latin authors do not clearly state what this cullet collection is for, the options are limited and the archaeology illuminating. Using the specific terminology of recycling set out in this thesis, they could undergo several types of remelting [Chapter 4.2.3] or reworking [Chapter 4.2.2]. For example, this glass could either be melted down in the formation of new glass - with anything from barely any

[4] 'Broken glass to exchange', authors own translation.

recycled component to 100% cullet production- or these shards could be used as is, such as fitted into mosaics. Due to the extreme scale of many cullet hoards found, as well as chemical signatures, it is clear cullet recycling is the most common end for this broken glass.

These authors seem to indicate, in light of archaeological evidence, that cullet was collected, sold to street merchants, transported or shipped en masse to a site where it was reformed into raw glass or vessels. This will be born out in the coming chapters, supporting archaeometric evidence showing that cullet recycling was common in the Roman period, and in fact accounts for a huge proportion of glass production, especially in Britain. Our interpretation of glass in the ancient world must be viewed through this lens, which can make rather extreme changes to our existing views of the change of period.

5.1.3 Post-Roman and Medieval Authors

After the satirists, glass making or recycling is rarely mentioned and sources specifically on manufacturing are rare. This means that practically no reference is made to glassmaking or working during the period of most interest to this thesis, the early medieval period, but only later works. It is such a medieval manufacturing text, however, that first records the inclusion of glass cullet in production.

Some of the several treatises that give a focus to glass include: those attributed to Theophilus Presbyter – an eleventh-century suspected monk, (H)Eraclius – a pseudonym covering three books composed in the ninth and twelfth centuries, Vannoccio Biringuccio – a fifteenth century metallurgist, Georgius Agricola – a German scholar and scientist, Neri – a seventeenth century glassmaker, and Neri's English translator and commentator, Merret. As well as those more central and germanic traditions, there exists two arabic influenced Spanish texts referencing glass but these are much latter, refering to the Renaissance, one by the Galician Don Chistóforo, *Epistola*

abbreviatora, and another by Hieronymous Múntzer, *Itinerarium Hispanicum*. These both include recipes and instructions but seemingly for a non-technical audience, and due to their late date will not be discussed further.

With the earliest of the Germanic texts falling in the later part of what in England is usually considered the Late Saxon period, these are far too late to really be indicative of what is occurring in the centuries preceding. This theme, a lack of evidence between the height of Roman Britain (second to third centuries), until the formation of large Anglo-Saxon kingdoms (eighth to ninth centuries), is oft repeated.

While unlike Pliny, many of these later authors seem far more concerned with true technical details, they all refer to the later plant-ash glass industry. As this marks a major change in glass production and industrial structure, allowing true European glass to be produced on a grand scale, it can not really be generalised to the earlier soda glass industry. These sources are also all continental, with the exception of Neri's translator, Merret, adding another level of impracticality.

The only one worth specific comment is Biringuccio's *De La Pirotechnia*, which explicitly mentions the recycling of glass. Vannoccio Biringuccio was very aware of Pliny's work, but was a specialist, a metallurgist, familiar with producing plant ash glass (Smith and Gnudi 1990, 126). He did, however, mention the use of cullet to produce glass, listing it as another option rather than melting frit to make glass easily at a low temperature [129]. It is not a focus of the work, but listed as an obvious source of glass. It is clear that this was assumed common. Biringuccio lauds glass as the greatest material humans can make, and extols its versatility.

5.1.4 Summary of Philological Studies

These philological studies, while brief, offer a tantalising glimpse into the understanding of glass production in the ancient world. While lacking in specifics, there is clearly a wide understanding of a trade in broken glass, and the significance of Syro-Palestine

in the story of Roman glass. While there is no clear evidence of understanding of cullet glass production in the Roman period, where there is much archaeological evidence, it is clearly known as a common practice by the 15th century. However, our understanding of glass production, specifically recycling has fortunately evolved far beyond this, thanks to chemical analysis. It is this that will be turned to in this thesis.

5.2 General Structure of Glass

Archaeological glass is a complex system, in some ways considerably more so than ancient metals. Glass, as a chemical definition, is a structural description, however colloquially 'glass', as it is used here, is to mean silica glass. *Glass* is a descriptor of state, meaning any noncrystalline solid (Daintith 2008). It is often explained as a solid with the internal disorder of a liquid, the relationship of atoms in the basic network beyond their immediate structure being random, with no long-range order. 'Glass' in this current context, we take to mean a silica glass, where the basic building blocks of this network are primarily silicon and oxygen.

Solid silica crystals, such as quartz and sand, are a strong lattice of silicon and oxygen, with silicon existing in the tetrahedral coordination of silica, with the resultant formula SiO_2 [Fig. 5.1]. This creates a strong material, with a melting point between 1650 - 1713 °C. However, *silica glass* is a disruption of this regular pattern where, although each silica still exists in a tetrahedral coordination with oxygen, the long range order does not exist [Fig. 5.2]. This is can be achieved by very rapid cooling of pure SiO_2, essentially freezing the molecules in place before they can reorder the lattice, but more commonly is the result of additions to the crystal. In the case of first millennium glass, it is not just a network of SiO_2 but is a modified network lattice. The production of a pure silica glass was not something achieved until the

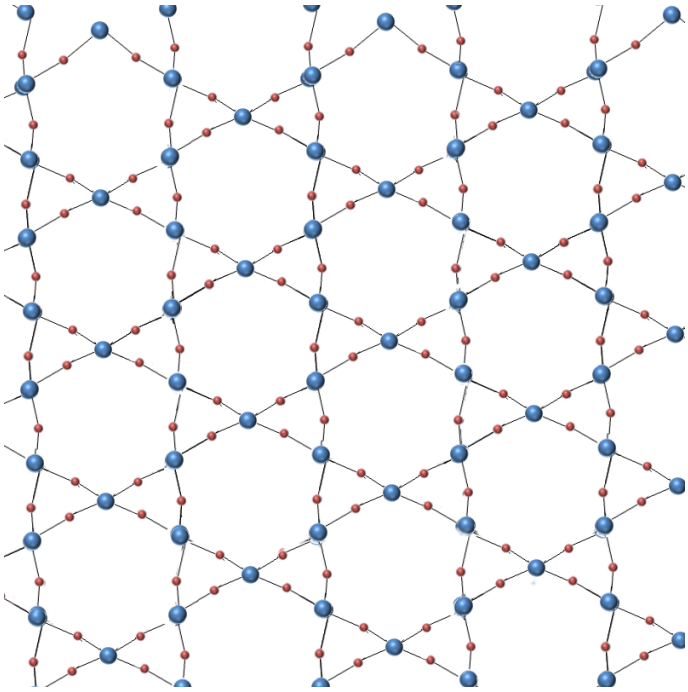

Figure 5.1: Structure of silica - pure silicon dioxide crystal arrangement, with blue indicating silicon in a tetrahedral arrangement and red the linking oxygen.

modern period. The modifier in this first millennium glass is most typically soda (Na_2O), whose ions disrupt the strength of the bonds between the silicon and oxygen and alters the lattice geometry, significantly lowering the required melting temperature, creating a structure that is malleable at temperatures achievable in Roman furnaces, and a capacity to hold less rigidly crystalline forms, allowing for an amorphous structures, unlike natural quartz. Rather than forming one complete lattice [Fig. 5.1], instead a more depolymerised structure is formed, just with a high degree of cross-linking. Not all oxygen atoms still have two covalent bonds, their valence capacity fulfilled by ionic bonding with sodium [Fig. 5.3]. Potassium, manganese and calcium are also commonly used in this same fashion, particularly in the case of plant ash glasses. These sodium ions are introduced into soda glass as predominately the compound natron ($Na_2CO_3{\cdot}10H_2O$).

Soda-silica glass causes one major problem. The glass produced is now particularly susceptible to attack by water, something not true of the strong covalent network of

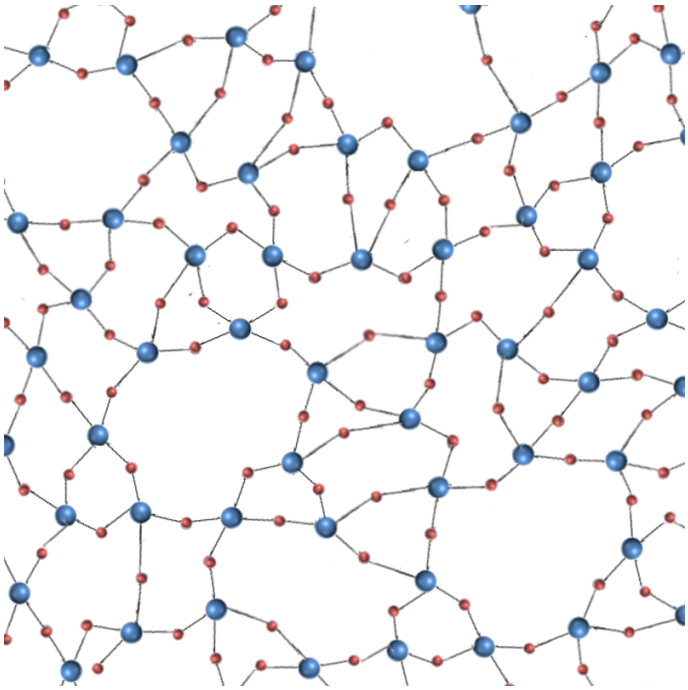

Figure 5.2: Structure of pure silica glass - tetrahedral silicon, in blue, and oxygen, red, in a glass structure, with short-range but no long-range order.

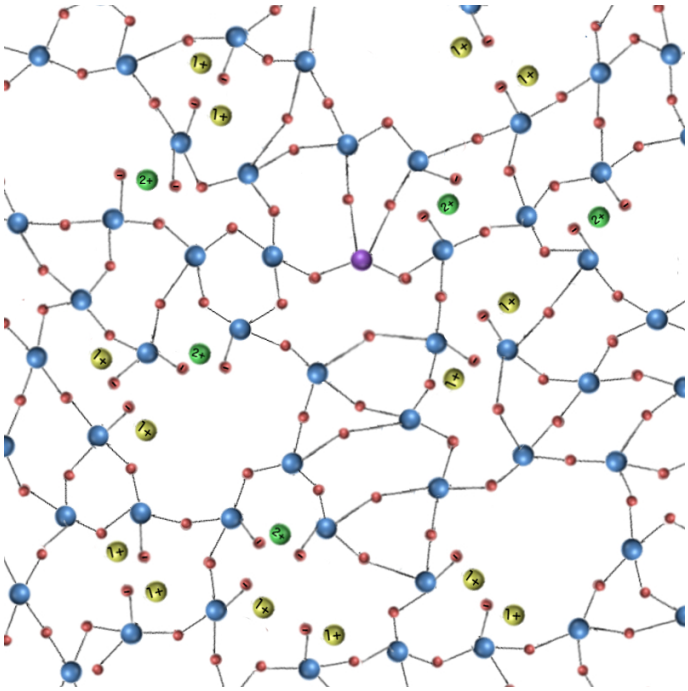

Figure 5.3: Structure of soda-silica glass - tetrahedral silicon, blue, and oxygen, red, altered with sodium, yellow, calcium, green and a silicon replaced with aluminium, purple.

quartz.

The sodium ions (Na^+) within the network can be replaced, by cation exchange, with protons (H^+) or more accurately, hydronium ions (H_3O^+). These then, through slow diffusion, draw water deeper into the structure, causing a very slow dissolution through further cation exchange. More problematically, this also produces the basic sodium hydroxide, which can directly attack the silicate structure. This all leads to corrosion and sometimes complete disolution. However, this can be counteracted by replacing some of the sodium ions with calcium ions, which are less easily displaced due to their greater ionic potential. This makes the glass less susceptible to hydration. This can be achieved by either the deliberate or incidental inclusion of seashells, limestone, or specifically lime (CaO). This stabiliser then forms some of the fundamental structure. Lime also acts as a flux, again reducing the temperature of manufacture, for ancient glass being between 900-1150 °C. This leads to a glass, predominately silica, network, which is workable at a reasonable temperature for ancient furnaces, and not easily dissolvable in water [Fig. 5.3].

While this is the basic structure of first millennium glass, there are also a great many additions and contaminants. Following is a survey of the different chemicals commonly found in glass, with the exclusion of silicon, their sources and uses, as well as their potential for the creation of recycling metrics. This information is also summarised both in a detailed table [Table 1] and in a basic elemental form [Table 2].

The elements discussed below have been arranged by most 'significant' origin. First major components (Chapter 5.3), then the elements usually associated with colouring (5.4), followed by traces related to sand (5.5.1), alkali (5.5.2) or colourants (5.5.3). As many minerals contain concomitant elements that end up in the final glass, as well as there being multiple sources for each element, these are very broad separations and not meant to be robust - For instance, both manganese and iron are

considered under 'colourants', however they are predominantly thought to enter glass through sand contaminates. Both, however, are very relevant and used as colourants, so are addressed under that earlier heading.

5.3 Traditional Main Ingredients

5.3.1 Sodium

Although the exact origin of the sodium in ancient glasses depends on the type of glass, it is almost entirely from the deliberate addition of a flux - either natural evaporates (notably Egyptian natron) or plant ash. In both examples, sodium reduces glass processing temperature to within practical limits, as discussed previously. For 'soda' glass, the majority of the sodium is added directly and deliberately as the evaporate natron. For most of the Roman period and much of the first millennium, this is thought to be be sourced from Egypt, particularly the Wadi Natrun and Naucratis. While there are other potential sources, such as the Fezzan or Greece, so far none have been shown to be chemically compatible (Degryse et al. 2008c; Devulder et al. 2014; Shortland et al. 2006). For Roman-style soda glasses, sodium forms between 12%wt and 19%wt of the glass.

The other major source of sodium is plant ash. For glasses made from plant ash, most of the action of the modifier and flux is performed by potassium or magnesium instead, but there is still between 0.5-3% sodium oxide for forest glasses, or between 10-15 % for halophytic plant ashes, such as seen in Islamic Glass. Plant ash is a combination of potassium, magnesium and sodium but tends to be very non-standard, due to variation in the individual plants and combustion conditions (Jackson et al. 2005). Contaminants likely to be resultant from plant ash are varied but can include: Ni, Cu, Zn, Rb, Sr, Zr, Ba and Pb [Al-Bashaireh et al. 2016; Tite et al. 2006; Wedepohl et al. 2011, sp. Jackson et al. 2005]. Plant ash glass is uncommon in our period, but

is usually much less standard in composition than natron glass.

For soda glasses, the mineral trona ($Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$) is usually attributed as the main part of natron. However, salts collected from Egyptian sources have often shown that trona is not the major mineral, and thus other elements could potentially enter the glass this way, though there are significant seasonal differences. Analysis by Shortland and colleagues [2006] showed halite (NaCl) was the most common component of raw natron, but also burkeite ($Na_6CO_3 \cdot 2SO_4$) and thenardite (Na_2SO_4). However, there is a limited reaction between silica and sodium chloride or sodium sulphate at high temperatures, which means that it was predominately the sodium carbonate reacting. Strongly burkeite rich salts such as predominate in the lake now are not suitable raw for glass making, but this is likely a matter of change over time.[5] For the most part, natron is contributing sodium with apparently little further contamination, save trace barium, phosphorus, uranium and boron (Degryse and Shortland 2009; Wedepohl et al. 2011).

As well as the deliberate addition, there is also a small contribution of sodium that is caused by either alkali or plagioclase feldspars in the sand (Henderson 1985, 271), but in relation to the flux, it is minimal to the point of negligible.

In relation to recycling, sodium has some potential as an indicator. A decrease in sodium, paired with an increased of certain other alkalis/alkaline (specifically potassium and calcium) can be indicative of a sodium glass either mixed with a plant ash glass, or doped with plant ash. The second possibility could have occurred as sodium is known to burn off through the glass remaining molten for extended periods of time (Freestone 2015, 30). This means that, particularly in the case of glasses that have been molten several times (ie. heavily recycled glass), the melt is likely to become too 'stiff' or 'fast' to work easily in the available furnaces. 'Fast' glasses, as they are

[5]For a further discussion of Egyptian natron and issues see Shortland et al. 2006 and Degryse and Shortland 2009.

called by modern glassblowers, are compositions that result in a glass that stops being malleable very shortly after being removed from the gloryhole, the working entrance to a glassmakers furnace. This could be counteracted by adding alkali, handfuls of plant ash, which might account for a 'transitional' glass compositions, neither plant ash nor soda. Such transitional glasses have been seen in multiple places, such as Beverley, and this is discussed further in Chapter 6.1.3.

5.3.2 Potassium

As mentioned, plant-ash alkali relies mostly on potassium as a network modifier. Potassium is not a significant component of natron glasses, accounting for less than 2.5%wt, and usually less than 1%. It is thought to be contaminant from the sand, particularly alkali feldspars (Henderson 1985, 271), and to a small degree in the natron itself (Wedepohl et al. 2011, 96).

However, in plant-ash glass, potassium is much higher, around 15 to 17%wt. As commented upon relative to sodium, this is variable based on plant type and combustion. However, potassium is usually a very significant proportion of the alkali in ash glasses.

Also as with sodium, the partial use of plant ash as an alkali in glass can be indicative of recycling (see: Chapter 6.1.3).

5.3.3 Calcium

Calcium in glass is problematic in source, as it can come from many different parts of the glass melt. The most obvious source is by the addition of shell grit, either deliberately or as a component of marine sand. Both chemical[6] and isotopic[7] evidence indicates Roman glass is predominately made from marine sands, which would

[6]eg. Degryse and Shortland 2009; Freestone 2005.
[7]For a survey of papers, see Degryse et al. 2008a

explain the source. While some authors favour a deliberate addition of shells, such as murex (Wedepohl and Baumann 2000), this thesis assumes that the inclusion was incidental, an idea supported by many others (Aerts et al. 2003). Seashell compositions vary, but they are predominately calcium carbonate ($CaCO_3$). As discussed under glass structure, lime components are highly effective as a stabiliser in glass and seriously reduce the weathering, which is common over time. An excess of calcium also, somewhat paradoxically, causes an increase in the melting temperature and thus a more difficult glass to work, and in significant enough quantities leads to devitrification.

As well as shells in the sand, there are many other calcium baring minerals that are common, such as titanite/sphene ($CaO{\cdot}TiO_2{\cdot}SiO_2$), plagioclase feldspars, and epidote ($Ca_2Al_2(Fe^{3+};Al)(SiO_4)(Si_2O_7)O(OH)$). Sandstone is also a potential origin of calcium, however this is easily apparent when used in glass because the ratio of CaO:MgO is close to unity, which is not seen in most Roman glass. In River Belus sand, calcium was measured at 8.81% (Turner 1954b), but resulting glasses range from 5-11%, which is seen across Roman glasses.

Plant ash is also a major contributor of calcium. In Islamic plant ash glasses, the calcium jumps up to around 10%, but again can be very variable due to incomplete combustion. In medieval plant ash glass, the calcium in much higher, sometimes being as high as 20%, due to the nature of the ash added, and the quantity require for fluxing.

In cases where calcium is resultant from marine sands, it can be used as a recycling indicator. There is a linear relationship between aluminium and calcium within each marine sand. However, when sands of multiple provenance are mixed, this is disturbed. This provenance can be seen clearly in multiple publications (ie. Schibille and Freestone 2013, Fig. 2; Freestone 2005, Fig. 3). Some glasses seem to fall on

mixing lines between these glasses, but in reality, due to the lack of clarity of glass types and overlapping values, the cases where this can be used are rare (see: Chapter 6.3.1). As well as this, high calcium, as high potassium, can be indicative of the addition of plant ash, which has potential for recycling studies (see: Chapter 6.1.3).

5.4 Deliberately Added Colourants

5.4.1 Manganese

Manganese is naturally present in glass sands, as well as being used as an additive to create both purples and blacks, and as a glassmakers soap, to decolourise. It colours in the manganic trivalent form, and functions as a decolourant in the manganous divalent form (Bamford 1977, 50). In other words, it exists in a balance of Mn^{2+} and Mn^{3+}, where if the balance tips towards M^{3+}, the glass shall be purple, to of Mn^{2+}, a pale yellow-green that is nearly colourless. In high enough concentrations, the purple colour appears black.

It is a far less effective decolourant than antimony, and its prevalence from the mid-third century onwards is usually thought to relate to a shortage of antimony. It is often argued that manganese above 0.3% is likely to be deliberately added, although there is some doubt around this number as Turner recorded this level directly in Egyptian sand, and at levels approaching 0.5% in Volturno sands (Brill 1999). There is, however, a difference between the ratio of the sand to the final glass compositions. The later HIMT-style glasses have assumed-natural magnesia from 1-3%wt (Foster and Jackson 2009; Freestone 2005). This is thought to be directly from the sands. At the reintroduction of plant ash, manganese greatly increases again, to around 5.5-7%, but this is due to ash composition and occurs, for the most part, outside the date range of the current study. Manganese is sometimes diagnostic of traditional glass groups [Table 3].

Additional manganese could have been increased in many ways, some of which would require processing before they could be used in the manufacture of glass. The purest form of manganese is pyrolusite (MnO_2), which is also the most common Mn bearing mineral. It is found in abundance across Europe. The name means 'fire wash' and has been argued in reference to its ability to 'wash' (oxidise) iron colours away (Palache et al. 1952). Other sources of manganese are more problematic because of their associations. These include psilomilane (ca. 75% MnO, 15% BaO, 5% K_2O and 1% CaO), diallogite (70% to 90% MnO, 2-3% CaO, 2-7% $MgCO_3$ and up to 11% FeO), 'wad'- a range of black manganese oxide or hydroxide mineral-rich minerals, which can contain up to 50% FeO, and rhodochrosite (crystalline $MnCO_3$, which almost never appears in this pure form) (Jackson 2005, 764-765). As natural iron in the sand is one of the problems the addition of manganese is trying to combat, and almost all of these are commonly found in association with or containing iron, these all seem unlikely choices. As well as this, each have further complications.

As well as these deliberate additions of manganese, there is also an association known between manganese and cobalt, meaning that in some cases it is possibly a contaminant in cobalt ores, but one would only expect this to be high enough to be apparent in blue glasses.

Manganese holds particular interest for recycling studies, as its introduction is paired with the decline of antimony. The relationship between the two has potential as a recycling indicator, which is discussed further in Chapter 6.2.1.

5.4.2 Antimony

A decolourant and an opacifer, antimony is not usually present above a few parts per million in common geological materials for glassmaking, so greater than around 50 ppm must be deliberately added. The main form of antimony that would have

been available to the Romans was stibnite (Sb_2S_3). Bindheimite ($Pb_2Sb_2O_6(O,OH)$) is also an option though, as with the previously discussed manganese ores, this is a problematic choice due to the other components. The introduction of more lead would be notable and there seems to be no significant correlation between antimony and lead in either reported studies nor this dataset. *'Stibis'* is used in its roasted form, antimony oxide (Sb_2O_5, Sb_2O_3), as a medicine and cosmetic in the Roman world, though there is no evidence this is how it is added to glass and it is problematic to add it that way (Pliny the Elder 1962, XXXIII.33).

The most common use of antimony is as a decolouriser. It is the most effective decolouriser used in first millennium glasses. Antimony, while having a lower reference reduction potential than manganese, is a more effective decolourant under the mildly reducing condition of ancient furnaces (Schreiber et al. 1987). Antimony in low quantities oxidises the iron, pushing the ratio of Fe^{2+} to Fe^{3+} to the right. $Fe^{2+}/\Sigma Fe$ determines the final colour of the glass; as divalent iron is a strong blue, but lower Fe^{2+} is a weak yellow. This, in a low concentration, it seems colourless. Fe^{3+} is also preferable as it's absorption bands (380, 420 and 435 nm) are weak, whereas Fe^{+2} has characteristically a very strong band around 1050nm. While this is outside the visible spectrum, the resultant spread around this peak is such that a glass of a ratio of 0.37 $Fe^{2+}/\Sigma Fe$ produces absorption nearly three times less at 540nm and four times less at 590nm than one of 0.25 (Bingham and Jackson 2008, 308).

In even higher quantities, antimony forms a precipitation with calcium within the glass ($Ca_2Sb_2O_7$ or $Ca_2Sb_2O_6$), rendering it opaque. If this is done without the addition of other colourants, it is white opaque. With other colourants, it achieves an opaque colour, though this is chemically more complex. Antimony can also be added as a compound, such as lead pyroantimonate ($Pb_2Sb_2O_7$), causing an opaque yellow. Opaque glasses are more common in mosaics and enamels than in vessel glass in the Roman period, though many examples and colours do occur, such as a pair of

chequerboard bowls from Kelshall near Royston (Cottam, pers. comm.).

Antimony also acts as a 'fining' agent, preventing bubbles from forming by degassing, though it is unknown as to whether it was added for this purpose. Sb_2O_5 forms at low temperatures in the furnace, using the oxygen present in the batch and the antimony in the stibnite (Sb_2S_3). As the temperature increases, antimony settles back to its trivalent form, expelling gaseous O_2, which is ejected on the cooling of the melt. This escaping gas facilitates the release of other vaporised impurities. These larger bubbles also incorporating smaller ones and expel them, preventing them from lingering in the final glass.

Antimony has a short life in Roman glass, meaning that it too has a significant potential for studying glass recycling. As with manganese, this will be discussed in detail in Chapter 6.2

5.4.3 Copper

Copper is rarely found in high quantities in the glassmaking sand, is expected to be less than 100ppm (Foster and Jackson 2010, 3072). It is, however, a very common additive in glass and of great abundance generally in the Roman world. It is thought to be mostly added as metallic copper, extracted from copper sulphide ores, but could have also been added as direct ores or bits of scrap bronze. The latter should be apparent by the fixed ratio with tin and lead. While there are a few glasses that might show this, it clearly isn't the standard.

Copper is useful for the making of a variety of colours: green, blue and opaque red. The final colour is less dependent on the content of copper, in terms of percentage, and more on the conditions of manufacture. Opaque red is formed if the copper is kept in strongly reducing conditions, causing the copper to precipitate as cuprite (Cu_2O)

or elemental copper within the glass, whereas blues and greens are differentiated by copper's oxidative states. The process is slightly different in each. Elemental copper forms colloids, and these Cu-nanoparticles cause light scattering and produce a very specific red due to scattering, referred to as 'sealing-wax', 'oxblood' or 'ruby' glass (Hughes 1972; Kunicki-Goldfinger et al. 2014; Weyl 1951). This red isn't directly caused by the copper itself, which is colourless. However, copper is usually divalent with some proportion of trivalent, and causes blues through to peacock greens. The colour is determined by both the amount of copper but particularly the relationship between these cuprous (Cu(I)) and cupric (Cu(II)) ions (Bamford 1977, 48; Möncke et al. 2014).

Copper is also commonly related to colouration by cobalt. However, as cobalt has a molar extinction coefficient around 30 times higher than copper, there is little evidence that copper is contributing to the colour at all. Rather, it seems likely that copper is present as contaminant, common in cobalt ores (Papageorgiou et al. 2012, 244). Cobalt itself is discussed further below.

Traces that also occur with metallic copper could, to some degree, enter glass through deliberate copper colourisation. Common traces in refined Roman copper are silver, nickel, arsenic, gold, cobalt and antimony. Of these, the last two could cause the most issues with complicating recycling metrics in glass studies. However, Roman copper coins, a relatively pure source of copper, have reported an antimony range up to 2.5%, thus the highest proportion possible of antimony in a glass, before taking into account limitations imposed by thermodynamics, is .025% or 250ppm. This is assuming glass with 1%wt copper, which in turn is contaminated with very high 2.5% antimony. One per cent copper is above the copper registered in over 75% of coloured glasses in this database, the higher interquartile being approximately 0.35%. This means that even in extreme cases, copper added to glasses may have introduced only up to 250ppm of antimony. However, this is assuming the antimony is

not a feature of the processing of Roman copper, a perhaps problematic assumption. This does, however, assume that it is indeed metallic copper added. There is also no apparent correlation between copper and either tin or zinc, the major alloying elements, meaning that the cause couldn't be things like scrap bronze.

Plant ash can have several hundred parts per million of copper, this is then unlikely to cause more than a few parts per million in a final glass due to ratios. It is also true that plant ash glass is not common in this period, so this can be discounted.

Copper is remarkably diagnostic for recycling as it is only likely to have entered red or blue coloured glasses in first workings, and in glasses in all other situations, particularly colourless or naturally coloured glasses, is indicative of recycling. See Chapter 6.2.4.

5.4.4 Iron

Iron is particularly common and, in fact, unavoidable in glass sands (Bamford 1977, 2). It is responsible for a range of 'naturally' coloured glasses, as well as deliberately added to achieve specific colours. In the final glass, iron is usually present as both ferrous and ferric ions, and the colour of natural glass is related to the balance. Iron glasses can range in colour from greens, purple-brown, blacks, blue and yellows, depending on the concentration of iron and other additives. The 'black' used in Iron Age British glass definitely requires deliberate additions of iron, above what is naturally present in glass sands, as do yellow glasses, which are coloured with due to the interaction between iron and sulphide (Schreurs and Brill 1984), and emerald greens, made from a combination of copper, iron and other reducing agents. However, much of the range of pale transparent yellow-green or the common blue-green Roman glass is likely natural iron within the sand.

Iron is a significant trace element in sands (Henderson 1985). Common iron

bearing contaminants in marine sands include chromite ($FeO{\cdot}Cr_2O_3$) and epidote (Ca_2(Al,Fe)3SiO_4)3OH). The sand around the mythical birthplace of glass, the River Belus, has natural iron of 0.13% appropriate for the values usually seen in Roman glass (Turner 1954b).

Each of the traditional groups of glass are somewhat defined by their iron concentrations [Table 3]. Due to the geographic and chronological relationship of these groups, especially the introduction of the distinctive HIT/HIMT-style glasses, there is some potential for using the ratios of iron in recycling studies, which is to be discussed in Chapter 6.1.2.

5.4.5 Cobalt

Cobalt is perhaps the best known colourant in glass. It has a long history, going back as far as some of the earliest Mesopotamian and Egyptian glasses and it is the most commonly used colourant in Iron Age Europe, despite its restricted sources (Henderson 1985). It is a far more effective colorant than most other metals, at least by a factor of five, meaning comparatively little cobalt is needed to make a deeply coloured glass. Cobalt is usually divalent in soda-lime-silica glass and the quality of the blue is also comparatively distinctive. Colour intensity is directly related to concentration of cobalt.

The source of cobalt is usually thought to be actual cobalt ore, rather than alums as in the Egyptian period (Rehren 2001), and in the Roman period seems to be in association with high manganese (Henderson 1990). Cobalt oxides can contain great variation in iron, nickel, copper. Examples include black trianite ($2Co_2O{\cdot}CuO{\cdot}6H_2O$), cobaltite (CoAsS), skutterudite (Co,Ni,Fe)As_3). Traces likely to end up in the final melt include Pb, Sb, Ni, Mn, Zn, Bi, As, In, Fe and particularly Cu, as discussed earlier (Gratuze et al. 1992b). A good deal of study of the origin of cobalt used in glass exists, and it suggests a single Eastern source of cobalt (Bidegaray 2014;

Gratuze et al. 1992b; Henderson 1990; Matin 2015).

Even small amounts of cobalt are likely to present a blue-colour, so it is less useful than copper in identifying colourless recycling, though it does have a place. However, cobalt glass of a much earlier base composition is known from several sites in Britain, including Lyminge, discussed in this text. So while the element cobalt seems to be less diagnostic for recycling metrics than copper, it seems to be an element that is often the driver of recycling.

5.4.6 Tin

Tin is a common addition to glass both before and after the Roman period, but less so during (Tite et al. 2008). It is both a colorant and an opacifier. When SnO_2 is present, glass is an opaque white, due to the formation of a precipitate, in much the same way $Ca_2Sb_2O_7$. However, tin is also responsible for the creation of opaque yellows. In exactly the same way as the white precipitate, if tin and lead are both present in sufficient quantities, a bright yellow cubic or orthorhombic lead-tin precipitate oxide forms, again analogous to antimony ($Pb_2Sn_2O_7$ or Pb_2SnO_4).

There is a chance scrap metal could have been the source of trace tin or lead, added as copper alloy. This is the only real potential for looking at recycling with tin, and doesn't seem apparent in the database presented here.

5.4.7 Lead

Lead is both natural in the sand, but also used in some glasses as an additive. It could easily be added as either metallic lead or galena, both being found at sites dating back at least as far as the Iron Age. At least by the 12th century, (H)Eraclius writes about metallic lead being added. *De Coloribus et Artibus Romanorum* states, "Take good and shining lead [sic] burn it in the fire until it is reduced to powder [sic] two parts may be of lead and one of sand [sic] then do as before directed for

making glass" (Merrifield 1849). However, sites such as a Rhodian Hellenistic glass-workshop contained sheets of leads and varying stages of opaque yellow glass beads (Triantafyllidis 2001, p. 136). Similarly, a medieval site in Galitch, western Russia, had crucibles with remains of glass and metallic lead stuck to the edges, indicating that metallic lead is used before and after the Roman period (Henderson 1985). It is sensible to think the same might be true of the later period.

As mentioned several times, lead is used in the opacification of particularly yellow glasses. Lead also causes an increased solubility of antimony, tin and copper oxides at high temperature, which then leads to better opacification generally as these crystals then precipitate out at lower temperatures (Henderson 1985). In smaller quantities, it also increases the brightness in glass, due to its high refractive index, and allows sharper edges for cut glasses. Lead also seems to be used in some very rare cases in significant quantities (ie. 30%), and it has been suggested this may be to extend the glass, such as seen in early medieval Spain (Duckworth et al. 2015).

As well as the deliberate addition of metallic lead, there is also the chance that in some cases lead entered as scrap bronze used for copper colouration, but due to the lack of a consistence ratio with copper and tin, it is not noticeable in this database, nor seen in any significant relation to any copper coloured glasses. Lead is also a common trace contaminant, particularly in the case of plant ashes.

Lead is known to increase through successive remeltings, probably because as copper, lead is used for the creation of various colours, which through inaccurate sorting could end up mixing with 'colourless' or 'naturally coloured' glass (Freestone et al. 2002). As such, it holds potential for a recycling metric (Chapter 6.2.5).

5.4.8 Gold

While gold can be sandwiched in between layers of glass, particularly colourless glass such as the extensive Wilshere Collection in the Ashmolean Museum, Oxford, it is

also added into glass melts as a colourant, producing a red often called 'Ruby Gold'. A particularly notable example of this is the Lycurgus Cup, which uses gold to achieve the red under transmitted light (Freestone et al. 2007). Gold functions similarly to cuprite in sealing-wax red, by colloidal colouration. Small droplets of gold glass exist as small spheres within the structure of the larger glass. They tend to range between 9-20nm in diameter and their scattering of light leads to the unique optical properties of this vessel. For this to have occurred, full ionic dissolution is required, so the gold can precipitate as a metal colloid. It requires a particularly oxidising melt, but this can be forced by additions such as antimony, in the case of the Lycurgus Cup, or $NaNO_3$ (Bamford 1977, 99). The Lycurgus Cup also contains colloidal silver, responsible for the reflected green colour, the two together leading to a dichromic effect. It should be stressed that Ruby Gold is uncommon, probably due to the difficulty in manufacture and the cost of gold.

Gold can also be related to some other colourants as trace, but this is uncommon due to its stability. Gold is not particularly helpful in recycling metrics, but is a feature of Roman glass production.

5.4.9 Silver

Silver colouration in Roman glass is rare, but is seen in the reflected colour in the Lycurgus cup, as discussed under gold. Silver however, is commonly a trace element in some colourants. It does not, however, seem to have potential for recycling studies.

5.5 Traces

5.5.1 Traces in sand sources

Sand has many possible traces beyond iron. Many are routinely analysed in glass and some can be relevant to glass recycling:

Magnesium: Magnesium is a common minor component in sands and is present in all Roman glass up to around 2% weight. It contributes to the stability of the glass network, like sodium or calcium, yet is not particularly diagnostic during this period. It tends to be higher in glasses from the second century onwards [Table 3], and can be used in conjunction with calcium to show if limestones rather than marine sands are used, uncommon in Roman glass. From the ninth century onwards, magnesia is much higher and compositions of Middle Eastern glasses show a subdivision between the Sassanian and Syrian-Islamic traditions (Freestone 2006).

Titanium: Titanium is a very common trace or minor element in sands, usually as titanite or sphene ($CaO{\cdot}TiO_2{\cdot}SiO_2$) or rutile ($TiO_2$) (Henderson 1985). Titanium is well known for its chronological relationship, particularly looking at the HIT/HIMT-style glasses. Given this, like the introduction of manganese, the change from a low to high titanium glass gives clear potential for identifying glass recycling. This has been well demonstrated by Aerts et al. (2003), showing that 1^{st} - 3^{rd} century samples from Germany and Belgium show a consistently low titanium, whereas 4^{th} - 5^{th} century glasses show a strong trend of increasing Ti, and concomitant Zr. Assuming that this represents the introduction of a new high Ti source of silica, the trend from low to high suggest recycled early material as a significant proportion of these newly formed glass objects.

Zirconium: Zirconium, like titanium, is common in sands. While titanium is usually present in concentrations an order of magnitude greater, it is concomitant in ratio with zirconium (Aerts et al. 2003). As such, while it can be diagnostic of recycled glass, Ti is a far better indicator, meaning Zr can be discounted. For later glasses, trace Zr can also enter the glass as plant ash.

Chromium: Chromium, while used as a colourant in glasses, does not serve this function before the modern period. The main source of chromium is the sand, specifically chromite ($FeO{\cdot}Cr_2O_3$) (Brems and Degryse 2014; Henderson 1985). As mentioned above, it is also associated with copper ores, so is potentially related to colouration in this sense.

High chromium is seen in Foster and Jackson's [2009] HIMT 1, also known from Foy's [2000, 2003] Groupe 1, as this production seems to show a less pure sand. This means there is potentially some usefulness in chromium in looking at mixing between HIMT-style and other glasses, such as with Ti. In reality, however, the concentrations are consistently so low (30ppm in HIMT1, and 10ppm in Levantine 1b (Foster and Jackson 2009)), and there are far more reliable indicators, do for this thesis chromium will not be used.

Strontium: While a small component of strontium can be introduced by plant ash in ash glasses, the sand and shells are the main source for Sr. Strontium isotopes have long been used as a provenenacing tool in geochemistry, even in archaeological tooth enamel studies. They have proven similarly useful for glasses, and have highlighted recycled glasses, especially when used in combination with absolute values of strontium (Degryse et al. 2006). This is discussed in Chapter 6.3.2.

Aluminium: Aluminium is also a common trace, predominately entering as part of the sand and shell fraction. Aluminium is present in seashells (Segar et al. 1971), as mentioned relative to calcium, but is also found in sand as a portion of plagioclase feldspars in sand (Henderson 1985). In River Belus sand, Al is as high as 4.26% (Turner 1954b). Due to the preportional relatioship expected between aluminium and calcium from the same source, there is some recycling potential, identifying mixed

sands. This is however limited and requires so many caveats as to be without much use on a large scale.

Barium: Barium, in naturally coloured glass, has been argued to have strong sand provenance links, but likely from marine lime components (Paynter 2006; Wedepohl and Baumann 2000). However, it is common in colorants and plant ash. As barium can be fairly variable in even a single sand source, it's potential for recycling is low.

Neodymium: Present in the sands used for glass making, in terms of simple parts-per-million, neodymium has not proven useful. However isotopically, it is far more versatile. The relationship between stable neodymium isotopes and the growth of neodymium which is the radiogenic daughter of samarium, is useful as a sand discriminant. This translates well into any produced glass, and it has potential for measuring glass recycling. This is discussed further under the isotopic systems for recycling (Chapter 6.3.2).

Nickel: Nickel can be used, in its divalent form, to cause colours- brown, pale yellow, through to purplish in potash glass- however it doesn't seem to be a common colourant in Roman glass (Bamford 1977, 38). It is associated with heavy elements in sand and Co and Cu colourants.

Phosphorus: Phosphorus is predominately present as a fraction of the sand, but is also present as trace within natron. While phosphorus, like sodium, has potential to be burned off, due to the lower content it is not deemed feasible for a large-scale recycling metric. Similarly, the correlation between iron and phosphorus within a glass could show a single glass source, so counter-indicate mixed recycling, however this would only be possible to demonstrate in very limited cases.

Other sand traces: Other traces in sand that do not seem to have recycling potential in most studies include lithium, vanadium, yttirum, niobium, tungsten, samarium, europinidin, dysprosium, ytterbium, cerium, lanthanum, bismuth, caesium, scandium, molybdenum, praseodymium, hafnium, thorium, gallium and beryllium. As well as this, uranium, which is also found in natron, and rubidium, which is also found in plant ash.

5.5.2 Traces related to alkali

Boron: Boron is a common trace in sand, but is also a part of natron. It is considered here under the term of the alkali as studies have shown a stronger relationship between the isotopic ratio of boron and the natron source in Roman glass (Devulder et al. 2014). However, as the study by Devulder and collegues showed, there is very little variation in this, indicating a single natron source for all the glasses analysed. Assuming, as the dominant model does, that almost all Roman period glass was made with one or perhaps a small handful of isotopically identical natron sources, this is not a particularly useful recycling metric. It perhaps has some place left in Late Antique studies but this is yet to be proven.

Other natron traces: Natron also contains sulphur (as thenardite) and chlorine (as halite). Both of these traces are very minor and do not seem greatly variable. Chlorine and sulphur could both potentially be lost from successive meltings,(Freestone and Stapleton 2015, 30) so could be seen as an internal recycling clock, though trying to make this a workable metric is not currently seen as possible at the scale necessary for discussing Roman glass. The potential for this will de discussed under future work.

5.5.3 Traces related to colourants

Two other elements that are common traces in colorants are arsenic and zinc, the latter of which is also common in plant ash also. Bismuth is also linked to cobalt. There is no evidence that either are of use in discussing the recycling of Roman glass.

Chapter 6

Glass Recycling in Archeometry

Particularly at the fringes of the Roman Empire, the recycled fraction of glass has been of great interest (Foster and Jackson 2009, 2010; Peake 2013b). Most focus, as this work does, on cullet recycling. Several different analytical techniques have been used to try and identify or quantify recycling in ancient glass, with varying degrees of success and caveats. They can be separated broadly into three areas of analytical focus: temporal changes in base glass, deliberate and incidental additions, and mixed provenances. Each can be measure through specific elements. All have some role to play in potentially identifying and quantifying recycling, and in reality all are a product of a combined understanding of recipes, chronologies and provenances. Under each of these broad categories nestle several related ideas, summarised as follows.

Temporal Changes in Base Glasses:

- Base Glasses 'Out of Time'
- Introduction of HIT-style Glasses - Fe, Ti, Mn
- Mixed Alkalis - Na, K, Mg, Ca

Deliberate and Incidental Additions/Losses:

- Mixed Decolourants - Mn, Sb
- Antimony in Coloured Glass - Sb

- Antimony 'Out of Time' - Sb
- Copper in Colourless Glass - Cu
- Other Colourant Trace in Glass - Co, Pb, Mn

Mixed Provenance:

- Isotopic Mixed Provenance - Nd, Sr
- Lime Mixed Provenance - Ca, Al

While there is a good deal of overlap in the method and theory of these techniques, the advantage of most is that they can be applied to legacy data without the need, necessarily, for further analysis. This means that data that has been collected for other considerations can be reassessed in the light of recycling, such is the case with the huge amount of isotopic data being amassed at Leuven under the direction of Patrick Degryse. This thesis is an effort to do precisely this with the major, minor and trace data generated from glass analysed in Britain.

Each technique is discussed in detail, with justification, as well as the potential for use of these elements as a metric within the database assembled here in.

6.1 Temporal Changes in Major Ingredients

At the height of the Roman Empire, primary glassmaking was exceptionally centralised, restricted to just a handful of major centres, creating just a few small groups of compositions (Freestone 2005). Although there seem to be some smaller workshops using sands across the Empire (Brems et al. 2012a,b), current research suggests they account for a negligible proportion of all Roman glass production.

As has been discussed at length in earlier chapters, there are essentially two very basic ingredients of first millennium glasses - a lime bearing silica source, and an alkali. The silica fraction is in the form of beach/river sand (or in some cases ground quartz, with the addition of shell). The alkali is either a natural evaporite salt, the

assumedly Egyptian sourced natron, or plant ash. The three main ways that these sources can be used to discuss recycling relate to the fact that they change over time. Primarily the concern across first millennium Britain is the change in alkali source from natron to plant ash, the mixed introduction of HIT-style glasses, and the appearance of glasses that are 'out of time'.

6.1.1 Base Glasses 'Out of Time'

This was chosen as the first category to discuss because, while not the most common appearance of recycling, it is the most obvious. Each glass type defined from the archaeological record has a relatively narrow range of primary production time. As such the appearance of a glass of a extremely outdated composition in a later context indicates some form of reuse - either recycled into a new object or curated.

This is most obvious in the case of entirely soda glasses after the change to a plant ash industry, such as seen in the Islamic tradition in the ninth century (Freestone et al. 2000). However, this can be seen also within natron glasses. Roman blue-green glass (manufactured in the 1^{st} - 3^{rd}) is seen in the early medieval levels at Lyminge, analysed for this study. They are found in late fifth to sixth century deposits. There is also a single shard of cobalt glass analysed from this site (SF 43), which is consistent with a Roman blue-green base glass coloured with Roman high lead cobalt. Again this is indicative of some form of recycling, this glass removed 200 years from the last primary manufacture of this type.

The appearance of particularly 'Roman' style glass amongst either HIMT or Levantine glass is also notable, such as a shard PCP-92-002, from the Petra church (Schibille et al. 2008). The rest of the window shards from this period are Levantine, indicating this one anomalous glass, which also is the only glass containing decolourants, probably had a different origin. The likely suggestion, give the particularly peculiarities of composition, is that earlier glass was recycled into this window.

These glasses are usually very easy to identify by their chronology [Table 3]. They can be considered by the relationship of several elements, notably Na, Ca, Al, K, Mg, Fe, Ti, P and S. If they can be clearly identified and labelled as recycled or reused. Using the nomenclature of Chapter 4.2, if their typology is contemporary to their find spots, this gives evidence of remelting practises, but glasses can also be reused, recovered or curated from older contexts.

6.1.2 Slow Mixing of HIT-style Glasses

The chronological relationships of base glasses is also what underpins this next recycling identifier. The introduction of new styles of glasses allows mixing to be highlighted. The subtler shifts in major elements over time are usually seen as changes in sand choices. First millennium glass falls into 9 or 10 groups: HIMT (High iron, manganese and titanium) 1 and 2, Roman blue-green, Levantine 1a, 1b and 2, Egypt 1 and 2, Serie 3.2, Roman Mn and Roman Sb. Roman blue-green glass is the most prolific glass from the first to third centuries, and tends to be seen as *the* glass composition prior to the fourth century. It is characterised by moderate iron oxide (0.6%), low magnesia (0.55%), low titanium oxide and moderate manganese oxide (0.26%).[1] Levantine glass, beginning in the fourth century, is low in iron oxide (0.4%) and soda (15%), but high in lime (5.5%), the soda and lime usually existing in an approximate 2:1 ratio. This is the type of glass seen at Jarrow (Freestone and Hughes 2006).

However, HIMT glass, as the name suggests, is high in iron, manganese and titanium, and was first identified as fourth century in Carthage (Freestone 1994). A now more problematic term, perhaps encompassing multiple origins, there is clearly major production/s of glasses that are high in titanium and iron, and sometimes manganese, seen across the ancient world, after the third century. There is debate as to whether this Mn is added separately, as an attempt to decolour this glass.

[1] These are the values from Freestone (2005).

The natural colour of this glass is more greenish-yellow than the blue-green of earlier Roman glass, and it seems antimony is no longer used as a decolourant. These HIT-style glasses appear in the fourth century and very quickly become the dominant glass in the Roman world.[2]

As this glass is introduced it is not seemingly viewed as any different to the pre-existing Roman tradition. There seems to be no difference in what is produced in this glass, except the shifting styles. The cullet of this glass is mixed indiscriminately with the glass of the preceding centuries, and the material made visually difficult, if not impossible, to distinguish. This causes a mixed chemical signature which clearly falls on a line between the known HIT-glasses and the blue-green glasses. These glasses have an elevation in iron, titanium and sometimes manganese, but does not reach the point of this primary production. In light of the trace elements, it is a combination of sources. Whether or not blue-green or Levantine glasses are being mixed might be apparent with lime, but this isn't as relevant as the fact that they *are mixing it*. The most logical explanation of this mixed type is cullet recycling, which can be identified by Mn, Ti and Fe ratios.

What is problematic, is that due to the large range of HIMT and the strong values, it very quickly obscures mixing. To demonstrate this, the mean values of HIMT 1 and blue-green glass from Foster and Jackson (2009) were hypothetically mixed in the simplest of models, taking no loss or thermodynamic considerations into account. When these new values are then compared to the ranges of values within one standard deviation of HIMT 1, blue-green and HIMT 2, reported in this same paper, the problem becomes quickly apparent [Fig. 6.1]. At a mix of 40% to 60% HIMT to blue-green glass, the latter becomes invisible in the mix. The values fall either on the extreme outliers of HIMT 1, or as a combination between HIMT 1 and

[2]The recent volume, *Things That Travelled* (Rosenow et al. 2018), contains examples of HIT-style glasses from Britain, Italy, Bulgaria and the Near East. See Freestone et al. 2018, p. 160 for lists of other papers dealing with HIMT.

HIMT	10%	20%	30%	40%	50%	60%	70%	80%	90%
Blue-Green	90%	80%	70%	60%	50%	40%	30%	20%	10%
Al	2.58	2.57	2.56	2.55	2.54	2.53	2.52	2.51	2.50
Fe	0.85	0.91	0.97	1.03	1.09	1.15	1.21	1.27	1.33
Mg	0.65	0.68	0.72	0.76	0.80	0.83	0.87	0.91	0.94
Ca	7.05	6.94	6.84	6.73	6.62	6.51	6.40	6.30	6.19
Na	17.39	17.58	17.77	17.96	18.16	18.35	18.54	18.73	18.92
K	0.77	0.74	0.71	0.68	0.65	0.62	0.59	0.56	0.53
Ti	0.11	0.13	0.16	0.18	0.21	0.23	0.26	0.28	0.31
P	0.09	0.08	0.08	0.07	0.07	0.07	0.06	0.06	0.05
Mn	0.67	0.78	0.90	1.01	1.13	1.25	1.36	1.48	1.59

	HIMT 1 MIN	HIMT 1 MAX	Blue-Green MIN	Blue-Green MAX	HIMT 2 MIN	HIMT 2 MAX
Al	2.2	2.78	2.36	2.82	2.02	2.48
Fe	1.13	1.65	0.69	0.89	0.62	0.82
Mg	0.82	1.14	0.55	0.67	0.67	0.85
Ca	5.44	6.72	6.6	7.72	5.43	6.57
Na	17.99	20.23	16.67	17.73	18.68	20.62
K	0.38	0.62	0.64	0.96	0.45	0.71
Ti	0.22	0.44	0.07	0.09	0.1	0.14
P	0.04	0.06	0.08	0.1	0.04	0.06
Mn	1.4	2.02	0.42	0.68	0.82	1.14

Figure 6.1: Using values reported in Foster and Jackson (2009, Table 4), this shows the mixing of different proportions of Levantine and HIMT glass. Blue indicates values that are consistent with HIMT 1 glass, red glass that is Blue-green and purple indicates values that could be consistent with either. Green indicates values that are consistent with neither, and yellow is those which are not consistent with the others, but is with HIMT 2.

2. Here one assumes the values are clearly enough recorded; in older reports, with a less complete range of elements, it becomes more problematic to identify this.

6.1.3 Mixed Alkalis

Of the changes in these major fractions over time, the one which has drawn the most attention in studies of recycling is the change of alkali, particularly the shift from natron to plant ash. However, the applicability of alkali changes to assess recycling only applies to a very specific circumstance, to glass that can be seen as 'transitional' Medieval glass. By AD 900, the bulk of glass making in Europe had shifted from being Roman-style natron glass, to medieval plant ash glass, often called 'forest glass' (Kuisma-Kursula et al. 1997; Silvestri et al. 2005). However, this happens very

quickly with the earliest example being Carolingian.

Plant ash is often viewed, with some just cause, as an inferior source material to natron or other 'clean' soda sources. Compared to natron, plant ash is far more variable in composition, due to inconsistencies between individual plants and the incompleteness of most combustion. It is likely to contain both more and a less standard range of contaminants. Despite the variability, wood ash glass is easy to identify due to a comparative elevation of K_2O, CaO and manganese (Henderson 1991a, 254). Although some later glasses are elevated in manganese for other reasons (ie. high iron, manganese, titanium (HIMT) glass), the potassium of plant ash glass sets it apart.

After the widespread adoption of natron, sourced primarily if not exclusively from Egypt, plant ash only seems to have been used only when natron was in short supply. Less-standardised composition and variable impurities leads to glass that can be particularly difficult to decolour, which was the dominant fashion from the Imperial period onwards and remained the preference for many high-value glasses. It is traditionally argued that its adoption in the West is due to a lack of connection to an Egyptian natron source, or a glass source exploiting it. Periods thought to have experienced restricted trade across the Mediterranean show a decrease of soda glass in the West, such that eventually by the end of the first millennium essentially all Western glass is wood ash glass (Freestone 2001).

However, it is also seen increasingly in the Islamic period in the Levant. Instead of forest glass, made from tree-ash, halophytic plant ash is used in the East (Henderson 2002, 596). It has been posited that environmental and political factors affected both the supply of natron in Egypt and the trade of it up into the Levant (Shortland et al. 2006). Essentially, by the ninth century fresh glass of either European or Eastern origin is plant ash. However, both before and after this change, a potential to discuss recycling appears.

The earliest example of known 'forest glass' is from the late eighth-century Carolingian palace complex at Paderborn. However, contemporaneous glasses seen in the green window glass at Beverley, Humberside clearly shows a mix of plant ash and natron (Henderson 1991a). While this could indicate a primary production using two different alkalis, plant-ash glass with the addition of older-style glass, shards of which are likely to enter the mix as cullet, seems more likely.

The Beverley glass evidently contains wood ash, highlighted by the inclusion of potash, lime and magnesium in high quantities compared to soda glass. However the relatively high percentage weight of sodium relative to potassium cannot be explained by wood ash alone, nor any other likely additions to the glass melt save natron, or a similar evaporite. As the manufacturers had to resort to plant ash as the alkali, it seems unlikely that they had access to fresh natron or natron glasses, or if they did it was limited. As natron has many other uses, mostly medical, it seems odd to waste this expensive commodity in a glass already adulterated with plant ash. Thus it is posited that the natron was probably added by way of natron glass cullet. In terms of the average weight percent in soda to plant ash, sodium drops from around 12-19% to 1.5-3%, and potassium oxide increases from <1% to 15-17% , calcium oxide from 5-11% to 11.5-16.5% and magnesia increases from around 1% to 5.5-7%.[3] The potassium oxide in the Beverley glass is notably low (7.5%), supporting the theory that not all of the alkali used is wood ash glass.

The dating of the site, 8th to 10th century, with a material cultural transition from local to Viking, is a period where one would be surprised to find extensive trade in fresh glass, specifically glass sourced from the Near East. Glass could have travelled through many hands, through the continent, and onto Britain, but evidence such as this green window glass showing this new composition implies a shortage or change

[3]Soda glass ranges taken from Freestone (2005), covering the averages of Levantine II glass from Bet Eli'ezer, Levantine I glass from Apollonia, HIMT glass from Carthage, Egypt II glass from Ashmunein and Roman blue-green glass from Leicester. The values for plant ash glass from Freestone (1992), colourless and blue glass from Westminster, green glass from Cluny.

of industry. Mixed alkali glasses clearly are not present prior to 851 at Beverley, then are not uncommon for a very short period afterwards. After this time, all glass is consistent with completely wood ash glass.

Only a small proportion of the total glass from Beverley has this transitional composition. Most had the expected late Roman composition of a soda-lime-silica glass (Henderson 1991a). It is clear there was still a source of natron glass available even into this later period in Northern Britain. Either Roman remnants were being recycled over and over, or glass that has been passing slowly through the continent, finally ends up in Britain. Either way, some of this glass is being 'watered down' with other sources of alkali, notably plant ash. Given this, and evidence from textual sources which have be discussed in detail elsewhere, it seems likely that the silica fraction entering the glass is not purely, and perhaps not at all, from fresh ingots. Recycled batches of cullet, bulked out with fresh, or cullet, plant ash glass is the most likely assumption.

There is also the potential that just plant ash could be added to a melt that had become too 'fast'. Multiple recyclings of natron glass would cause a loss of volatiles such sodium, as well as phosphorus and chlorine. A loss of sodium makes the glass harder to work at a lower temperature. In practical terms, this makes blowing, particularly mould blowing, far more difficult, with the glass requiring multiple returns to the glory hole. This can be counteracted by the addition of more alkali, ie. handfuls of ash, a very easy thing to accomplish in a small wood burning furnace.

A brief note should be made that ash glasses in the first millennium fall into two categories, forest and halophytic plant ash glass. The latter is common in the Near East, North Africa and Spain, corresponding to what becomes the Islamic tradition, and the former is the European tradition. There is some some indication of a prefer-

ence of plant species, beech for Forest glass and Barilla or Salicornia (glasswort) for Islamic glass. The rather unique processes of halophytic plants incorporate far higher amounts of sodium than other vegetation, in fact growing with partial or full root submergence in salt water. As such, when ashed, these plants have a much higher sodium content than tree ash. However, both potash and magnesia are appreciably lower (typical values of halophytic plant ash glass: Na 12%, K 2%, Ca 10% and Mg 3%). This means that a glass with values such as Beverley's are not consistent with Islamic plant ash glass but with the forest glass, which leads to a much higher potassium value. The elements considered for analysis of this are Na, K, Ca and Mg.

6.2 Deliberate and Incidental Additions

Apart from the variation in the base composition of glass, the main deviation from the standard compositions occurs with deliberate additions used for aesthetic purposes. Almost all early research on glass compositions focused on deliberate additions to silica-lime-alkali glass (ie Brill 1968; Sayre and Smith 1961). Usually used for aesthetic purposes these include decolourants, such as antimony oxides, colourants, such as copper oxides, and other specialised additives, such as lead for brilliance. These have been a fervent focus point of recycling studies, particularly the decolourants of antimony and manganese. This thesis will discuss five potential additive recycling indicators: mixed decolourants, antimony in coloured glass, antimony 'out of time', copper in colourless glass and other trace colourants in glass.

6.2.1 Mixed Decolourants

From the late first century AD onwards, the technique and taste was developed for colourless glass. Previously, high status glasses had been opaque, heavily coloured and patterned such as mosaic glass vessels (eg. Fig. 6.2). The new decolourised glass,

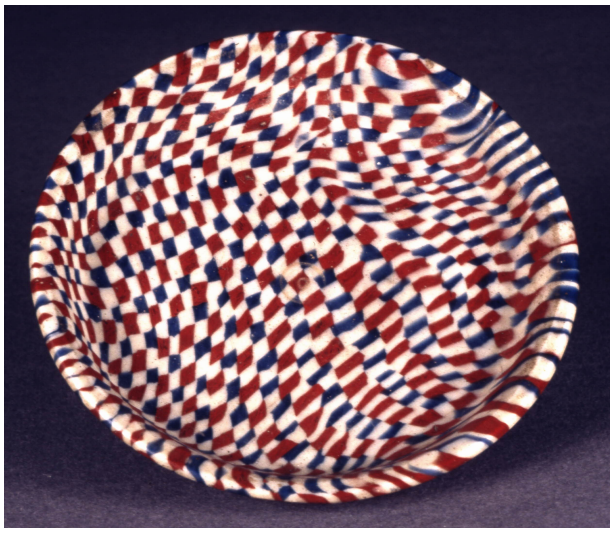

Figure 6.2: Polychrome Mosaic Bowl, found in Turin. (British Museum, Registration No.: 1922,0517.1, Image No.: AN368069001 © The Trustees of the British Museum.)

evocative of rock crystal, quickly became preferable in most cases. While originally both expensive and difficult to produce, decoloured glass soon became the standard, particularly for tableware, and it remained so until the Late Antique period, when the availability of materials once more changed (Cool 2006, 226). Glass once more became a comparatively elite product, even when naturally coloured, and seems to have remained until brown and green forest glass became the standard, while colourless glass remained highly elite, if present at all. It is this penchant for decoloured glass that gives us an indication of recycling.

To summarise the procedure, glass is decolourised by a redox process. Oxidising agents are added to reduce the transition metals that traditionally colour glass, which have been introduced as natural impurities. Without this reaction, glass exists in a range of hues, yellows, blues and greens, of different intensities. The two traditional substances used to 'wash' glass are antimony and manganese compounds. These afford two possible ways to identify recycling, and can highlight two different forms of recycling.

Each of these decolourants used during the Roman and Early Medieval periods

have specific chronological constraints, with a shift from antimony to manganese occurring around the end of the third century (Jackson 2005). It is usually agreed that deliberate addition of both antimony and manganese to a single glass batch was very unlikely. There are glasses, however, from as early as the second century, showing a mixed compositions (Jackson 2005). For instance, an ICP-AES study of 128 colourless shards from 19 sites in Britain, dating from the late 3^{rd} to 4^{th} centuries, highlighted one compositional group with moderate levels of both antimony and manganese, and it was suggested that this was a recycled group (Foster and Jackson 2010). Essentially, cullet decoloured by antimony and manganese, often indistinguishable to the eyes of a worker, was melted together to create a mixed decolorised glass.

It must be taken into account that this is not the only explantation of mixed decolourants (Jackson and Paynter 2016). However, if neither decolourant alone is high enough to be responsible for removing the colour from glass, but each is also too high for incidental inclusion (0.5% Mn and 100ppm Sb), recycling is a likely candidate. These account for the largest proportion of glasses in Foster and Jackson's study (group 3, n = 69, 54% of the shards analysed) and support the theory that ancient glass recycling is conscious, discriminate and exceedingly common. Colourless glass, in this case, is clearly attempted to be recycled separately from coloured glass and while this will be shown to not always be the case (Chapter 6.2.2), it seems to be recognised as the preferable arrangement.

This same mix of decolourants is seen at what could be considered almost the opposite end of the Empire to Britain, in the Levant. At the Late Roman site of Khirbet et-Tannur this mixed-decolourant glass seems to be occurring (Schibille et al. 2012b). Transport of raw glass to Jordan from coastal Levant seems as if it should pose far less problems than to Roman or Post-Roman Britain. There are two other things at play here, both that the Levantine coastal trade seems strongly maritime

focused, but also one must consider cost as well as pure availability. Cullet recycling processes requires no further raw materials, though it should not be forgotten that cullet itself could be seen as a commodity. As well as this, the temperature required to melt shards is far lower than to create fresh glass.

Both sourcing and economics can be major driving factors in recycling, and while Khirbet et-Tannur seems as if it should find glass more physically accessible, it is clearly more complex than that. A preliminary statistical examination of data collected from published British sites, in expectation of this thesis, showed that mixed decolourants become more common across time, becoming notable dominant by the fourth century (Sainsbury 2016).

6.2.2 Antimony in Coloured Glass

Following on from the idea of glass containing decolourants, another obvious indication of recycling is the appearance of decolourants in naturally or deliberately coloured glass. This has been discussed under Chapter 5.4.2. The addition of Mn or Sb is expensive, unnecessary and, particularly in the case of coloured glass, unhelpful. For instance, the addition of a decolourant to an intentionally brightly coloured vessel makes no sense technologically, unless part of the glass entering the mix had already undergone the addition of expensive decolourants. Silvestri (2008) used such an argument to discuss the proportion of recycled material in the 'naturally' coloured glasses of the *Iulia Felix* shipwreck (also known as the Grado wreck). Particularly she highlighted cases of glasses that show no visual indication of attempts at decolouring but contained elevated antimony and manganese (Group Ic1b). Glass of this type has proven common across the first millennium and across Europe and the Mediterranean.

Both antimony and manganese oxides are expensive additions to glass and, above around 100ppm Sb and 0.5% Mn, are exceptionally unlikely to be natural contaminants. This has been observed by many, including Jackson et al. (2003b) in relation

to the likely glass-working site of Coppergate, York. Manganese is less useful than antimony, as known what percentage of the Mn is deliberate addition, as apposed to native within sand would require a clearer knowledge of which sands were used in the original glass production. Something which is not possible in most archaeometric case. At the site of Coppergate, a group of coloured glasses contain antimony in percentages nearly as high as that observed in contemporary colourless glasses. There are, of course, two logical explanations in such cases. One, that this is a failed batch, intended to be colourless, or two, that it is indicative of recycling.

Colourless glass cullet could have easily been mixed with coloured cullet, producing a glass with insufficient decolourant to render the glass decolourised but higher in antimony than would be naturally occurring in any of the glass components. It is interesting that in Jackson et. al's data from the fourth century, the cullet seems quite mixed, whereas the glass upon the *Julia Felix*, dating from the 2^{nd} to 3^{rd} centuries, the glass cullet has clearly been sorted with some care paid to the colour (Silvestri 2008). Both geography and chronology are likely relevant to this.

When the antimony and manganese oxides of all of the coloured glasses in this current database are plotted against each other, it can be seen that a large amount of third century glasses, as well as glasses only broadly datable as 'Roman', show more than 0.3% Sb, which is most easily explainable by recycling. As mentioned, the elevated levels of manganese seen primarily in glasses dating from the third century onwards, is more problematic. Around this period, the standard composition of much glass changes to HIT-style glasses. This would explain the variation. However, HIMT glass from Carthage has shown an average manganese value of 2.66% (Freestone 2005), much of the British glass falls well below that. As such, mixing is still a valid explanation, though one would expect a proportion of the cullet could be HIMT glass, rather than manganese being used as a decolourant.

Antimony in coloured glass can also be explained by a different sort of recycling,

which in this case we have called 'incorporation'. It seems to have been common in the Late Antique period to add brightly coloured small pieces of glass to essentially fresh melts. The typical example is the recycling of glass tesserae as prepared blocks of pigment. These very brightly coloured tesserae are usually scavenged from their previous uses, as seen at Aiano-Torraccia di Chiusi in Tuscany (Cavalieri and Giumlia-Mair 2009), and are very usually opaque. The opacifer in the Roman world was, rather confusingly, also antimony. When added in a significantly higher quantities than required to decolourise, it acts as an opacifier (See Chapter 5.4.2). Thus, the appearance of antimony in coloured glass could easily be the result of tesserae as dye, as is also seen by Wolf et al. (2005) at Sion, Switzerland, and by Schibille and Freestone (2013) San Vincenzo al Volturno, Italy, among others (Sanke et al. 2002).

The inclusion of antimony in coloured glass can really only be explained in an economic sense by one form of recycling or another; whether by inclusion recycling of tesserae or cullet recycling of colourless and coloured glass together. Manganese is slightly more problematic as it is found in high concentrations in all later glass (so called HIT-style glasses) regardless of colour, and thus must be considered in more depth.

For the sake of this thesis, over 100ppm of antimony in coloured glass is considered indicative of an 'apparently recycled' glass.

6.2.3 Antimony 'Out of Time'

Antimony has one more crucial use as recycling indicator its appearance 'out of time'. In 1961, Sayre and Smith noted that there was a distinct group of antimony glass, with a specific chronology. Many further studies have concluded that all across the Roman world, antimony was used as a decolourant in glass until, at the end of the third century, the less effective decolourant manganese beings to appear with and/or replace the antimony (Freestone et al. 2002; Jackson 2005; Mirti et al. 1993; Velde

and Gendron 1980). As antimony is the better decolourant, this change is likely driven by something other than technical choice. Antimony in glass first appears in around the during the Late Bronze Age, in the production of opaque whites and yellows, but falls out of use in the mid-fourth century AD. When the source was originally considered to be Eastern Europe or Iberia, this was linked to key historical events; Dacia experienced troubles in the late-third and most of the fourth century from Gothic incursions, and Ibera was ceded to Persia in 363. However, this is speculation, and the actual source of antimony is not confirmed.

As has been mentioned in relation to mixed decolourants, antimony is not present above a few parts per million in either the sands, quartz pebbles nor common alkalis used for first millennium glass. It is deliberately added. Glasses that are in forms dating from the late third century onwards and shown to contain any antimony, whether in the amounts used for full decolouration, mixed decolourants, or in coloured glasses, indicates glass that has probably been recycled.

There are notable quantities of colourless, high antimony glasses in Britain across the fourth, fifth and sixth centuries. It seems that a concerted effort was made to recycle this expensive colourless glass separately in later periods. This will be discussed further in coming chapters.

6.2.4 Copper in Colourless Glass

Similar to decolourants, the presence of some colourants or other additives in high concentrations, despite the glass not visually demonstrating that colour, can indicate recycling. The most obvious example is copper, commonly used to colour glass, being found in colourless or naturally coloured glass. Freestone et al. [2002] noted an increase in copper in Cypriot, Italian and Northern British glass relative to a raw chunk at Apollonia in Israel, seen as contamination from successive recycling. Each site moving at a further distance away from the primary site exhibited more and more

copper. This same elevation in copper is seen on many late Romano-British sites, noted by Foster and Jackson [2010], where over 50% of samples contain greater than 100ppm of copper, too low for deliberate copper addition but too high for incidental addition, as native in glass making ingredients.

As discussed earlier, copper is one of the most common colourants, and thus is generally present in a lot of glass cullet. It enters glass either through the intentional addition of copper or copper salts for the colouration of glass, or tainted cullet. The latter, the addition of a small amount of the copper-coloured glass is recycled into a predominately colourless melt, is the most common. This is often only as decorative element, such as blue trails and blobs on predominately colourless vessels; a common decoration on Roman forms [Price and Cottam, 1998] and remaining so into the Early Medieval period. It is clear that for the most part, in the Roman period, glass recycling seems to have implemented a sorting of colours, but this is an imperfect system, leading to an accelerated amount of copper in recycled glass.

6.2.5 Other Colourant Trace in Glass

As well as copper, several other colourants are potentially related to recycling, particularly lead, cobalt and tin (Wolf et al. 2005). As well as this, nickel and zinc have shown to elevate, being common traces in colourants (Heyworth et al. 1991). While there is also some potential for iron, manganese and titanium, this is likely related to the inclusion of HIT-style glasses so it will be discussed separately (Freestone and Hughes 2006).

Of these others, the one most commented on is lead, as it is assumed to be a matter of contamination from continued recycling, traces from crucibles etc, but this is a problematic assumption as lead is also deliberately added for brilliance, particularly for glasses that are going to be cut (Baxter et al. 2005). Iron is similarly thought to increase though successive recycling and could be either from deliberate colourants

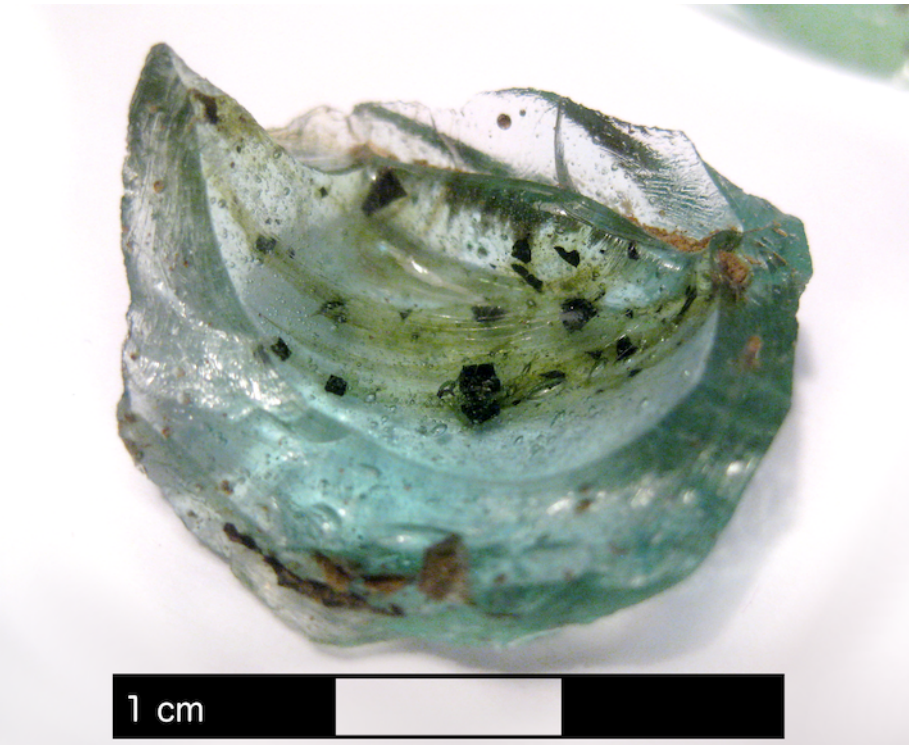

Figure 6.3: Iron-scale trapped within a moile, the glass cracked off the blow pipe, excavated from Lyminge (SF 457). The spreading green from the iron-scale indicates the increased dissolution of iron into the glass.

added by the included cullet, or from contaminants, such as iron scale from blow pipes [Fig. 6.3].

While all of these traces are useful in certain circumstances, the possible range is such that general comments can't easily be made. This means in practice none of these are currently of use as a general metric. Also, it has been suggested that with successive recycling, all glass should essentially become indistinct, which makes such determinations even more problematic (Jackson 1996; Mirti et al. 2001). For a uniform approach, copper seems the element with the most potential, after antimony and manganese.

6.3 Mixed Provenance

As well as glasses made at different times having different signatures related to basic changes raw ingredients, the same is true of glasses produced in different areas and this too can be used to highlight recycling. This is more difficult then the metrics described above as the overwhelming factor dominating the types of glass available at sites seems to be chronological, rather than regional. It seems that single areas of production dominate for most periods. However, there is still potential, both chemically and isotopically.

6.3.1 Chemical Mixed Provenance

There are approximately 9 primary glass groups in the first millennium. Our understanding of them has developed over time, through the work of a variety of authors, and a combination of the groups included here (Table 3) as well as other analyses which are individually not relevant to this current study. These are Egypt 1, Egypt 2, HIMT1, HIMT2 (Weak HIMT, Series 2), Levantine 1, Series 3.2, Levantine 2 (Bet Eli'ezer), Roman Sb, Roman Mn.

While there is significant variation in trace elements, these groups primarily differ in major and minor elements in the sands, such that they can be differentiated on plots such as TiO_2/Al_2O_3 against Al_2O_3/SiO_2. Due to this, it can be theorised that a degree of the spread between these groups is a mixing or blurring of these primary groups. However, due to the extreme mixing thought to occur in all Roman glass, ie. the prevalence of cullet recycling, it is difficult to delineate the primary natural spread of each group. Depending on the period and the glasses present, at some times our understanding is better than others.

Perhaps the most useful and simplest of these provenance metrics for seeing recycling is that of calcium. When calcium in marine sands has a linear relationship

with aluminium, this is related to the origins of the sands, and as such, the ratio and absolute values have between the two has been shown to be different and somewhat discriminant for the major groups of the first millenium, ie. Levantine 1, Bet Eli'ezer, Egypt 1 and 2, Roman blue green, Roman antimony glass (Schibille and Freestone 2013). However, as there is a great deal of overlap, it is difficult to discuss discrete groups. It seems likely that some of the unusual groups, which also have raised impurities (Šmit et al. 2013), are a matter of the mixing of groups. The fact that these groups are not closely defined means there are far preferable metrics.

6.3.2 Isotopic Mixed Provenance

As has been discussed, most isotopic systems in glass indicate sand provenance. Signatures that are inconsistent with any one sand source may therefore indicate recycling. While the neodymium/samarium system may highlight some mixing, strontium is the best contended for a systematic metric.

The most pertinent use of strontium isotopes in relation to this current study is included in the paper by Degryse et al. (2006). This paper looks at the secondary 'workshop' production of glass at Sagalassos in southwestern Turkey. While glass analysed at this site shows two large discrete groups of Sr ratios, there is another set of glasses that fall on a continuum between the two. Although it could be a matter of a heterogenous silica source or several sands being mixed together prior to production, Degryse et. al. favour the explanation that it is indicative of recycling, with end members being HIMT and blue-green glass. This is consistent with their other studies of first millennium glass.

There is some suggestion that heterogeneous lead signals throughout a single glass type would indicate more than one sand source used, and again cullet is suggested, though it could simply be a variation across the sands used (Degryse et al. 2006). As it currently stands, lead isotopes do not seem very useful for glass recycling.

While both neodymium and strontium isotopes have shown some potential for assessing recycling, both the lack of broad study and the prohibitive cost of the procedure mean that the most obvious choice for assessing recycling, at present, is compositional analysis. This is also because there is a huge wealth of existing data that can be drawn upon, allowing us to step back and consider compositional changes in a much broader sense, across space and time.

Chapter 7

New Analyses

As discussed in the Methodology, an aim of thesis was to expand the database collected with fresh analysis. For this, two sites were chosen, Dorchester-on-Thames in Oxfordshire and Lyminge in Kent.

7.1 Dorchester-on-Thames

The bulk of the fresh analyses in this thesis were performed on the glass excavated from the site of Dorchester-on-Thames, Oxfordshire. This excavation, jointly run by *Oxford Archaeology* and the *School of Archaeology, University of Oxford*, covers areas both in the Minchin Recreation Ground and Village Allotments in Dorchester-on-Thames. [Fig. 2.4, 7.1]

Of the 371 shards and beads of glass excavated in the seasons of 2013 and 2014 in the Village Allotments, 151 were selected to be analysed. The glasses selected have been summarised [Table 5]. A discussion of the catalogue and the justification for these choices is included 'Dorchester-on-Thames Glass' [page 141], as is a brief discussion of the catalogue of the glass from the site from the excavations in 2013 and 2014. Before this, it is worth iterating why the site of Dorchester-on-Thames was chosen for study.

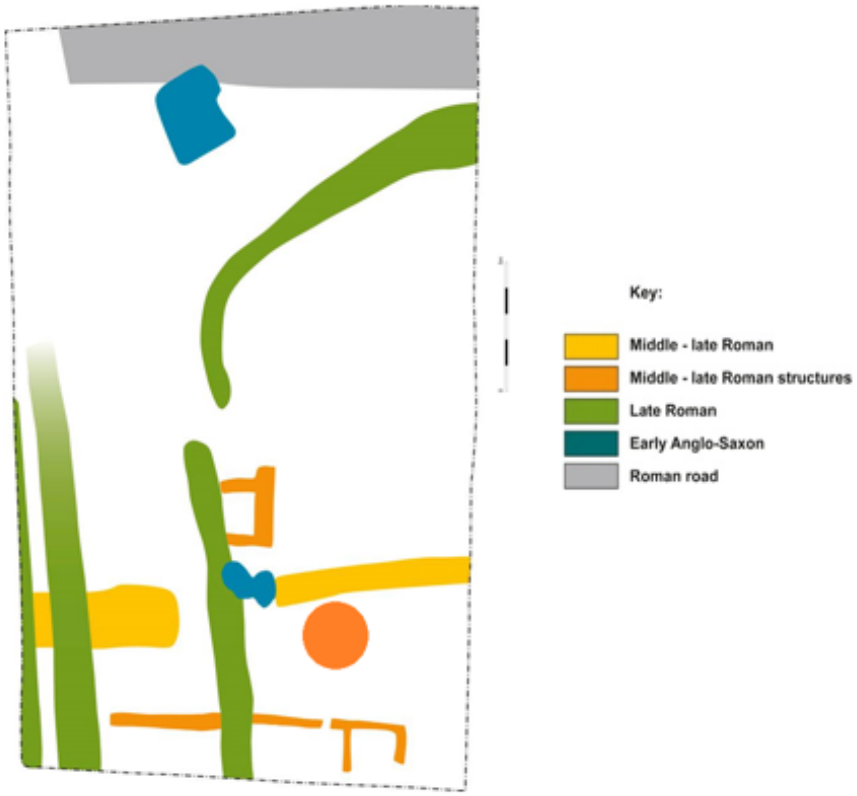

Figure 7.1: The layout of Dorchester-on-Thames excavations, used with kind permission of Wendy Morrison.

The History and Excavations

Falling between the confluence of the most significant river in history of Britain, the Thames, and the smaller but still vital Thame, the present village of Dorchester-on-Thames has a long history.

This site has been used for seemingly the entire human history of Britain. This begins in the Neolithic, where this focal crossing is teeming with burial mounds, mortuary enclosures and similar features. This ceremonial significance continues into the Bronze Age, and becomes urbanised in the Iron Age. To the South West of both the modern village and the Roman site, the Dyke Hills ramparts enclose what is believed to be an oppidum, which although unconfirmed by excavation, would make the site a prime spot for Roman establishment after the occupation.

The newly arriving Roman forces frequently took control over major river crossings, sometimes on top of, sometimes abutting, existing Iron Age settlements. In the case of Dorchester-on-Thames, a fort was constructed to the North. This fort was eventually partly covered by the later walled Roman town that was situated here (Rodwell 2009).

What is more unique about the story of Roman Dorchester is not its genesis, which follows a fairly common path. It is the fact that it remained a site of some importance as the Romans withdrew, existing into the confusing new 'post-Roman' world. Dorchester remained so connected in fact that in AD 635, it was established by Birinus as the first bishopric in the kingdom of Wessex. It remained a bishopric until the Norman Conquest, when in 1071 the seat was eventually transferred to Lincoln by William I (Booth et al. 2012; Rodwell 2009).

Because of this unusual situation, the town never really shifting far, it forms the perfect place to study periods of transition and as such, it is the perfect addition to

this database. The prevalence of Late Roman and Early Medieval glass also helps add to the paucity of data in such a period.

Dorchester-on-Thames has also been both blessed and cursed by its proximity to the university town of Oxford. The concurrent rise of the university and the continuation of Dorchester even into the medieval period means that it has been extensively explored and commented on for a good number of years.[1] One of these early contributors was the antiquarian Hearne (1711). This was followed by many years of study, particularly focused on the abbey. As well as these academic sojourns, Dorchester has also been the subject of a large number of excavations, though many small scale, with the continuous occupation and extensive gravel exploitation leading to a huge number of commercial digs, especially in the last twenty years.

The first series of systematic excavations from Dorchester-on-Thames were done in 1962 and 1963, by Frere (1984) for the then *Ministry of Works*. Prior to the current excavations at the site, this remained the most significant work on Roman Dorchester (Morrison 2009, 28). This, like many excavations at Dorchester, was prompted by housing development and was centred on the Village Allotments. As it transpired, the planned development never went ahead and thus the allotment saw not only two seasons by Frere, but is also the main focus point of the present excavations.

What is currently known about Dorchester-on-Thames from these various excavations is considerable, and has been neatly summarised in a small monograph published by the local parish (Booth et al. 2012), and more fully catalogued in Rodwell (2009).

Dorchester was one of only two nucleated Roman settlements in the Oxford region,[2] lying on the road connecting the two important settlements of the town, Silchester, and the fort, Alchester. The formal defences of the city seem to have enclosed

[1] Camden's Britannia mentions the Roman origins of Dorchester, and that coins are often found, and his eighteenth century translator and commentator, Richard Gough, comments on the stone and metal still coming out of the ground, and the well known earthworks (Camden 1806).

[2] The other is Alchester, which lies 17 km northeast of Oxford, and also seems to have been built on top of, or adjacent to, a previously existing Iron Age settlement (Sauer 2006, 7).

an area of approximately 5.5 hectares, and explorations have suggested they began as earthworks, potentially in the later second century, before being replaced with a stone wall during the later Roman period (Booth 2014, 265). There doesn't seem to be much military evidence related to the transformation of Dorchester from fort to town but agriculture and industry become very intensive in the later Roman period, especially pottery production.

Dorchester seems to have flourished throughout this period, with other excavations revealing an extensive cemetery at Queenford Farm (Chambers 1987), which covers the transformation to Late Roman, where burials become poorly furnished and heads east-facing, indicating Christian burials. What is more interesting is that the radio-carbon dates of the later burials at Queenford Farm show it was in use until at least the early-fifth century, which is near contemporaneous with nearby early Anglo-Saxon cemetery at Wally Corner, Berinsfield (Boyle et al. 1995). Queenford Farm is around half a mile northeast of Dorchester Abbey, and Wally Corner, just less than one mile north of the Abbey, yet both seem to have been in use contemporaneously, displaying two very different cultural assemblages. It appears that both a Late Roman christianised population and a Germanic 'pagan population' both existed here.

Early Anglo-Saxon finds and features occur consistently within the walled area of Roman Dorchester (and beyond, for example at Bishop's Court just to the west). These are closely juxtaposed with the latest Roman and (apparently) very early Anglo-Saxon activity within Dorchester. Particularly early Saxon pottery occurs in association with large amounts of Roman finds in middens. Within what became the cloister of the Abbey, there is the first evidence of Early Anglo-Saxon occupation; A sunken feature building. This very early sunken feature building is detailed by Frere (1984, 123) and discussed further by Morrison (2009, 49-51). This is one among many. The Anglo-Saxon Chronicle describes this area as British until 571 (Rodwell 2009). After this, there begins a series of more typical Anglo-Saxon timber-framed

building.

There seems to be agricultural activity occurring inside the city walls during the Late Roman period, but the city is clearly still connected with the Roman world as of the 250 coins at the site, a large proportion come from the very last period of coin issued to Roman Britain (AD 388-402). All of this, along with significant amounts of Germanic metalwork, has lead many to focus on the potential interaction between the Late Roman and early Anglo-Saxons here. The contemporaneous 'Roman' and 'pagan' cemeteries has helped spur this.

Dorchester has always stood out as having a large amount of metalwork from this late period, sometimes with difficulty differentiating between Germanic incomers before or after 410, who are historically viewed very differently. Two burials at Dyke Hills and one near the Minchin Recreation Ground have males with significant metalwork, but more interestingly, the associated women have a mix of Romano-British and continental Germanic material. This is particularly interesting in potentially informing our understanding of continuation versus discontinuity, at least in the area of Dorchester-on-Thames.

Glass, too, is potentially a way into understanding this.

Dorchester-on-Thames Glass

This is the first focussed analytical study of glass to come out of excavations at Dorchester-on-Thames. In Foster and Jackson (2009), 9 glasses from Frere's excavations were analysed: 2 from 1962 and 7 from the 1963 excavation. This current ongoing excavation have produced 371 glass finds from 2013 and 2014, including individual shards, collections of multiple, joining shards and beads. The glasses were characterised by their colour in transmitted light, except in the case of a single shard (DOT07.4 - 8365) which was a very very dark green in transmitted light, but clearly

an example of Roman 'black' glass.[3] While a great many of the other papers included in the database use a dizzying array of different colour descriptions, such descriptors are hugely subjective, and thus very difficult to compare paper to paper, let alone archaeologist to archaeologist. Similarly, the application of colour systems like the Munsell Colour Charts tend to be too specific for large scale analyses, glass colour being easily influenced by minor furnace conditions or deposition. For this reason, the glasses have been fairly broadly categorised. Some colours, such as the ubiquitous Roman 'blue-green' fell into a very narrow range of shades. However, there was a great range of green colours, so a differentiation was made between the very soft greenish or yellow tint, that is likely incidental, labelled as 'naturally coloured' and a stronger coloured greens, actually labelled 'green'.

The range of colours observed was green (188, of which 20 were very strongly coloured), nearly colourless (95), blue-green (51), yellow (9), blue (6), brown (4), black (2), white (2), colourless (1), and some too weathered to identify original colour (5). As well as this, there were 8 samples of glass slag, potentially from either metalworking or glassworking, but more likely the former. 150 glass samples were selected for analysis, with balance given relative to percentage of colours found on site [Table 5, 7; Figs. 7.2 - 7.11] . However, as discussed previously, only 104 glasses were actually analysed.

The glass was spread over a huge range of contexts; Roman, Late Roman, Early Medieval and one likely modern piece. The hope is that by tracking such a long spread over a single site the continuity or otherwise of the transition period will be able to be assessed.

[3]A better term is 'black-appearing' glass, as it is never black but rather very very dark, usually green, glass. True black glass does not appear in this period.

Figure 7.2: Glass from Dorchester-on-Thames: Left to Right, Top to Bottom: 9443, 9676, 9292, 9422, 9199; 9023, 8901, 8968, 8985, 8668; 4336, 3788, 4298, 3948, 8626.

Figure 7.3: Glass from Dorchester-on-Thames: Left to Right, Top to Bottom: 8468, 8740, 8365, 4737; 8322, 3846, 3343, 4022, 3213; 8452, 9779, 3773, 8962, 4748.

Figure 7.4: Glass from Dorchester-on-Thames: Left to Right, Top to Bottom: 3177, 3188, 3254, 3271, 3332; 3357, 3435, 3439, 3501, 3518; 3524, 3556, 3584, 3597, 3640.

Figure 7.5: Glass from Dorchester-on-Thames: Left to Right, Top to Bottom: 3643, 3656, 3658, 3711, 3719; 3779, 3819, 3986, 4006, 4041; 4122, 4136, 4174, 4196, 4210.

Figure 7.6: Glass from Dorchester-on-Thames: Left to Right, Top to Bottom: 4288, 4328, 4363, 4387, 4415; 4437, 4455, 4518, 4597, 4617; 4644, 4650, 4738, 4740, 4752.

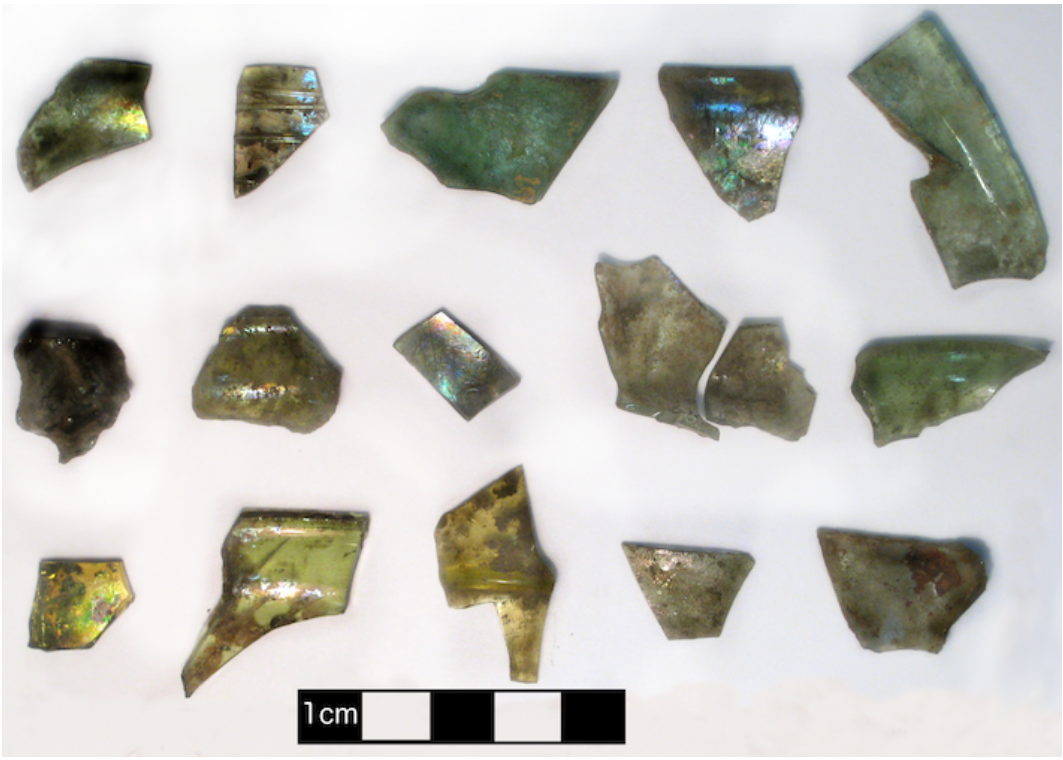

Figure 7.7: Glass from Dorchester-on-Thames: Left to Right, Top to Bottom: 4751, 8473, 8506, 8548, 8593; 8651, 8720, 8913, 9079, 9257; 9260, 9290, 9408, 9481, 9553.

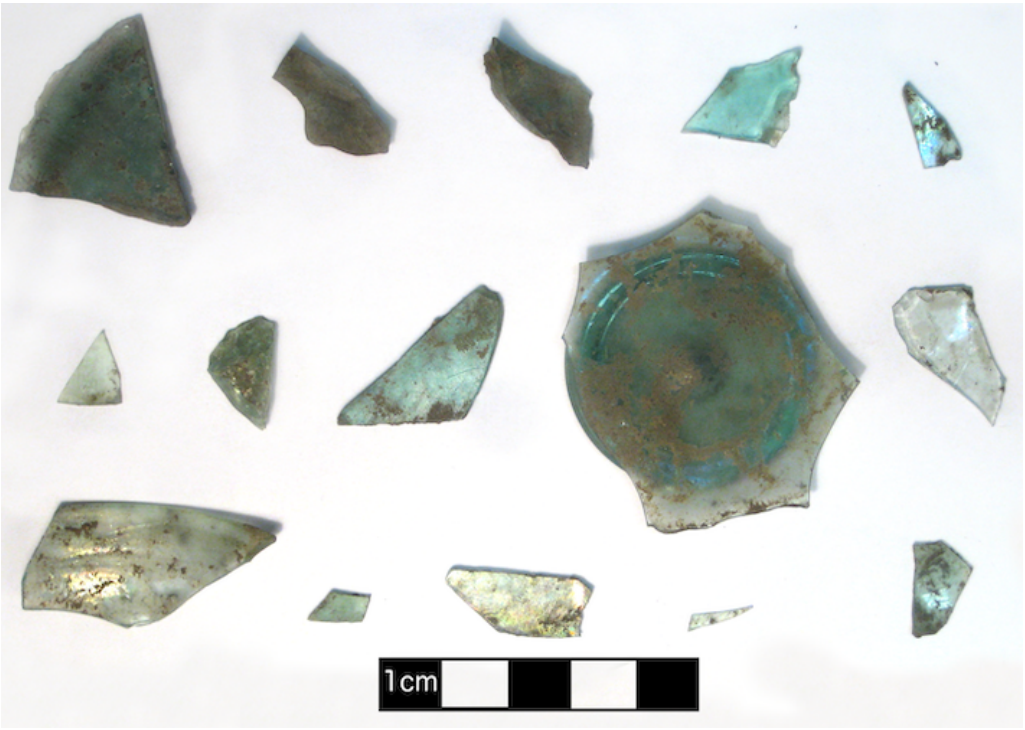

Figure 7.8: Glass from Dorchester-on-Thames: Left to Right, Top to Bottom: 3040, 3279, 3361, 3436, 3531; 3745, 3756, 3771, 3872, 4049; 4096, 4100, 4265, 4315, 4318.

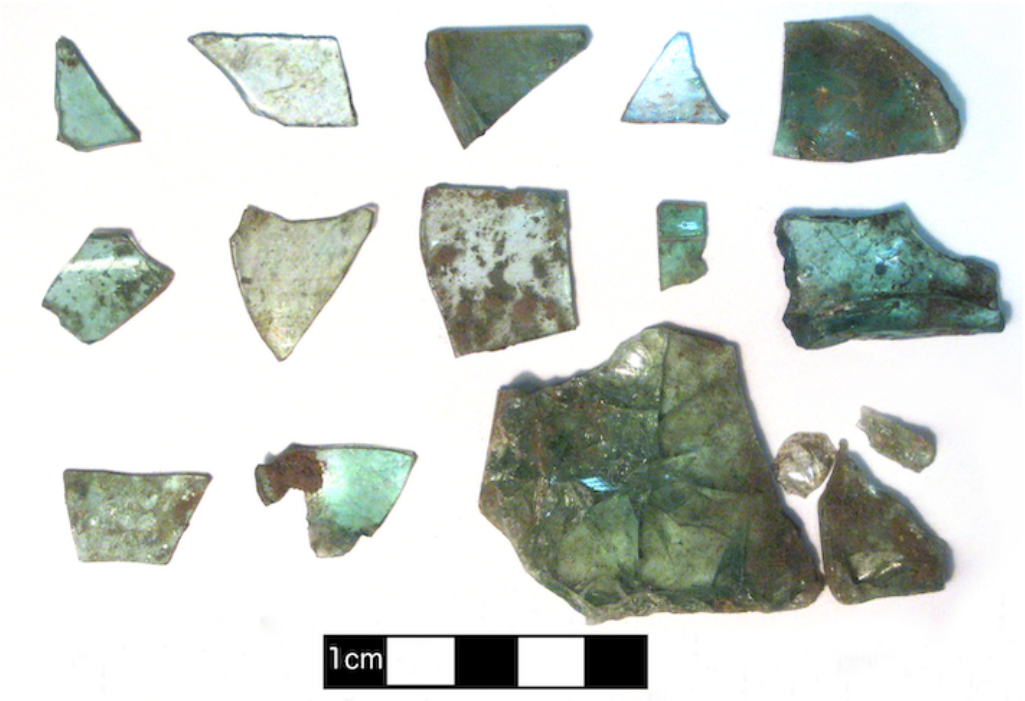

Figure 7.9: Glass from Dorchester-on-Thames: Left to Right, Top to Bottom: 4439, 4746, 8342, 8438, 8534; 8664, 8784, 9221, 9281, 9434; 9496, 9625, 9636.

Figure 7.10: Glass from Dorchester-on-Thames: Left to Right, Top to Bottom: 9132, 9509, 3053, 3054, 9746; 3371, 3699, 3903, 4009, 4283; 4333, 4475, 4537, 4604, 4753.

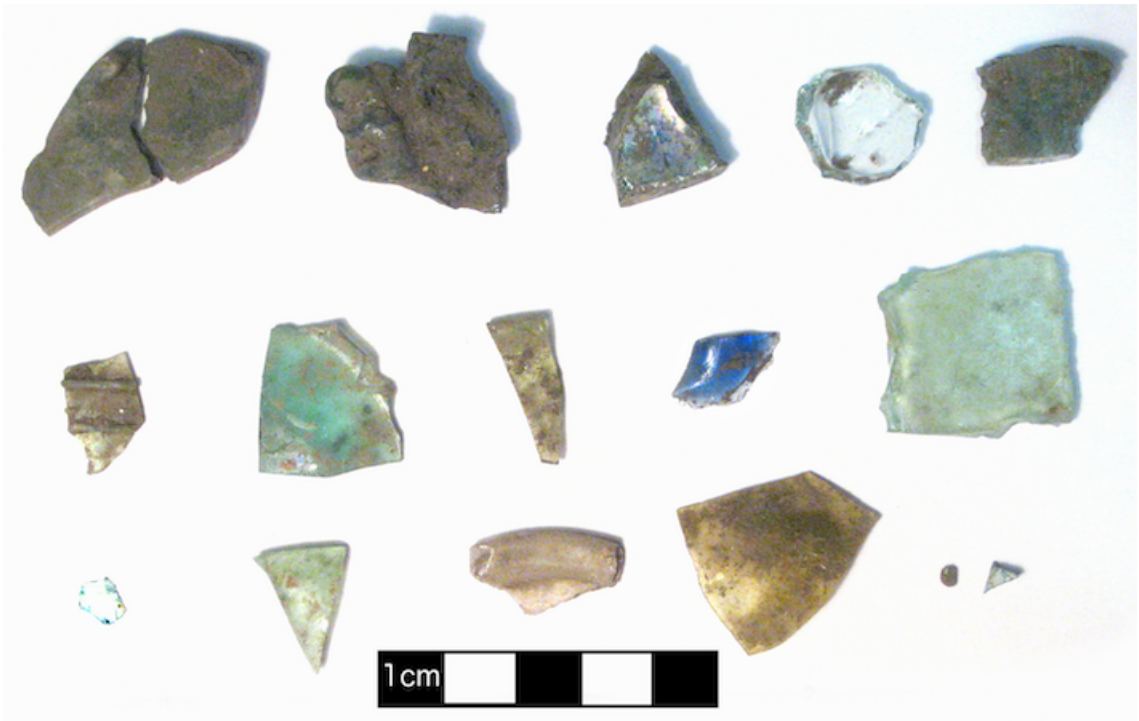

Figure 7.11: Glass from Dorchester-on-Thames: Left to Right, Top to Bottom: 3093, 3131, 3486, 3788, 4213; 4605, 8535, 8583, 8592, 8901; 9023, 9069, 9199, 9573, 9716.

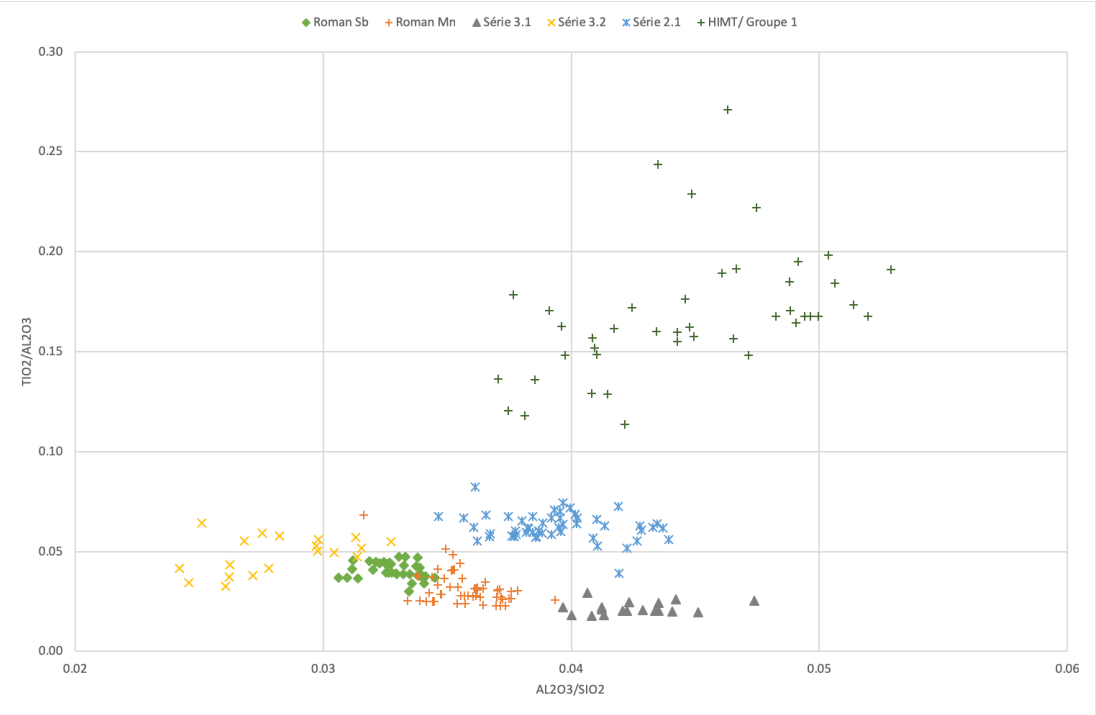

Figure 7.12: TiO_2/Al_2O_3 vs Al_2O_3/SiO_2 for glass groups. The data used for this comes from Silvestri et al. (2008)(Roman Mn and Sb) and Foy et al. (2001) (Série 2.1, 3.1, 3.2 and Groupe 1).

Summary of Dorchester-on-Thames Glass Results

The glass from Dorchester-on-Thames is closely grouped, with no clear relationship between chronology and composition.

One of the main ways of identifying glass type is a plot of TiO_2/Al_2O_3 vs Al_2O_3/SiO_2. As discussed previously, all three of these elements relate, if not exclusively, primarily to sand. Figure 7.12 shows this, with existing studies on glass groups occupying separate areas of the plane. The addition of Dorchester-on-Thames glass to this plot shows the concordance of Dorchester glass to existing groups [Figure 7.13]. These glasses can be assigned to these existing groups based on this concordance. It is clear that the glasses are spread across many of these [Figure 7.14, Table 7.1]. It should be noted that chronology assigned to glasses here is based on site stratigraphy, dated both through pottery and radiocarbon.

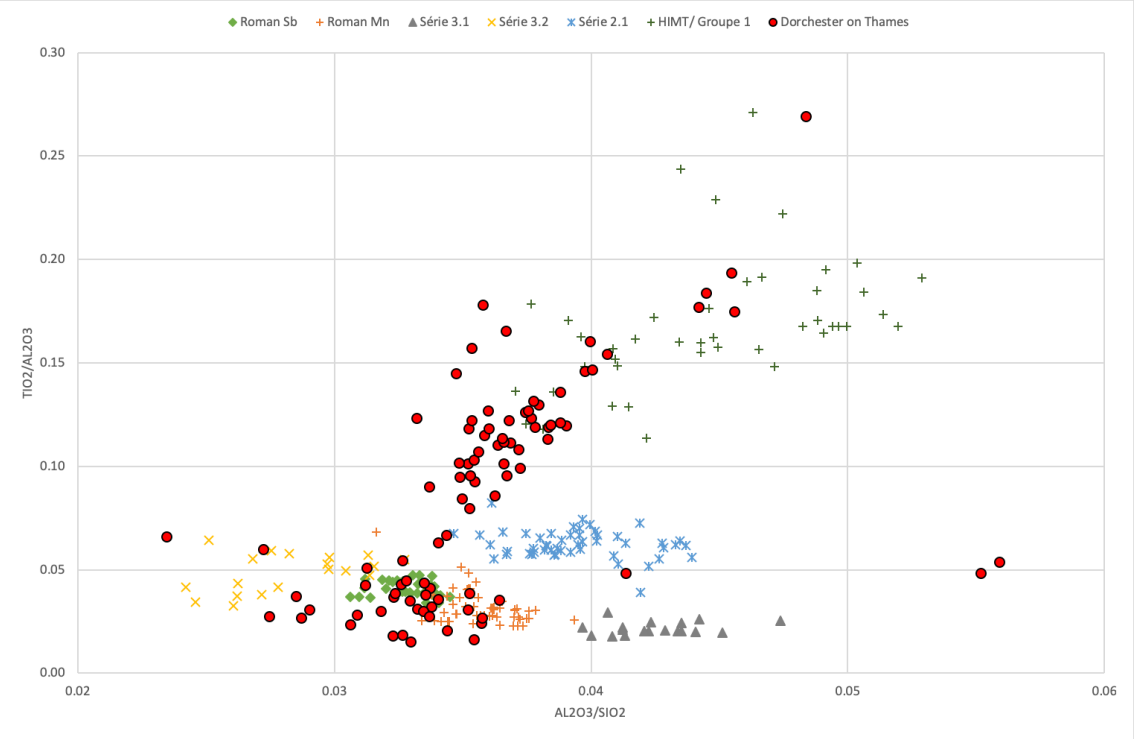

Figure 7.13: TiO_2/Al_2O_3 vs Al_2O_3/SiO_2 for glass groups and Dorchester-on-Thames glass.

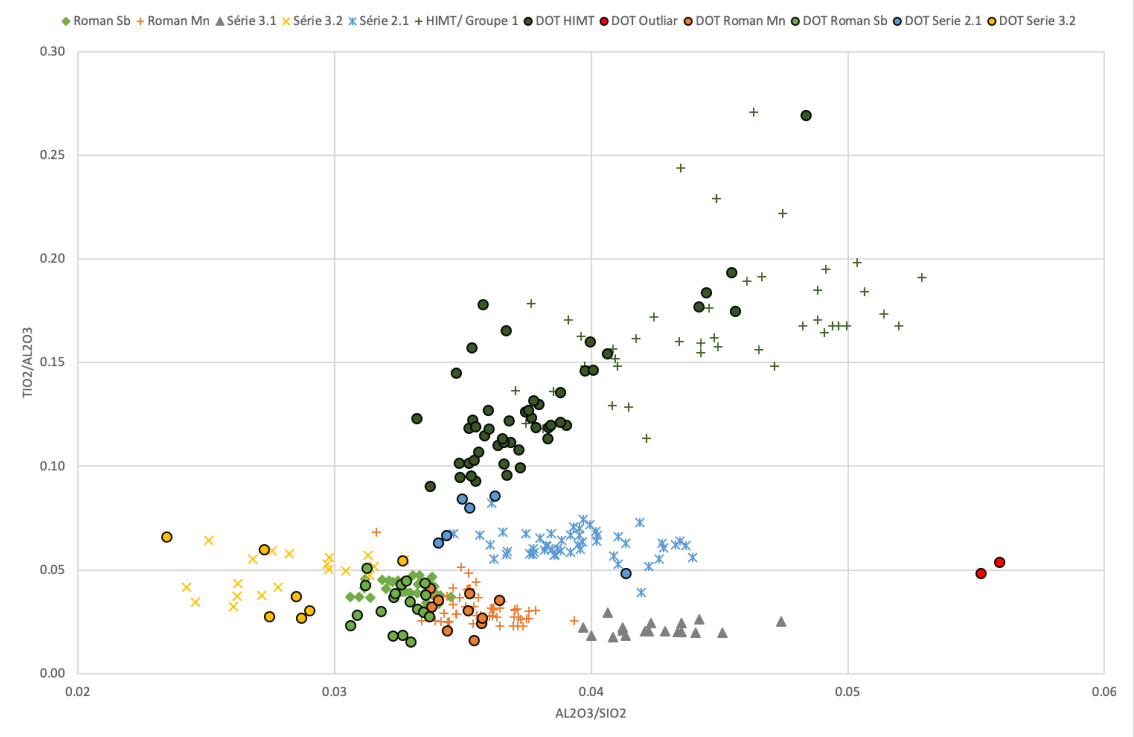

Figure 7.14: TiO_2/Al_2O_3 vs Al_2O_3/SiO_2 for glass groups, with Dochester-on-Thames assigned to groups.

Table 7.1: Glass from Dorchester on Thames, arranged by glass group, and the chronology of finds.

SFN	Colour	Description	Glass Groups	Chronology
9023	Nearly Colourless	fragment	Rom Mn	Roman
9069	Blue-green	fragment	Rom Mn	Roman
8535	Blue-green	fragment	Rom Sb	Roman
9290	Green	fragment	Rom Sb	Roman
9408	Green	fragment, decorated	Rom Sb	Roman
8720	Green	fragment	Rom Sb	Roman
8913	Green	fragment	Rom Sb	Roman
9079	Green	fragment	Rom Sb	Roman
9573	Green	fragment	Rom Sb	Roman
8583	Green	fragment	HIMT	Roman
9746	Green	fragment, flat	HIMT	Roman
9257	Green	fragment, rim open vessel	HIMT	Roman
9260	Green	fragment	HIMT	Roman
8506	Green	fragment, rim open vessel	HIMT	Roman
8548	Green	fragment, cracked off rim	HIMT	Roman
8593	Green	fragment, flat	HIMT	Roman
8651	Green	cullet	HIMT	Roman
9716	Blue, opaque	fragment	Serie 3.22	Roman
9199	Nearly Colourless	fragment, rim or maybe base	Serie 3.2	Roman
9132	Slag	Slag	Outlier	Roman
8592	Blue	fragment	Outlier	Roman
9553	Green	fragment	HIMT	Third century
8901	Nearly Colourless	window glass	Rom Mn	Fourth Century
9481	Green	fragment	Rom Sb	Fourth Century
3771	Blue-green	fragment, flat	Rom Mn	Early Med
3501	Green	fragment, flat and thick	Rom Sb	Early Med
3177	Green	fragment, melted	HIMT	Early Med
3643	Green	fragment	HIMT	Early Med
4738	Green	fragment, base	HIMT	Early Med
3656	Green	fragment	Serie 2.13	Early Med
4096	Blue-green	fragment, rim open vessel	Serie 3.2	Early Med
9509	Slag	Slag	Outlier	Early Med
3819	Green	fragment, cracked off rim?	HIMT	Fifth century
8473	Green	fragment, trail decoration	HIMT	Fifth century
4333	Nearly Colourless	fragment	Rom Mn	Sixth century
4213	Blue-green	fragment	Rom Sb	Sixth century
4475	Nearly Colourless	fragment	Rom Sb	Sixth century
4363	Green	fragment	Rom Sb	Sixth century
4265	Blue-green	fragment	Rom Sb	Sixth century
3872	Blue-green	Ring		
4605	Green	fragment, trail decoration	HIMT	Sixth century
4604	Nearly Colourless	fragment	HIMT	Sixth century

Table 7.1: Glass from Dorchester on Thames, arranged by glass group, and the chronology of finds, *continued*.

SFN	Colour	Description	Glass Groups	Chronology
3903	Nearly Colourless	fragment	HIMT	Sixth century
4136	Green	fragments, three, trail decorated	HIMT	Sixth century
4174	Green	fragment	HIMT	Sixth century
4196	Green	fragment	HIMT	Sixth century
4210	Green	fragment	HIMT	Sixth century
3986	Green	fragment, rim open vessel	HIMT	Sixth century
4617	Green	fragment	HIMT	Sixth century
4644	Green	fragment, melted	HIMT	Sixth century
4650	Green	fragment	HIMT	Sixth century
4740	Green	fragment, rim open vessel	HIMT	Sixth century
4752	Green	fragment, flat	HIMT	Sixth century
4387	Green	fragment, trail decoration	HIMT	Sixth century
4415	Green	fragment	HIMT	Sixth century
4437	Green	fragment	HIMT	Sixth century
4455	Green	fragment	HIMT	Sixth century
4518	Green	fragments, many	HIMT	Sixth century
4597	Green	fragment, melted	HIMT	Sixth century
4751	Green	fragment, cracked off rim?	HIMT	Sixth century
4009	Nearly Colourless	fragment	Serie 2.13	Sixth century
4041	Green	fragment	Serie 2.13	Sixth century
4122	Green	fragment	Serie 2.13	Sixth century
4283	Nearly Colourless	fragment	Serie 3.2	Sixth century
4537	Nearly Colourless	fragment	Serie 3.2	Sixth century
4328	Green	fragment	Serie 3.2	Sixth century
4100	Blue-green	fragment	Outlier	Sixth century
4136	Green	fragments, three, trail decorated	Outlier1	Sixth century
3093	Green	fragment	Rom Mn	Unknown
4753	Nearly Colourless	fragment, thick	Rom Mn	Unknown
3371	Nearly Colourless	fragment	Rom Mn	Unknown
3040	Blue-green	fragment, flat and thick	Rom Mn	Unknown
3436	Blue-green	fragment	Rom Mn	Unknown
3054	Green	fragment	Rom Sb	Unknown
3524	Green	fragment, thick	Rom Sb	Unknown
3556	Green	fragment, folded rim open vessel	Rom Sb	Unknown
3361	Blue-green	fragment	Rom Sb	Unknown
3131	Green	fragment, melted	HIMT	Unknown
3053	Green	fragment	HIMT	Unknown
3640	Green	fragment, rim open vessel	HIMT	Unknown
3188	Green	fragment, trail decoration	HIMT	Unknown
3271	Green	fragment, melted, two	HIMT	Unknown
3332	Green	fragment, cracked off rim?	HIMT	Unknown
3357	Green	droplet	HIMT	Unknown

Table 7.1: Glass from Dorchester on Thames, arranged by glass group, and the chronology of finds, *continued*.

SFN	Colour	Description	Glass Groups	Chronology
3435	Green	fragment, heavily scratched, potentially wheel abraided	HIMT	Unknown
3658	Green	fragment, possibly melted	HIMT	Unknown
3711	Green	fragment	HIMT	Unknown
3719	Green	fragment	HIMT	Unknown
4006	Green	fragment, melted	HIMT	Unknown
4288	Green	fragment, melted	HIMT	Unknown
3756	Blue-green	fragment, thick	HIMT	Unknown
3699	Nearly Colourless	fragment	HIMT	Unknown
3584	Green	fragment, wheel abraided decoration	Serie 2.1	Unknown
3597	Green	fragment	Serie 2.1	Unknown
4049	Blue-green	fragment	Serie 3.2	Unknown
3279	Blue-green	fragment	Serie 3.2	Unknown
3486	Yellow	fragment	Outlier	Unknown
3788	Nearly Colourless	Fragment, likely shoulder	Outlier	Unknown
3518	Green	fragment	Outlier	Unknown
3254	Green	fragment, rim open vessel	Outlier	Unknown
3439	Green	fragment	Outlier	Unknown
3779	Green	fragment	Outlier	Unknown
3531	Blue-green	fragment	Outlier	Unknown
3745	Blue-green	fragment	Outlier	Unknown

Unlike as will be discussed with the glass from Lyminge, this glass includes both HIMT glass, absent from Lyminge, and some unusual outliers (12 glasses). Nine of these are removed from this chart as they fell far in away outside the other values present, skewing the axes. At least one represents a failed analyses (DOT 6.13), and two are slag pieces (DOT 11.1, 11.2). Of the six others, one is from a sixth century context, and the rest are unknown. Only two show any significant visual appearance of weathering, potentially explaining their odd results. Aside from these outliers, two glasses (DOT12.2, DOT11.7) have very low alumina (less than 0.2 wt%) and titanium (0.001 and 0.037 wt%), but are not identified as outliers, due to the calcium and alumina.

Looking at the relationship between these groups and the colours, none is immediately apparent. There is a prevalence for green in HIMT glass, which is to be expected, and the colourless HIMT glasses are towards the lower end of this group, which might

Figure 7.15: TiO_2/Al_2O_3 vs Al_2O_3/SiO_2 for Dochester-on-Thames, separated by colour and glass group.

indicate mixed glasses, but more evidence is needed. The range of colours at Dorchester is limited- blue, green, blue-green, nearly colourless and yellow. Of the yellow glasses, the two analysed are both outliers. More colours were intended to be analysed, but these were among the glasses that were culled from this study due to time constraints. As such, the nature of colouration of glass from Dorchester-on-Thames will require further analysis.

The reason that Dorchester-on-Thames was selected was the continuity of the site. As such, 68 of the glasses as analysed can be broken down into time periods, based on stratigraphic information. The glasses have thus been plotted by 'Roman' glasses, including glasses securely dated to the first to fourth centuries, and the 'Early Medieval' glasses, including the fifth and sixth centuries [Figure 7.16, 7.17].

Considering first the Roman period glass, it is immediately problematic that there is a Série 3.2 glass. This glass currently dates from the fifth century at the earliest

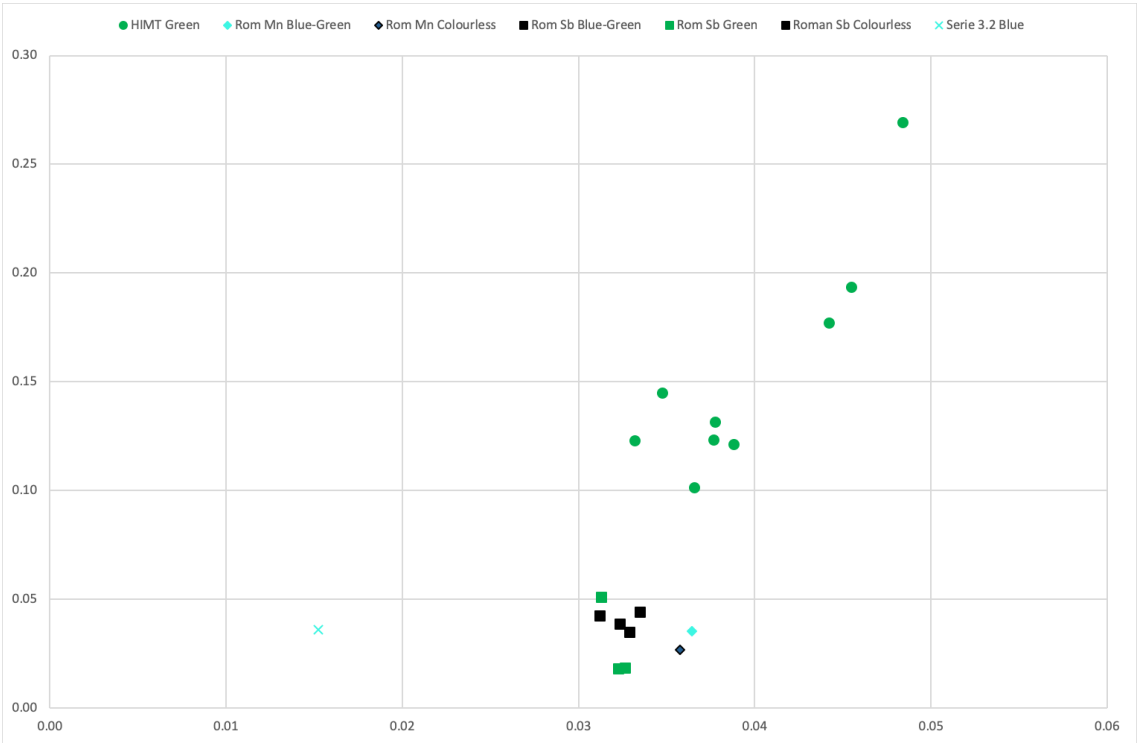

Figure 7.16: TiO_2/Al_2O_3 vs Al_2O_3/SiO_2 for Roman period Dochester-on-Thames, 22 glasses, separated by colour and glass group.

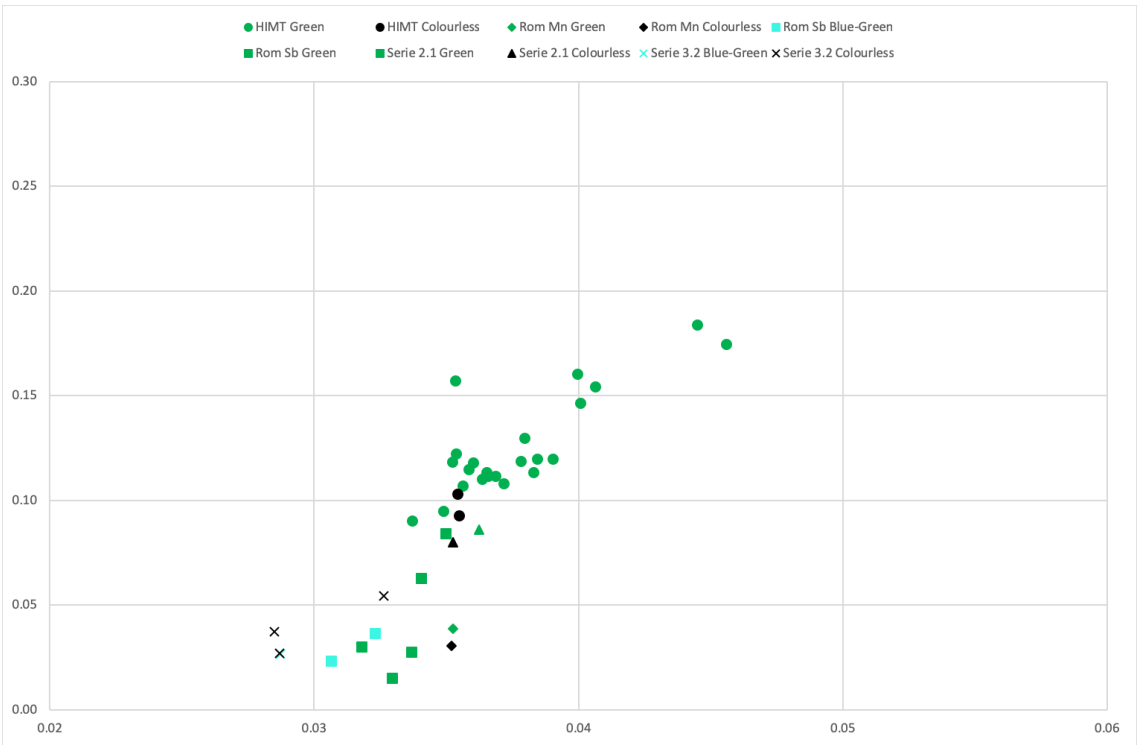

Figure 7.17: TiO_2/Al_2O_3 vs Al_2O_3/SiO_2 for Early Medieval period Dochester-on-Thames, 40 glasses, separated by colour and glass group.

(Foy et al. 2001). It seems more likely that the glass assigned as such is either an outlier of Roman Mn glass, or else requires unique explanation. This glass, DOT 12.4, when considered by lime and alumina, is clearly not consistent with Roman Mn Glass. It contains calcium of 12.92 wt% as well as slightly high magnesium (1.39 wt%). It is a cobalt coloured blue glass, with notable traces of antimony (66ppm).

There are two possible origins of this sherd, a confusion of context or recycling. It could have travelled forward in time, being recycled, or backwards, intruding into this layer during deposition. A similar composition was seen in blue-bodied fragment of an oinochoe from the third century BC (Arletti et al. 2009). A similar composition is also seen when Roman cobalt glass has been melted with medieval glass. This composition is very similar to the blue glass at San Vincenzo (Schibille and Freestone 2013) though with less natron and slightly higher calcium. Such a mixture and the explanation of intrusion, seems more likely. The analysis of trace elements beyond the current scope is required to be sure.

Looking at the Early Medieval period, it shows clear continuity from the Roman. The HIMT glass clearly shifts downwards in both ratios, closer to the Roman material, creating a group of glasses defined by their intermediate results [Figure 7.17]. This implies that the HIMT glass glass is being mixed with the persisting earlier Roman material.

This raises questions about the glass assigned to Série 2.2 in the Early Medieval period. They are also potentially HIMT glass, recycled with Roman glass, rather than actually this group. To try and ascertain the origin of these glasses, they were plotted on axes of calcium oxide versus alumina, which shows something interesting [Figure 7.18]. While there is no reason to doubt the Série 3.2 glass in this period, three of the four Série 2.1 glasses are at the extreme lowest alumina and lime found in this glass group. These glasses are more easily explained by a mix of particularly

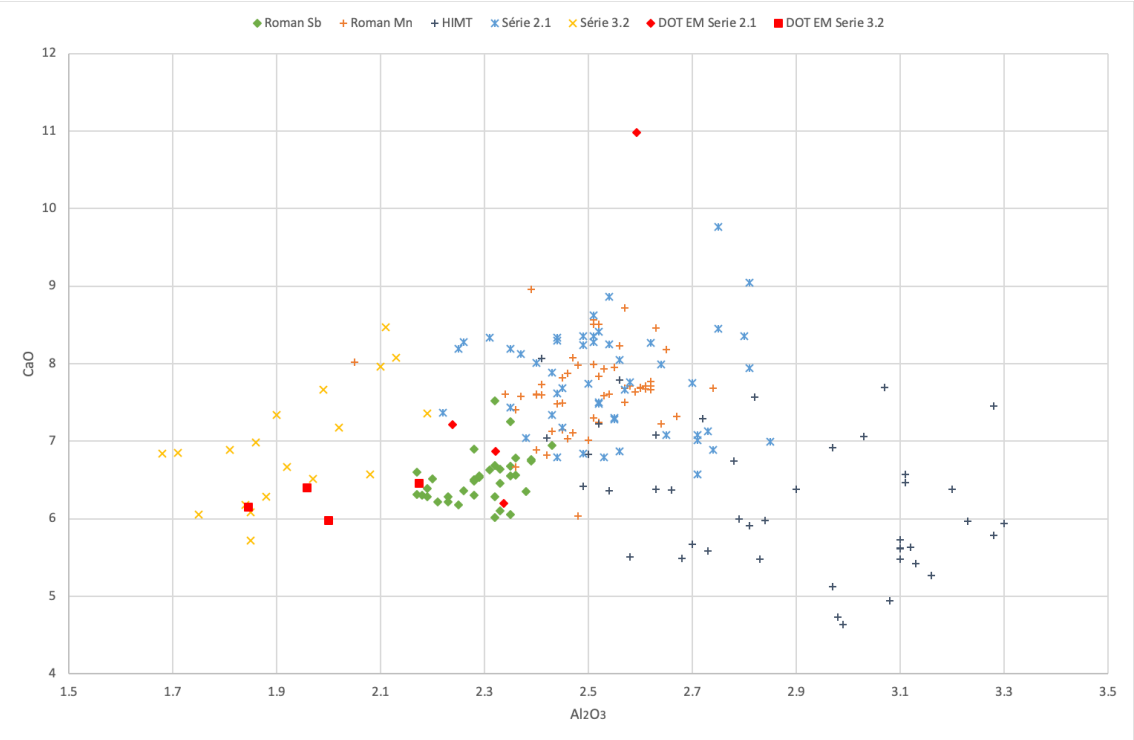

Figure 7.18: CaO vs Al_2O_3 of glass groups, and Early Medieval period Dochester-on-Thames from Série 2.1 and 3.2.

Roman Sb glass and HIMT glass. The is corroborated by the fact that, despite being both green and nearly colourless glasses, all contain over 100 ppm of antimony. The other glass, DOT 6.2, is unique. Apart from the outliers discussed, it contains some of the highest values for potash (6.58 wt%), calcium (10.98 wt%) and iron oxide (1.45 wt%). It also contains over 2000 ppm of antimony. This glass is most easily explained by glass that has been doped with plant ash. That is, an early glass type, extended out with the addition of more ash, as discussed in Chapter 6.1.3. This means this glass, the only Série 2.1 glass is consistent not with this assignment, but is likely a recycled Roman glass.

In both centuries the two Roman groups, Roman Mn and Sb, they raise an interesting question. While they are differentiated based on sand, they are defined by Silvestri et al. (2008) based on the presence or absence of antimony or manganese.

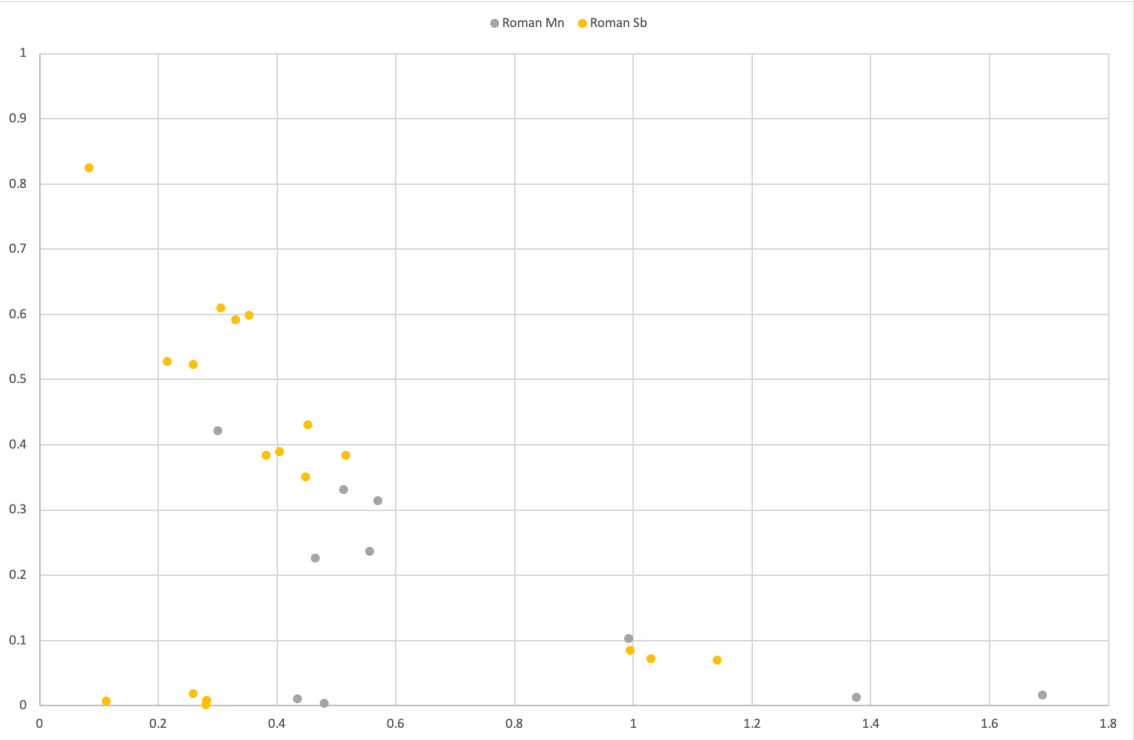

Figure 7.19: Sb_2O_3 vs MnO of glasses grouped into Roman Mn and Sb.

These groups are produced from the first to third century Roman productions. While the dating of these glasses from Dorchester is not always clear, all those featured in these discussions are later. However, these glasses do not contain expected levels of antimony and manganese, relative to their sand type [Figure 7.19].

When all the glasses are considered for these two decolourants, only the HIMT glasses seem to plot together, due to their manganese. However, almost all contain some amount of antimony, with an average of 0.03 wt% and a median of 0.02 wt%. This is despite the fact that antimony is not common in HIMT glass. These glasses also have elevated copper and cobalt, but the values for these elements are tightly grouped. Looking back at the discussion of sand types, it seems not unlikely that the HIMT group is recycled, including a large proportion of Roman Mn and Sb glass. This is born out by the location of the group on Figure 7.19. Their close relation is interesting.

When considering colour and glass type, HIMT once more stands out. The major-

ity of the glass is a natural green. The few HIMT glasses of other colours are closest to the Roman glasses. It does not seem unlikely that these are formed by recycling, whether cullet or incorporation.

Taking all this into consideration, the original assignation of groups has been altered [Figure 7.20] and the table altered [Table 7.2]. In addition to the points made above, several assumptions were made for the assignment of these new groups. Any group ending in (Sb) is glass of that type but with greater than 0.01% Sb in non-colourless or opacified glass. The same cut off point was used for glass groups ending in (Co). For the group of Roman Sb glasses, there was a dislocation in values of material. All with higher antimony had not higher than 0.55 wt% Mn, then there was no material until 0.9 wt% Mn, which had some of the lowest antimony in this glass type. This break, the author believes, demonstrates a 'clean' and a 'mixed' Roman Sb glass.

The disentanglement of copper and colourant proved difficult, so it was set aside. However, a few comments should be made. The lowest value of copper in any glass not already indicated as recycled is 30 ppm, though the average is 250ppm. This demonstrates that even the glasses not clearly identified as recycled might well be so.

Table 7.2: Glass from Dorchester on Thames, arranged by glass group, and the chronology of finds, adjusted for recycling.

SFN	**Colour**	**Description**	**Glass Groups**	**Chronology**
8535	Blue-green	fragment	Rom Sb	Roman
9290	Green	fragment	Rom Sb	Roman
9573	Green	fragment	Rom Sb	Roman
8720	Green	fragment	Rom Sb (Co)	Roman
9079	Green	fragment	Rom Sb (Co)	Roman
8913	Green	fragment	Rom Sb (Recycled)	Roman
9408	Green	fragment, decorated	Rom Sb (Recycled)	Roman

Table 7.2: Glass from Dorchester on Thames, arranged by glass group, and the chronology of finds, *continued*.

SFN	Colour	Description	Glass Groups	Chronology
9023	Nearly Colourless	fragment	Rom Mn (Recycled)	Roman
9069	Blue-green	fragment	Rom Mn (Recycled)	Roman
8506	Green	fragment, rim open vessel	HIMT	Roman
9257	Green	fragment, rim open vessel	HIMT	Roman
9260	Green	fragment	HIMT	Roman
8651	Green	cullet	HIMT (Co)	Roman
8548	Green	fragment, cracked off rim	HIMT (Sb, Co)	Roman
9746	Green	fragment, flat	HIMT (Sb, Co)	Roman
8583	Green	fragment	HIMT (Sb)	Roman
8593	Green	fragment, flat	HIMT (Sb)	Roman
8592	Blue	fragment	Recycled	Roman
9199	Nearly Colourless	fragment, rim or maybe base	Recycled	Roman
9716	Blue, opaque	fragment	Recycled	Roman
9132	Slag	Slag	Out	Roman
9553	Green	fragment	HIMT (Sb, Co)	Third century
8901	Nearly Colourless	window glass	Rom Mn	Fourth Century
9481	Green	fragment	Rom Sb (Co)	Fourth Century
3501	Green	fragment, flat and thick	Rom Sb	Early Med
3771	Blue-green	fragment, flat	Rom Mn (Recycled)	Early Med
3656	Green	fragment	Ash Doped (Recycled)	Early Med
3177	Green	fragment, melted	HIMT (Sb)	Early Med
3643	Green	fragment	HIMT (Sb)	Early Med
4738	Green	fragment, base	HIMT (Sb)	Early Med
4096	Blue-green	fragment, rim open vessel	Serie 3.2 (Sb)	Early Med
9509	Slag	Slag	Out	Early Med
3819	Green	fragment, cracked off rim?	HIMT (Sb)	Fifth century

Table 7.2: Glass from Dorchester on Thames, arranged by glass group, and the chronology of finds, *continued*.

SFN	Colour	Description	Glass Groups	Chronology
8473	Green	fragment, trail decoration	HIMT (Sb)	Fifth century
3872	Blue-green	Ring base	Rom Sb	Sixth century
4213	Blue-green	fragment	Rom Sb	Sixth century
4265	Blue-green	fragment	Rom Sb (Co)	Sixth century
4363	Green	fragment	Rom Sb (Co)	Sixth century
4475	Nearly Colourless	fragment	Rom Sb (Co)	Sixth century
4537	Nearly Colourless	fragment	Rom Sb (Recycled)	Sixth century
4333	Nearly Colourless	fragment	Rom Mn (Recycled)	Sixth century
3903	Nearly Colourless	fragment	HIMT	Sixth century
4210	Green	fragment	HIMT	Sixth century
4415	Green	fragment	HIMT	Sixth century
4604	Nearly Colourless	fragment	HIMT	Sixth century
4617	Green	fragment	HIMT	Sixth century
4644	Green	fragment, melted	HIMT	Sixth century
3986	Green	fragment, rim open vessel	HIMT (Co)	Sixth century
4136	Green	fragments, three, trail decorated	HIMT (Sb)	Sixth century
4174	Green	fragment	HIMT (Sb)	Sixth century
4196	Green	fragment	HIMT (Sb)	Sixth century
4387	Green	fragment, trail decoration	HIMT (Sb)	Sixth century
4437	Green	fragment	HIMT (Sb)	Sixth century
4518	Green	fragments, many	HIMT (Sb)	Sixth century
4605	Green	fragment, trail decoration	HIMT (Sb)	Sixth century
4740	Green	fragment, rim open vessel	HIMT (Sb)	Sixth century
4752	Green	fragment, flat	HIMT (Sb)	Sixth century
4455	Green	fragment	HIMT (Sb, Co)	Sixth century
4597	Green	fragment, melted	HIMT (Sb, Co)	Sixth century

Table 7.2: Glass from Dorchester on Thames, arranged by glass group, and the chronology of finds, *continued*.

SFN	Colour	Description	Glass Groups	Chronology
4650	Green	fragment	HIMT (Sb, Co)	Sixth century
4751	Green	fragment, cracked off rim?	HIMT (Sb, Co)	Sixth century
4009	Nearly Colourless	fragment	HIMT (Recycled)	Sixth century
4041	Green	fragment	HIMT (Recycled)	Sixth century
4122	Green	fragment	HIMT (Recycled)	Sixth century
4328	Green	fragment	Serie 3.2 (Co)	Sixth century
4283	Nearly Colourless	fragment	Serie 3.2 (Sb, Co)	Sixth century
4100	Blue-green	fragment	Out	Sixth century
4136	Green	fragments, three, trail decorated	Out	Sixth century
3054	Green	fragment	Rom Sb (Co)	Unknown
3361	Blue-green	fragment	Rom Sb (Co)	Unknown
3524	Green	fragment, thick	Rom Sb (Co)	Unknown
3556	Green	fragment, folded rim open vessel	Rom Sb (Recycled)	Unknown
4049	Blue-green	fragment	Rom Sb (Recycled)	Unknown
3040	Blue-green	fragment, flat and thick	Rom Mn (Recycled)	Unknown
3093	Green	fragment	Rom Mn (Recycled)	Unknown
3371	Nearly Colourless	fragment	Rom Mn (Recycled)	Unknown
3436	Blue-green	fragment	Rom Mn (Recycled)	Unknown
4753	Nearly Colourless	fragment, thick	Rom Mn (Recycled)	Unknown
3254	Green	fragment, rim open vessel	HIMT	Unknown
3640	Green	fragment, rim open vessel	HIMT	Unknown

Table 7.2: Glass from Dorchester on Thames, arranged by glass group, and the chronology of finds, *continued*.

SFN	Colour	Description	Glass Groups	Chronology
3699	Nearly Colourless	fragment	HIMT	Unknown
4006	Green	fragment, melted	HIMT	Unknown
3131	Green	fragment, melted	HIMT (Sb)	Unknown
3188	Green	fragment, trail decoration	HIMT (Sb)	Unknown
3332	Green	fragment, cracked off rim?	HIMT (Sb)	Unknown
3357	Green	droplet	HIMT (Sb)	Unknown
3711	Green	fragment	HIMT (Sb)	Unknown
3756	Blue-green	fragment, thick	HIMT (Sb)	Unknown
3435	Green	fragment, heavily scratched, potentially wheel abraided	HIMT (Co)	Unknown
3053	Green	fragment	HIMT (Sb, Co)	Unknown
3271	Green	fragment, melted, two	HIMT (Sb, Co)	Unknown
3658	Green	fragment, possibly melted	HIMT (Sb, Co)	Unknown
3719	Green	fragment	HIMT (Sb, Co)	Unknown
4288	Green	fragment, melted	HIMT (Sb, Co)	Unknown
3584	Green	fragment, wheel abraided decoration	HIMT (Recycled)	Unknown
3597	Green	fragment	HIMT (Recycled)	Unknown
3279	Blue-green	fragment	Serie 3.2 (Sb, Co)	Unknown
3745	Blue-green	fragment	Serie 3.2 (Sb)	Unknown
3439	Green	fragment	Out	Unknown
3486	Yellow	fragment	Out	Unknown
3518	Green	fragment	Out	Unknown
3531	Blue-green	fragment	Out	Unknown
3779	Green	fragment	Out	Unknown
3788	Nearly Colourless	Fragment, likely shoulder	Out	Unknown

There does seem to be an increase in clear recycling evidence in the Early Medieval glass, though it is not as great as one might expect. While 70% of glasses from the

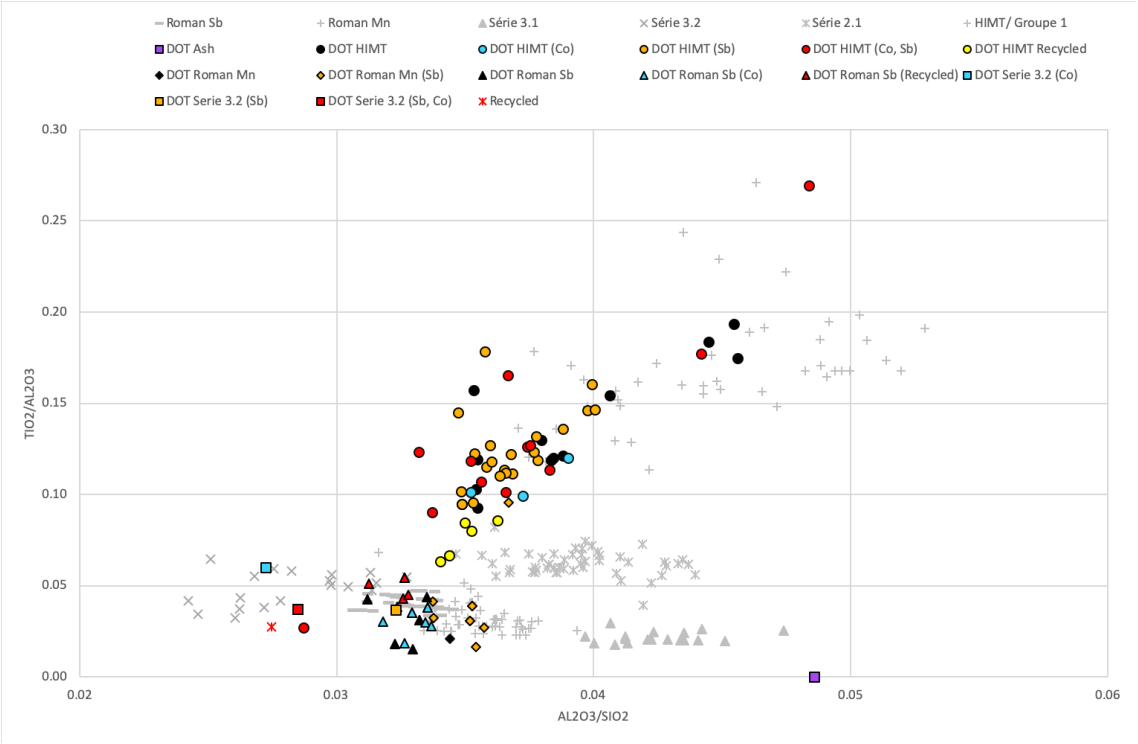

Figure 7.20: TiO_2/Al_2O_3 vs Al_2O_3/SiO_2 for glass groups and Dorchester-on-Thames glass, rectified in the light of recycling.

Roman period at Dorchester-on-Thames show evidence of recycling, this only rises to 78% when compared to the Early Medieval glass. After the removal of the blue Roman glasses and outliers (as defined by glass groups), there is an increase in the average amount of copper per glass in the Early medieval period (400ppm as apposed to 200ppm). It seems that this might well be evidence of continued recycling, an idea strengthened by the fact that all glasses corresponding to the Early Medieval glass groups fall below this average value. That is, sixth century glasses that are of Roman compositions are more likely to show this elevation in copper.

It seems that these groups of glasses, closely grouped in many respects, are indicative of many successive recycling across some period of time. Dorchester-on-Thames glass is all heavily reliant on recycling, however what is not clear is where this recycling is taking place, something that requires further archaeological investigation.

Figure 7.21: The layout of Lyminge excavations.

7.2 Lyminge

As with Dorchester, the excavations at Lyminge are ongoing. The current excavation is run by the *Department of Archaeology, University of Reading*, assisted by *Kent Archaeological Society* and *Canterbury Archaeology Trust*, under the direction of Gabor Thomas. The current excavations centre on Tayne Fields, though the first year also included settlement areas further South [Fig 2.4,7.21].

A huge number of shards and glass objects have been uncovered from Lyminge, including over 250 from the period of interest. This was thought to be an unprecedented amount of glass for the period, but as recent years have shown, there is far more Early Medieval glass that ever expected. Still, the Lyminge assemblages is uniquely large and fine. The glass is still being catalogued by Rose Broadly, UCL, but 37 shards have been selected for analysis [Table 6].

History and Excavations

Like the site of Dorchester-on-Thames, the small Kentish town of Lyminge has long been known for its Anglo-Saxon heritage. Various sources had indicated that once a 'double' monastery, monks and nuns, existed here. Founded in the 7^{th} century, and under the rule of a royal abbess, it would have existed as only part of the network of religious houses across the kingdom of Kent, those houses born from St Augustine's 597 mission to christianise the Anglo-Saxons.

Like Dorchester, the first excavation work was pioneered by antiquarians. The parish churchyard and surrounds was explored in the mid-nineteenth century by the then vicar of Lyminge, Canon Jenkins. This work was published extensively, especially in *Archaeologia Cantiana*, e.g. Jenkins (1874). This work exposed both a seventh century minster-church, and the core buildings of the monastic settlement. However, as with Dorchester, further investigation into the site has shown a longevity beyond this period.

The first major excavation work came from a surprise discovery by farming contractors who were erecting a prefabricated mushroom shed. In placing postholes, they struck bones and metal. Alan Warhurst, working at the Maidstone Museum, was called in for emergency excavation and soon discovered a slew of further inhumations (Warhurst 1955). Eight graves were discovered, and it was deemed the site was that of a Jutish cemetery of the sixth century.

Along with other Jutish finds from the area, this spurred further excavation, which uncovered 36 more inhumation graves, making a total of 44 (Warhurst 1955). Glass, in some form, was found in 12 graves. Beads (blue, green and clear glass in Graves 16, 24, 27, 32), set into buckles and attachment plates (blue, ruby, red and green in Graves 1, 17, 32, 36, 39), as well as wine-coloured glass in perforated studs (Grave 3), a purse mount with pale and dark green cloisonné (Grave 27), and brooch with red glass (Grave 39). There was also a claw beaker, discovered with the body of a

woman approximately 25 years old (Grave 41), and a cylindrical glass bottle, with unidentified contents, with a 20 year old woman (Grave 13). Both vessels suggest a mid-fifth century manufacture.

In 2005, *Canterbury Archaeological Trust* did some small-scale excavation of 8^{th} to 9^{th}-century occupation just South of the present churchyard, which spurred the *University of Reading*, Gabor Thomas, to begin large Anglo-Saxon excavations in 2007. The first proper trenches were opened in 2008, which exposed, among other things, a Middle Saxon granary and threshing floor. Excavations continued throughout 2009, but it was in 2010 that evidence of pre-monastery occupation was first uncovered; several sunken-feature buildings and a large timber hall. The huge number of finds associated with this occupation, including a large amount of luxury vessel glass, clearly date from the 5^{th} to 7^{th} century.

AHRC funding in 2012 allowed a new area of excavation to be explored, Tayne Field, which remained the focus for exaction for the 2013 and 2014 seasons. A further sunken-featured building and more timber halls were exposed next season and it was one of these halls which fundamentally altered the understanding of the site.

A post-in-trench construction, measuring an impressive 21 x 8.5m, this is potentially *the* most important early Anglo-Saxon building yet excavated in Kent (Thomas and Knox 2012). Dating from around 600 AD, this type of extensive high-status hall is rare, but common to the few Anglo-Saxon royal complexes, serving as a communal building, likely for ceremonial feasts and assemblies.

As with Dorchester, it seems river connections featured heavily in the success of the site. The hall was constructed such that it overlooked and was somewhat bordered by a spring which bubbles up, forming the headwater of the Nailbourne River (also known as the upper Little Stour). Such connections are obviously of strategic advantage, and might have contributed, as with Dorchester, to the longevity of the site.[4]

[4]These excavations has also highlighted Mesolithic occupation at the site, with a large amount of flint etc, as well as much later occupation, after the monastery, dating to the 'Saxo-Norman' period

It is clear that long before the seventh century monastery, Lyminge was a key site, and glass was in great abundance. The origin and nature of this glass and potential glass working on the site, still requires investigation.

Lyminge Glasses

The majority of archaeological work on the glass was done by Rose Broadley, at UCL.[5] After the 2010 season, there were 140 shards and objects discovered, the vast majority of which date from the early 6^{th} to mid 9^{th} century AD, 95 shards of which were vessel glass (Broadley 2011). Compared to other Anglo-Saxon sites, such as Monkwearmouth and Jarrow (57 shards), Flixborough (69) this was already an extensive set, putting it on a par with a few other exceptional assemblages, Barking Abbey (148) and Brandon, Suffolk (230). After two more seasons, this has now significantly increased, with early Saxon pieces alone numbering greater than 250 shards, more than 100 found in 2014 alone many in a single large pit that is yet to be fully excavated [Broadly, pers. com.].

As can be expected, the earlier seasons, 2007-2009, yielded mostly shards outside of the scope of this thesis (8^{th} to 9^{th} century). However, in 2010, there was a distinct sub-group of much earlier glass discovered, 6^{th} to early 7^{th} century. The majority are a group of colourless cone beakers with self-coloured trails, many of the Kempston type, thought to be manufactured in Kent. Their find spots were concentrated in the fill of Sunken Feature Building 2, where three blue-green shards, one with trail decoration, were also found. Sunken Feature Building 3 contained a notable late globular beaker.

Along with the vessel glass, three finds are worth mentioning specifically, in terms of understanding the early Anglo-Saxon glass at Lyminge. A piece of melted glass,

(late 11th-late 12th centuries AD).

[5]The author extends her thanks to Ms Broadley, and the site director, Dr Gabor Thomas, Reading, for access to the glass used in this study.

potentially a manufacture drop (SF 59), a possible moil with clear iron-scale from a blow-pipe (SF 457) and what seems to be raw glass, which is visually indistinguishable from a lump of raw glass from Appolonia (SF 697). Together, these hint at a tantalising image. Were blown glass vessels being manufactured at the site of Lyminge during this period? And whats more, glass made from fresh imported Levantine glass? Analysis will make this clearer.

37 shards were selected as a pilot study to begin to examine this significant dataset. An effort was made to pick multiple shards of diagnostic groups at the site, as well as shards to cover the range of colours at the site. 22 visually Anglo-Saxon shards are separated between blue-green (5), nearly colourless (5), green (4), brown/amber (2), dark blue (2), yellow (2), and a single shard each of turquoise and smokey green. 15 visually Roman shards were also selected and all, except one green handle (SF 689), were blue-green. The separation of these two glass types is based on typology and colour, not context (See: Table 7.3).

Summary of Lyminge Glass Results

As with Dorchester-on-Thames, the glass from Lyminge was considered against Figure 7.12. When the glass from Lyminge is added, it is immediately apparently that this glass isn't primarily HIMT or Egyptian glasses, and thus these groups are cut from further plots here. [Fig. 7.25]. This glass becomes popular across the fourth and fifth century, but isn't apparent at this site, which implies that this isn't a continuous industry, with endless connection to these later glass sources.

When a more focused view is taken, what is first apparent is that the glass at Lyminge is very varied in composition [Fig 7.26] This glass doesn't group clearly, either amongst itself or with existing glass groups. It seems that the glass at Lyminge is from a from a variety of original sources. While Série 3.1 is an early medieval

Figure 7.22: Glass from Lyminge: Left to Right, Top to Bottom: 799, 689, 699, 594, 520; 454, 501, 312, 157, 208; 550, 275, 380, 358, 555.

Figure 7.23: Glass from Lyminge: Left to Right, Top to Bottom: 2.105, 2.192, 42, 23, 348; 624 458, 463, 404, 107; 935, 631, 134, 278, 43.

Figure 7.24: Glass from Lyminge: Left to Right, Top to Bottom: 483, 678, 306, 59; 457, 412; 697.

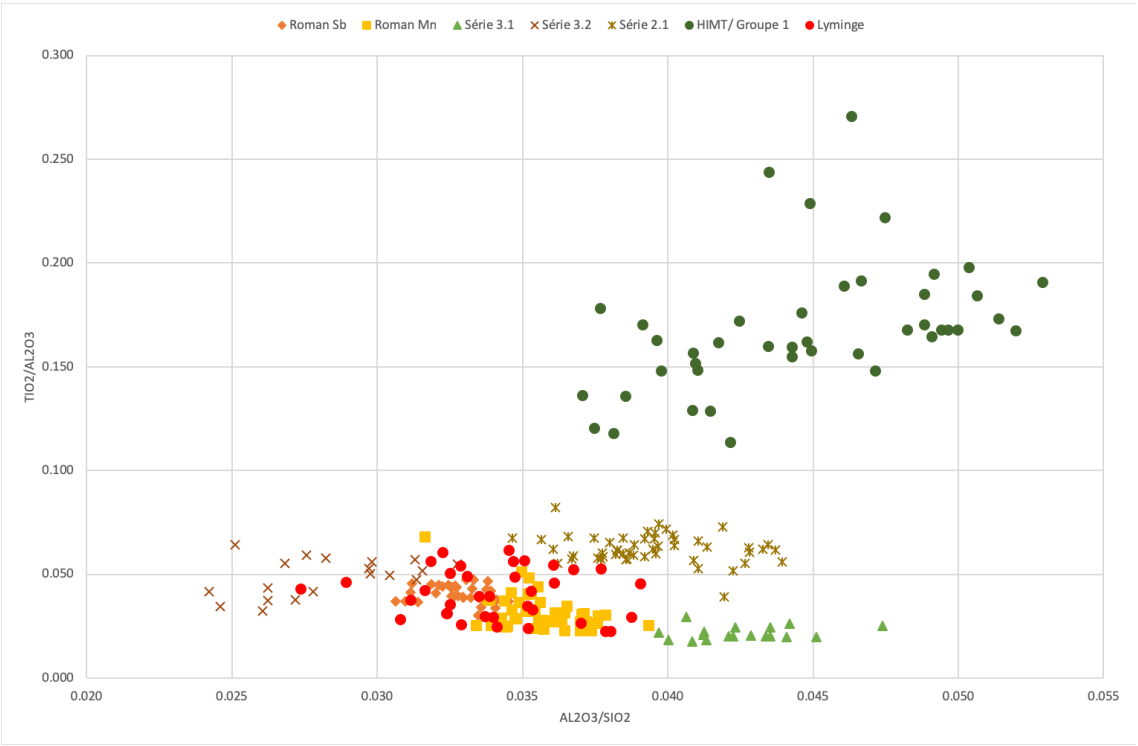

Figure 7.25: TiO_2/Al_2O_3 vs Al_2O_3/SiO_2 for glass groups, with Lyminge glass added.

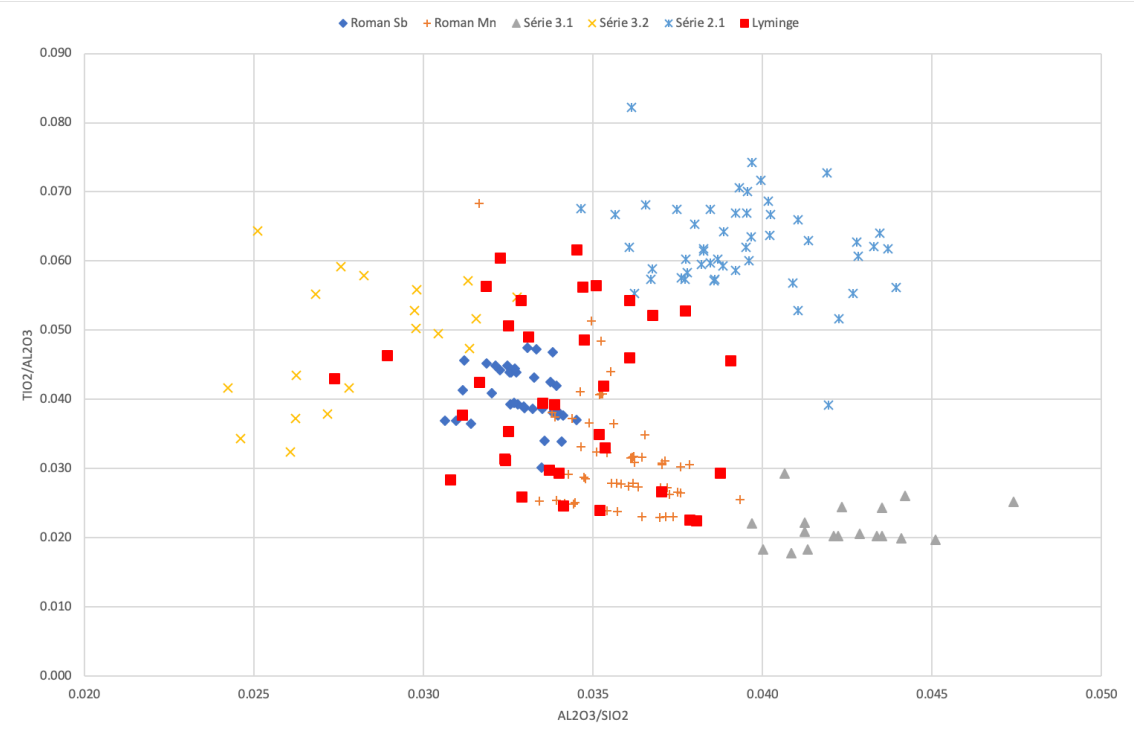

Figure 7.26: TiO_2/Al_2O_3 vs Al_2O_3/SiO_2 for glass groups and Lyminge glass, without high Titanium groups.

composition, it isn't apparent here. Lyminge glass instead can be assigned to Foy's Série 2.1 and 3.2, as well as Silvestri's Roman compositions [Fig 7.27]. Of the 36 analysed glasses at Lyminge, 7 belong to Série 2.1, 6 to Série 3.2, 12 to Roman Mn and 11 Roman Sb. This means that over 60% of the glass at Lyminge is consistent with Roman glass rather than 'Anglo-Saxon' period glass.

The relationship between the glass assigned to these groups, and reference groups is interesting. Looking first at the glass assigned to Silvestri's Roman Mn and Roman Sb glasses, it is clear that there is a difference [Fig. 7.28]. Silvestri's groups, identifiable by different sands, as seen above, are named for the fact that one contains the decolorant antimony, and the other only manganese.

Both of Silvestri's glasses groups belong to the first to third century production, where as at Lyminge they are seen both in the Roman and Anglo-Saxon forms, and in both Anglo-Saxon phases. One piece, SFN 59, which appeared to be a molten

Table 7.3: Glass from Lyminge, arranged by glass group, and the typology of the vessels. Vessels identified as Roman by typology or colour have been highlighted grey.

SFN	Colour	Description	Glass Groups	Phase
689	green	handle	2.1	Anglo-Saxon Phase 1
624	nearly colourless	kempston beaker fragment	2.1	Anglo-Saxon Phase 2
404	yellow	fragment of a claw	2.1	Anglo-Saxon Phase 1
43	dark blue	fragment	2.1	Medieval
483	amber	fragment with fine trails	2.1	Anglo-Saxon Phase 1
306	smokey green	fragment	2.1	Anglo-Saxon Phase 1
458	nearly colourless	fragment with white opaque trails	2.1	Anglo-Saxon Phase 1
2.105	nearly colourless	kempston beaker fragment	3.2	Anglo-Saxon Phase 1
2.192	nearly colourless	kempston beaker fragment	3.2	Anglo-Saxon Phase 1
23	yellow	fine regular trails	3.2	Anglo-Saxon Phase 1
348	green	fragment	3.2	Anglo-Saxon Phase 1
935	blue-green	fragment	3.2	Unphased
631	blue-green	fragment	3.2	Anglo-Saxon Phase 1
555	blue-green	window glass	Rom. Mn	Anglo-Saxon Phase 1
380	blue-green	window glass	Rom. Mn	Medieval
208	blue-green	fragment, flat	Rom. Mn	Anglo-Saxon Phase 1
157	blue-green	fragment	Rom. Mn	Anglo-Saxon Phase 1
520	blue-green	fragment, flat (possibly window)	Rom. Mn	Anglo-Saxon Phase 1
594	blue-green	thick fragment	Rom. Mn	Anglo-Saxon Phase 1
278	turquoise	fragment	Rom. Mn	Anglo-Saxon Phase 2
678	amber	fragment of a claw	Rom. Mn	Anglo-Saxon Phase 1
59	green	molten, possible drop	Rom. Mn	Saxo-Norman
457	blue-green	possible moile with iron-scale	Rom. Mn	Anglo-Saxon Phase 2
412	green	fragment	Rom. Mn	Anglo-Saxon Phase 1
458	opaque white	fragment with white opaque trails	Rom. Mn	Anglo-Saxon Phase 1
358	blue-green	square bottle fragment	Rom. Sb	Medieval
275	blue-green	frontius bottle	Rom. Sb	Anglo-Saxon Phase 2
550	blue-green	fragment	Rom. Sb	Anglo-Saxon Phase 1
312	blue-green	fragment	Rom. Sb	Anglo-Saxon Phase 1
501	blue-green	fragment	Rom. Sb	Anglo-Saxon Phase 1
454	blue-green	Thick handle	Rom. Sb	Anglo-Saxon Phase 1
799	blue-green	shoulder of a handled square bottle	Rom. Sb	Anglo-Saxon Phase 1
42	green	fragment	Rom. Sb	Anglo-Saxon Phase 1
463	nearly colourless	fragment with white opaque trails	Rom. Sb	Anglo-Saxon Phase 1
134	blue-green	fragment with fine trail	Rom. Sb	Unphased
697	blue-green	raw glass, multiple shards.	Rom. Sb	Anglo-Saxon Phase 1

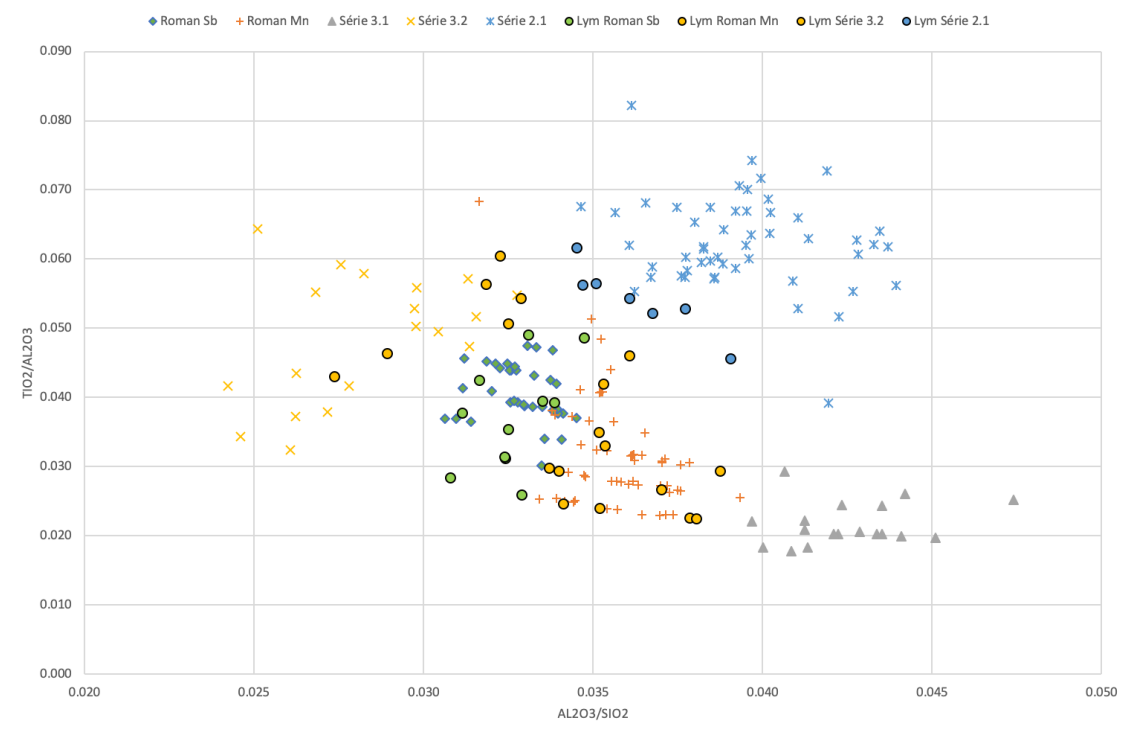

Figure 7.27: TiO_2/Al_2O_3 vs Al_2O_3/SiO_2 for glass groups, with Lyminge assigned to groups.

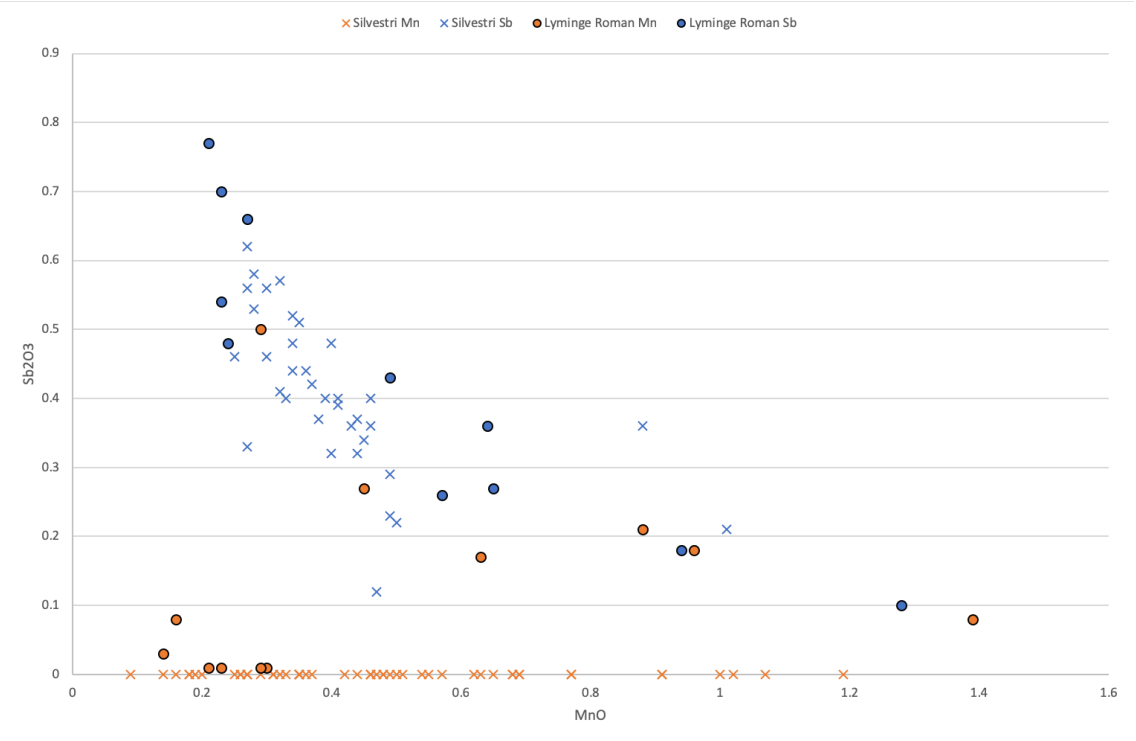

Figure 7.28: Sb_2O_3 vs MnO of glass from groups Roman Mn and Roman Sb, from Silvestri's study and Lyminge.

drop, is been identified as Roman Mn, but with 0.08 wt% Sb_2O_3. As antimony is no longer added to glass from the mid-third century, it seems likely that the Anglo-Saxon glasses in this spread indicates long-term recycled material. This is supported by relationship between Mn and Sb, and glass type. Glasses that would be assumed to have no antimony, indicated in Figure 7.28 with orange circles, have a spread of values. For the most part, these glasses have lower, but some content of antimony. For those that have been identified as Roman Sb group, they too have a spread of values and often higher manganese than usual for this glass.

These two groups are predominately blue-green coloured, though contain both the traditional Roman and a distinct darker blue-green, labeled here turquoise. They also included all the objects though to relate to manufacture, a possible moile, a molten drop, and 'raw' glass. Only one glass from either of these groups has cobalt or copper below what can be used for an indicator of recycling, and as this is a Roman Mn glass, with low antimony, it further corroborates that all of these glasses are recycled Roman glass, potentially glass that has been recycled multiple times. There seems to be very little connection internally, which implies that either this glass has been recycled in continued small batches, or traded in from a variety of sources.

For the rest of the glass, seven shards of Foy Série 2.1, and five of Foy Série 3.2, the majority of this glass was found in phases of the site dominated by the sixth century sunken feature buildings, and are a range of colours. Both groups are far more varied in colour than either of the Roman groups, and contain all of the kempston beaker shards. These glass still contain much evidence of recycling.

Aside from the strong likelihood for the glass of blue-green to be a Roman composition (16 of 18 glasses) there is very little relationship between colour and composition.

Comparing the glass seen at Lyminge to small amounts of Anglo-Saxon vessel glass analysed elsewhere, we see something interesting. The glass at Lyminge seems

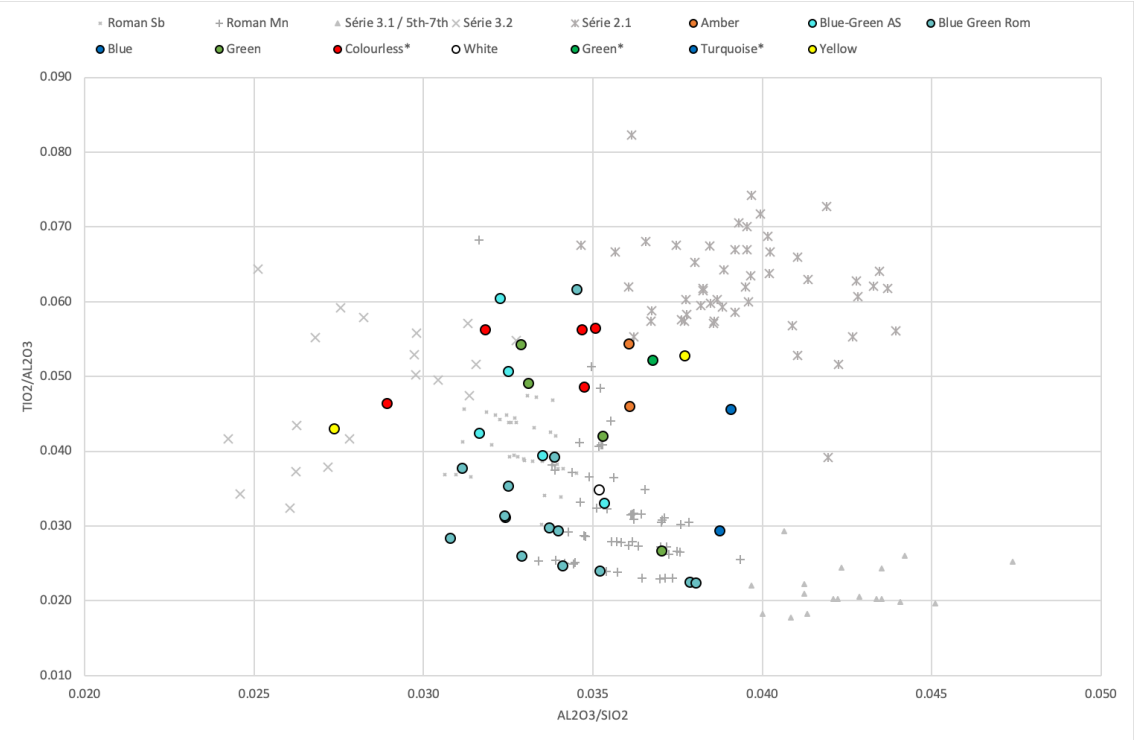

Figure 7.29: TiO_2/Al_2O_3 vs Al_2O_3/SiO_2 for glass groups and Lyminge, with colour of Lyminge glasses indicated..

consistently lower in titanium, relative to aluminium, than those glasses analysed from the British museums collection. This is particularly interesting as much of this glass is from geographically close locations, 15 of the glasses are from Kent, from a study of 29. This dissimilarity is held out in other ways. While only 15 of the vessels have been analysed for antimony, only those from Period 1 showed any antimony, and in much lower amounts than in the Lyminge glass (Freestone et al. 2008a, Table2).

While the Period 1 glass seen by Freestone et al. is potentially a recycled form of HIMT Roman glass, none of the glass at Lyminge shows any significant amount of any high titanium or mangaese. There is one notable similarity between the glass held by the British Museum and the glass studied here. In the glass of the Série 3.2 group, there is a slight rise in both K_2O and MgO. The glasses from Lyminge that are high in magnesia and potash are all Anglo-Saxon in appearance and typology, when identifiable. These five glasses have a linear relationship between the potash

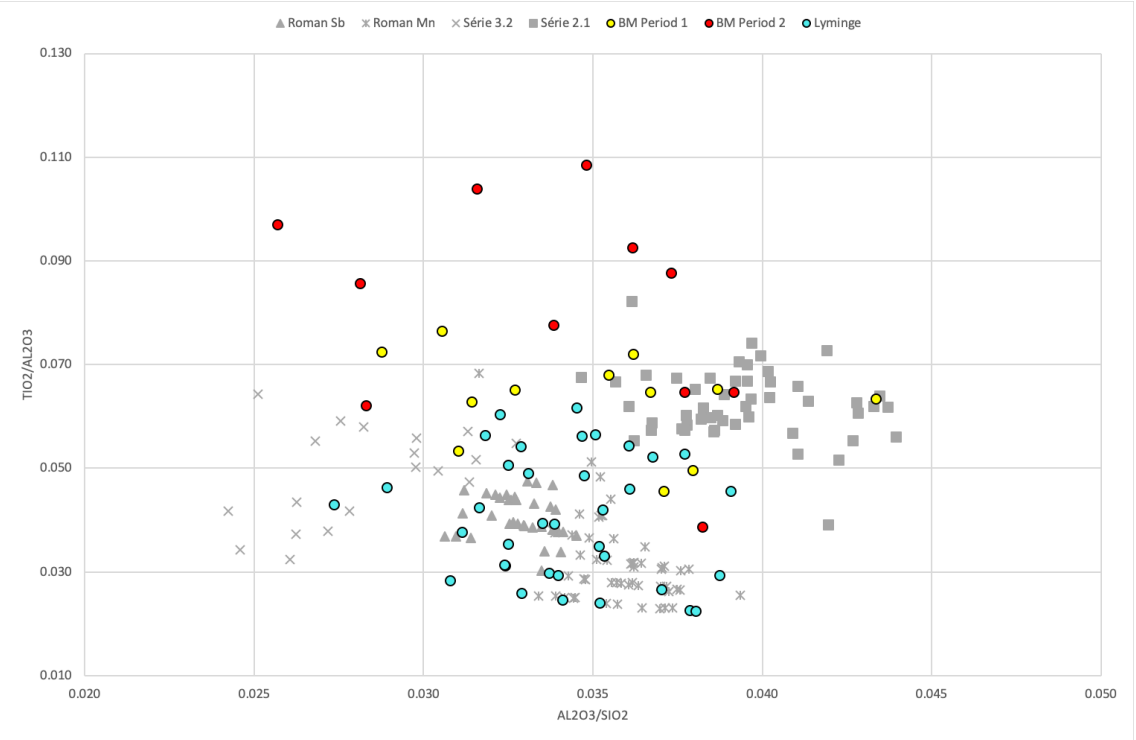

Figure 7.30: TiO_2/Al_2O_3 vs Al_2O_3/SiO_2 for glass groups and Lyminge, with glass from the British Museum collection added.

and magnesia, which might indicate that these sherds are all from a single batch, which has been laced with plant ash.

When the presence of antimony in all groups is considered, it is apparent that this mixing is not limited between just the Roman and later groups, but across them. It seems likely that the earlier material, Roman Mn and Sb, has been recycled into this much later glass. As antimony is no longer added to glass from the mid-third century, it seems likely that this Anglo-Saxon glass is material that has not been recycled once, but is part of a continued system of recycling.

This is most notable with the shard, small find number 458. This is a piece of colourless glass with applied white trails, and the trails were thick enough to be be analysed separately. The trails are a Roman Mn glass, with moderately high antimony (0.21 wt%) and lead (0.92 wt%), whereas primary production of the main vessel is Série 2.1 glass. This implies that, at the least, the trails are recycled Ro-

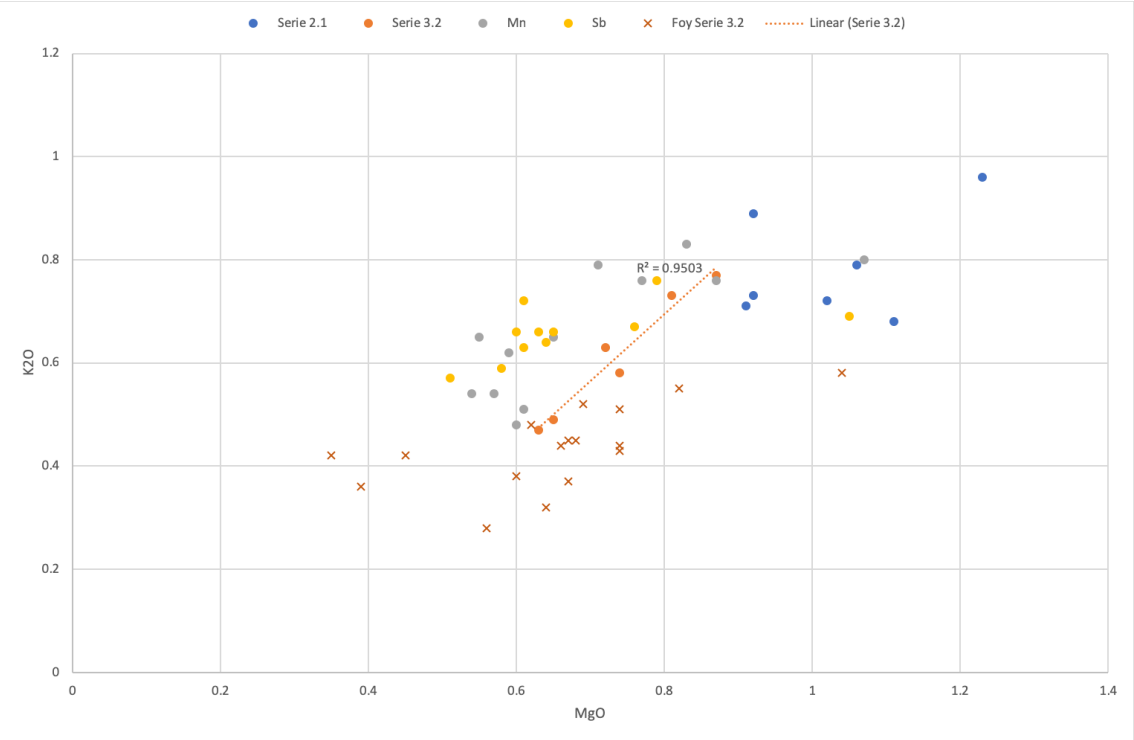

Figure 7.31: TiO_2/Al_2O_3 vs Al_2O_3/SiO_2 for glass groups and Lyminge, with glass from the British Museum collection added.

man glass, however the Série 2.1 far outdates that production. This glass, like the other colourless Série 2.1 glass from Lyminge, has notable amount of antimony (0.14 wt %), as well as copper and cobalt (0.04 and 0.01 wt% respectively). This glass, despite primarily being a contemporary glass composition, contains both evidence of recycling in unexplained colourants (Cu, Co) and the use of ingredients no longer used (Sb). This implies a deliberate choice of recycling, for desired effect. It is likely that a Roman glass, which had already been recycled centuries earlier, was found and remelted onto a vessel, made of a glass that, although more contemporary in production, had also undergone recycling events.

Recycling is clear at Lyminge also in the only cobalt blue sherd, which is a solidly Roman in colourant composition, with high lead, but which falls into the Série 2.1 glass group. In such a case, it is likely that a strongly coloured glass, perhaps a tesserae, was melted into an otherwise uncoloured Série 2.1 glass.

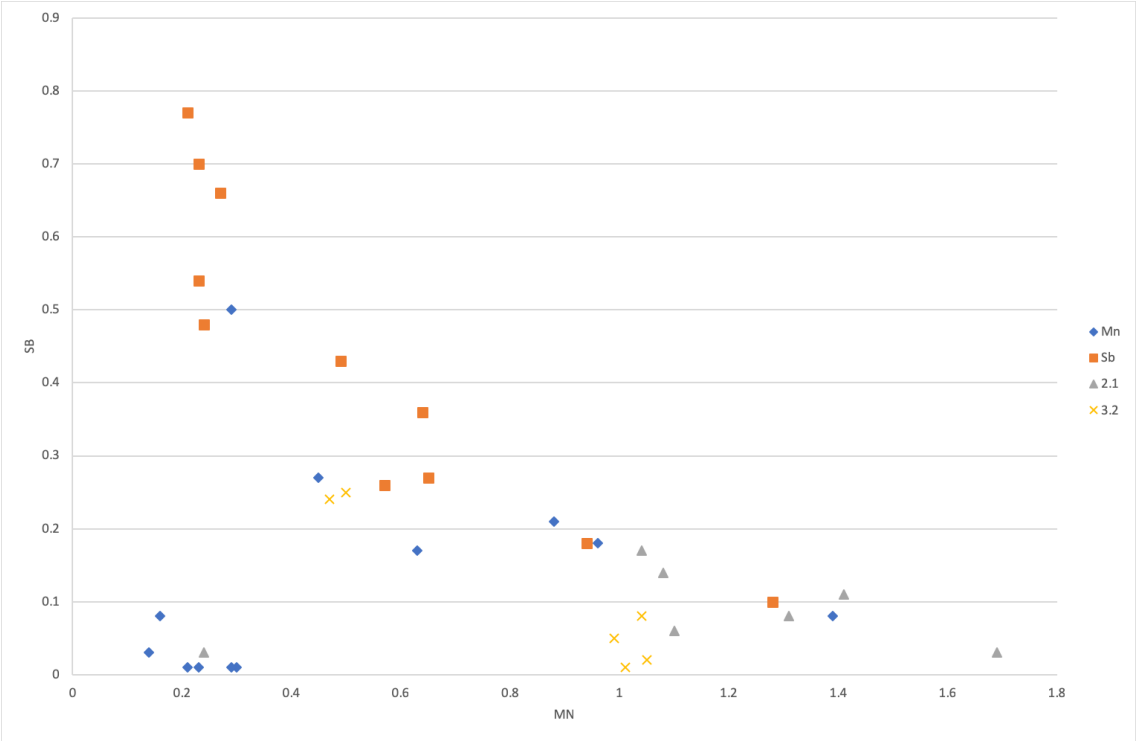

Figure 7.32: Sb_2O_3 vs MnO of glass from Lyminge, separated by group.

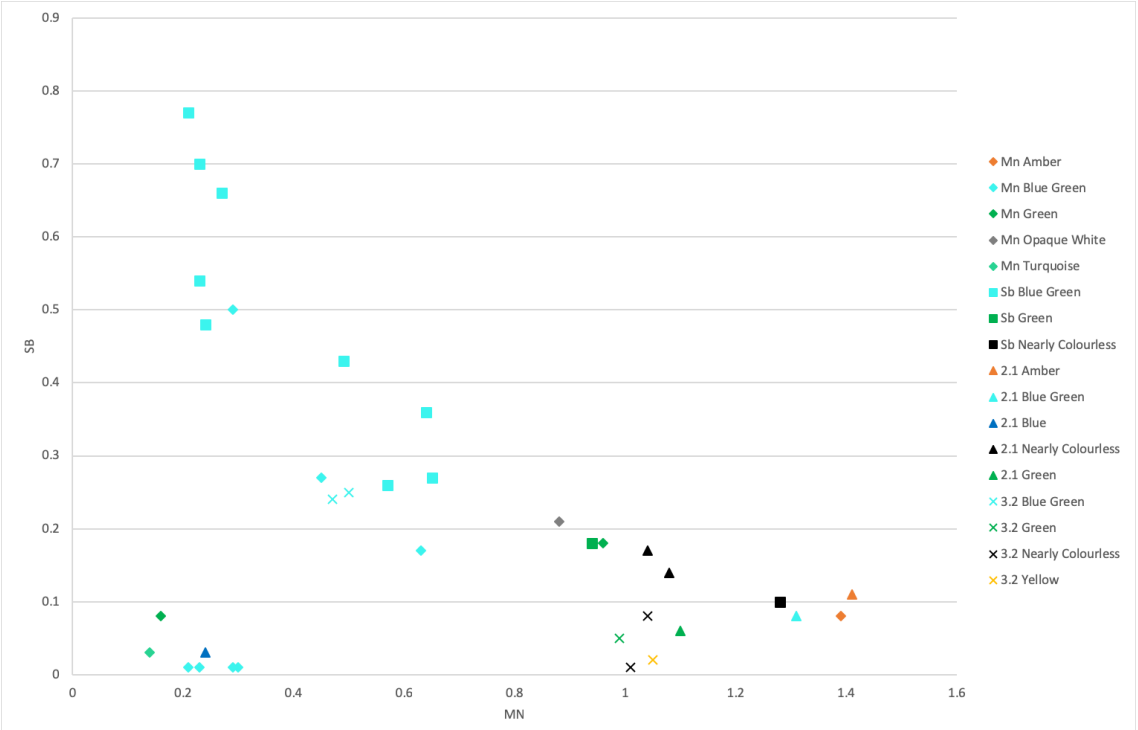

Figure 7.33: Sb_2O_3 vs MnO of glass from Lyminge, separated by group and colour.

A full analysis of the colourants hasn't yet been made, however a few preliminary comments can be made. The blue-green glasses tend to plot together, with the exception of half of the Roman Mn glasses and the single Série 2.1 glass. Three of five glasses that were Anglo-Saxon blue green and one that is notably turquoise all have copper over 1.6 wt%, and with the exception of the turquoise, antimony over 0.24 wt%. However, these glasses are not similar in base glass; Two glasses are Série 3.2, and one from each Roman group. These seem like multiple recycling events. As mentioned, the dark blue glass is cobalt coloured and almost certainly recycled. The green glasses, or a large proportion of them, are very similar. It is possible that these represent a single recycling event, likely at Lyminge itself.

Other than this there are no other strong correlation of colour groups yet apparent, aside from the fact that almost all colours have high manganese and notable traces of antimony, again implying recycling.

Looking only at blue green glass, the largest single group, we might be able to unpick the relationship between the glasses and primary and tertiary sources.

While there is some relationship between colour and trace, in colour production, eg. opaque white, much seems to be part of another pattern [Fig. 7.34]. In blue green glasses, the higher the titanium, an indication of the the addition of HIT/HIMT glass, out of production by this period, correlated to higher values of antimony, lead, copper, and to a lesser degree, cobalt [Fig. 7.35]. This appears a very recycled mix.

The Lyminge glass as a whole is notably different to the Dorchester-on-Thames glass. It has a significantly lower component of HIMT glass. This is interesting archaeologically as it seems to imply that rather than a continuous pool of glass here, there is a break, and then the Roman glass is being exploited by the much later occupation at Lyminge. As will be noted in the next few chapters, this is not the

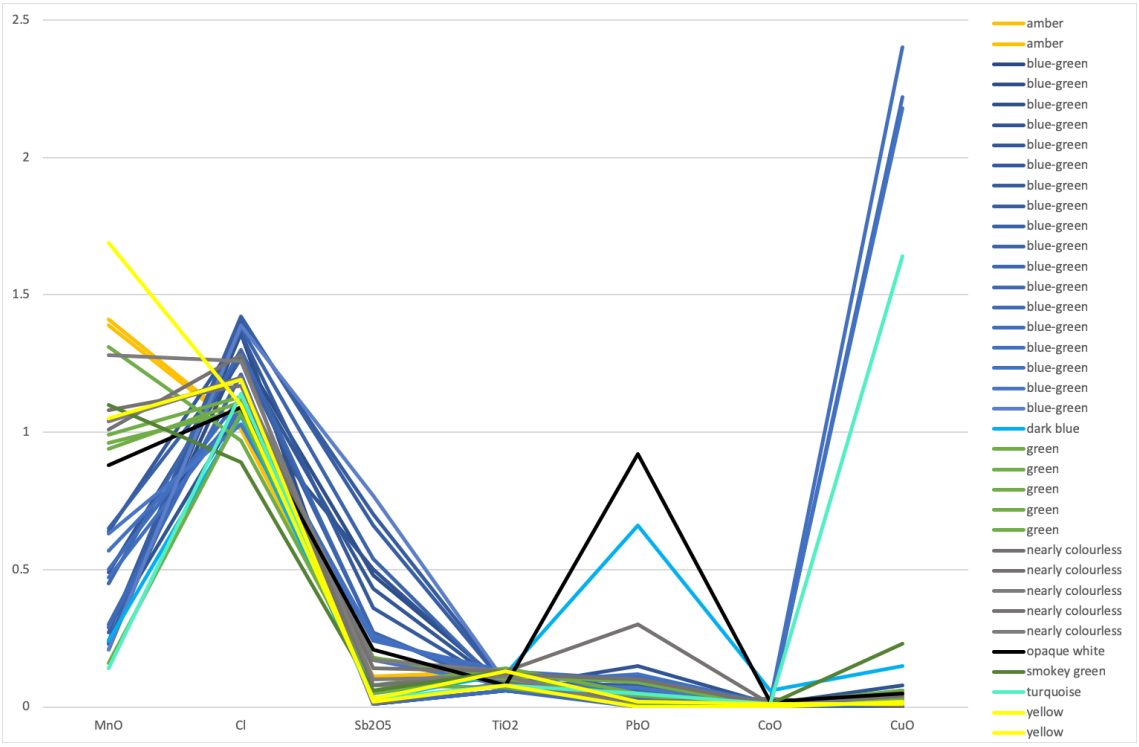

Figure 7.34: Weight percent of various elements related to colouration and recycling in individual glasses, with glass colour displayed by line colour.

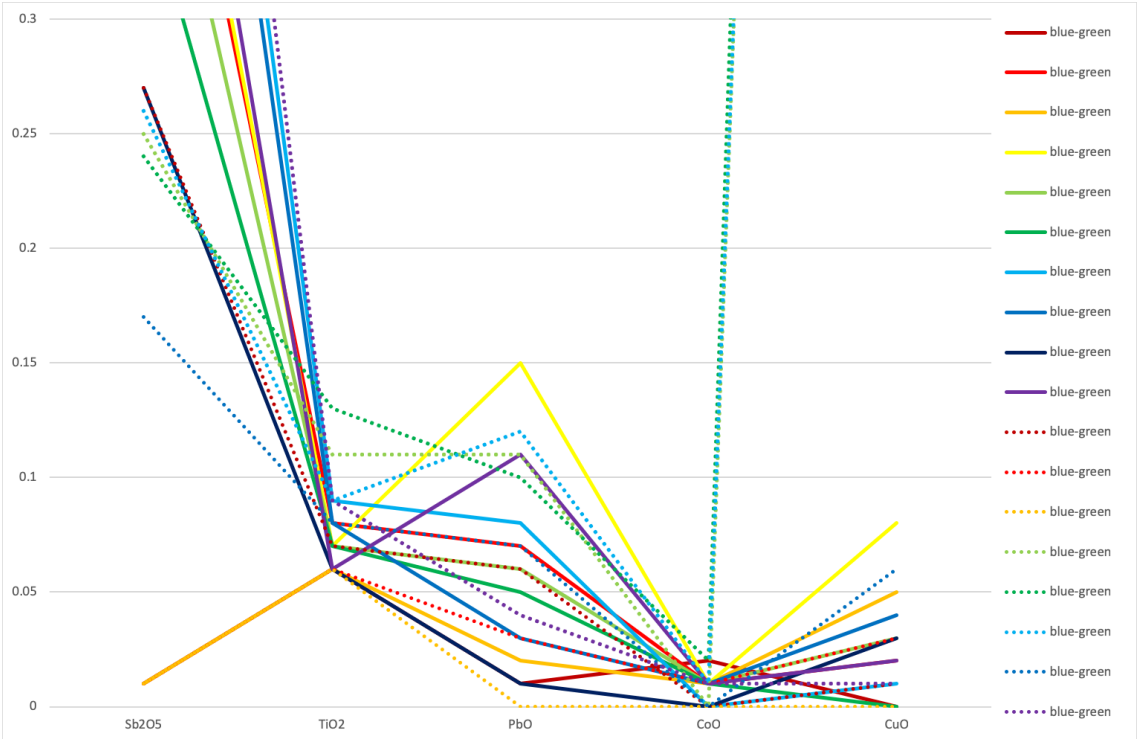

Figure 7.35: Weight percent of various elements related to colouration and recycling in blue-green glasses, with line colour indicating individual glasses.

case in other sites in Kent.

The fact that the glass is notably different from the material studied from Faversham, thought to be the home of Kempston beakers, is interesting. This, along with the evidence of glass working, implies that some of the beakers at Lyminge were not produced at this assumed site, but within the bounds of Lyminge itself.

Chapter 8

Glass Databases

Every new analytical glass paper published tends to create, as well as these new analyses, its own small reference database. The previous chapter referred to such heavily, ie. Figure 7.12. These usually include the same 100 or so glasses that are traditionally used to define glass groups, or published averages of these. A summary of such groups and their publications can be seen in Table 3.

Rather than just relying on these averages, separating glass into discrete production groups, this thesis is trying to look at the mixture between these. Here a database has been collated using all the available raw data for individual glasses in Britain, from 1^{st}-8^{th} centuries, as well as a range of comparable datasets from Europe. These databases are outlined in Chapter 8.1 and 8.2. These glasses haven't been sorted into these glass groups, but considered as a single flow of material, with many sources and mixing.

In addition to the published glass collected, freshly excavated glass from two sites, that have layers dating from the Late Roman through to the Early Medieval period, have been analysed by the author and added to the database; 104 glasses from the site of Dorchester-on-Thames, Oxfordshire, and 36 from Lyminge, Kent. These 140 glasses yield possibly the most extensive dataset from Britain for this later period,

aside from a recent bead study by Peake (2013b).[1] When these glasses are added to the previously published glasses, this forms the most extensive glass database for ancient Britain, which will allow this thesis to comment on the nature of glass trade and use in the period of change from Roman to Medieval Britain.

There are many problems of bias, weaknesses and caveats within the data that is available to this thesis, some of which were discussed under the Methodology (Chapter 2). While each of the major, overarching issues, and their potential impact upon any conclusion drawn from this study, have been noted, there are also problems with papers individually. As such, each paper must be considered individually. There is then the problem of comparability of multiple analysts and techniques, and the areas of their focus. This is the most fundamentally problematic of the issues facing this thesis, as it relies on the assumption that all of the collected data is at least broadly comparable.

Assuming the range of techniques doesn't cause an issue, the next problem is the relationship between the density of data across time and geographical spread. In other words, are the patterns that can be seen in this thesis actually related to the structure of the database, rather than any archaeological information? This problem is perhaps even more challenging, as this thesis almost entirely relies on the analytical work of others, which carries its own temporal and regional agendas.

There are clear areas of data bias, which that have been of interest to specific authors, or to which analysts have had particular access - for instance L'Aquila in Italy and York in Britain. However, despite these issues, there is still a lot that can be achieved by this form of legacy data approach, and several things that can be done to try and understand the strength and limitations.

[1]Few studies of Anglo-Saxon glass exist. The British museum allowed analysis of 29 glass vessels from their collection by Freestone et al. (2008a). Given estimates done by Evison (2000, 5), this was thought to represent in excess of 5% of the the total glass vessels recovered from early Anglo-Saxon sites at the time. However, this estimation must be reevaluated as Evison had 200 shards from Anglo-Saxon Period I, a number now exceeded by Lyminge alone for this period.

First each database will be briefly introduced, then these overarching issues discussed.

8.1 British Glass Database

Values for 3263 English glasses, focused between the first and eighth centuries, are used in the database, taken from 43 separate publications, assembled by the methodology detailed in Chapter 2. As discussed, there are limitations in different techniques, and not all authors analysed for the same elements. At any point when a discussion focuses on a material a paper has not analysed for, all glasses from said paper have been removed from the statistical analyses to avoid confusion and bias. A table of each paper, including the sites, period and techniques used, has been included for ease [Table 8.1]. As well as this, there is also a brief summary of each paper or dataset, including information about necessary conversions and assumptions used to allow inclusion in the database. They have been arranged alphabetically by author.

Each paper was summaries into a table, as iterated in the methodology. As well as the data included there, there are columns for all elements encounter in any paper in this study: SiO2, Na2O, MgO, Mg, Al2O3, K2O, K, CaO, Ti, TiO2, Mn, MnO, MnO2, Fe, FeO, Fe2O3, Sb, Sb2O3, Sb2O5, Cu, CuO, Cu2O, Ni, NiO, Sr, SrO, Zn, ZnO, Co, CoO, Cr, CrO, Cr2O3, As, As2O3, Sn, SnO2, P2O5, Pb, PbO, S, SO3, Cl, ClO3, Li, V, V2O5, Y, Ba, BaO, Nb, Zr, ZrO2, Ce, La, Rb, Sc, B, Mo, Ag, Pr, Nd, Hf, Th, U, Ga, Be, Cs, Bi, W, Sm, Eu, Dy, Yb, In, Gd, Tb, Cd, P, Au, Tl, Ho, Er, Tm, Lu, Ta. This allowed for the recording of oxide given in the paper, and while this has been assumed to be correct, this is not necessarily so.

This comes to the problem of data cleaning. In this project, minimal cleaning was employed. That is, if the paper existed in any of the publications discussed in the methodology, fell within the correct geographical and temporal restrictions,

and the glasses were analysed for at least five elements, it was included. Due to the disparate nature of many reports, especially those not prepared for publication in a traditional sense such at the Ancient Monument Laboratory Reports, no information on detection limits or accuracy was recorded. In fact, many papers were unclear on whether or not they analysed for silica, or its values were achieved by subtraction. The approach was taken that the sheer number of results would overwhelm bias and problematic techniques. This has been reconsidered by the author, and the database is being improved prior to publication, with a weighting technique. Results will be deemed to be five start if they 1- use external standards, 2- show multiple results or sigma values for studies, 3- are clear about all techniques used (ie. if some elements are analysed for by different methods), 4- include the detection limits of machines and 5- record the values achieved for external standards. While this could still mean that the results were problematic, one would be able to assess in what day, and to what degree such results could be relied upon. As it is, all papers were deemed acceptable for inclusion in this study.

A digital version of this data accompanies this thesis, which contains a break down of sites and associated authors.

Table 8.1: Summary of papers containing analytical data of English glass, from the first to eighth centuries, including find spots when known and techniques used. Places in italics are non-English sites that were included in any of these papers.

Paper	**Count**	**Sites**	**Technique**
Bateson and Hedges 1975	30	Brough (5) Appleton (2) Brettenham (2) Bury-St.-Edmunds (2) Campsfield (2) Ditchley (2) Suffolk (2) Woodeaton (2) Asthall (1) Bardwell (1) Bath (1) Derbyshire (1) Unknown, England (1) Great Wallingfield (1) Icklingham (1) Ixworth(1) Kent (1) Lancing Down (1) Shakenoak Villa, Oxfordshire (1)	XRF
Baxter et al. 1995	120	Colchester, Essex	ICPS
Baxter et al. 2005	245	Colchester, Essex	ICPS
Bayley 3635* (Ancient Monument Report Number, no publication date)	88	Dover, Kent	ED-XRF
Bayley 4183*(Ancient Monument Report Number, no publication date)	10 *(& 4)*	Wharram Percy, Yorkshire (2) Watling House, London(1) Old Sarum, Wiltshire (1) Southampton, Hampshire (1) Hamwih, Hampshire (4) Chiddingfold, Sussex (1) *Winetavern St, Dublin (2)* *San Vincenzo, Molise, Italy (2)*	ED-XRF
Bayley 2003	3	Chichester, West Sussex (2) Heybridge, Essex (1)	SEM-EDX
Bayley 2005	4	Castleford, Yorkshire	SEM-EDX
Bimson and Freestone 2000	9	Sutton Hoo, East Anglia (3) Taplow, Buckinghamshire (2) Broomfeild, Essex (2) Faversham, Kent (1) Wingham, Kent (1)	ED-XRF

Table 8.1: Summary of papers containing analytical data from English glass, *continued.*

Paper	**Count**	**Sites**	**Technique**
Brill 1999	36 & *313*	Jarrow & Monkwearmouth, Tyne and Wear (33) Lullingstone Villa, Kent (3) *Peloponnese, Greece (82)* *Unknown (54)* *Grosseto, Italy (48)* *Veneto, Italy (26)* *Ravenna, Italy (21)* *Split-Dalmatia County, Croatia (19)* *Gelderland, Netherlands (12)* *South Jutland County, Denmark (10)* *Primorje-Gorski Kotar, Republic of Croatia (7)* *Condeixa-a-Nova, Portugal (5)* *Attica, Greece (4)* *Monmouthshire, Wales (4)* *Province of Siena, Italy (4)* *Newport, Wales (3)* *Livorno, Italy (2)* *North Rhine-Westphalia, Germany (2)* *Republika Srpska, Bosnia and Herzegovina (2)* *Rhineland-Palatinate, Germany (2)* *County Meath, Ireland (1)* *Fribourg, Switzerland (1)* *Limburg, Belgium (1)* *Manisa Province, Turkey (2)* *Jerusalem, Israel (1)*	Not recorded *(Note: This book contains many more sites, but these were not entered into the English or European Database)*

Table 8.1: Summary of papers containing analytical data from English glass, *continued.*

Paper	**Count**	**Sites**	**Technique**
Cagno et al. 2013	19	London, Greater London (13)	SEM-EDX
	(& 379)	Colchester, Essex (6)	LA-ICP-MS
		Augst, Switzerland (41)	
		Liberchies, Belgium (26)	
		Avenches, Switzerland (23)	
		Meteren, Netherlands (18)	
		Tienen, Belgium (17)	
		Oudenburg, Belgium (15)	
		Haifa, Israel (14)	
		Olbia, France (12)	
		Treignes, Belgium (12)	
		Oresac, Croatia (11)	
		Ste Menehould, France (11)	
		Heerlen, Netherlands (10)	
		Matagne-la-Petite, Belgium (10)	
		Ribnica, Slovenia (10)	
		Trou de Han, Belgium (10)	
		Trier, Germany (9)	
		Ghurob, Egypt (7)	
		Nijmegen, Netherlands (7)	
		Roly, Belgium (7)	
		Rome, Italy (7)	
		Tongeren, Belgium (7)	
		Hoogeloon, Netherlands (6)	
		Velzeke, Belgium (6)	
		Florennes, Belgium (5)	
		Magdalensberg, Austria (5)	
		Rumst, Belgium (5)	
		Tiel, Netherlands (5)	
		Elkab, Egypt (4)	
		Kontich, Belgium (4)	
		Lauw, Belgium (4)	
		Dilsen, Belgium (3)	
		Odijk, Netherlands (3)	
		Anthee, Belgium (2)	
		Broechem, Belgium (2)	
		Braga, Portugal (2)	
		Celje, Slovenia (2)	
		Faulquemont, France (2)	
		Krui shoutem, Belgium (2)	
		Nismes, Belgium (2)	
		Nivelles, Belgium (2)	
		Reims, France (2)	
		Vechmaal, Belgium (2)	
		Aalter, Belgium (1)	
		Amay, Belgium (1)	
		Auvelais, Belgium (1)	
		Unknown, Cyprus (1)	
		Dourbes, Belgium (1)	
		Eindhoven, Netherlands (1)	
		Elewijt, Belgium (1)	
		Emblem (1)	

Table 8.1: Summary of papers containing analytical data from English glass, *continued.*

Paper	**Count**	**Sites**	**Technique**
		Unknown, Germany (1) *Grandes-Armoises, France (1)* *Grobbendonk, Belgium (1)* *Ham, Belgium (1)* *Izier, Belgium (1)* *Liege, Belgium (1)* *Marche-les-Dames, Belgium (1)* *Marseille, France (1)* *Menen, Belgium (1)* *Mohn, Germany (1)* *Pry, Belgium (1)* *Riemst, Belgium (1)* *Roche-Ste-Anne, Belgium (1)* *Trebnje, Slovenia (1)* *Unknown, Turkey (1)* *Wasserbillig, Luxembourg (1)*	
Cagno et al. 2014	6 *(& 38)*	Colchester, Essex (6) *Avenches, Switzerland (6)* *Augst, Switzerland (8)* *Heerlen, Netherlands (10)* *Lahun, Egypt (1)* *Unknown, Egypt (4)* *Bahnasa, Egypt (1)* *Abydos?, Egypt (1)* *Roly, Belgium (7)*	SEM-EDX LA-ICP-MS
Foster and Jackson 2009	376	Barnsley Park, Gloucestershire (24) Barton Court Farm, Oxfordshire (7) Beadlam Villa, North Yorkshire (45) Caister-on-Sea, Norfolk (48) Dalton Parlours, West Yorkshire (11) Dorchester, Dorset (10) Dorchester-on-Thames, Oxfordshire (9) Frocester Court, Gloucestershire (26) Canterbury, Kent (31) Lullingstone Villa, Kent (18) Portchester Castle, Hampshire (9) Billingsgate, London (20) Towcester, Northampton (37) Shakenoak Villa, Oxfordshire (19) Bath, Somerset (18) Wellington Row, North Yorkshire (19) York Fortress, North Yorkshire (6) York Minster, North Yorkshire (19)	ICP-AES

Table 8.1: Summary of papers containing analytical data from English glass, *continued*.

Paper	**Count**	**Sites**	**Technique**
Foster and Jackson 2010	128	Barnsley Park, Gloucestershire (13) Beadlam Villa, North Yorkshire (5) Caister-on-Sea, Norfolk (26) Dalton Parlours, West Yorkshire (5) Dorchester, Dorset (15) Frocester Court, Gloucestershire (7) Towcester, Northampton (1) Shakenoak Villa, Oxfordshire (18) Canterbury, Kent (25) Lullingstone Villa, Kent (3) Portchester Castle, Hampshire (5) Billingsgate, London (1) York Fortress, North Yorkshire (4)	ICP-AES ICP-AES
Freestone and Hughes 2006	10	Jarrow and Monkwearmouth, Tyne and Wear	SEM-EDXA ICP-AES ICP-MS
Freestone et al. 2008a	29	Faversham and Howletts, Kent (11) Broomfield, Essex (2) Mucking, Essex (2) Sittingbourne, Kent (2) Bishopsbourne , Kent (1) Castle Eden, Durham (1) Desborough, Northamptonshire (1) Droxford, Hampshire (1) East Shefford, Berkshire (1) Great Chesterford, Essex (1) Kempston, Bedfordshire (1) Longbridge, West Midlands (1) Rainham, Greater London (1) Taplow, Buckinhamshire (1) Unknown (1) Wye Down, Kent (1)	SEM-EDXA ICP-AES ICP-MS
Henderson 1996	14	Fishbourne, West Sussex	?
Heyworth and Warren 1988	8	Maiden Lane, London	ICPS
Heyworth 1987	41	Wakerley, Northamptonshire	ED-XRF
Heyworth 1988a	28	Beckford, Worcestershire	ED-XRF
Heyworth 1988b	28	Great Chesterford, Essex	ED-XRF
Heyworth 1989	19	Uley, Gloucestershire	ICPS
Heyworth 1990d	1	Windchester, Hampshire	ED-XRF
Heyworth 1990c	2	Trowbridge, Wiltshire	SEM
Heyworth 1990b	82	Empingham, Leicestershire	ED-XRF
Heyworth 1990a	41	Moorgate, London (26) Watling House, London (6) Copthall Avenue, London (4) Norton Folgate, London (4) Tower of London, London (1)	ICPS

Table 8.1: Summary of papers containing analytical data from English glass, *continued*.

Paper	**Count**	**Sites**	**Technique**
Heyworth 1991	479	Hamwih, Hampshire (273) Windchester, Hampshire (145) Ipswich, Suffolk (7) Maiden Lane, London (7) Repton, Derbyshire (44) Helgö, Sweden (13) Quentovic (La Calotterie), France 15)	ICPS
Heyworth 1992	30	National Gallery, London (2) Bedfordbury, London (21) Maiden Lane, London (7)	ICPS
Heyworth et al. 1990	120	Colchester, Essex	ICPS
Hunter and Heyworth 1998	273	Hamwih, Hampshire	ICPS
Jackson 1992	476	Fishergate, North Yorkshire (31) Worcester, Worcestershire (25) Coppergate, North Yorkshire (242) Mancetter, North Warwickshire (103) Leicester, Leicestershire (75)	ICPS
Jackson 1996	45	Fishergate, North Yorkshire	ICPS
Jackson 2005	78	Leicester, Leicestershire (8)) Mancetter, North Warwickshire (9) York, North Yorkshire (61)	ICPS
Jackson et al. 2003b	47	Coppergate, York, North Yorkshire	ICP-AES
Mortimer 1991	2	Carisbrooke Castle, Isle of Wight	SEM
Mortimer 1995	2	Westminster Abbey, London	ED-XRF
Mortimer 1996a	22	Barrington, Cambridgeshire	SEM-EDX
Mortimer 1996b	30	Mucking, Essex	SEM-EDX
Mortimer and Baxter 1996	53	Lincoln, Lincolnshire	ICP
Mortimer and Horsley 1997	25	Ipswitch, Suffolk	XRF EDX
Paynter 2006	40	Binchester, Durham	ICP-AES SEM-EDS
Paynter and Kearns 2011	176	West Clacton Reservoir, Essex	ICPMS SEM-EDS
Sanderson et al. 1984	187 *(& 12)* Only 51 are not in summary form	Hamwih, Hampshire (25) Binchester, Durham (17) Castleford, West Yorkshire (13) Wroxeter, Shropshire (15) Cadbury Congress, Bristol (39) Spong Hill, Norfolk (21) Windchester, Hampshire (39) Repton, Derbyshire (18) Dorestadt, Holland (12) Heglö, Sweden (8)	ED-XRF
Sainsbury, present work	141	Lymine, Kent (37) Dorchester-on-Thames, Oxfordshire (104)	EMPA

Table 8.1: Summary of papers containing analytical data from English glass, *continued*.

Paper	Count	Sites	Technique
Stapleton et al. 1999	6	Barlaston, (2) Whitby (2) Suffolk (1) Lincolnshire (1) Ireland (6)	XRF-EDS SEM
Wilthew 1985	114	Finglesham, Kent	ED-XRF
Wilthew 4650	99	Alton, Hampshire	ED-XRF

8.1.1 Bateson and Hedges, 1975

Bateson and Hedges (1975) is the analysis, both typological and technological, of thirty Roman enamels from a variety of sites. Due to the nature of the collection, only a small proportion are located to specific sties. They are analysed by a range of XRF, and some by XRD.

Baxter, Cool, Heyworth and Jackson, 1995

Baxter et al. (1995) is one of the first of a series of papers of glass from the Romano-British levels of Colchester. The glass from Colchester is perhaps the best studied from an individual site in Britain. Colchester (Camulodunum) was the site of the first legionary fortress in Britain, and then had served a a provincial capital. It is also strongly associated with revolt of Boudicca and the Iceni. What this means is that the site has long been the focus of Antiquarian interest, as well as over 50 years of excavation.

This paper was an analysis of 120 shards of vessel glass, by ICPS, to demonstrate and explore the compositional variation within glass from a single site, rather than in relation to outside source/provenience. In particular, the paper focused on four typological groups, dating from AD 65/70 to late second century. Cast vessels, facet

cut, wheel-cut beakers and cylindrical double base cups were selected, and all were colourless. No standards or details of where the analysis took place was reported.

This paper was particularly interesting as it was one of the first that a relationship between form and composition, following on from the unsuccessful (Heyworth et al. 1990). Rather than demonstrating an ideal composition for a specific type, rather it showed 'volatility' of the composition within types. Both the latest (Cylindrical cups) and to a lesser extent the earliest (Cast vessels) have a fairly stable composition across the set. However, the two middle groups are far more variable. The meaning of this in terms of glass sourcing and recycling is potentially interest.

Baxter, Cool and Jackson, 2005

Baxter et al. (2005)'s analyses of 245 vessels from Romano-British Colchester, Essex, was a continuation of the earlier work published on the the Colchester glass, Baxter et al. (1995). It followed the same techniques as the earlier paper, with improvements to the ICPS, which was undertaken at Royal Holloway. Also, a greater number of glasses from each typological group were analysed. Several standards were used for calibration, however the individual values were not reported. These were the Royal Holloway internal standard, KC11, as well as five glass standards: Corning glass standards A and B, European Science Foundation glass standard 76-C-150, National Bureau of Standards SRM621 and Society of Glass Technology Standard glass 4.

This paper showed a more complex range of chemical variation within each type of vessel, with clear subgroups. This paper suggests that perhaps more glass sources are used in this period than the few Syrio-Palestian ones suggested by Freestone and others, but allows either interpretation.

Bayley, 3635

One of a series of analyses done by Bayley (3635) for the Ancient Monuments Laboratory (AML) of English Heritage. As the early AML reports did not include publication dates, only accession numbers, they have been recorded. This study was ED-XRF of 88 beads from burial contexts Saxon Dover, held by the British Museum. The study was primary concerned with colouration or decolouration in monochromatic and polychromatic beads. It implied that the colourless beads were not made out of recycled Roman glass, due to the lack of antimony. However, some of the colourants, especially black, showed a good deal of mixing. No details on analysis were recorded.

Bayley, 4183 (Including 3701 & 3938)

The last in a series of reports of red Early Medieval glasses from Britain for the AML by Bayley. This paper also included previously published results.Firstly, two shards of opaque red glass from the medieval urban site of Wharram Percy in Yorkshire were analysed and compared to two shard of opaque red glass known from Italy (Bayley 3701). These were done by ED-XRF. There was seemingly little relationship between the English and Italian Red glasses. The report was then extended by another six British red glasses, published as Report 4183. These included four glasses from Hamwih and one each from modern Southhampton and Old Sarum (Bayley 4183). This last paper, combining these ten results with a further four, one each from Watling House in London and Chiddingfold, Sussex, as well as 2 from Winetavern St Dublin. Information about the ED-XRF was not included.

The main aim of these experiments was to source where the glass at Wharram Percy was coming from. Unfortunately these analyses did not illuminate this.

Bayley, 2003

This is a short paper by Bayley, included in the Annales du Congrès de l'Association International Pour l'Histoire du Verre, analysed three pieces of red opaque glass from Roman Britain, focusing on what is evidence of red glass production and what it instead applies to enamelling. Two samples are from Chichester, and one from Heybridge. These analyses were done by SEM-EDX. The Chichester glass was found with evidence of production or working materials, and the Heybridge in a Roman ditch.

Bayley, 2005

As above, this is another short paper by Bayley, analysing lumps of what she deduced as red raw enamel in a potential working site. These samples are all from Roman Castleford in Yorkshire, and were analysed by SEM-EDX.

Bimson and Freestone, 2000

This paper by Bimson and Freestone is focused on Anglo-Saxon glass insets in early medieval artefacts, from the collection of the British Museum. It is the analyses of six notable pieces of inset glass, from Sutton Hoo, the Taplow burial, as well as two brooches from Wingham and Faversham. This is then compared to three more analyses of contemporary vessel glass. They were analysed by SEM-EDX, and Corning standards used, though values not reported. This paper concluded that there was not a specific manufacture for Anglo-Saxon enamel, but rather scraps of glass, including Roman cullet were used.

Brill, 1999

This is a small selection of material from Brill's extensive volume, Chemical Analyses of Early Glasses. With the volume of this size, analysed with many techniques, only

a small amount were relevant to this study. The majority of these are from the sites of Jarrow and Monkwearmouth.

Cagno et al., 2013

Cagno et al. (2013) is a paper concerned with 'black appearing' Roman glass. In reality, very strong shades of greens, blues and purples, such that they seem almost black. This project was a huge collating of 'black' glasses from across the Roman provinces, from the first to fifth centuries. It includes 398 shards of vessels, jewellery and inlays, analysed by both an SEM-EDX and LA-ICP-MS, using Corning B and NIST standards, though unpublished. 19 of these samples are English, 13 from London and 6 from Colchester, and the rest are broadly spread across the Empire. 159 are Belgian, 64 Swiss, 50 from the Netherlands, 29 French, 14 Israeli, 13 Slovenian, 11 Croatian, 11 German, 11 Egyptian, 7 Italian, 5 Austrian, 2 Portuguese and 1 each from Turkey, Cyprus and Luxemborg. The European glasses have been added to the appropriate databases. This belongs to a collection of papers by Cagno and colleagues on black glass, from across the Empire, concerned with with understanding how and where these glasses were produced.

Cagno et al., 2014

This paper was published as an addition to the collection of 'black' glasses published in Cagno et al. (2013). It was methdologically identical, and added a further 44 shards of vessels, jewellery and inlays. Six of these shards are from Colchester, however the rest are non-British: 14 Swiss, 10 from the Netherlands, 7 Egyptian, and 7 Belgian. The paper has shown that there is both great compositional variation regionally and chronologically, including some being manufactured using plant ash glasses.

This paper recorded glasses by Isings number only, but in the database have been added to type.

Foster and Jackson, 2009

Foster and particularly Jackson have studied a huge amount of glass from particularly Roman contexts in Britain. This paper is concerned with the seemingly naturally coloured vessel glass in Roman Britain, from the fourth and fifth centuries. Analyses are used to track the grouping and shift of these glasses, to understand the nature of the glass in Late Roman Britain. This paper reports the values of 376 'naturally coloured' glasses, analysed by ICP-AES, however, the analytical program included a further 141 other glasses, 128 of which were colourless and reported in Foster and Jackson 2010, also included in this database. Together these glasses spread almost the entirety of Roman Britain, a break down of the locations is included in Table 8.1 and won't be repeated here for the sake of brevity.

These analyses were completed at the Royal Holloway and Bedford New College, and the values for the external standard, Corning B, were reported.

Foster and Jackson, 2010

This paper is the sister paper to Foster and Jackson 2009. It contains the values of all the colourless glass from this analytical project, a total of 128 glasses, from a variety of locations across Britain, again reported in Table 8.1. The analytical process is exactly as the above paper, and once again, the analysed values of Corning B were reported.

The paper was concerned with the nature of colourless glass in Britain, it's chronology, longevity of composition, sourcing and recycling. It indicates an increased mixing and recycling in the 4th century in Britain, which mimics other industries, and is here related to Britain's place within a Roman economy.

Freestone, Hughes and Stapleton, 2008

This study, completed as part of a larger British museum catalogue of their Anglo-Saxon Glass (Evison and Marzinzik 2008), it is one of the largest targeted analyses of Anglo-Saxon vessel glass at only 29 glasses. The majority of these glasses are from Faversham (7), and Kent more generally (another 8). However, there is a broad spread across England [Table 8.1], as well as the main Anglo-Saxon types covered, cone beakers, claw beakers, globular beakers, bag beakers, palm cups, and a drinking horn.

The analyses were completed at the Imperial College, Natural History Museum and UCL, and calibrated by Corning glass standards A and B along with a number of commercially available glass standards, however the results for these standards were not reported. For the first time, this paper showed two clear and distinct glass patterns, related to an early and later early Anglo-Saxon tradition.

Freestone and Hughes, 2006

This specialist report formed part of the excavation record of Cramp's excavation of Wearmouth and Jarrow monastic sites (Cramp 2006). Freestone and Hughes analysed ten shards of the window glass from the early medieval abbey at Jarrow in Northumbria, to try and ascertain how the glass reached this comparatively remote point, and whether that was consistent with records of the work, ie. Bede. Analyses were done by SEM-EDXA, ICP-AES and ICP-MS but no information on standards was included.

When inputing this data into the present database, the values for copper and lead used are the values as given by the ICP-AES analysis, except in the cases of 6828-3-Y and 6828-6-Q, both of which were below detectable limits. For these, the results from ICP-MS was used instead.

Henderson, 1996

ICPS analysis of 8 vessels from an early medieval site in London, Maiden Lane. This forms part of the report from this site.

Heyworth and Warren, 1988

The glass report from the Chichester excavations. 14 glass vessels analysed by EMPA.

Heyworth, 1987

ED-XRF analysis of 41 glass beads from 35 Pagan Saxon female burials at Wakerley, Northamptonshire by Heyworth (1987), for the Ancient Monuments Laboratory of English Heritage. Sample surface preparation was not possible, which means results must be treated carefully. Details on calibration are not included in publication. The paper is focused on colouration and the relationship to shape, which showed no particular correlation.

Heyworth, 1988a

28 beads from two different Pagan Saxon cemeteries at Beckford were analysed by ED-XRF, (10 from Cemetery A and 18 from Cemetery B). Again, Heyworth (1988a) did this analysis for the Ancient Monuments Laboratory of English Heritage. Colourants were again the main focus of the work, and the details of analysis and calibration are not included. Sample surface preparation was again not possible.

Heyworth, 1988b

Continuing of his focus on beads from early Saxon burials, a further 28 from Great Chesterford were analysed by ED-XRF for the AML. Again, sample surface preparation was not possible. The agreement between this work and others shows that the beads in circulation in Britain were part of the same manufacturing tradition.

Colourants were again the main focus of the work, and the details of analysis and calibration were not included.

Heyworth, 1989a

19 shards of blue-greenish window glass from the Romano-British ritual complex on West Hill, Uley. There are 9 Roman glass shards, which date from the late fourth to fifth century, and then a futher 10, visually distinct, post-Roman shards. The date of these latter shards is more problematic but likely seventh to ninth century. They were analyses by ICPS at Royal Holloway and Bedford New College.

The two types were shown as chemically distinct, and the streaking that is present in the post-Roman glass appears to be a failed attempt at red glass.

Heyworth, 1990b

The individual ED-XRF study of a shard from Trowbridge Castle. The shard was blue vessel glass, decorated with an attached blue, yellow and white reticella rod, dating from the eighth to tenth centuries, potentially of English manufacture. It showed as consistent with other glasses from the period. While this falls just outside the main time period of this thesis, it was retained as one of the few Western samples.

Heyworth, 1990c

Further studies of beads from Pagan Saxon burials, 65 beads from Empingham were analysed by ED-XRF for AML. These beads were analysed the same as previous studies by Heyworth, and showed consistent compositions.

Heyworth, 1990d

This paper is the ICPS analysis of 41 glasses from five sites across London, with the majority coming from Moorgate (26). These glasses were predominately remains from

glass working, such as furnace waste etc. These span from the beginning of Roman Britain to end of the third century. The work was focused on trying to understand the industry in London, where the glass is sourced from and how it is used. The details of standards were not published.

Heyworth, 1991

Heyworth's doctorate thesis from the university of Bradford, covering a huge range of early Medieval glass. 273 fragments from Southampton were analysed, 145 from Windchester, 7 from Ipswich, 7 from Maiden Lane, London, 44 from Repton as well as 13 from Helgö in Sweden and 15 from Quentovic (La Calotterie) in France. These glasses were all analysed by ICPS.

Heyworth determined a difference between the early medieval vessel glass and the late Roman, yet still a fairly standard production. There was greater variation in the composition of the early medieval window glass, suggesting more localised production.

Heyworth, 1992

Another AML report, analysing 30 Early Medieval vessel glasses from four sites across London by ICPS. Standards were used for calibration though the full details not included.

Heyworth, Baxter and Cool, 1990

A study of 180 colourless glass shards from Colchester by ICPS. Typologically distinct tableware dating from the mid-first to the late-second century was chosen. Multi-element rock standards were used for calibration but details were not included.

This paper was the predecessor to Baxter et al. 1995 Unlike the later papers, this showed no correlations to forms.

Heyworth, 1991

The doctoral thesis of Heyworth, including an intensive survey of glass from Windchester, Hampshire (145), as well as including small comparative glass sets of Repton, Derbyshire (44), London (7) and Ipswich, Suffolk (7).

Jackson, 1992

The PhD thesis of Jackson, whose career since has been strongly focused on European Roman glass. This thesis involved attempts to better understand glass-making at York, Leicester, Mancetter and Worcester, through the ICPS analysis of 476 glasses. It was also concerned with potential British primary production.

Standards included both a silicate rock KC10-13, and synthetic glasses, 76-C-144, 76-C-150, 76-C-151 and 77-C-33, the measured values of which were reported.

Jackson, 1996

A short paper by Jackson on transition from Roman to Early Medieval glass and the relationship between the two. It includes ICPS analysis of 45 glasses from Fishergate in York, and shows a potential continuity.

Jackson, 2005

A paper focusing on the nature of colourless glass in Roman Britain, to better illuminate the contemporary theories around the organisation of glass production in the Roman world. It includes 78 ICPS analyses from three British assemblages, spanning the first to fourth centuries, and was calibrated using European Science Foundation standards: 76-C-144, 76-C-150, 76-C-151, and 77-C-33. Accuracy and precision details published, but not the precise results for each standard.

Jackson, et al. 2003

An analysis of the material from a likely glass factory in York, at Coppergate. This analysis, done by ICP-AES, and included a great deal of crucible material. The paper was focused on trying to understand the nature of this site.

Mortimer, 1991

An AML report by Mortimer on two early Saxon vessels from the Isle of Wight. These vessels were analysed by SEM-EDX, though there is little detail on methodology. Antimony is deemed as not present, though this might also be due to the problem of this technique, or low value, rather than true abscence.

Mortimer 1995

Analysis of the two colours on a single fragment of Saxon glass from Westminster Abbey. The analysis was done by SEM-EDX, as was Corning A standard, and the results published. The vessel appears to have been made from Roman cullet.

Mortimer, 1996a

AML report of the SEM-EDX analysis of 20 glass beads, 22 samplings, from the early Anglo-Saxon cemetery in Barrington. Standards used were Corning A, B and Sheffield's internal standard. The paper was particularly concerned with colouration.

Mortimer, 1996b

Another AML report of 26 Anglo-Saxon beads, 30 samplings, from the Mucking Anglo-Saxon cemeteries, analysed by SEM-EDX. Again focused on colouration, this paper used the same standards at the preceding Mortimer 1996a, and once again published the standards.

Mortimer and Baxter, 1996

53 fragments of colourless Roman glass analysed by ICPS for the AML reports, from Lincoln. The paper was looking for typological relationships to composition but the evidence was inconclusive.

Mortimer and Horsley, 1997

Another AML paper studying beads found in sixth and seventh century burials. These 25 beads were analysed by XRF, as well as EDX on a subset. They are made from a variety of different materials, and different techniques, though there seemed to be a relationship between material and technique.

Paynter, 2006

A paper by Paynter on 40 samples of colourless tableware from Binchester. They were analysed by ICP-AES and 15 of these samples also analysed by SEM-EDS. Corning A standard was used and the results published. The paper is concerned with the type of glass at Binchester, specifically relationships between composition and typology and how that related to the sourcing of the glass on the site.

Paynter and Kearns, 2011

An English Heritage Research Department Report, the current incarnation of what was the Ancient Monuments Laboratory reports, on the glass tesserae of West Clacton Reservoir. This paper included the analysis of 35 samples of glasses tesserae and matching glass cake by SEM-EDS, and 24 of these further examined by ICP-MS. Three standards were used, Corning A, Corning B and NIST 620, and their results reported.

Glass tesserae are relatively rare in Britain, especially in as wide a colour range as found at this site, so they were extensively studied. It was hoped to ascertain

whether all colours had a common based glass, understand how they were produced and possibly secure the date. Interestingly, both the red and green tesserae were plant ash glass, which means that they were likely produced separately to other glass industry. The uniqueness of both of these colours has been seen in other places.

Peake, 2003

This is the doctoral thesis of James Peake, including the SEM and LA-ICPS analysis of 642 glass beads from a variety of early medieval sites. The focus on the work is on the nature of the glass beads at Empingham.

Sanderson, Hunter and Warren, 1984

This paper was designed to test the applicability of ED-XRF to solve problems within first millennium glass in Britain. Standards were used but no details were reported in this paper.

187 glass from across British sites were analysed, across multiple periods, as well as 12 from Dorestadt in Holland and 8 from Helgö in Sweden. The variation across these sites shows potentially in the later glass industry a greater variation of sources is being used.

Stapleton, 1999

Opaque red enamels, examined semi-quantitatively using XRF on 41 objects, and 11 quantitatively using ED-SEM. Of these 11 enamels, only 6 of them are English. The paper was focuses on the connection between Ireland and England.

Wilthew, 4435

This paper is another AML report, covering the XRF analysis of beads from an early Saxon cemetery, in Finglesham, Kent. 103 of the beads were monochrome, and 11

are polychrome, across 13 graves. The paper was concerned with colouration.

Wilthew, 4650

An AML report of 99 beads from the Alton, Hampshire, early Saxon cemetery site. This XRF study was also concerned with how colouration occurred in Saxon beads.

8.2 Comparative European Glass Database

As well as this detailed British database, a comparative European database was needed. All the papers included are recorded, Table 8, and detailed in Appendix 2. 2484 glasses from across Europe make up this database and the same considerations that were used for the input of British glasses, though with less precise geolocation, as this is less relevant for the current study.

8.3 Comparing Datasets

8.3.1 Analysts and Techniques

As will be detailed in reference to chemical studies of glass, and reported in Table 4, there are notable differences in the techniques used to analyse glass over the last forty years. As well as this, the individual protocols used by different laboratories, let alone each analyst, have potential to create false architecture within the database.

As can be seen in Figure 8.1, the majority of certain types of data have been created by specific authors. For instance, over 90% of ICP-AES data for glasses from Britain have been created by Jackson and colleagues, which is over 50% of all ICPS analyses of British glass. When generalised to types of analysis, this preference of specific authors becomes even more apparent (Figures 8.3, 8.4, 8.5).[2] While this is

[2]It should be noted that many of these techniques are done in conjunction, as shown in figure 8.2.

unsurprising in that Jackson and colleagues have created far and away the majority of the British data, and there are very pragmatic reasons why most authors tend to prefer a single type of analysis. Often this relates to the machines the analysts have access to, rather than necessarily it being the most advantageous technique. This tendency could be potentially problematic when it comes to considering statistical significance. Jackson and colleagues data is overwhelmingly Roman, meaning that higher trace amounts of some elements likely related to recycling will have only been recorded here as other techniques such as EDS-XRF tend to lack sensitivity. Thankfully, the other major source of ICPS data is Heyworth, whose work is mostly focused on Early Medieval glass.

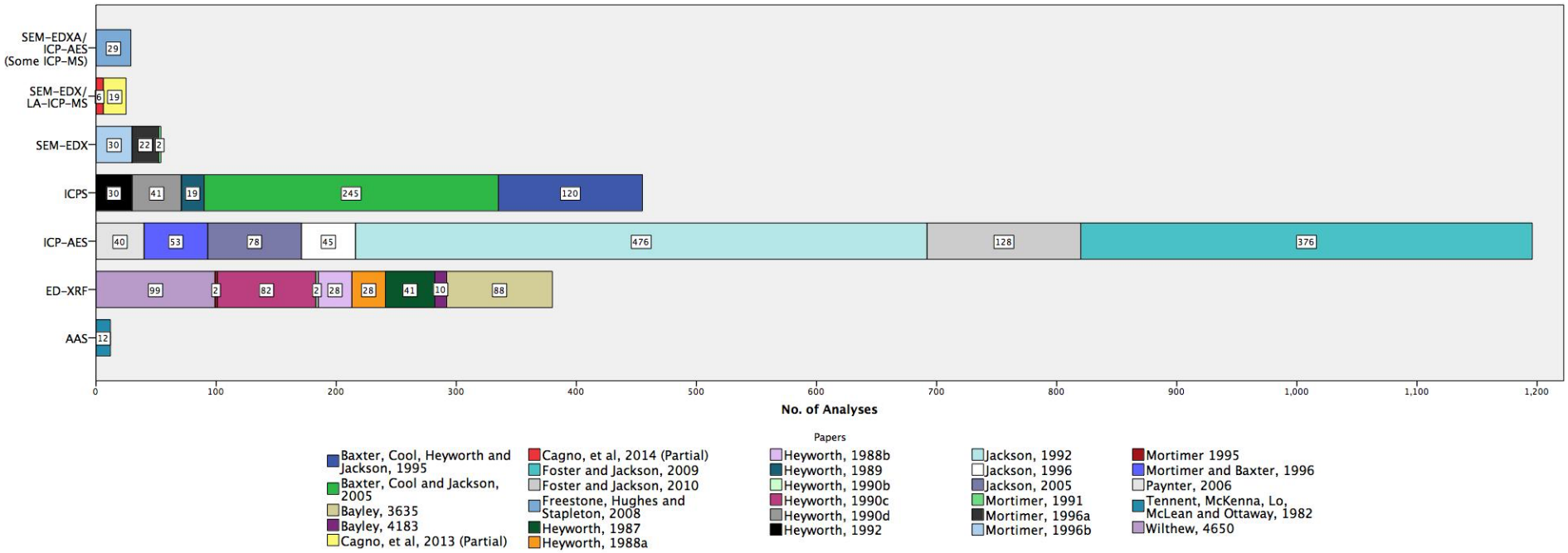

Figure 8.1: British Papers by Analyses, which demonstrates the vast majority of data is ICP-AES, but created by only a few publications.

In this original conception of this database approach, it was hoped that the results from published measurements of standards could be used to consider the comparability of these papers. However, while many authors use the same standards, particularly Corning A and B, to internally calibrate their work, very few papers included the values they achieved for these standards. Of the papers that deal with British glass, these are Foster and Jackson 2009, Foster and Jackson 2010, Jackson 1992, Mortimer 1995, Mortimer 1996b, Paynter 2006, as well as this thesis [Table 9]. Twelve elements were common to these papers and analysed for Corning A and B. When these were considered together, only one paper stood out as problematic [Table 9]. Mortimer 1995, the only analysis done by SEM, published values for Corning A and B that were notably inconsistent with other results. Two thirds and half, respectively, of measured values fall outside one standard deviation of the mean of other analysed values. These values are also slightly different from published values for these standards (Schibille 2011; Vicenzi et al. 2002). However, one can not discount all analyses done by SEM because of this. Mortimer's paper is comparatively early, and later works have shown consistently accurate and precise SEM results. As such, it seems no calibration can be safely made and thus all papers, even Mortimer, must be taken at face value, with the hope that the density of data will account for any mistakes. The whole approach, looking at broad brush-strokes rather than minutia, allows for the inclusion of such fuzzy data.

However, it is still worth comparing analysts and techniques, separating British data into broad categories of ICPS (Figure 8.3), XRF (Figure 8.4), SEM (Figure 8.5) and EMPA, to see which of this data is correlated to which authors. For XRF, both Wilthew, and Sanderson, Hunter and Warren together each account for 27% of glass analysed, as well as another 23% by Heyworth. Bayley accounts for a further 12%, however she also accounts of a smaller proportion of SEM. Freestone on the other hand only accounts for 1% for XRF and 24% of SEM. Far less of the total glasses,

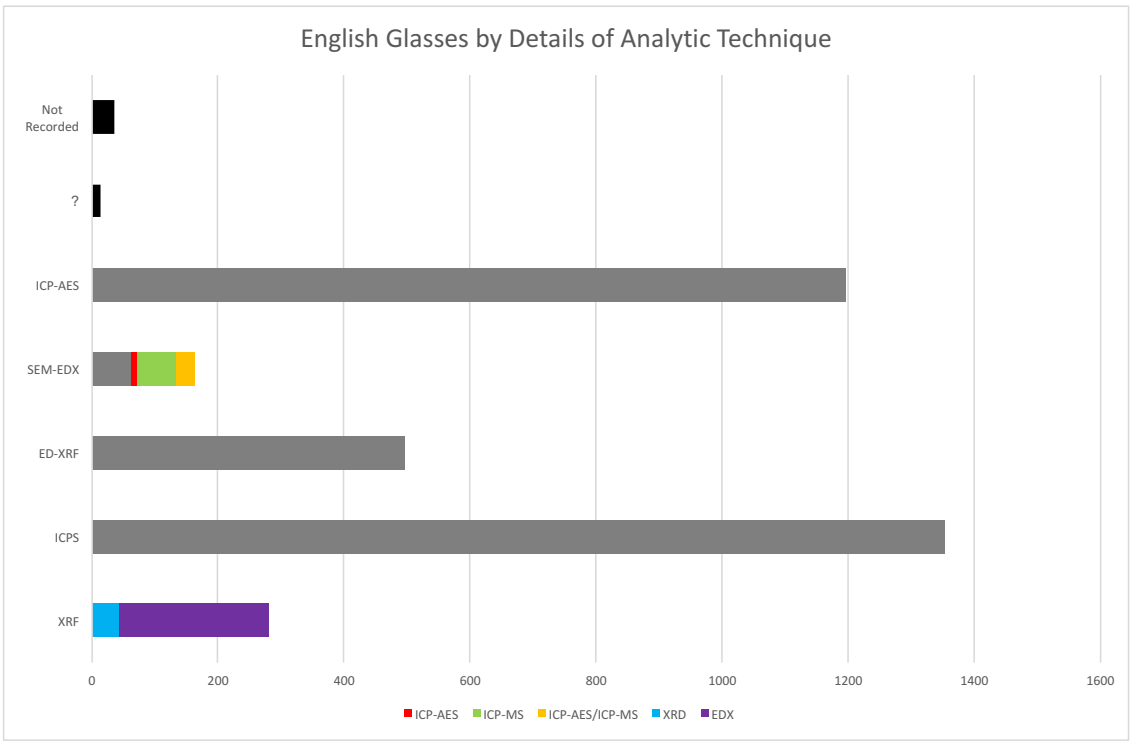

Figure 8.2: Chart of Techniques used on English Glass, with glass analysed by multiple techniques indicated by colours.

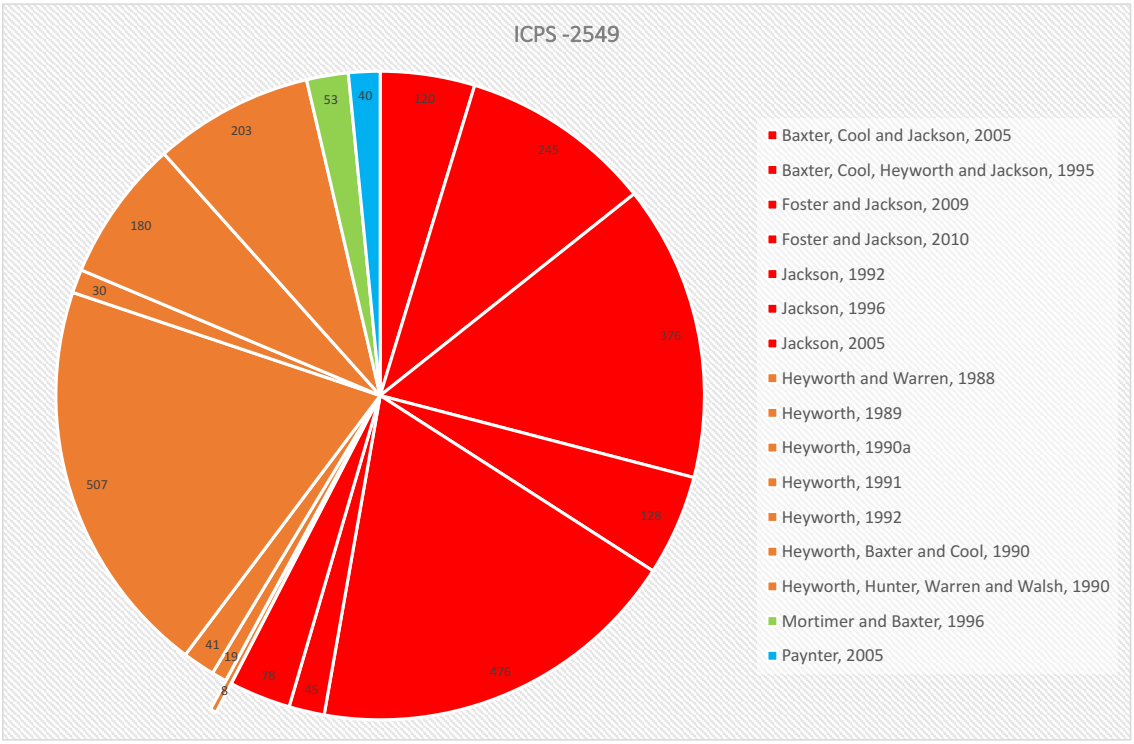

Figure 8.3: Piechart of ICPS analyses.

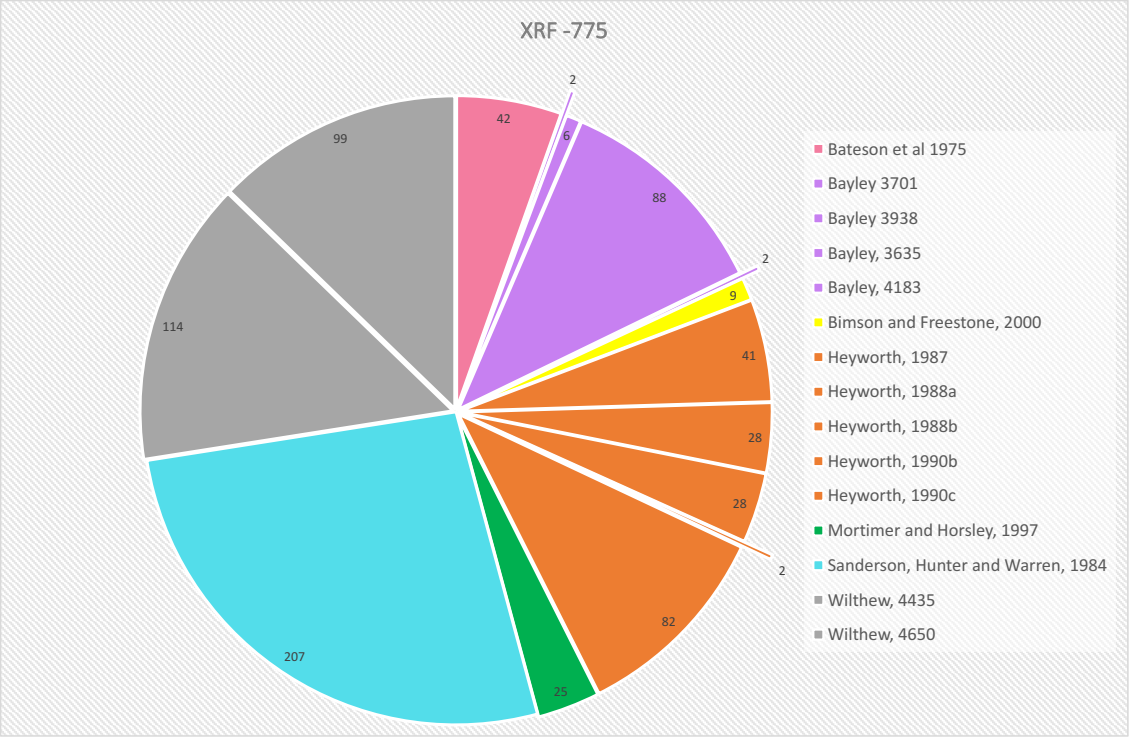

Figure 8.4: Piechart of XRF analyses.

however, are analysed by SEM. Apart from Freestone, this is dominated by Mortimer (46%), Paynter (22%), and Cagno (15%).

By far and away the most common analysis for British glass (2549 glass, 70%), Jackson also accounts for the vast majority of this ICPS data (58%) with the next largest contribution by Heyworth (39%). The only other two authors who use ICPS are Paynter and Mortimer. While much of the European glass was analysed by microprobe, only this thesis analysed British glass using this method as the main technique.

Considering this split of authors is relevant not just because of the idiosyncrasies of each author and technique, but also because there is usually a very strong relationship between authors and the geographic location of the glass, as well as the period from which it dates. To demonstrate this, two maps have been generated, one showing the spread for authors who worked in the study area (Figure 8.6), and the periods of which the glass in the fishnet cells dated from (Figure 8.7).

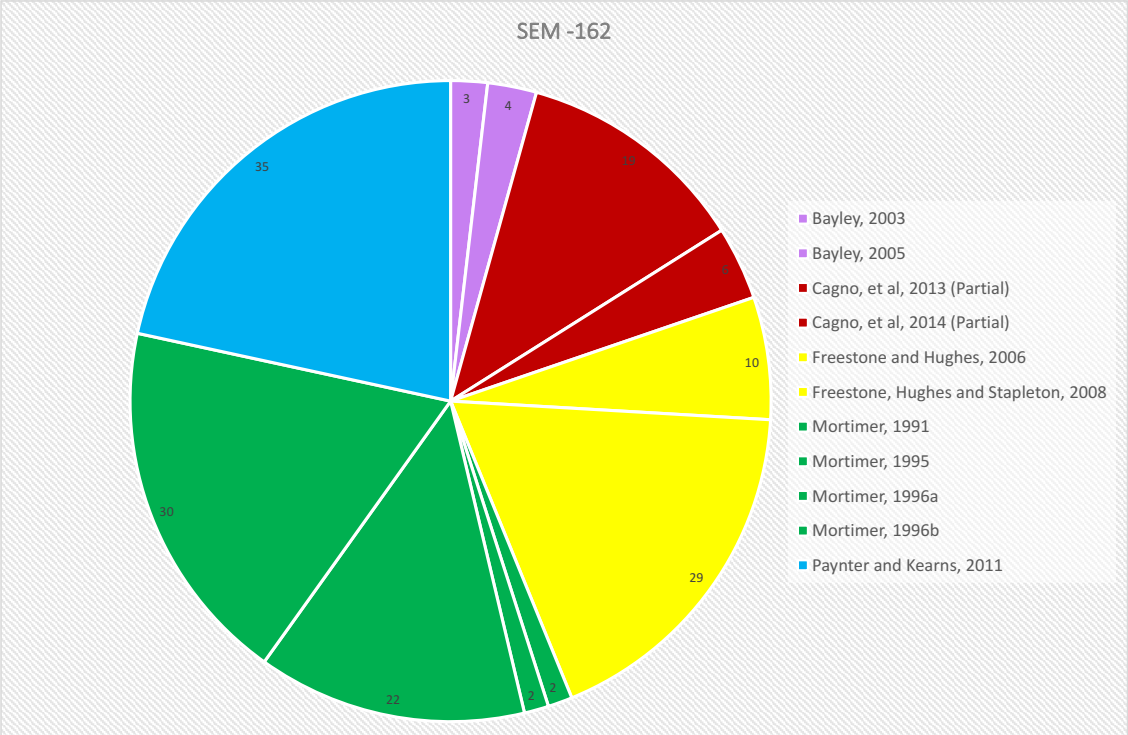

Figure 8.5: Piechart of SEM analyses.

Jackson, who as has been mentioned, produced the most data, has data covering 19 cells, whereas Freestone, whose data accounts for much less of the total number of glasses analysed, covers 17 different cells. This clearly demonstrates that multiple factors must be considered when looking at the spread of this data; the density of data in any cell, the range of authors producing it, and the spread of that data across Britain. Some authors, such as Jackson, have done large-scale in depth studies of specific sites, whereas others were driven by different questions, e.g. Freestone et al. 2008a.

Many of cells are only accounted for by one publication (30/54), and a further 13 are covered by a single author. However, while it was expected that authors would show a great deal of regionality, it appears that many of the authors with more than one study area show a great deal of variability of location. Perhaps the most regionally bounded of such authors in Heyworth, most of whose studies fall on or below the Fosse Way.The spread across Britain of the major authors, specifically

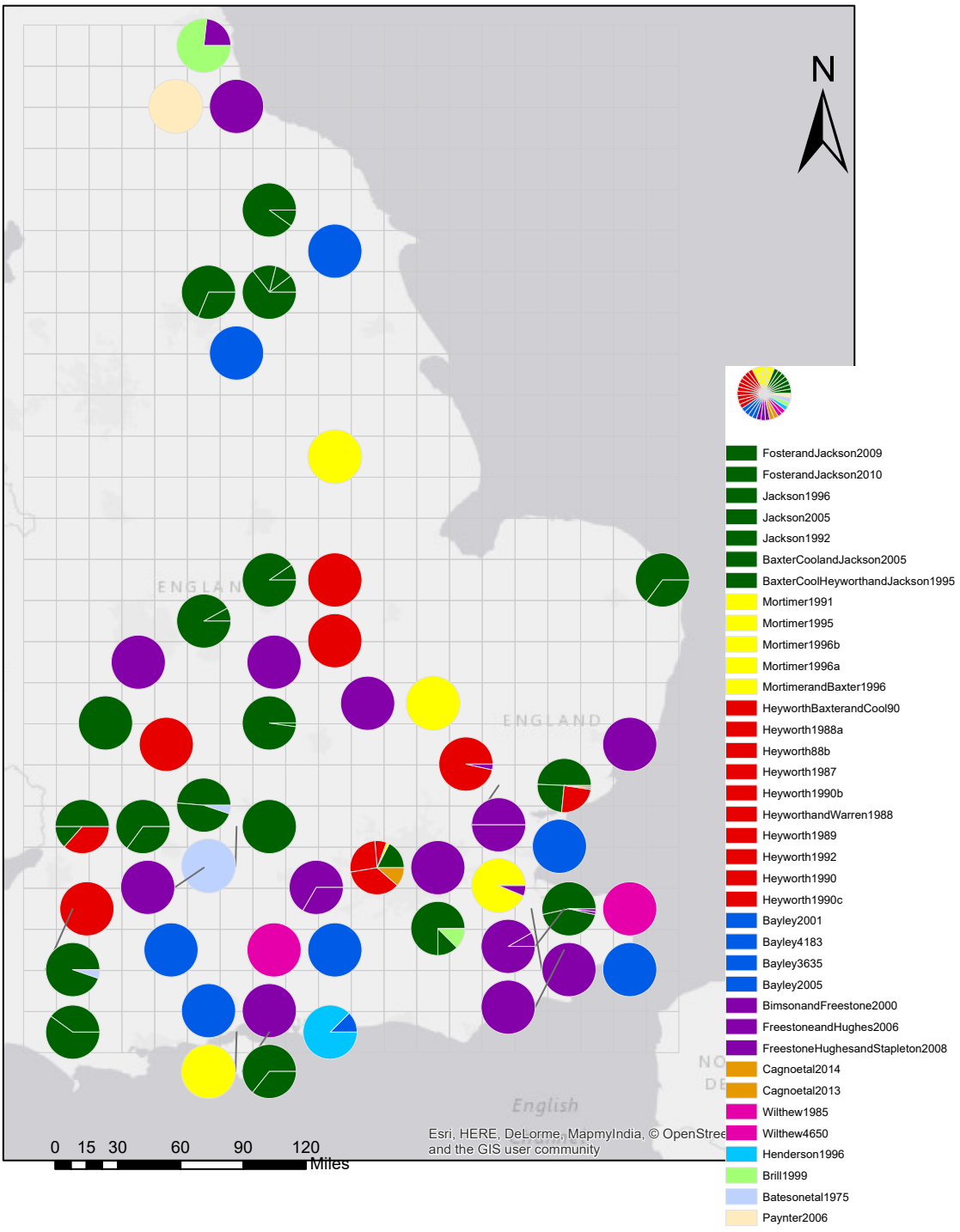

Figure 8.6: [Map displaying the regionality of analysts, the colours used indicated the main analyst on each paper.

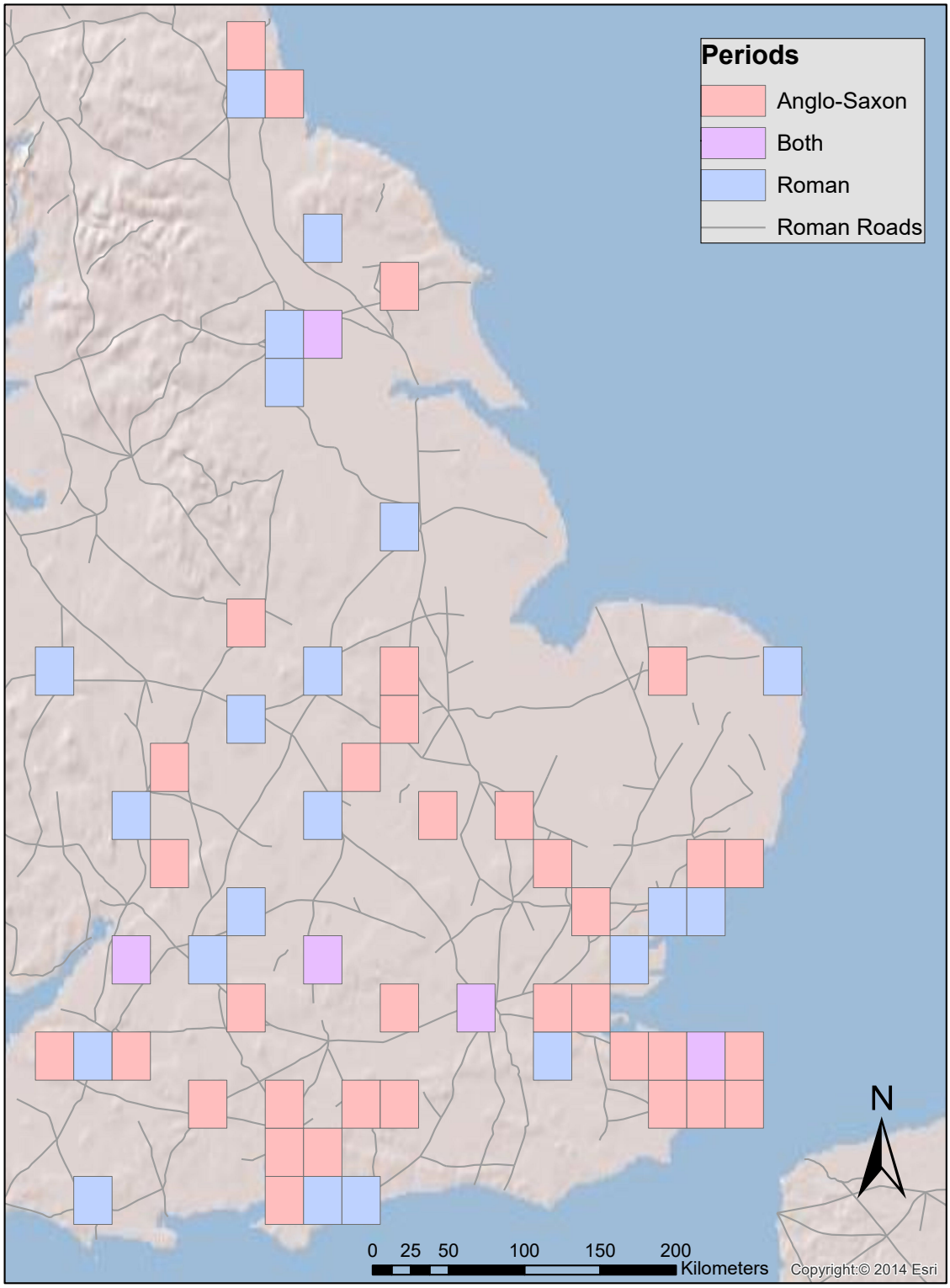

Figure 8.7: Map of periods from which the glass in any fishnet cell dates from.

Jackson, does indicate that this data is comparable for geographic consideration.

Comparing this back to techniques, using each line created by the fishnet as a latitudinal divide, it becomes clear that the ICPS data is consistently used across England (Figure 8.8). Over 80% of glass was analysed with ICPS, some also with SEM. It is in all populated rows but the most northerly, numbered on the figure as cells 480-499. This, however, does not indicate a constant count of glass. Of the 24 rows, the 6 most southern already contains 80% of all the glasses analysed, and of that data, 68% of this is created by ICPS analysis. Jackson's ICPS counts for a total of 40% of data in this lower section, and 44% of glass above this. While this sounds broadly comparable, there is the problem that Jackson applied her techniques, large-scale, to a handful of sites, as apposed to it necessarily being broadly spread, as discussed above.

As well as the potential issues caused by variability of techniques, there is also the problem of variability or lack thereof, of locality or chronology. Most authors, like speciality of technique, have the preponderance of their data falling into set areas and time periods, which merely solidifies any biases raised by the techniques. The concern for this thesis was that the areas of interest for Roman studies would not be comparable to those of Early Medieval investigations.

As one of the driving motivations of this thesis was to look potential relationships between geography and chemical composition, one of the most limiting factors is the spread of the data. When the data is simply all plotted, it is clear there are areas of much higher analysis concentration. While some of this relates to the density of Romand and Early Medieval occupation, much of it relates to modern exploration and excavation. As large British focused studies such as EngLaID show, the vast majority of explored sites fall in a few small areas traditionally. As well as this, certain periods being of more interest to of antiquarians, and more prosaically, funding bodies.

Thankfully, however, both Roman and Early Medieval material appears to have

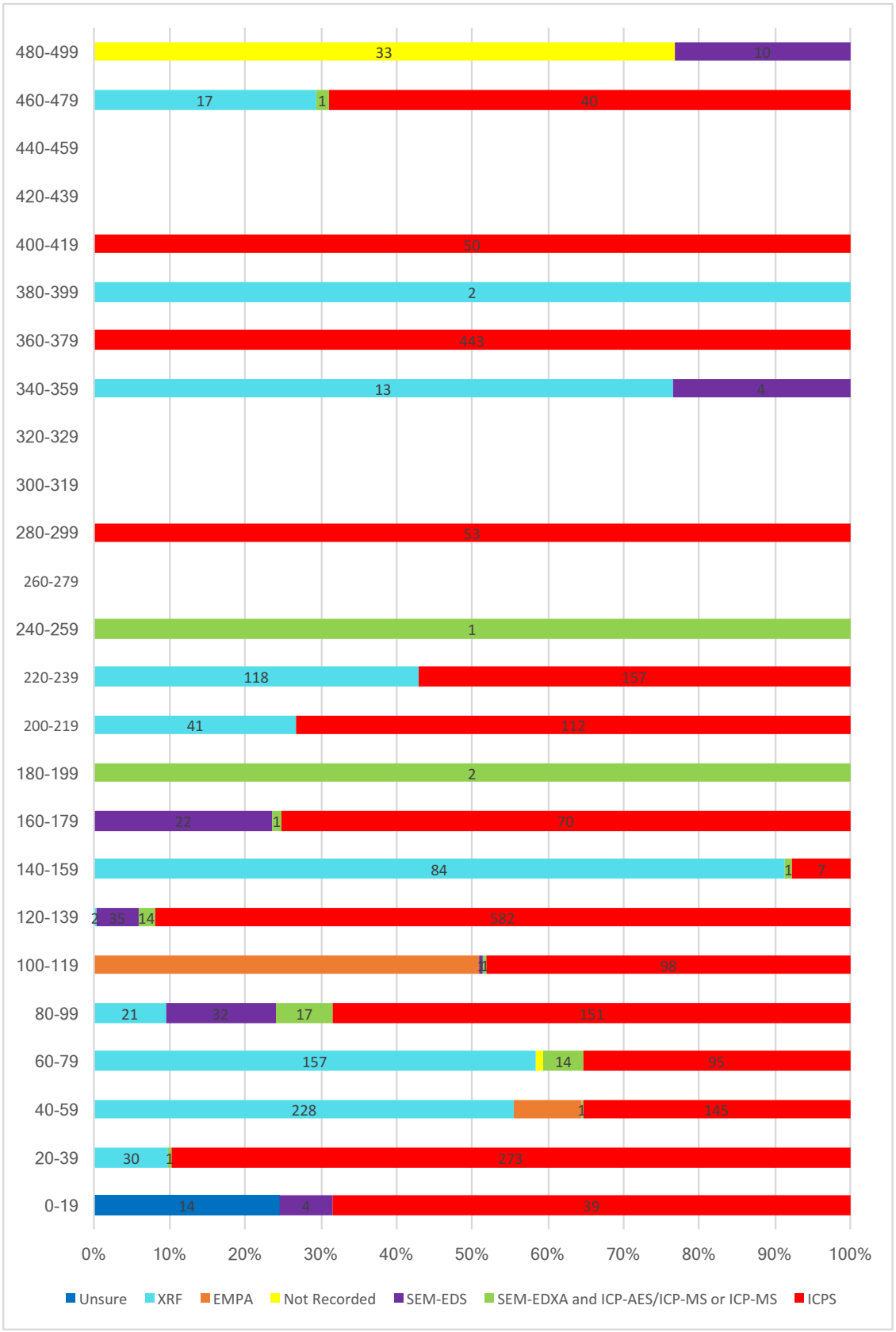

Figure 8.8: Chart of geography of techniques. Each bar indicates a row of fishnet cells, moving from South (0-19) to North (480-499). The colour indicates percentage of assemblage at that latitude analysed by each technique.

been analysed across the full length of England (Figure 8.7). The Roman material, despite accounting for a far greater amount of the total glasses analysed, is only present in 26 cells, five of which also contain Early Medieval material. Early Medieval material, as well as the five that contain both, is found in a further 35 cells. This means that while the total of Roman glass is much higher, the spacial resolution of the Early Medieval glass is preferable. This is partly because the Roman material in common and tends to be the focus of large-scale studies, whereas until recent Early Medieval collections of glass, aside from beads, were rarely even 100 sherds. The paucity of this Early Medieval data in England, in terms of total numbers, thus proves less of an issue due to the geographic spread.

One final consideration has been made about the range of the database, which is the type of site. The sites with their period and type have been tabulated (Table 10) and also plotted (Figure 8.9), so that the spread of the sites is apparent. Cemeteries and burials account for far in away the most cells, accounting for the total sites of 22 cells, and part of a further cell. This is partly linked to the spread of Early Medieval sites mentioned above. All cemeteries and burial sites studied are Early Medieval, and the majority of sites from these dates are such sites.

Settlements and urban sites, the two next most widely spread type of sites. These are grouped together as the Roman 'urban' and Anglo-Saxon 'settlement' are broadly comparable in this context as major occupation sites, despite a good deal of variation between the two. Only the site of Hamwih has been catalogued as both urban and Early Medieval. Many of the forts also have associated occupations beyond military sites, e.g. *colonia*.

Turning to the table, it is clear that there is a bias of Roman predominately large living sites (i.e. Urban, settlement or fort) to mortuary sites.[3] Just considering these

[3]These comments concern only the sites that are purely Roman or Anglo-Saxon in date, and the main type of site. For instance, many types of settlement sites might have associated burials, but they have been classified by the excavation as settlements.

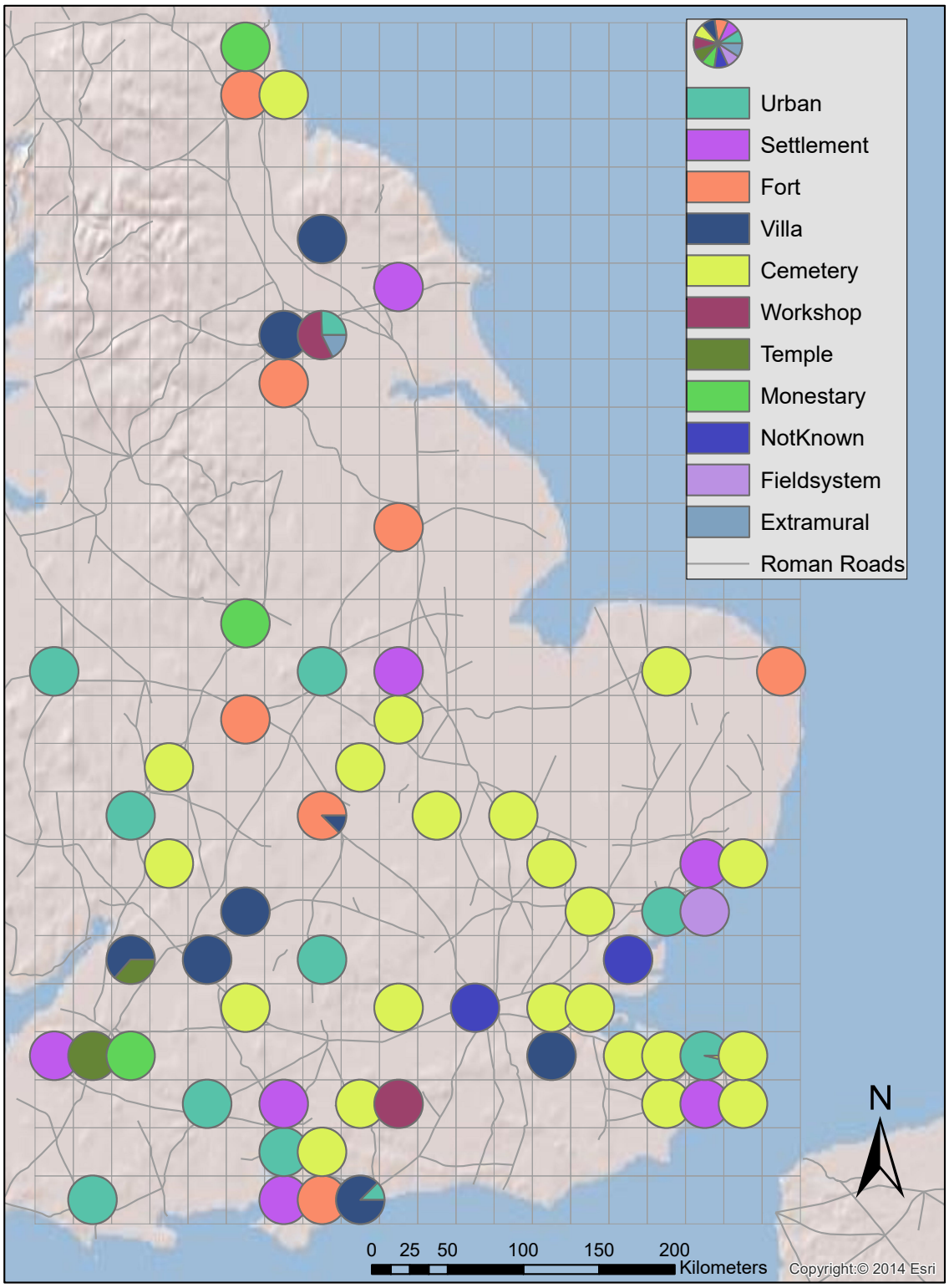

Figure 8.9: Map of site types. Site types have been generalised, such that 'Cemetery' is also used for single burials. For more details on individual sites see Table 10.

three types of site, there 474 sherds of glass, but none from sites dominated by burials. Anglo-Saxon material accounts of 314 glasses from living sites, but a whopping 831 analyses from cemeteries and burials. These are predominately beads. The other category worth mentioning for Roman glass in villas, which account for another ca. 200 glasses.

This comparison on Roman living sites to Early Medieval sites of the dead has potential to affect the sort of glass available and this will be discussed in reference to the analytical values.

Similarly, when one looks at the European data, there is a pattern of who uses which techniques, but this has not been included in this thesis due to brevity.

Chapter 9

The Geography of Glass Recycling

9.1 Copper Evidence

Copper is known to accumulate in repeatedly recycled glass, and this means, more than other metrics, copper has the potential to show not just recycled glass but *how recycled* the glass was. That is, how many times vessels and cullet have been melted and reformed. In this dataset, not only do the number of glasses containing copper increase across the centuries but also the actual weight per cent of copper. This implies either increasingly careless recycling practises, glasses deliberately coloured with copper not being recycled separately, or the long-term continuous recycling of the same glass, with the continued additions of small amounts of copper-coloured glass, through design elements, leading to the total amount of copper in colourless or naturally coloured glass slowly accumulating over time.

For this dataset, greater than 100ppm of copper in naturally coloured or de-coloured glass is seen as recycled. This translates in weight per cent as 0.01 wt%. However, it is likely that even 0.005 wt% is recycled. For each century, a map has been created [Figures 9.1-9.7]. Glass that falls in the first two bins, below detection or less than 0.005 wt%, shows no evidence of being recycled. From this point onwards,

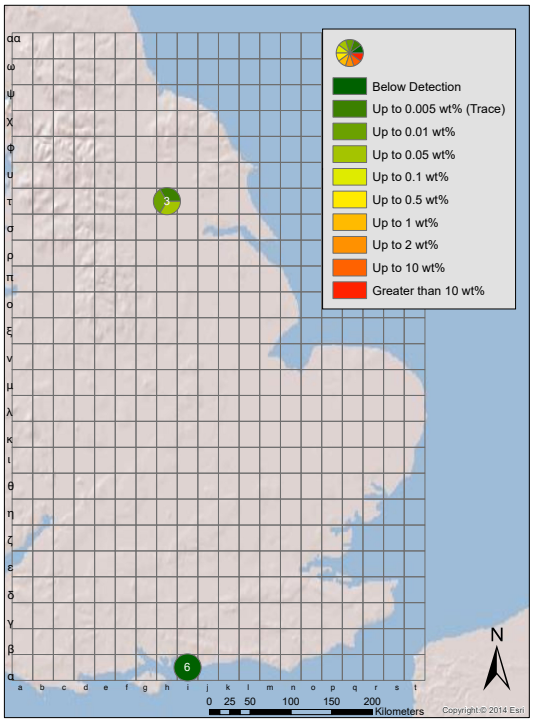

Figure 9.1: Map of Copper Concentration in Colourless or Naturally Coloured Glass in First Century in England.

recycling is implied as discussed earlier.

For interpreting these maps, the colours of the pie correlate to the percentage of the assemblage within that fishnet cell location that falls into each compositional range. The number label on each rectangle shows the pure count of glasses at that cell.

There is one notable caveat about these maps, that the below detection bin might be overpopulated. Some analytical techniques have higher detection limits, meaning that the first bin is occasionally overpopulated. This seems very likely to have happened in the Figures 9.6 and 9.7, as seen by the lack of population of bin 2. However, as this is likely only to disguise the 'possibly recycled' bin, it should not greatly affect the outcome from these maps, except to disguise some evidence of recycling.

The map of the first century, Figure 9.1, shows that only a very small number of colourless or naturally coloured glasses in the first century have been analysed for

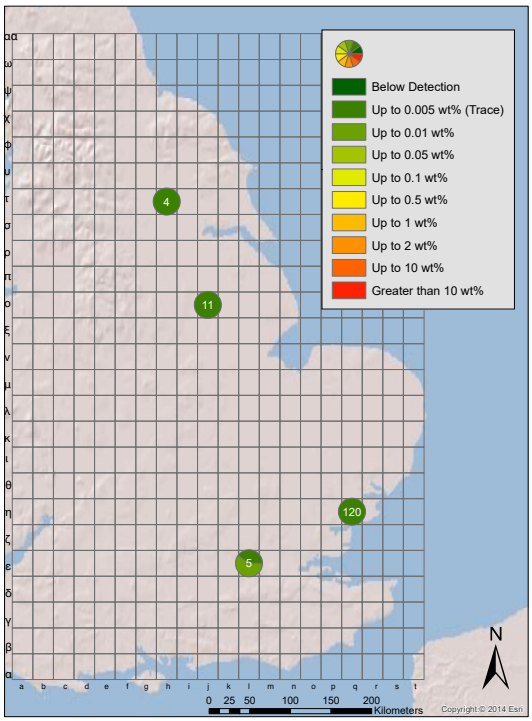

Figure 9.2: Map of Copper Concentration in Colourless or Naturally Coloured Glass in Second Century in England

copper. The largest number of glasses from single source in this period is only 6 glasses, coming from the site of the villa at Fishbourne (αi), one of the earliest and largest villas in Roman Britain, on the outskirts of Chichester. York (τh) also has several glasses, with variable amounts of copper. At least one is likely recycled.

The very clean glass at Fishbourne is perhaps unsurprising as glass is rare in Britain for much of the first century and the material at this site is high status (Cunliffe et al. 1996). However, York, which is more varied in terms of site, is also more varied in terms of copper values, extending into high copper amounts.

Figure 9.2 is more illuminating. In the second century, London's (ϵl) glass shifts to a majority of slight higher weight percent copper. This is a period of rapid expansion after the establishment of London as an urban centre and provincial capital, surrounded by more settlement. London skews significantly higher than other sites

of this century, with over half of glasses having detectably high copper.

Twice the number of glasses from Lincoln (oj) were analysed, though none with detectable copper. All of the glasses from the heavily analysed site of Coppergate, York (τh), are similarly low. Colchester (ηq), which accounts for far in a way the greatest amount of second century British glass analysed, only has detectable copper in one of 120 colourless or naturally coloured glasses. The difference between London and Colchester is very interesting, as two of the very large Roman British sites, both in the South East. This is exacerbated by the comparative number of samples. Potentially, Colchester, as an initially military site, had more importation of fresher glass, but as military sites elsewhere tend to have more recycling, this is requires further consideration (Fleming 2012). It is potentially that the organisation of this is better, leading to less elevation of copper, but copper alone is insufficient to comment on this. The other problem is of bias, that the Colchester glass was selected specifically due to its very decoloured material. A final thought on the variance between these sites is style; potentially blue decorative elements are more common in the cosmopolitan London.

Twelve different areas of glass have been analysed from the third century and they show a range of variance [Figure 9.3]. The Colchester glass is extensive, and also fairly clean in terms of copper, as in the previous century. The majority of other sites are also focused in this lower group, 0.005 wt%, however several are either higher, or both higher and more variable. Around half the glass from Leicester (μh) has below recordable amounts of copper or between 0.005 wt% and 0.05 wt% copper.

This same pattern is apparent in Mancetter (λf), though in Mancetter there is a greater amount of copper skewing higher. One glass from Mancetter has the highest third-century value for copper, with 0.0619 wt%. Also, the single glass from Lullingstone Villa (δn) analysed falls in the slightly higher bin of up to 0.01 wt%. While

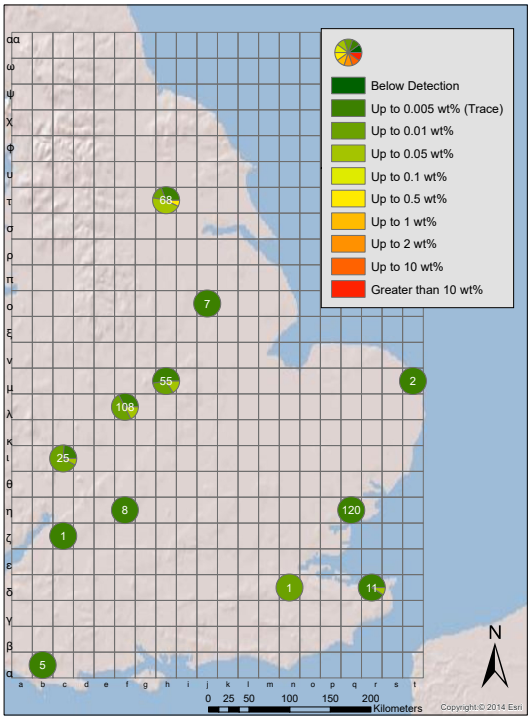

Figure 9.3: Map of Copper Concentration in Colourless or Naturally Coloured Glass in Third Century in England.

the high and variable York glass seems a continuation of the previous century, these other sites show change.

The glass from the fourth century is far more variable and shows a significant increase in the amount of copper [Figure 9.4]. While a small amount of glasses show low copper across Britain, 40-50% of the assembled in each cell fall between 0.005 wt% and 0.01 wt%. Most sites other material is distributed either side of this. However, at the villa at Dalton Parlours (τg), the glass has a much lower amount of copper. More interestingly, Dalton Parlours villa stands clear of the grouping of the northern sites included in this century. These glasses come from a variety of sites both within the city of York (Eboracum), surrounding sites, as well as the further afield such as the Beadlam villa (ϕh).

The most variable of all of these glasses are those from intramural sites in York

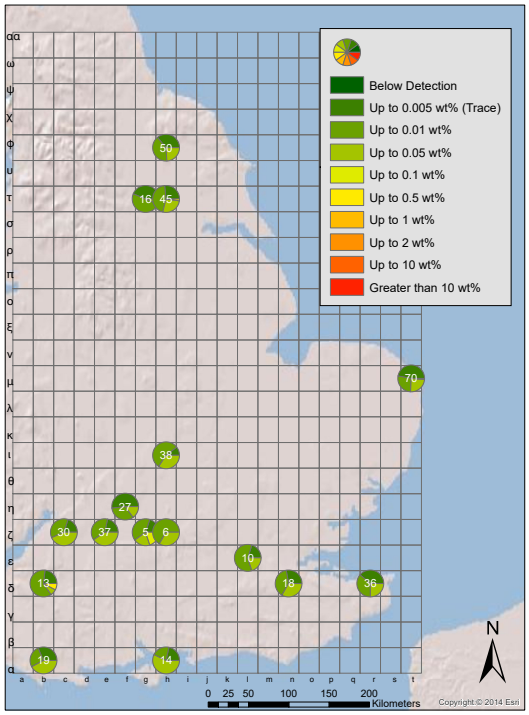

Figure 9.4: Map of Copper Concentration in Colourless or Naturally Coloured Glass in Fourth Century in England.

itself, some plotting higher into the 0.05 wt% copper bin. Again for York this seems to follow the pattern seen in London of variable urban sites, but all these northern sites seem to use this same recycled glass, except Dalton Parlours.

Shakenoak villa (ηf) also has a large amount of low copper glass, which is also apparent here in the century before. Caister-on-Sea (μt) is also notably low. The other cells are variable, including sites such as Bath (δb), Dorchester-on-Thames (ζh), Towcester (ιh) and Barton Court Farm (ζg). It is worth noticing that there are several even higher sites, predominately closer to Severn estuary, in the sites of Dorchester (αb), Barnsley Park villa (ζe), and Frocester Court villa (ζc). These glasses all are more commonly around 0.05 wt% copper, implying that they are recycled. As well as this, the site of Portchester Castle (αh), in the pre-castle Roman levels, has a much higher proportion of these very high copper glasses. There are also five glasses with exceptionally high copper, 0.5 wt%, one each from Towcester, Dorchester and Bath,

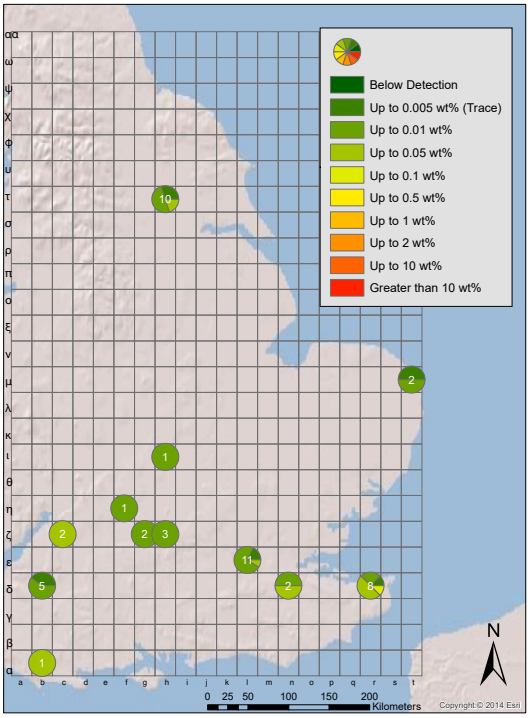

Figure 9.5: Map of Copper Concentration in Colourless or Naturally Coloured Glass in Fifth Century in England.

as well as two from York. It is very surprising that these western glasses are clearly more highly recycled in this century.

Moving into the fifth century, Figure 9.5, in the same southwest portion of the country where elevated copper was common in the previous century, cleaner glass is common, though a much small number have been analysed. The exception is the temple site of Uley (ζc). Dorchester and Uley both exclusively have glasses that fall into 0.01 - 0.05 wt%. This is particularly interesting as it shows a clear difference between these sites and the rest of Britain.

It is curious as to how this glass relates to that in the Atlantic façade of Britain, though no glass from this region is analysed.

Caister-on-Sea and Bath are both particularly different, a stark contrast to the south eastern sites of Canterbury (δr) and Lullingstone whose glasses are far more

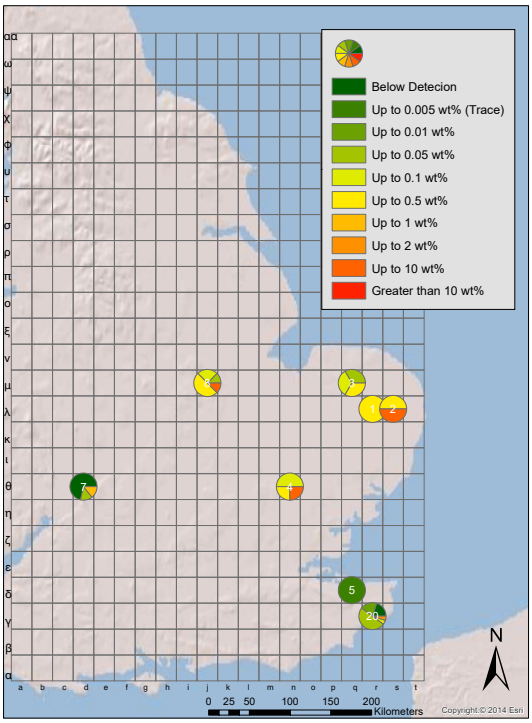

Figure 9.6: Map of Copper Concentration in Colourless or Naturally Coloured Glass in Sixth Century in England.

variable. London and York are both very variable but with more low copper than seen in many places.

Figure 9.6 demonstrates some thought-provoking variation. The sixth century glass in this map comes predominately from beads, most analysed around a similar time by Michael Heyworth. These visually appear to be remelted Roman blue-green glass. The exceptions are vessel glass from the site of Lyminge (γr), which was analysed for this thesis by the author, and glass from Faversham and Howletts (δq), analysed by Freestone and colleagues for the British Museum. Other sites are represented by only single analyses. The variation across the beads is marked, but perhaps more surprising is the variation across the vessel glass at Lyminge, Faversham and Howletts (γr and δq). The Lyminge glass is variable, but less than a quarter has less than 0.05 wt%, whereas the glass at Faversham and Howletts is uniformly low,

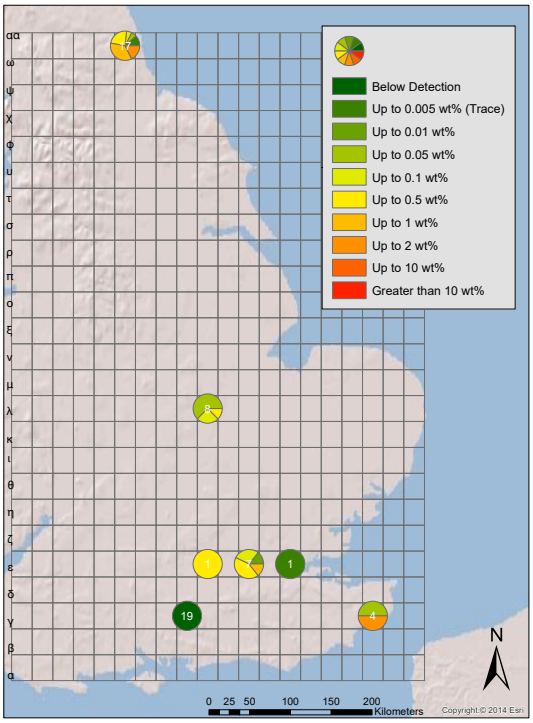

Figure 9.7: Map of Copper Concentration in Colourless or Naturally Coloured Glass in Seventh Century in England.

containing only trace amounts of copper.

Two of the seven Beckford (θd) beads have copper below the detection limit, indicating potentially less recycled material. Empingham (μj), however, which contains a similar amount of glass beads from a similar burial context, is compositionally entirely dissimilar. Instead, over 60% of the Empingham glass contains greater than 0.1 wt% copper, and the other three glasses still contain more than 0.01 wt%. The glass of these beads is significantly higher than other earlier sites in Britain. Similarly, the two colourless glasses at Great Chesterford (θn) fall each in the 0.05 and 0.1 wt% bin.

It is noteworthy that although the Empingham beads are clearly heavily recycled, this is not true of all the beads of this century. Similarly, the range of values of the glass in Lyminge is very comparable to glasses of the previous century.

In the seventh century, there is a drop in the average value of copper [Figure 9.7].

19 beads from a cemetery in Alton (γi) were analysed by the same methodology as the sixth century material, but copper was below detection in every glass. The Lyminge glass, however, is much higher in copper than the sixth century glasses, indicating that it is likely highly recycled. While there are no directly comparable sites, the other vessel and window glass is that from Jarrow ($\alpha\alpha$f). This glass is consistent with recycled Roman glass.

What these many maps together highlight is both some very surprising geographical patterns, as well as patterns within certain types of sites. The few glasses from first century show a difference between the city of York and the villa of Fishbourne. However, while London and York in the next two centuries still have a mix of high copper, the other major site, the fort of Colchester shows very clean glass. The rest of the third century sites show an accumulation of recycling. The significance of this is hard to assess, as the Colchester glass was specifically selected due to its colourlessness nature. Only the most decoloured glass was selected. The fourth century shows an increase of copper, which seems a consistent in the fifth century with less analyses. While the sixth century is dominated by glass beads, the vessel glasses of both this and the next century seem notably recycled.

9.2 Antimony Evidence

Antimony has several uses as a recycling metric - in coloured, colourless and opaque glass. In coloured glass, it can indicate a glass dyed by the addition of opaque tesserae or the addition of antimony-decoloured cullet to the melt. In other decoloured or naturally glass, where there is not significant antimony to function as the decolourant or as an opacifier, it can indicate the mixing of antimony colourless cullet with naturally coloured cullet. As well as this, the production of antimony glass is thought to finish

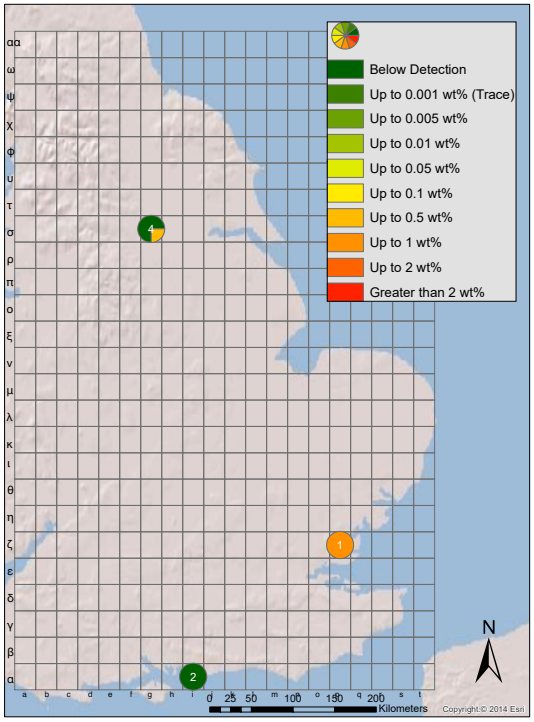

Figure 9.8: Map of Concentration of Antimony in Opaque and Translucent Glass in First Century in England.

around 300/350. As such, glasses dating form the fifth century onwards that are either antimony decoloured or opacified are likely recycled or reused.

The three possible uses of antimony as a geographic recycling indicator must be split into several sets of maps; transparent coloured glass, colourless glass and, opaque and translucent glass.

Rather than separate these all maps by colour of glass, they have been separated century. That is, all three antimony maps from each century are considered together. As will become apparent, this is because there is a clear pattern across time across all uses of antimony.

Looking at the first century, and first turning to the opaque glasses, it is clearly that these are mostly not antimony opacified glasses [Figure 9.8]. This isn't surprising as all 7 of these glasses are red, which is often opacified only by the formation of cuprite. What is interesting here is that not only are two antimony opacified, but 1

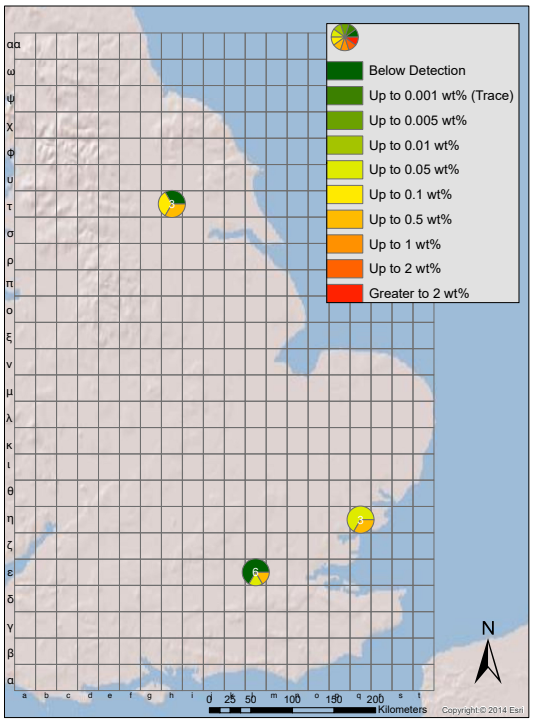

Figure 9.9: Map of Concentration of Antimony in Transparent Coloured Glass in First Century in England.

of 4 samples from a single manufacturing site show antimony. This is lower than the usual antimony decoloured glass, which supports the idea of recycling from opaque colours.

Turning instead to the transparent glasses, the situation is clearer [Figure 9.9]. There is no known colourless glass analysed in Britain from the first century. For the coloured glass, there is clear sign of an industry already at home with recycling. While just under half of the glasses analysed for this period show the expected low values for antimony, less than 0.001 wt%. However, nearly 30% are consistent with the colourless glass of the next century. That is, the antimony is high enough that without the addition of significant colourants, this glass would be colourless. The rest of these glasses fall on a continuum between the two groups. This implies material recycled, perhaps even the incorporation of tesserae.

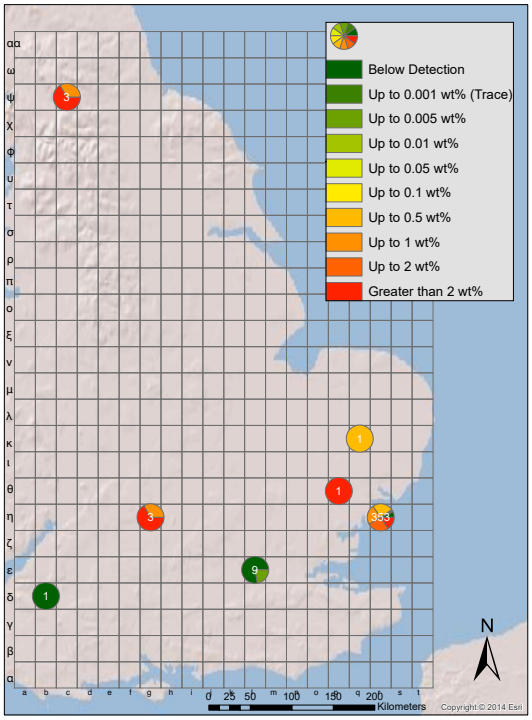

Figure 9.10: Map of Concentration of Antimony in Opaque and Translucent Glass in Second Century in England.

Moving into the second century, opaque glasses appear more standardised [Figure 9.10]. They average over 1 wt% antimony, with a few exceptions - which are all either cuprite red glasses or translucent blacks, known to be formed without the addition of antimony. All other colours marked as translucent or opaque show high antimony. While it is tempting to see a pattern across the South of England, as there is a lack antimony here, it is impossible given the problem of colour. Only one cell shows a sizeable number of glasses, which corresponds to West Clacton (ηr), from which a great number of tesserae were analysed. This single site shows the variance seen across all of England.

Colourless glass is found in only three cells in second century England, with one large grouping, near the West Clacton glass, at Colchester (ηq) [Figure 9.11]. All, however, show the clear dominance of an antimony decoloured glass with greater than 0.1 wt% up to 0.5 wt%. This is consistent with other works which show the range in

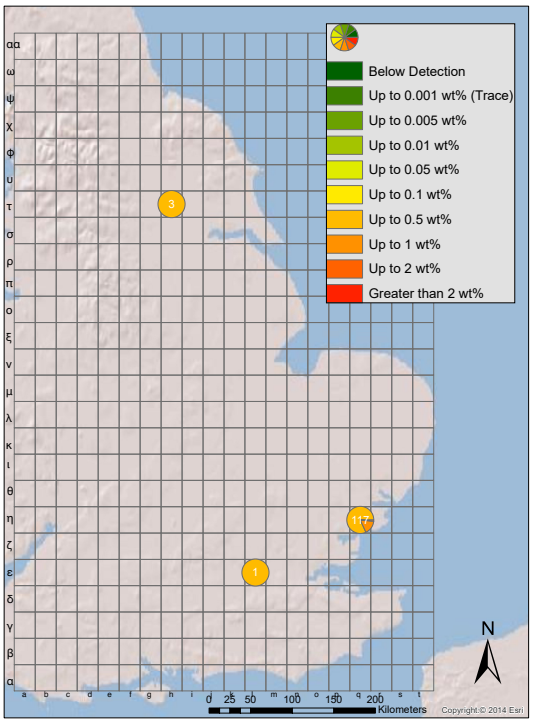

Figure 9.11: Map of Concentration of Antimony in Colourless Glass in Second Century in England.

antimony decoloured glass is usually not above 1 wt% (Rosenow and Rehren 2014, 117-118).

The second century coloured glasses show a change from the century before, and perhaps begin to show the first indication of regionality [Figure 9.12]. The glasses in the north are much cleaner, with much less antimony in coloured glasses. Colchester shows varied recycling, as does London (ϵl). Over 50 % of these southern sites have antimony consistent with colourless glass. This is not the case in York (τh), which by this time was a thriving centre. It is hard to estimate due to the small sample size at York, but is an interesting finding as it seems to show notably different glasses to the South.

Only a single translucent glass from the third century has been analysed, and no opaque glass. It is black, and while not antimony opacified, there is still a good deal

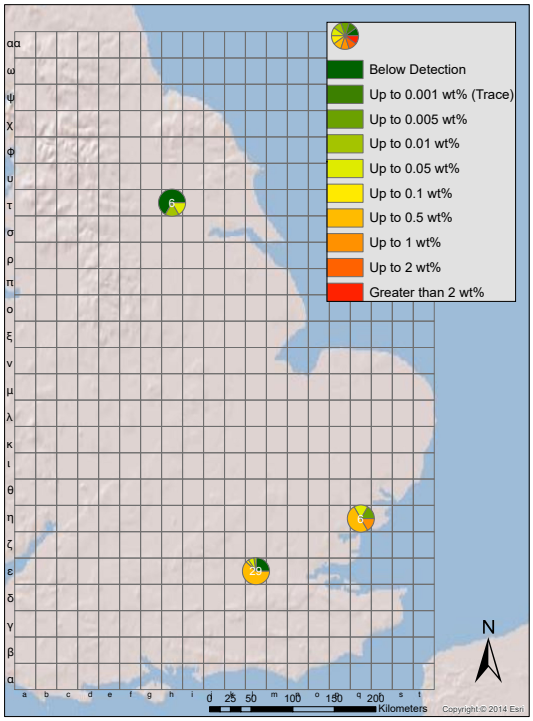

Figure 9.12: Map of Concentration of Antimony in Transparent Coloured Glass in Second Century in England.

of antimony (over 0.01 wt%). This is likely recycled glass and is found in London.

Colourless glass in this period is still uniform across most of England, with the exception of two areas in the centre of the country [Figure 9.13]. Both of these cells show lower antimony, some less than 0.01 wt%. These are very low for the production of antimony glass. A likely explanation is that these glasses have been recycled with a pale natural glass to produce more colourless glass for less.

This is particularly interesting when it is compared to the coloured glasses of this period [Figure 9.14]. High antimony is also seen in these glasses. It shouldn't be occurring but is clear all over England, with the exception of these same central areas, and to a smaller degree, York. More than half of the glass in both these areas is consistent with antimony decoloured glass. The fact that coloured and colourless glass seems interchangeable is interesting, and seems to imply a single recycling system with very little care as to curating colourless glass. If the coloured glass in the central

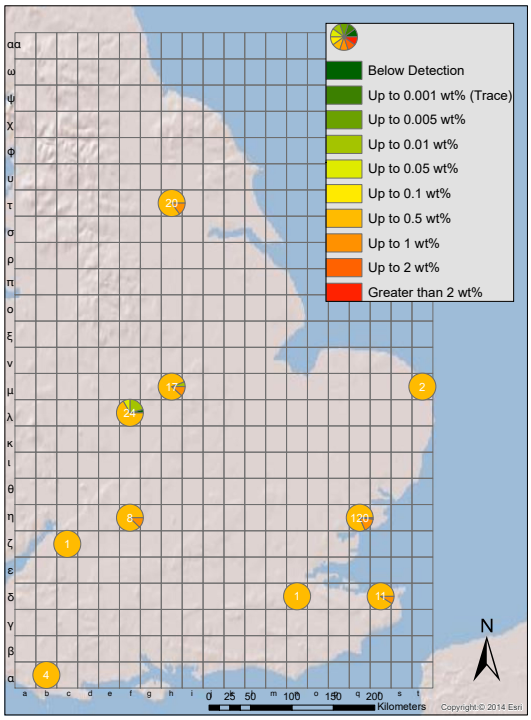

Figure 9.13: Map of Concentration of Antimony in Colourless Glass in Third Century in England.

sites was considered separately, they might seem less recycled. They are far lower in antimony. However, as the same pattern is seen in the colourless glass, it seems less antimony glass is available in this area. These sites are the fort of Mancetter (λf) and urban site of Roman Leicester (μh).

In the fourth century, there is a great deal of opaque glasses with antimony [Figure 9.15]. However, the weight percent of antimony in these glass has dropped slightly. This is not surprising as this is consistent with the shift away from antimony.

This shift away from antimony is also seen looking at the fourth century colourless glasses [Figure 9.16]. These are almost entirely antimony decoloured glass, though with some evidence of this glass being recycled with other glasses. The lower antimony, potentially recycled, glasses seems particularly common to the East of the Severn Estuary. This finding is particularly interesting as this corner of Gloucestershire, Wiltshire and Oxfordshire is notably variable in many elements analysed for

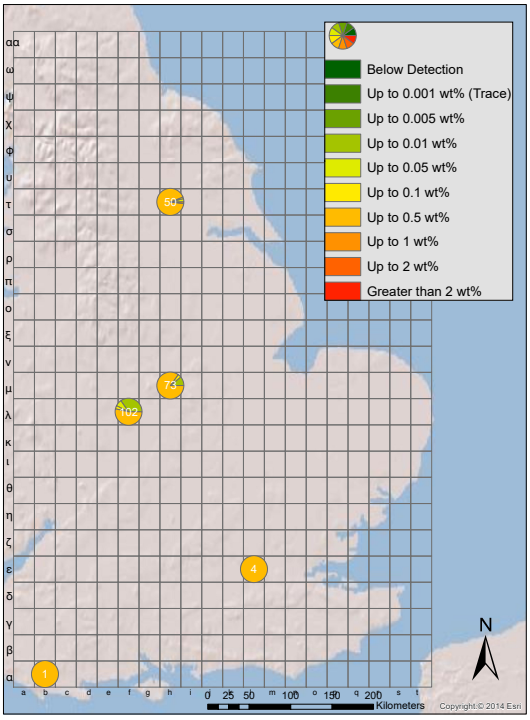

Figure 9.14: Map of Concentration of Antimony in Transparent Coloured Glass in Third Century in England.

this study. This will be discussed further below. There are two possible explanations for these anomalous results. Either these sites are being less careful with their recycling, or this glass is being deliberately eked out, stretched out with fresh glass that was of a lower quality and not decolourised to extend the good colourless glass as long as possible.

The coloured glass shows no clear pattern of recycling in this century [Figure 9.17]. All across England there is a range of antimony content in coloured glasses. Some of the higher values of antimony are possibly indicative of opaque glass being used as a dye pack. However, as such a small range of opaque glass has been analysed in Britain it is hard to be sure. It is interesting that there seems to be a small pocket with higher average values of antimony, once again near the Severn. This further supports the idea of greater recycling here.

There is no analysed opaque or translucent glass from the fifth century analysed

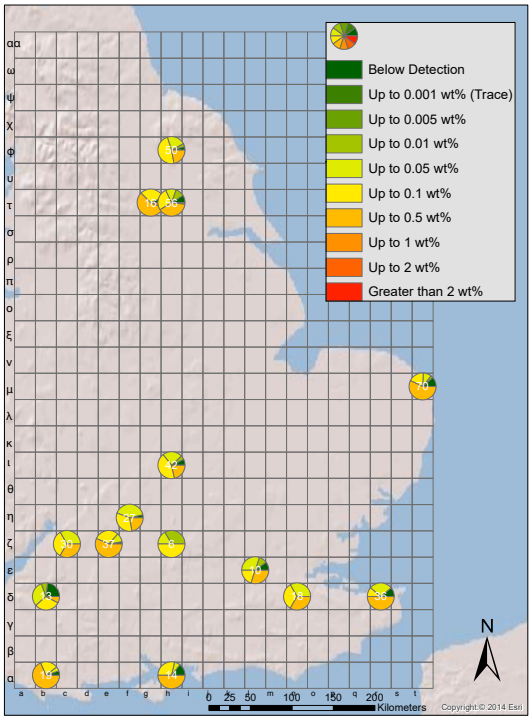

Figure 9.15: Map of Concentration of Antimony in Opaque and Translucent Glass in Fourth Century in England.

[Figure 9.18]. Similarly, there are only three colourless glasses from this period analysed. While there is very little glass from this century analysed for antimony (n: 47), this is still a very small proportion of the glass (approximately 6%). As all three of these dispersed glasses have average values of third century colourless antimony glass. It seems likely that such glasses are a hangover from previous centuries. It is interesting note that these are of the highest values seen in colourless glasses of the previous century.

Across the coloured transparent glass, there is a greater variance [Figure 9.19]. While almost all glass shows elevated antimony, there are interesting pockets of higher antimony glasses. Again, the glasses immediately to the east of the Severn show a much higher antimony, as does a single cell in Kent, urban and extra-mural early medieval Canterbury (δr). This seems to indicate a heavier reliance on Roman antimony rich glasses, whether tesserae or indiscriminate mixing of Roman decoloured

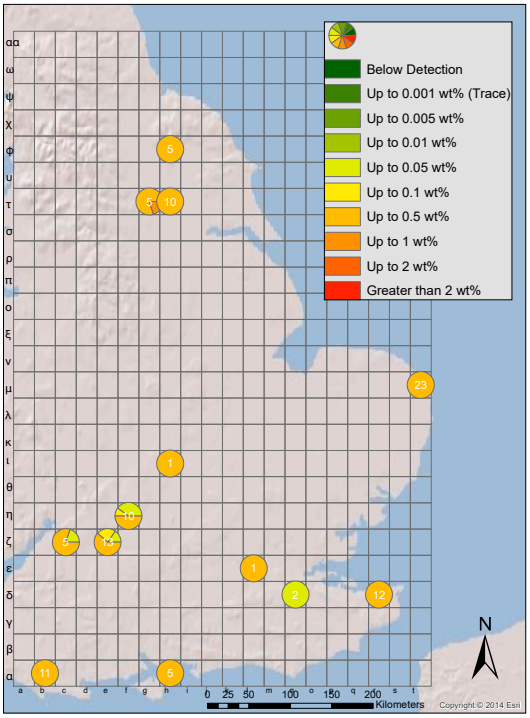

Figure 9.16: Map of Concentration of Antimony in Colourless Glass in Fourth Century in England.

glass into the mix. The glass workers of London, and these few other southern coastal sites, appear to have had slightly more access to a new glass without antimony glass.

What is notable as well is that the only northern site, York, has the second largest collection of fifth century glasses. They are all, however, uniform, with only 0.01 wt% of difference between the glasses. This might indicate a glass that has been recycled together multiple times, blurring any uniquness. This glass is found at more than one site across York.

The sixth century, however, shows a real moment of change [Figure 9.20]. The opaque and translucent glass of this period again shows a clear difference. East Anglian glass is clearly still antimony opacified glass, at much higher levels of antimony than even the fourth century glasses. The earlier opaque glasses analysed are almost entirely vessel glass, whereas these are beads. These beads are far more consistent with the second century opacified tesserae, such as the large collection from the West

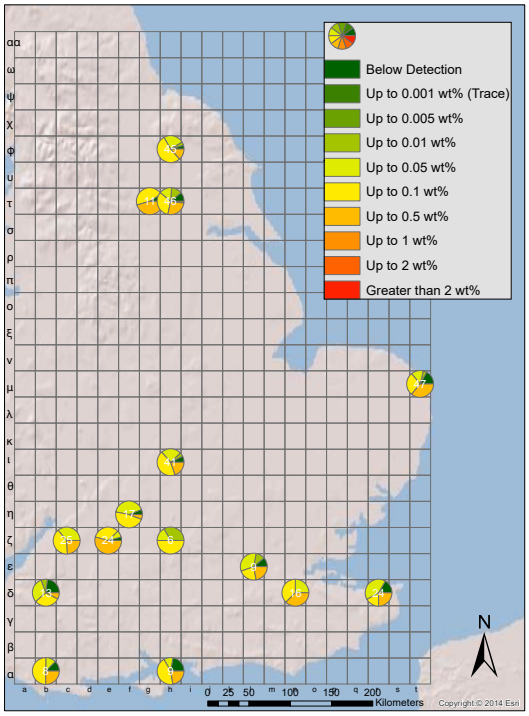

Figure 9.17: Map of Concentration of Antimony in Transparent Coloured Glass in Fourth Century in England.

Clacton Reservoir (ηr)(Paynter and Kearns 2011). It seems likely that a great deal of these beads seem to have been recycled Roman material, especially tesserae. It is interesting to note that this areas of East Anglia has a far greater amount of antimony, perhaps indicating a more direct scavenging of tesserae. These results are borne through in other elements.

While there is a small amount of material with elevated antimony in the other sites along the Jurassic Ridge, there is a great deal more glass without. Unlike during the Roman period, this is not as restricted to single colours. The glasses that contain antimony are not a single colour, or type. It seems that prior to the fifth century, that particularly antimony decoloured glass was recycled together, as indicated with other elements, after this period antimony is found spread throughout all glass types.

There are 10 colourless glasses in this late period [Figure 9.21]. While some of this glass shows no antimony, over half of the glasses still contains antimony. In fact, 20%

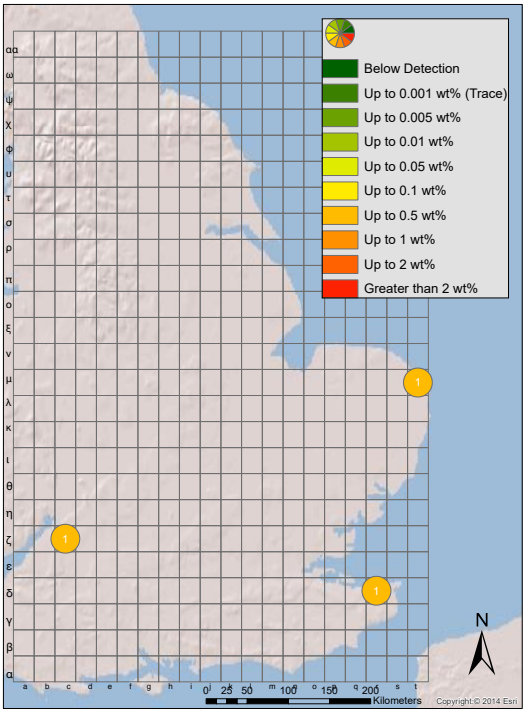

Figure 9.18: Map of Concentration of Antimony in Colourless Glass in Fifth Century in England.

of these glasses are still consistence with Roman colourless glass and a further 40% have enough antimony to require antimony to have been deliberately added at some point in the production cycles. It seems very clear that this Roman glass is still part of the system, having been perpetually recycled. Unfortunately there is insufficient glass for geographical conclusions.

The coloured glass of the sixth century again shows elements of regionality [Figure 9.22]. Of the 16 glasses analysed from Lyminge (γr), 2 glasses show extremely elevated antimony, a further 10 show glasses with antimony consistent with values of Roman colourless glass, and the other 4 still show an elevation above 0.01 wt%. In short, this glass, all vessel glass, is entirely consistent with recycled glass.

Similarly, almost all of the glass from East Anglia in this period is also elevated. Only 3 of the 71 colourless glasses from East Anglian have no detectable antimony, less than 4%. These glasses, unlike the Lyminge glasses, are beads.

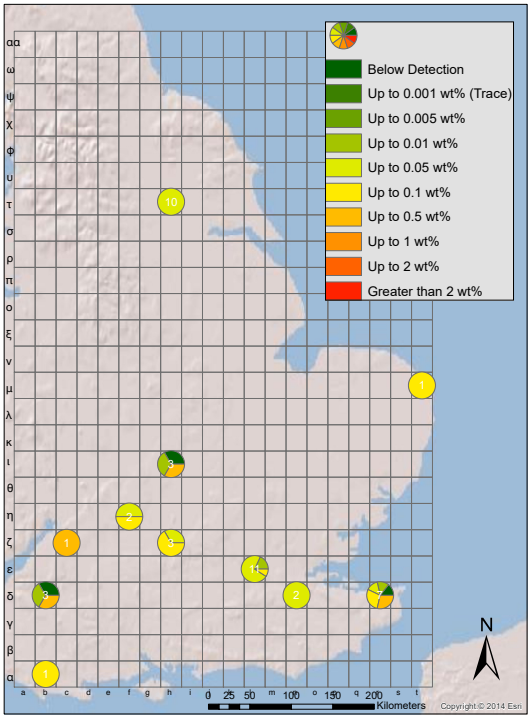

Figure 9.19: Map of Concentration of Antimony in Transparent Coloured Glass in Fifth Century in England.

The other glass, from the more central sites of Empingham (μj), again dominated by beads, and Great Chesterford (θn), also a bead assemblage, are notably different. These both have a great deal of 'clean' glass and a far lower antimony in any of there glass. Yet still, it remains in much smaller proportions, in 2 of Great Chesterford's 7, and 17 of Empingham's 27. This is consistent with the opaque glasses. Unfortunately the lack of data resolution fails to answer the question, but it could be that Empingham was using more recycled Roman glass, whereas the East Anglian glass is more freshly scavenged. As will be discussed below, the glass at Empingham also seem to be extended with lead. Even when this is corrected for though, it has much lower antimony.

In the final century considered, the opaque glasses, while only three, all contain high antimony of the early Roman opaque glasses [Figure 9.23]. There are also ten translucent glasses in this century, those from the Jarrow ($\alpha\alpha$f) windows, and of these,

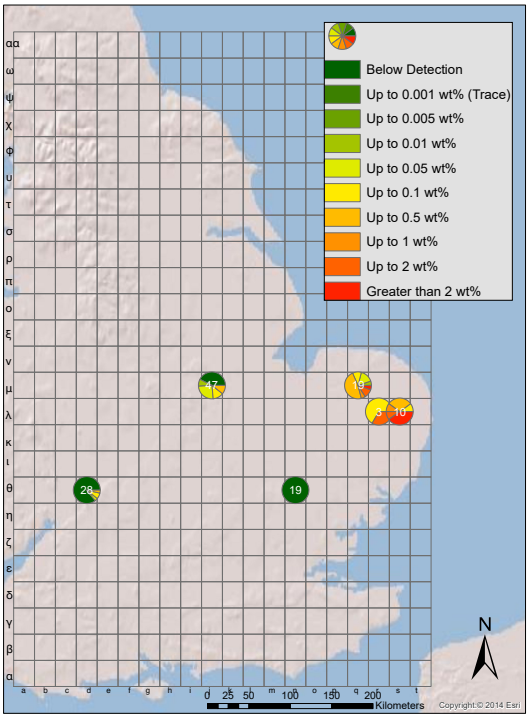

Figure 9.20: Map of Concentration of Antimony in Opaque and Translucent Glass in Sixth Century in England.

3 contain no antimony, and the rest antimony in common with Roman colourless glass. It is likely with such high antimony that these could have been formed by the addition of opacified coloured recycled material to either a fresh melt, or a naturally coloured cullet melt.

There is also an analysis listed as colourless transparent from Jarrow, which contains this same high antimony [Figure 9.24]. That is, it is exactly consistent with Roman colourless glass. The other colourless glasses of this century are beads from the Wakerley cemetery (λj). Of these, 6 are consistent with later colourless glass, that is, without antimony. However, one shows evidence of a Roman colourless glass that has been recycled with later colourless glass, as it is between the two values.

Turning to the colourled glass, Wakerly again shows up as a centre of mostly clean glass, with a small amount of recycled material, shown by the elevation of antimony [Figure 9.25]. Aside from this site, London, and Lyminge, all the other scattered

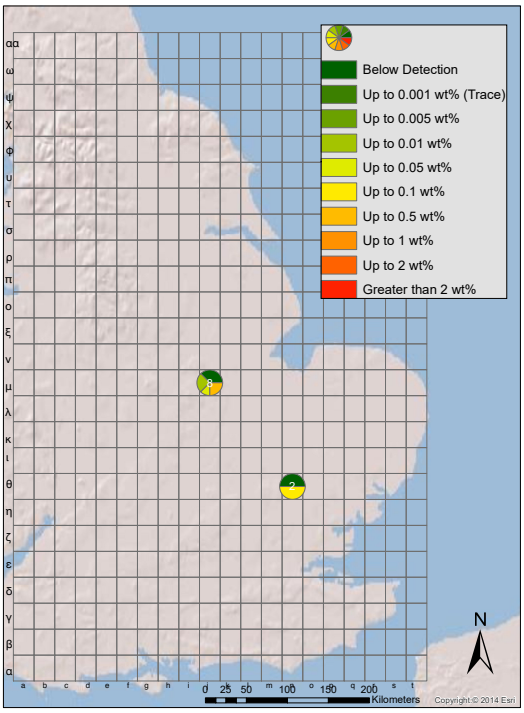

Figure 9.21: Map of Concentration of Antimony in Colourless Glass in Sixth Century in England.

glass in the South of England shows up as devoid of antimony, or antimony below detection. This implies that there is a clean source of glass available along this coast. The appearance of recycled glass at Wakerley could be due to the type, beads, or the central location. London, because of the population density.

Interestingly, looking at the only northern site, again glass from Jarrow and Monkwearmouth, show a very different story. While some of this glass is further analyses of the window glass, categorised by others as translucent, much is also vessel glass. Less than a quarter of the glass here is without antimony. Most of the coloured glass present shows a very high level of antimony. So high, in fact, that it is far beyond what would be expected for mixed decolored and coloured transparent glass, and is again more indicative of glass that was potentially coloured by the addition of antimony-rich opaque tesserae. The same might be true of some of the London and Lyminge. Coloured glasses are less ambiguous as the inclusion of any antimony in

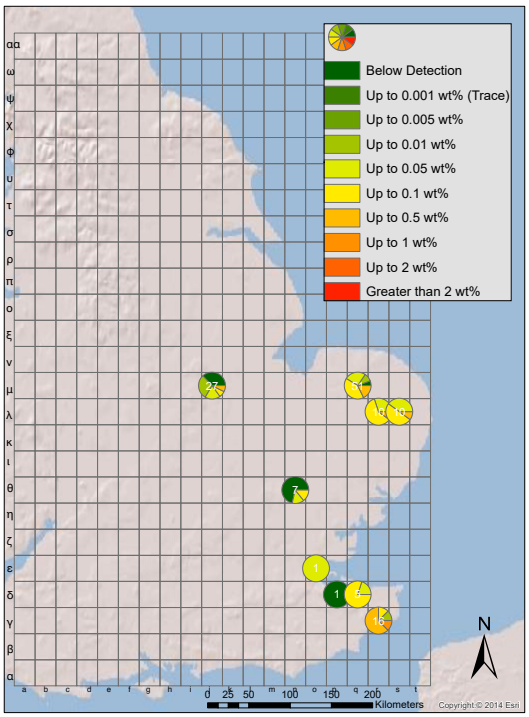

Figure 9.22: Map of Concentration of Antimony in Transparent Coloured Glass in Sixth Century in England.

translucent coloured glasses only makes sense in the context of recycling.

The quantities of antimony in glass in England are very changeable. In the first century, England inherits a system of glassmaking already comfortable with recycling, with most transparent coloured glass showing evidence of recycling.

In the second century, while the colourless glass is consistent with fresh glass, whereas the coloured glass still seems recycled. The antimony in the North is lower. As we move into the third century, a greater amount of regionality seems to come into the glass, which is carried through into the fourth century. By this point, all types of glass show elements of recycling.

There is very little evidence from the fifth century, however the glasses near the Severn show a strange result. The sixth century, dominated by beads, shows a difference between East Anglia, Central England and Kent. Some areas seem to be recycling from a more immediate, antimony rich source, where as others seem to

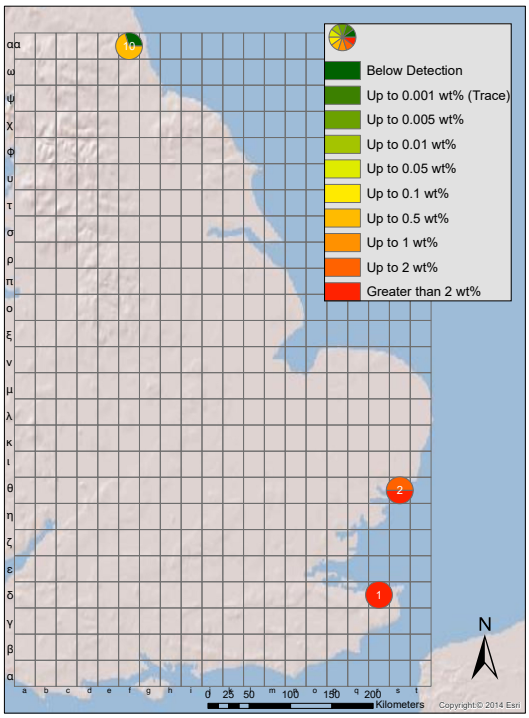

Figure 9.23: Map of Concentration of Antimony in Opaque and Translucent Glass in Seventh Century in England.

show a continued Roman cycle. The seventh century shows a final disappearance of the Roman antimony, either flooded out by continued later glass types, except for the anomaly of Jarrow and Monkwearmouth.

9.3 Cobalt Evidence

Before we consider the patterns of cobalt as a recycling agent, it is first prescient to consider how common it is as a colourant in Britain. For this, two maps have been made, Figure 9.26 and Figure 9.27. The first of these contains all glasses identified by the original author as blue, analysed for cobalt, and the second, all glasses but blue glasses. Considering blue glasses, it is clear that cobalt is the common colourant in blue glass in England, present in around 70% of samples. The other samples are likely coloured by copper. However, the range of values for cobalt is particularly

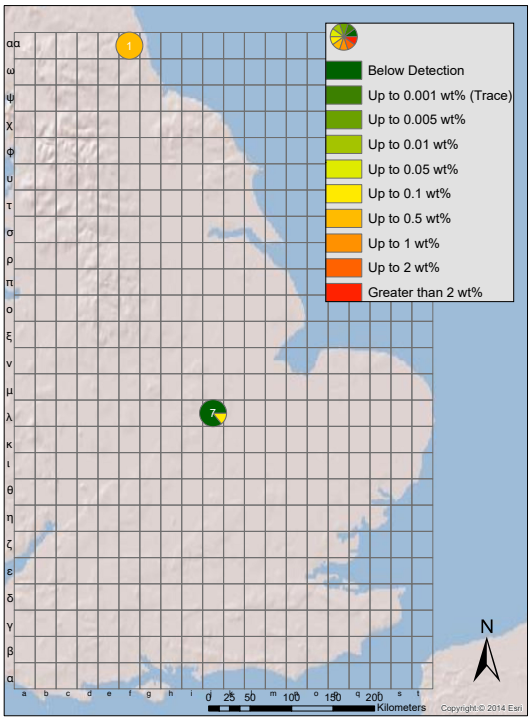

Figure 9.24: Map of Concentration of Antimony in Colourless Glass in Seventh Century in England.

interesting, with two notable groupings. 18% of glasses contain between 0.005 to 0.0005 wt% cobalt, where as very little contain between 0.005 and 0.05. Half of all cobalt values fall between 0.05 and 0.5 wt%.

Looking at this geographically, it is clear that there are areas of much higher cobalt content, and those of lower, as well as areas which are more mixed. The furthest north locations have a range of values, almost all of the blue glass in East Anglia is high cobalt, whereas along the Jurassic ridge there is very little cobalt. There is still trace cobalt in many of these glasses. This doesn't seem to be a product of techniques and is key to keep this in mind as when we look at patterns of cobalt in non-blue glasses.

When we instead look at the map without blue, Figure 9.27, this same pattern is apparent. A higher amount of cobalt is still present in East Anglia, with less towards Central England. However, in these non-blue glasses there seems to, strangely, be a higher amount of low cobalt. This is very likely caused by the same as increased

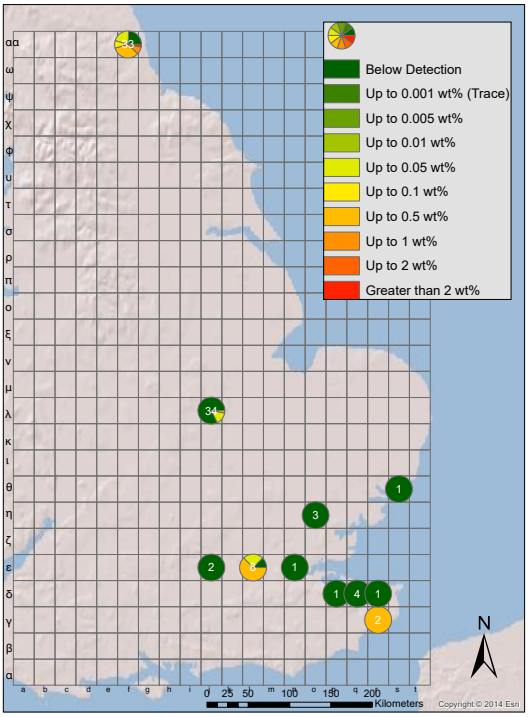

Figure 9.25: Map of Concentration of Antimony in Transparent Coloured Glass in Seventh Century in England.

copper - where blue decorative elements have been included in recycled coloured melts. This will be examined per century.

Turning to the first century, there are very few glasses analysed for cobalt, only 8 samples [Figure 9.28]. While nothing can really be drawn from this, it is interesting to note that all have less than 100ppm but not below detection.

The second century has a far greater number of analysed glasses, as well as glasses that have no detectable cobalt - around 30% [Figure 9.29]. London (ϵl) is the only site with notably higher and more variable amounts of cobalt, potentially indicating a more common mixing pot. This has also been seen in antimony in the second century in London. What is interesting geographically is that East Anglia, which has the greatest amount of cobalt in other centuries, is not particularly significant here, except the slight elevation at Colchester (ηq). It is also interesting that almost all of Colchester falls into the same bin. The adjacent cell, which contains West Clacton

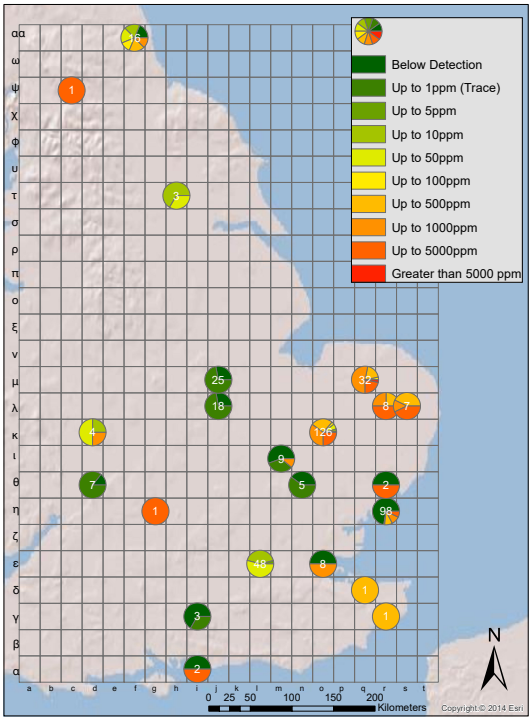

Figure 9.26: Map of Concentration of Cobalt in all First to Seventh Century Blue Glasses in England

Reservoir (ηr), which is entirely tesserae, has an elevation of cobalt. This is only surprising as it isn't blue.

Moving into the third century, Colchester looks identical to the century before [Figure 9.30]. Unfortunately the low count from London means it is not possible to compare across centuries. York (τh) is more varied, as a large city, but much of central England shows an elevation in the average amount of cobalt in non-blue glasses. What is interesting is that, as seen in other elements, the glass closely to the east of the Severn is cleaner. The third century is also the first period for which we have glasses from the southern coast. These glasses are all comparatively clean, or have much lower traces of cobalt.

The fourth century is very confusing, with little seeming geographical patterns [Figure 9.31]. There are the seven glasses, four in East Anglia and three on the border of Oxfordshire that show very high cobalt, though they are not comparable

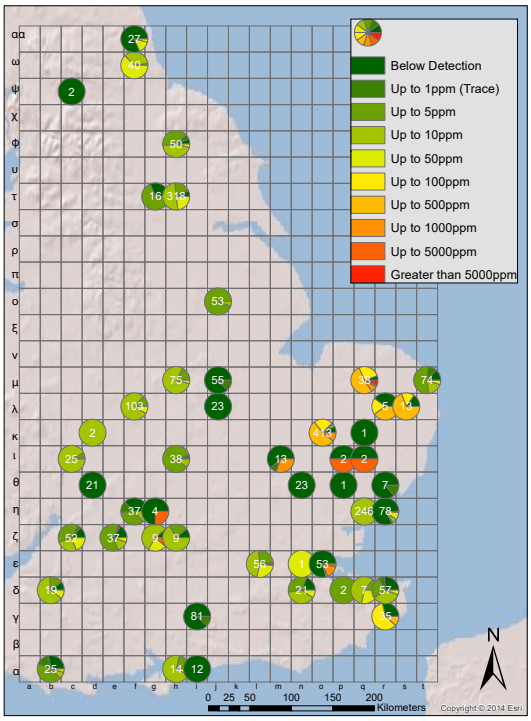

Figure 9.27: Map of Concentration of Cobalt in all First to Seventh Century Not Blue Glasses in England

to anything else. The edge of Oxfordshire, Wiltshire and Gloucestershire again seem to have low or below detectable cobalt.

The fifth century shows a common low average which could be indicative of perpetual recycling [Figure 9.32]. again near the Severn there are several cleaner glasses. There are also three high cobalt glasses, two of which are in the site of Caister-on-Sea (μt). This is strange as other indicators show lower recycling.

The sixth century shows an abrupt change [Figure 9.33]. In East Anglia and Kent show a high degree of very cobalt rich glass, whereas the other sites show no detectable cobalt. While these analyses are older, so it might be a matter of less accurate techniques, none of these glasses would have greater that 0.01 wt%. That is, none of these glasses would enter into the same high categories as seen in East Anglia and Kent. It is possible that these glasses are using older Roman glass, whereas East Anglia and Kent show a fresher access to cobalt glass. These beads are also notable

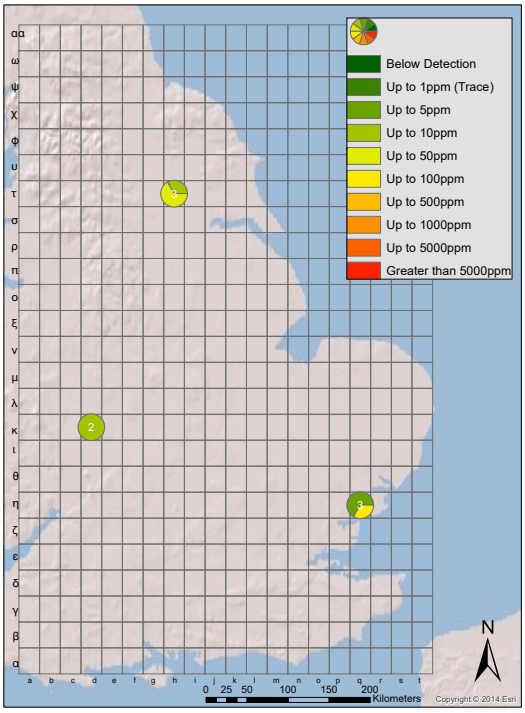

Figure 9.28: Map of Concentration of Cobalt in Non-Blue Coloured Glass in First Century in England

in their antimony, further supporting the idea of tesserae recycling.

As move into the seventh century, things change again. The few analyses done are clean of cobalt, expect for London (Maiden Lane), Lyminge (γr) and the glass from the twin Monasteries of Monkwearmouth and Jarrow ($\alpha\alpha$f) [Figure 9.34]. While these are only 3 of the 4 sites with 5 or more glasses analysed, the beads from Wakerley (λj) all appear to be clean. This is interesting as beads are often seen as more recycled that windows and vessel glass, which all the other material is. However, this is consistent with the recycling patterns seen in antimony.

The patterns of recycling highlighted by cobalt are very similar to those seen in antimony. First and second century glass don't have strong indication of recycling shown by cobalt, except London. The third century shows a widespread low level of cobalt, with only a small amount of regionality. Several glasses do stand out as very high cobalt glasses in the fourth and less so in the fifth century, especially in East

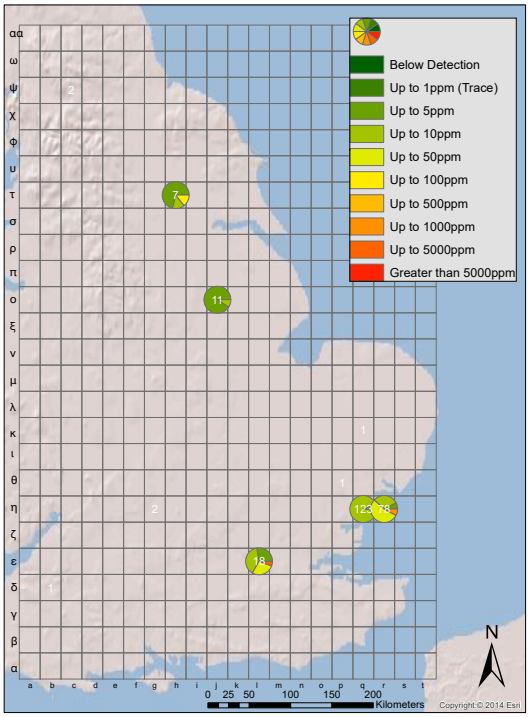

Figure 9.29: Map of Concentration of Cobalt in Non-Blue Coloured Glass in Second Century in England

Anglia. In the seventh century, cobalt shows almost exactly the same patterns as antimony.

9.4 Lead Evidence

Lead is usually added to glass either as a colourant, brightener or to extend glass. Enamels, as well, tend to have higher lead to help the viscosity of glass and the adhesion to the copper alloy. Enamels aside, lead has been shown to accumulate in recycled glasses. In amounts less than a few weight percent, this is probably accounted for by lead added as colourants, then being recycled. Despite their high lead, enamels have been retained in these maps but will be clearly indicated.

Looking at the first century, the three high lead glasses are all red enamel [Figure 9.35]. The vessel glass all contain fairly low lead, but most contain a small amount.

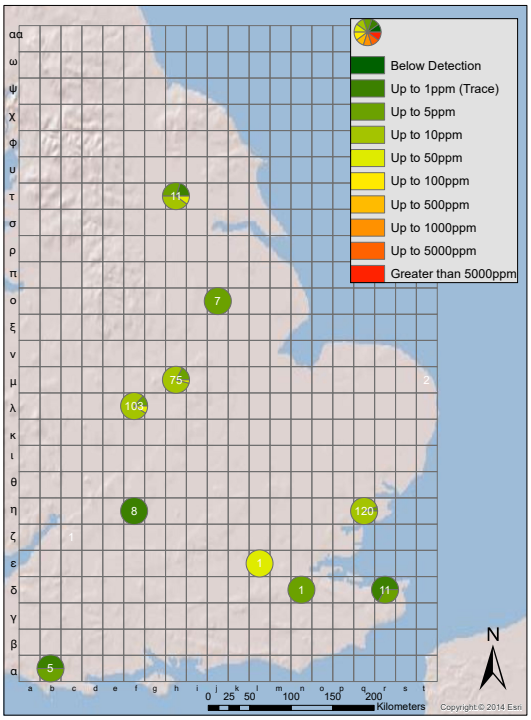

Figure 9.30: Map of Concentration of Cobalt in Non-Blue Coloured Glass in Third Century in England

They range from below detection up to 0.05 wt%. There isn't enough spread to address regional variation.

In the second century, again the lead seems more related to typology than locality [Figure 9.36]. The site of West Clacton Reservoir (ηr), with hundreds of tesserae, show a range of high lead glasses. All the other sites are enamel, except Colchester, Lincoln, York and London (ηq, oj, τh and ϵl). These are all vessel glass, most with less than 0.25 wt%. While London and Colchester seem to have an average a little higher than the Northern sites, there is very little regional evidence.

In the third century, several sites show up with high amounts of lead, including Colchester, York, as well as in Oxfordshire and Kent [Figure 9.37]. These glasses are all blue-green or colourless, and vessel glass, so the lead only makes sense in the context of continued recycling.

Again in the fourth century, enamels stand out due to their high lead [Figure

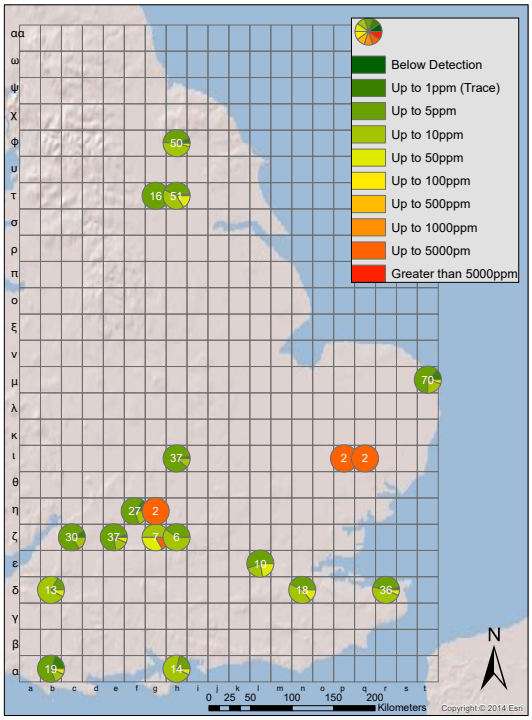

Figure 9.31: Map of Concentration of Cobalt in Non-Blue Coloured Glass in Fourth Century in England

9.38]. Ignoring these four glasses, there are still many glasses with elevated lead. While York remains notable, there is no Colchester glass from this period. However, East Anglia still has a few very high lead glasses in the Late Roman fort of Caister-on-Sea (μt). Along the Severn, in Wiltshire, Gloucestershire and Oxfordshire, there is also elevated lead. This is the same strange area of grouping seen in antimony and cobalt.

The fifth century again has fairly low lead, with the exception of a single glass vessel from Frocester Court (ζc) and another single glass from Canterbury (δr) [Figure 9.39].

Once again in the sixth century, lead variance is related to typology [Figure 9.40]. The sites of Wakerley(λj), Beckford (θd) and Great Chesterford (θn) are all predominately bead assemblages. One of the beads at Wakerley has nearly 50% lead. The higher lead glasses in East Anglia are also beads, though they have far lower lead.

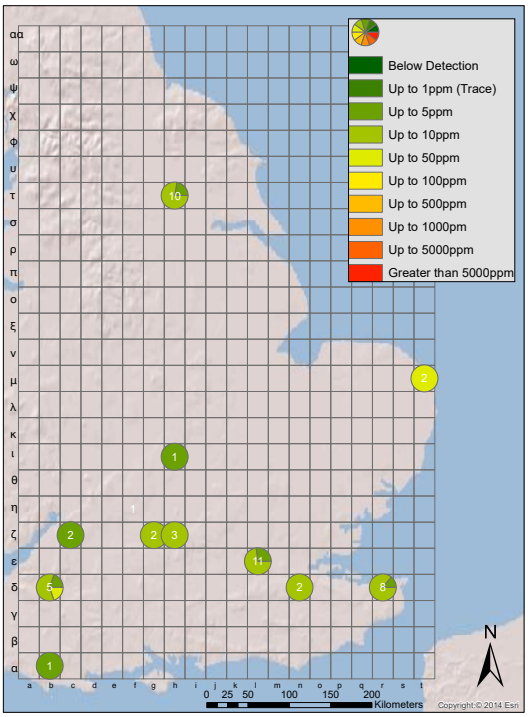

Figure 9.32: Map of Concentration of Cobalt in Non-Blue Coloured Glass in Fifth Century in England

Taken in conjunction with the results seen in antimony and cobalt, it might seen that these glass are similar values, but extended with lead. However, even taken into account the lead, this is not the case. The only other site of this period with notable lead is Lyminge (γr), which is entirely vessel glass. The lead in this case seems to be further evidence of Lyminge's reliance on recycling.

Lead in vessel glass is far more common in the seventh century; Jarrow ($\alpha\alpha$f) window and vessel glass has up to 0.5 wt% lead, one the insets from Sutton Hoo has 2.5 wt% lead [Figure 9.41]. Lyminge, Faversham (δq) and surround settlements, as well as Trowbridge and London (Maiden Lane) all also have high lead vessel glass, with at lease one glass over 0.5 wt%. As well as the vessel glass, the beads continue to have much higher lead, as seen at Alton (γi) and Wakerley. Some glass with lower lead continues to be present in this period, but it is less common. This immediate departure from the much lower lead of the centuries before is either a product of a

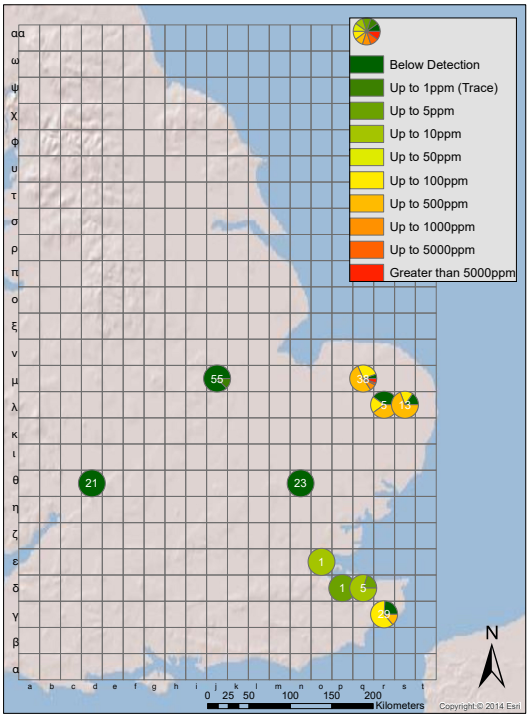

Figure 9.33: Map of Concentration of Cobalt in Non-Blue Coloured Glass in Sixth Century in England

change in recycling, or a new type of glass. This is far too early for lead flux glasses in Britain, so it seems it must be the former.

9.5 Tin Evidence

Tin is common as an opacifier, for the formation of specific colours, particularly yellow and white, and thus the elevation in other colours can be related mixing. Throughout the Roman period, the only glasses with elevated tin are tesserae and enamels. However, as we move into the Early Medieval period there is a significant change. While tin is not often analysed for in vessel glass, it isn't found in Roman vessels. Because of this, it isn't usually analysed for, as is apparent is Figures 9.42 to 9.45. There is not a single fifth century analysis of glass, yet an explosion of tin studies in beads from the sixth and seventh centuries.

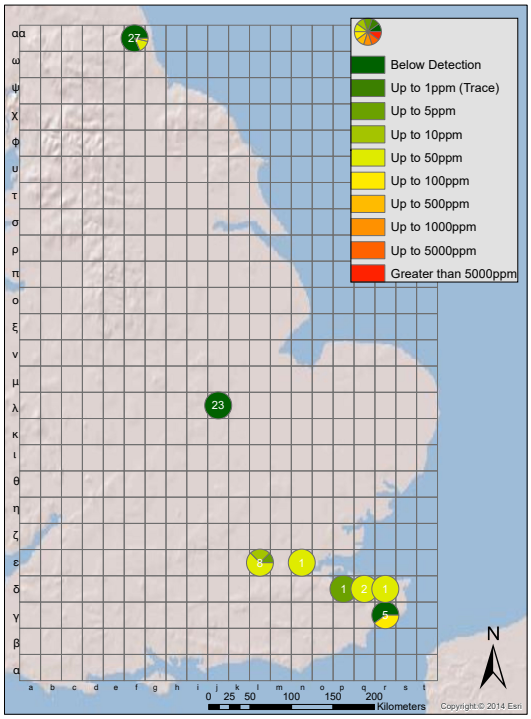

Figure 9.34: Map of Concentration of Cobalt in Non-Blue Coloured Glass in Seventh Century in England

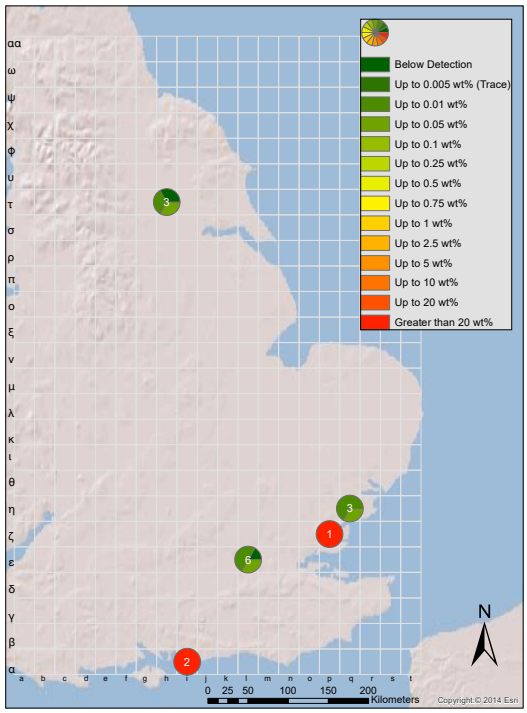

Figure 9.35: Map of Concentration of Lead in Glass in First Century in England

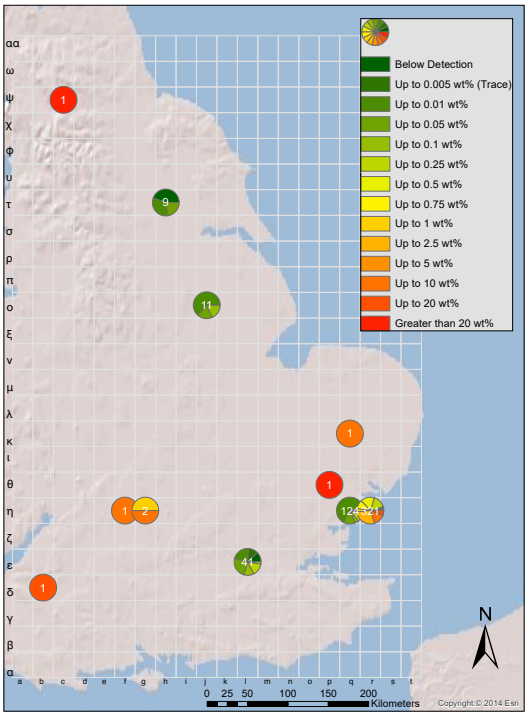

Figure 9.36: Map of Concentration of Lead in Glass in Second Century in England

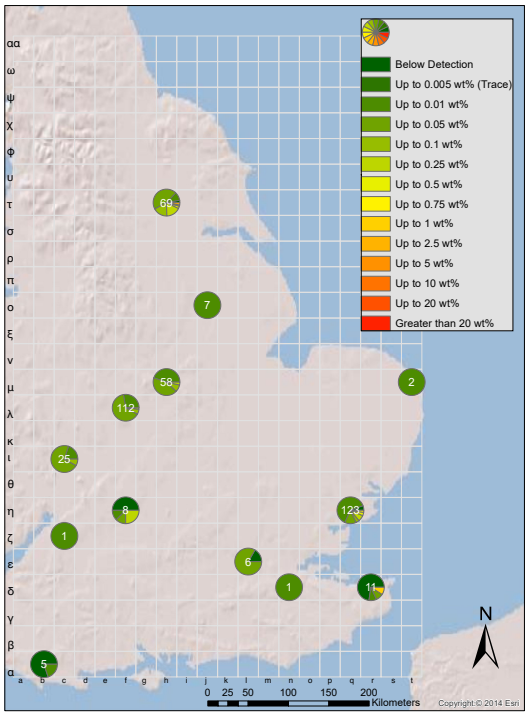

Figure 9.37: Map of Concentration of Lead in Glass in Third Century in England

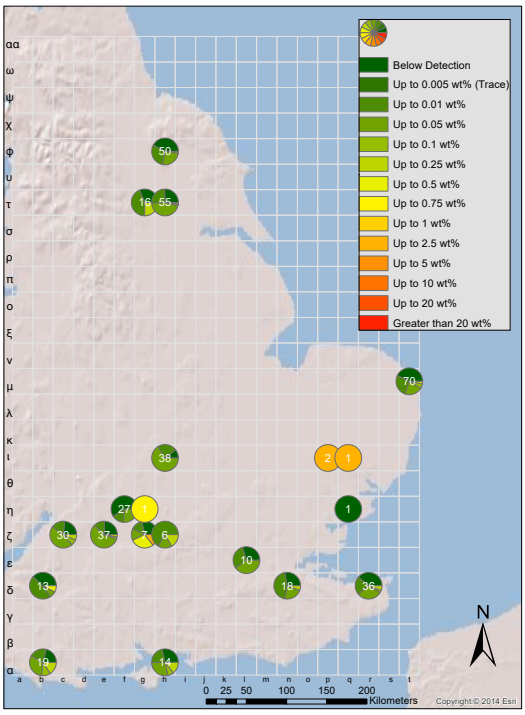

Figure 9.38: Map of Concentration of Lead in Glass in Fourth Century in England

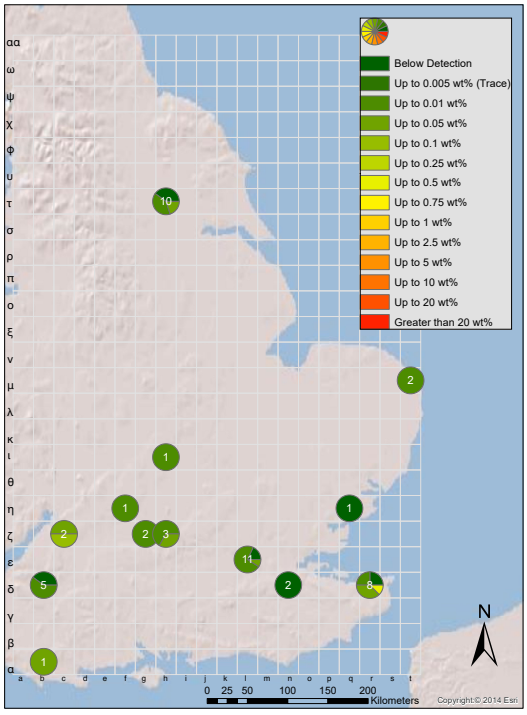

Figure 9.39: Map of Concentration of Lead in Glass in Fifth Century in England

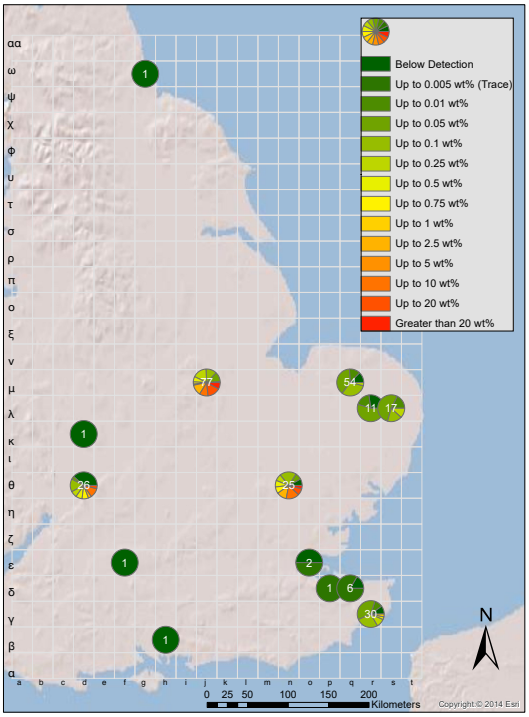

Figure 9.40: Concentration of Lead in Glass in Sixth Century in England

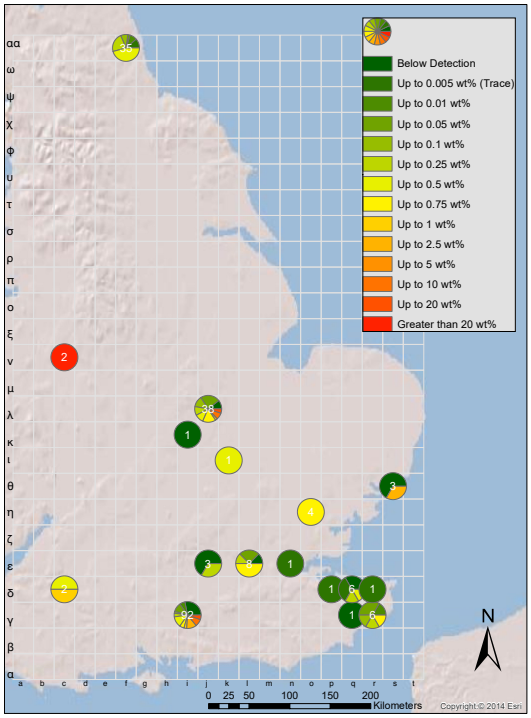

Figure 9.41: Map of Concentration of Lead in Glass in Seventh Century in England

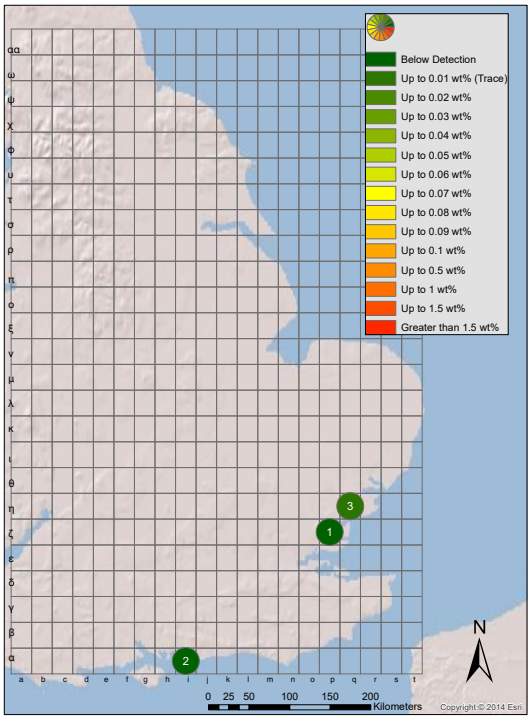

Figure 9.42: Map of Concentration of Tin in Glass in First Century in England

The three sites with a total of 6 glasses were analysed from the first century [Figure 9.42]. The three glasses are vessels from the early levels at Colchester (ηq), and the rest are manufacturing evidence and traces of red enamel. None of these contain measurable tin, so no evidence of recycling.

The second century, while originally looking very different, is perhaps more similar than otherwise, at least in terms of the vessel glass [Figure 9.43]. All vessel glass has no detectable tin. However, the majority of second century glass analyses for tin is tesserae and enamel. However, the tin apparent does not seem to be directly relevant to the coloration of this opaque glass. The single black enamel contains no in tin, whereas the white and orange enamels are each high tin, which isn't surprising as tin is commonly used in the formation of these colours. However, only 26% of the 58 opaque yellow enamels and tesserae, which are commonly coloured with either lead or tin, contain tin. This might indicate a preference for lead yellows. However, 9% of the 191 blue glasses, 38% of the 56 green glasses and a staggering 92% of the 26

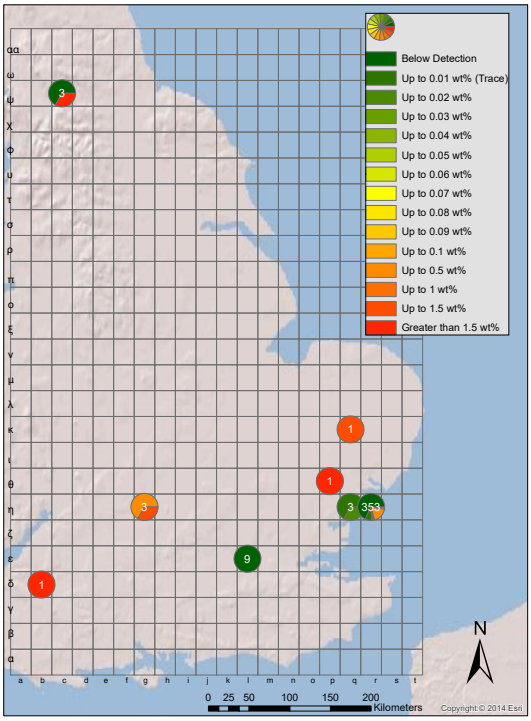

Figure 9.43: Map of Concentration of Tin in Glass in Second Century in England

red glasses contain greater than 0.1 wt% tin. The red is particularly interesting, as this would be consistent with these glasses being coloured with the addition of scrap copper-tin alloys.

The third century unfortunately only has a single glass analysed for tin, black vessel glass from London (єl). This is low, consistent with the black glass from the previous century. The fourth century is similarly lacking in detail, the three glasses are all polychrome enamels. Two analyses are from the blue and white of a single polychrome enamel, and the other the white from a similar blue and white. The high tin in this blue might be related to recycling or simply the mix of the two colours, the leaching of tin.

There are no glasses analysed from the fifth century at all.

The sixth century, the first Early Medieval period with analysis for tin, is dominated by beads [Figure 9.46]. Like enamels, the elevation of tin in these glass could simply be related to colour. However, once again, this doesn't seem to be the case. Of

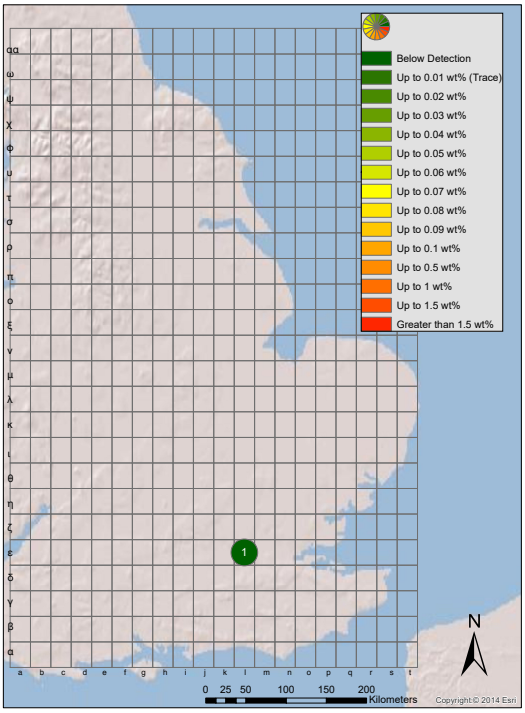

Figure 9.44: Map of Concentration of Tin in Glass in Third Century in England

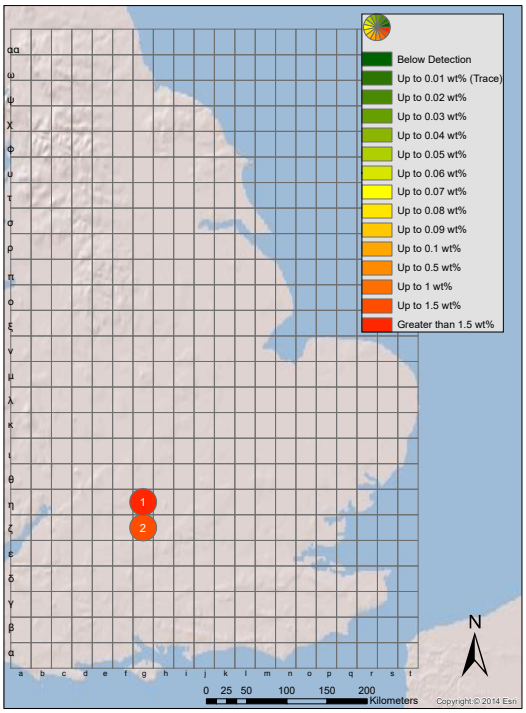

Figure 9.45: Map of Concentration of Tin in Glass in Fourth Century in England

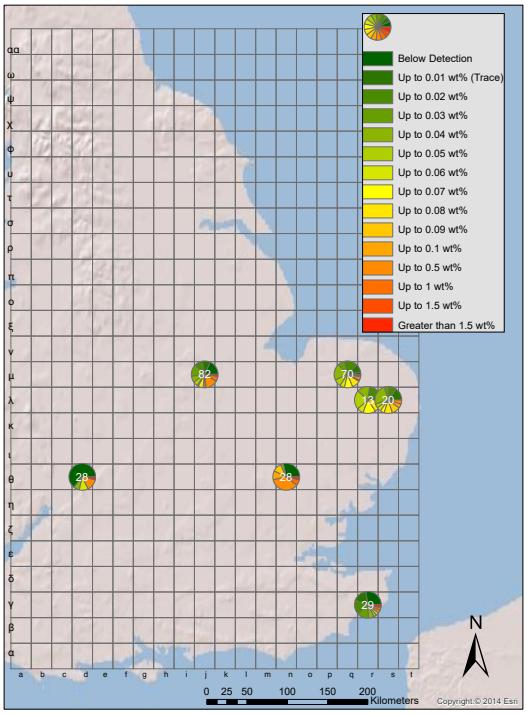

Figure 9.46: Map of Concentration of Tin in Glass in Sixth Century in England

44 polychrome beads, 59% contain greater than 0.1 wt% tin, but as a great many of these include yellow and white, this is likely not significant. 6 of the 11 yellow beads have high tin, again likely colouration, with the other glasses being lead yellows. The glasses that are more interesting are the white glasses, only 22% of which include tin. As tin is the only colourant at the period used for the creation of white, this is very interesting. It indicates the other white beads are very likely recycled antimony white glasses. As for other beads with unexpected tin, 20% of the five black beads, 17% of the 24 green beads, 11% of the amber beads, 7% of the 15 red beads and only 2% of the 85 blue beads. There seems to be no patterning across sites as to the recycling elements of these colours.

Lyminge (γr), analysed for this thesis, contains only vessel and window glass. However, unlike in the previous periods, there are many glasses with a significant amount of tin. The fifteen highest vessel glasses are indistinguishable from the beads, however, unlike the beads, none of these are translucent or opaque.

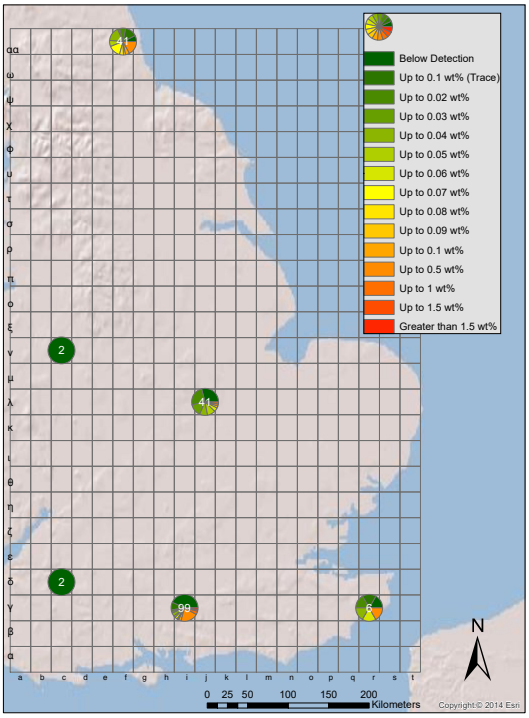

Figure 9.47: Map of Concentration of Tin in Glass in Seventh Century in England

In the seventh century, vessel and window glass is also seen at Jarrow and Monkwearmouth ($\alpha\alpha$f), Trowbridge, as well as at Lyminge [Figure 9.47]. The rest of the English glass is predominately beads, with a few enamels.

The two vessel samples from the southwestern site of Trowbridge are 'clean' of tin. Jarrow stands out at quite high in tin for non-opacified glass, as do some of the vessels from Lyminge, again raising questions of recycling for coloration.

It is difficult to make any generalisations about tin because there are so few analyses. However, in the second century there is no evidence of vessel recycling in tin. The exceptions are enamels and tesserae. Both show very high tin, which does not properly correlate to colour. The next significant amount of glass is from the sixth century, dominated by beads. These beads are similarly bizarre, relative to colour. However, both this and the next century's vessel glass are both high in tin. Lyminge, however, is much cleaner in the seventh century.

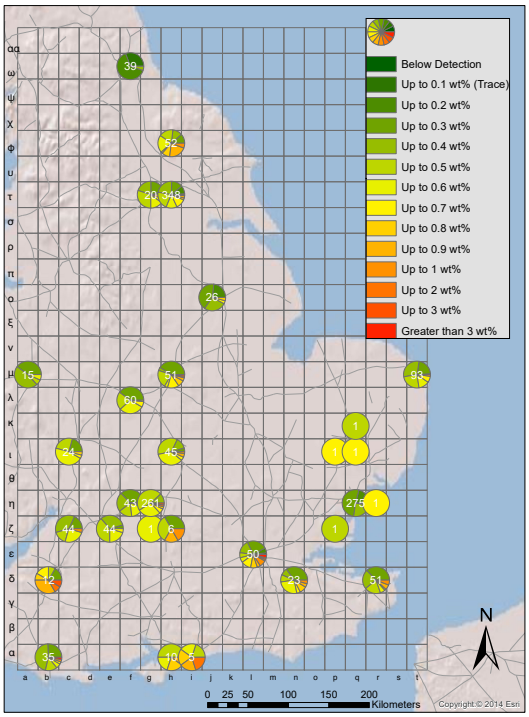

Figure 9.48: Map of Concentration of Iron in all First to Fourth Century Not Green Glasses in England

9.6 Iron Evidence

Iron is omnipresent in glass sands. However, it is key in differentiating glass production groups. As well as this, it can also be used as a glass colourant, particularly in the formation of green glass. Like copper and cobalt, the glass coloured by iron must be dealt separately. If you compare Roman glasses which are not green [Figure 9.48] to only the green glasses [Figure 9.49], it is apparent that almost all the high iron glasses are green. This same pattern is not seen in the Early Medieval period [Figure 9.50, 9.51]. To try and asses the range of iron and potential recycling and reuse of Roman glass in the Early Medieval period, the choice was made to only map colourless, natural and blue-green glass, so any confusion added by coloured glass is removed.

There are 18 first century glasses analysed, the iron levels of all of which are

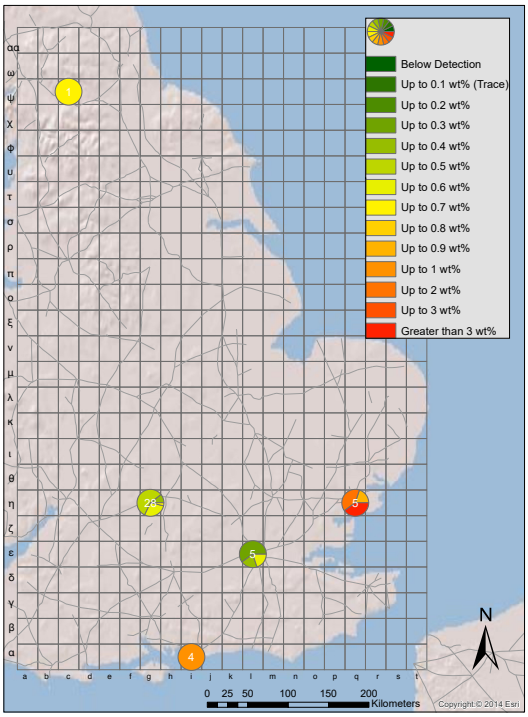

Figure 9.49: Map of Concentration of Iron in all First to Fourth Century Green Glasses in England

consistent with Levantine glasses, as would be expected [Figure 9.52].

Similarly, the second century is predominately Levantine, but also contains a great deal contain iron high enough to be consistent with HIT-style glasses [Figure 9.53]. This is too early for such glasses and they are only apparent at two sites, Lincoln (oj) and London (ϵl). It is more likely from the inclusion of green cullet, in these large centres. It is interesting to note that Colchester (ηq), as a large military site, doesn't contain any indication of such. Whether this is evidence of less recycling or lack of green inclusion is unknown.

The third century shows more of this higher iron glass, though in very different regions [Figure 9.54]. Much of the glass from sites in York (τh) seem to have very high iron, but also are more variable. Even more varied but with less individual high iron glasses, the urban site of Worcester (θd) is notably different. It seems that the glass here has all been recycled with higher iron tainting most of the glasses. There is also

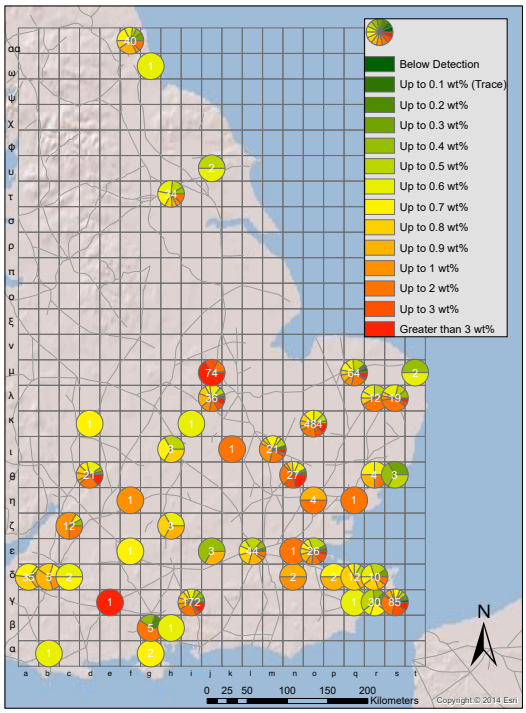

Figure 9.50: Map of Concentration of Iron in all Fifth to Seventh Century Not Green Glasses in England

a single strange colourless glass from Frere's excavations at Dorchester-on-Thames (ζh), which is incredibly high. What is interesting is that the higher amounts of iron are more consistent with HIT/HIMT glasses, but this is too early for such glass again.

In the fourth century, there is a not only a great influx of HIT/HIMT glasses, there is also a mixing of this glass with existing Roman glass [Figure 9.55]. The South of England, with the exception of Dorchester (αb), seems to hold most of this glass. The average iron content is much higher in many of these sites, with the exception of the villa at Frocester Court , the Uley Temple complex, and Shakenoak Villa (ζc and ηf). The other sites are mostly urban sites, which might have a high level of both import and glass mixing. What is interesting as well is that the only site in East Anglia seems to be relying very heavily on older-style Roman glass. This is predominately glass from the Late Roman fort at Caister-on-Sea (μt), which might be consistent with the suggestion of industrialised recycling at Roman military sites,

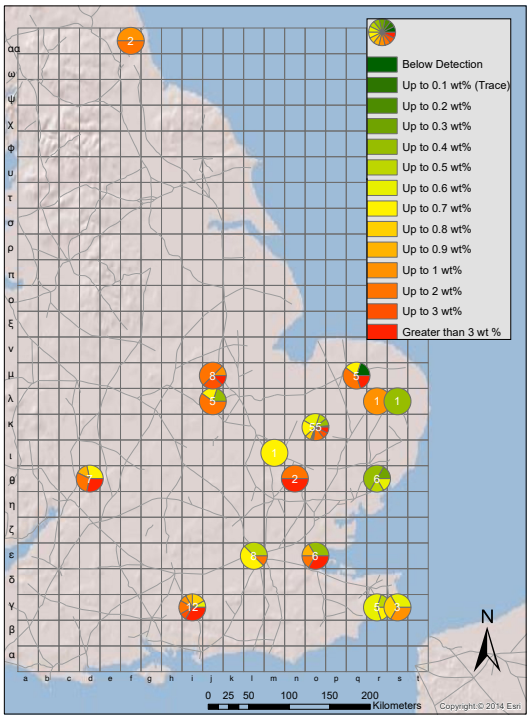

Figure 9.51: Map of Concentration of Iron in all Fifth to Seventh Century Green Glasses in England

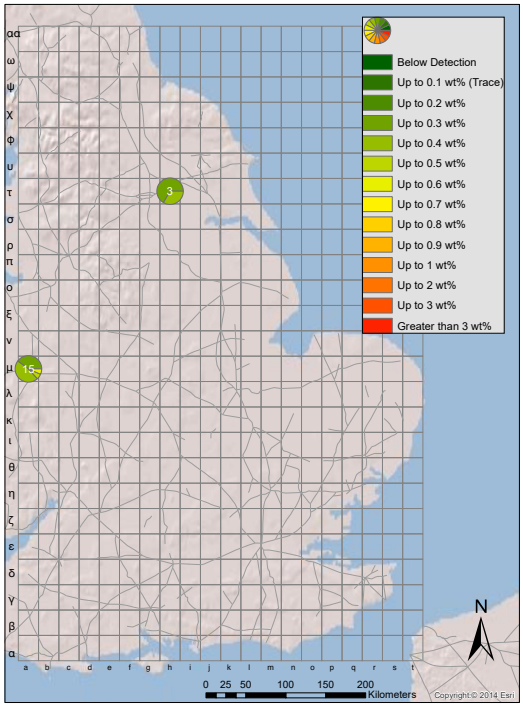

Figure 9.52: Map of Concentration of Iron in Glass in First Century in England

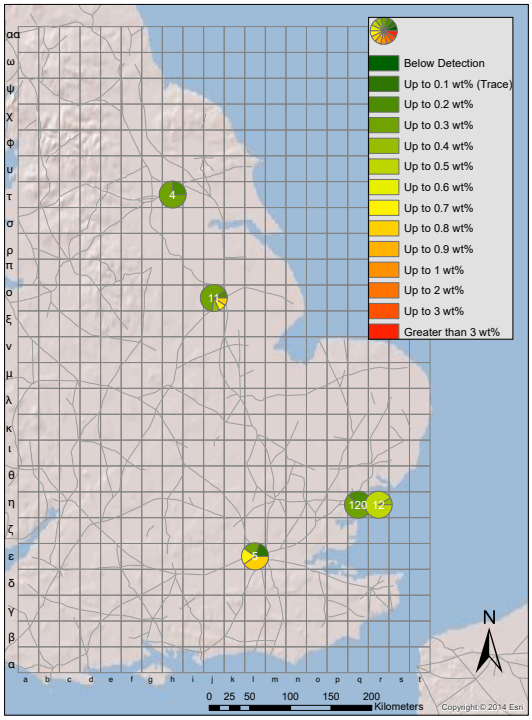

Figure 9.53: Map of Concentration of Iron in Glass in Second Century in England

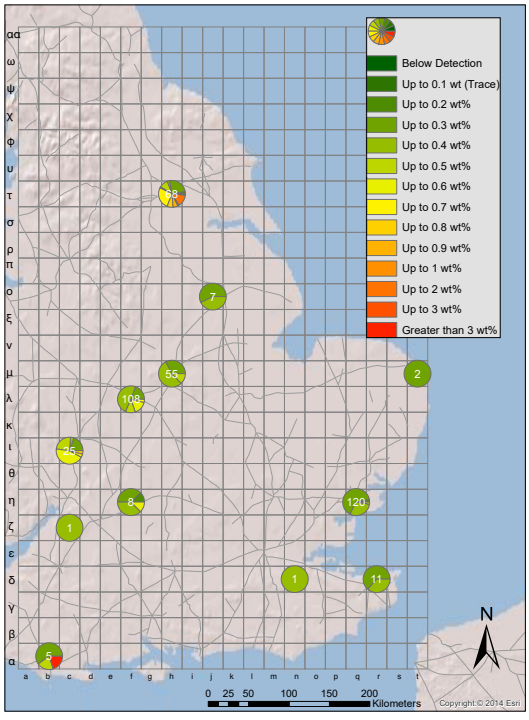

Figure 9.54: Map of Concentration of Iron in Glass in Third Century in England

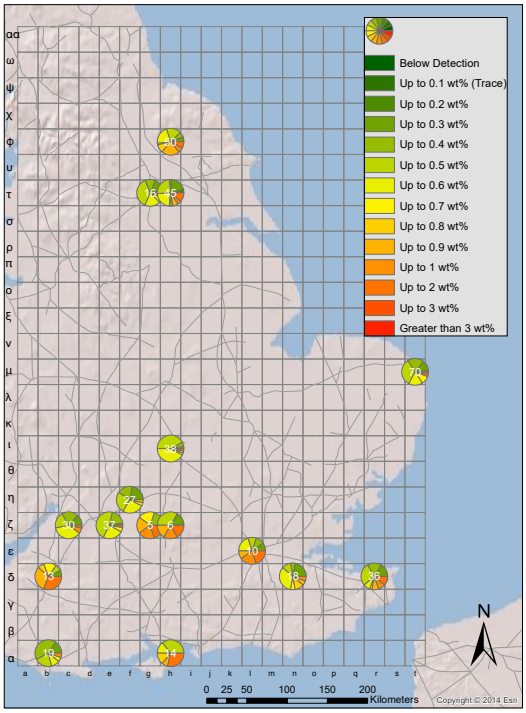

Figure 9.55: Map of Concentration of Iron in Glass in Fourth Century in England

discussed elsewhere.

As in the defining feature of the fifth century, there is comparatively little analyses [Figure 9.56]. However, glass seems to be consistently HIT/HIMT glass with a few strange exceptions - Uley (ζc), Caister-on-Sea(μt) and Canterbury (δr). The first two seem a continuation of what is seen in the fourth century and although not as obvious in the fourth century, Canterbury also seems to have a lower amount of mixing. This might be because this site is receiving fresher glass so doesn't need to recycle as frequently. Uley, on the other hand, has both low HIT/HIMT glass, but high amounts of copper. It seems that this glass is overly reliant on heavily recycled earlier Roman material.

In the sixth century, there are many sites with very mixed iron contents, but there is also a large amount of glass that is broadly more consistent with the earlier lower iron glass [Figure 9.57]. Lyminge (γr) has been discussed in more detail in the proceeding chapter, but contains an average which is slightly lower than the sites near

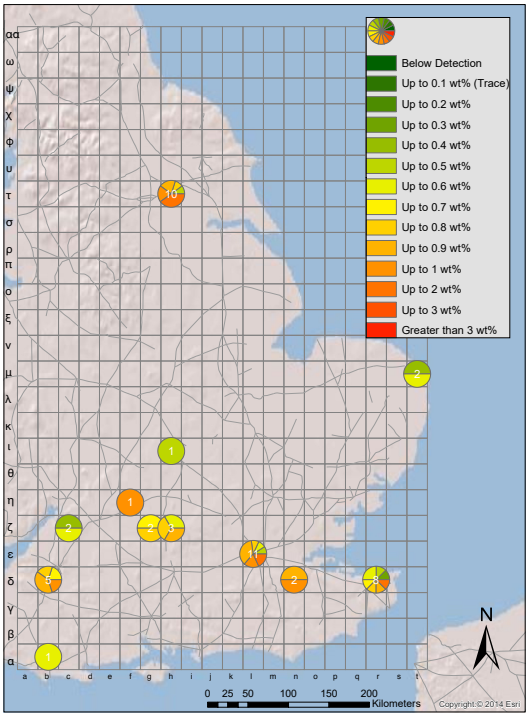

Figure 9.56: Map of Concentration of Iron in Glass in Fifth Century in England

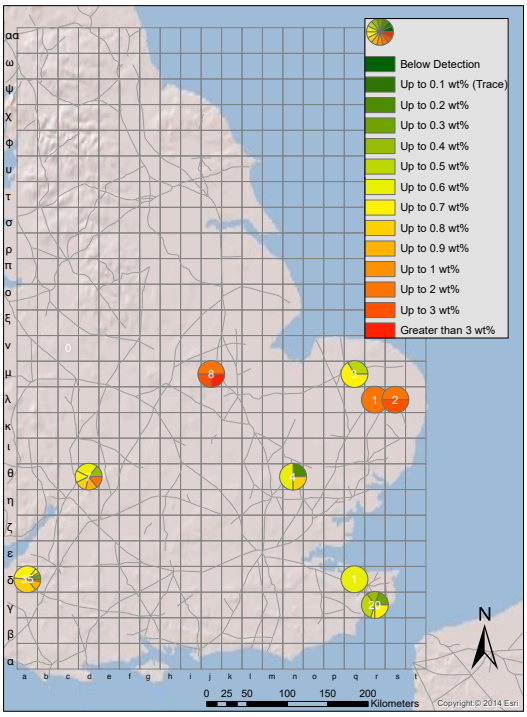

Figure 9.57: Map of Concentration of Iron in Glass in Sixth Century in England

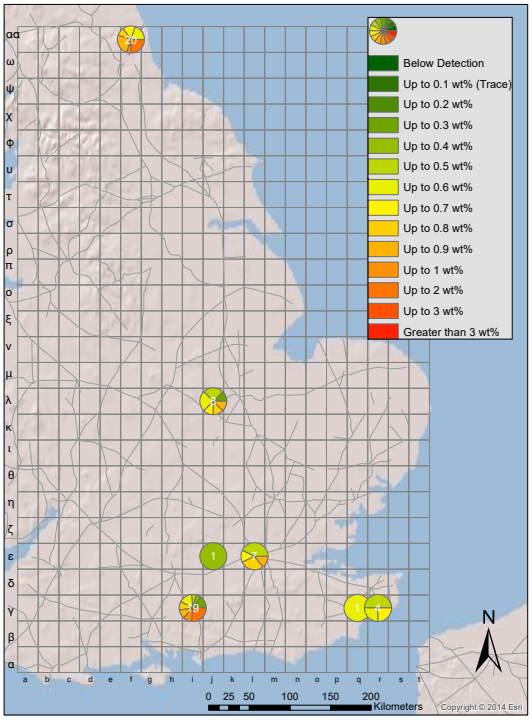

Figure 9.58: Map of Concentration of Iron in Glass in Seventh Century in England

the Severn. As well as this, there are 11 shards with very high iron, spread across many sites. What is interesting is that of the three cemeteries in Norfolk, Spong Hill, Bergh Apton and Morningthorpe (μq, λr, and λs) only two have this very high iron, whereas Spong Hill is much lower. This might be related to sample size.

By the seventh century, it seems that much of this higher iron glass has, like the antimony glass, either recycled to the point it isn't apparent, or replaced [Figure 9.58]. The averages are higher than in the Roman period, yet it still is much lower than many of the high iron raw glass sources. Only a small proportion of glasses seem consistent with Anglo-Saxon glass and none of this glass is apparent in Kent.

The first and second centuries show very little evidence for or against recycling, however there are some interesting glasses in London and Lincoln. Third century begins to highlight sites with more recycling, particularly York and Worcester, but interesting Colchester remains without. Moving into the fourth century, there is a clear mixing of HIT/HIMT glasses, recycled into the pre-existing earlier glass. Again,

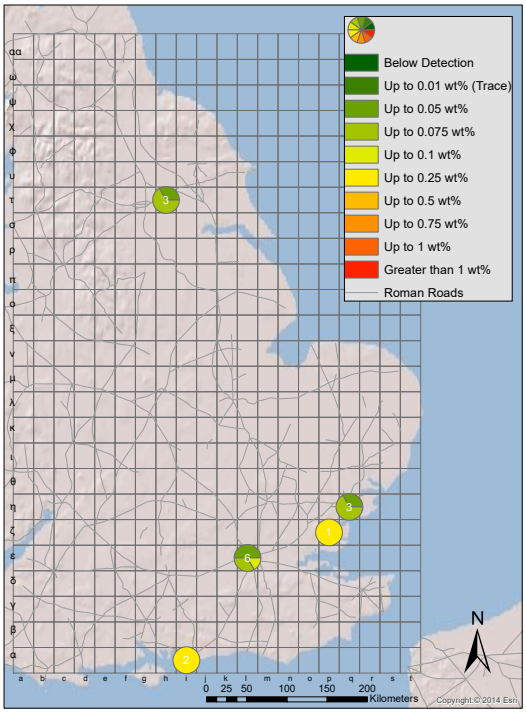

Figure 9.59: Map of Concentration of Titanium in Glass in First Century in England

a fort, Caister-on-Sea, stands out. This site continues to be unique in the fifth century, where a greater amount of mixing is occurring. The sixth century still shows first to third century Roman glass. The seventh century also does so, but also with a clear evidence of a departure from earlier periods.

9.7 Titanium Evidence

Titanium in glass is usually linked to the introduction of HIT or HIMT glasses. As such, it can show how these glasses are introduced and mixed with existing glass. It is also a trace in some colourants.

When looking at the first century, there are three analyses that are notably high, and these are all enamels [Figure 9.59]. The other glasses have the low titanium of Levantine glass.

In the second century, there are still several high Ti glasses [Figure 9.60]. However,

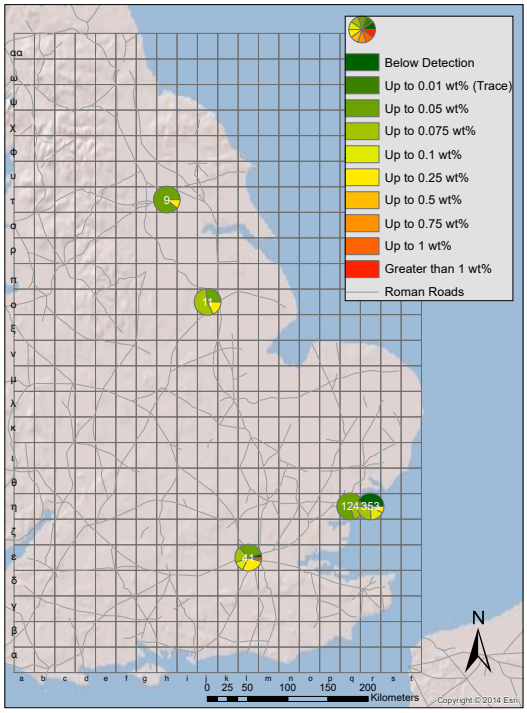

Figure 9.60: Map of Concentration of Titanium in Glass in Second Century in England

these are not enamels, these are predominately blue-green, natural and colourless vessels, though London (ϵl) also has black glass jewellery that is very high in titanium. There is less explanation as to why. However, similarly to enamels, West Clacton (ηr) shines out as bizarre, with both very low and very high titanium. This is because they are tesserae.

In the third century, before HIT/HIMT glass is introduced in Britain [Figure 9.61], there are however, a few strange glasses. A black glass in Colchester (ηq), a colourless cup from Shakenoak Villa (ηf), and a notable number of blue-green vessel glasses in York (τh). It is worth noticing that the average of titanium in this century is notably lower than the second century, 0.05 wt% as opposed to 0.08 wt%. However, there is very little very low titanium glass left in the third century.

The fourth century marks the introduction of HIT/HIMT glass [Figure 9.62]. There is a notable rise in titanium, averaging 0.09 wt%. There is a clear match

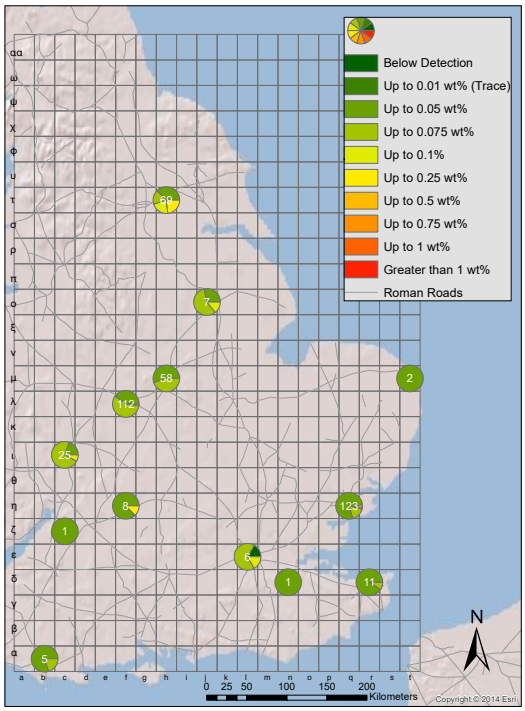

Figure 9.61: Map of Concentration of Titanium in Glass in Third Century in England

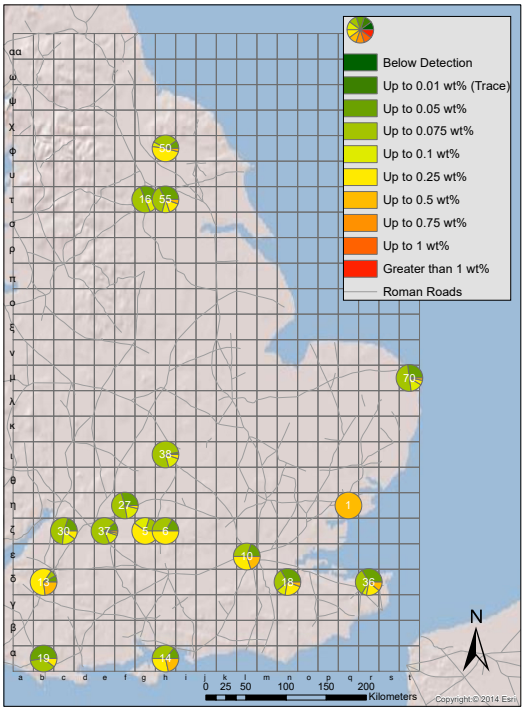

Figure 9.62: Map of Concentration of Titanium in Glass in Fourth Century in England

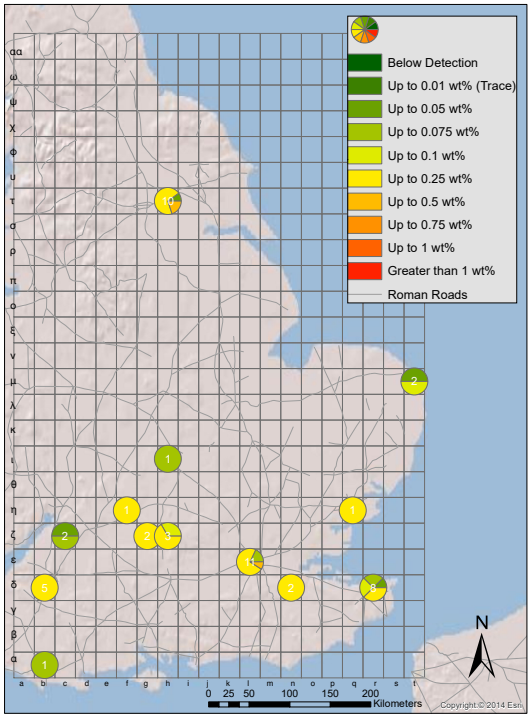

Figure 9.63: Map of Concentration of Titanium in Glass in Fifth Century in England

between this and the results seen for iron. The areas of Uley (ζc), Frocester Court (ζc), Shakenoak Villa(ηf), as well as Caister-on-Sea (μt) and Dorchester (αb), all also have this earlier composition of iron. Titanium analyses has also added sites near the first grouping, including Asthall, Barnsley Park Villa (ζe) and Towcester (ιh). York and the villa at Dalton Parlours (τg) are also have less high titanium glass, though the nearby villa at Beadlam (ϕh) has a great amount of titanium.

The fifth century does not have any of the very high HIT/HIMT glasses except a single glass in London and York [Figure 9.63]. However, the majority is still HIT or HIMT glass. The average of titanium is much higher, 0.15 wt%, compared to the previous century. A few places still have notably low glass as well, including Kentish cemetries, Dorchester, Uley, Towcester and Caister-on-Sea. In terms of colour and typology, there is no pattern between the low and high glasses, location seems to be the main determining factor.

The sixth century again seems to show an influx of lower titanium glass [Figure

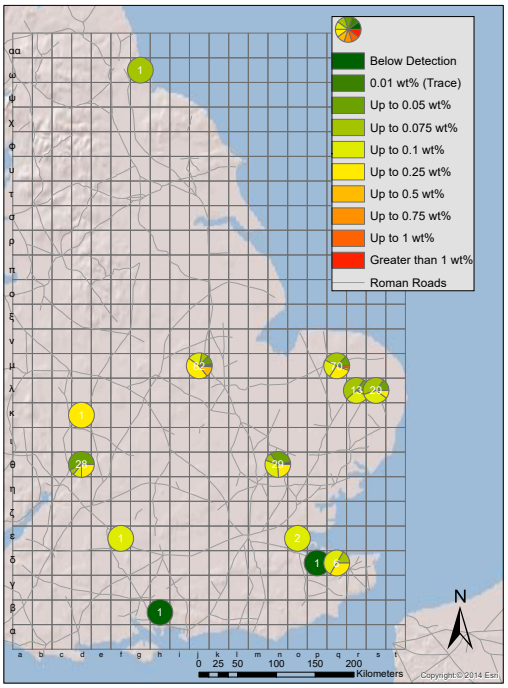

Figure 9.64: Map of Concentration of Titanium in Glass in Sixth Century in England

9.64]. This is consistent with previous findings of Anglo-Saxon glass, though it is interesting as in other elements Anglo-Saxon glass doesn't seem apparent. This glass doesn't seem to be reaching central England.

The seventh century again continues this decrease, except for some of the Alton (γi) beads, and the windows and vessels of Jarrow ($\alpha\alpha$f) [Figure 9.65]. These retain some much higher titanium. Even with these included, the average value of titanium is 0.04 wt%, as apposed to the previous century, 0.11 wt%. Along Kent and down the Thames Estuary shows a change.

The first century has low titanium, consistent with Levantine glass. This would be expected in the second century too, but the cities of Roman Britain are different. York continues like this into the third century, with strangely elevated titanium. The four century is once again defined by the influx of HIT/HIMT glasses, though this glass is not available everywhere. Titanium increases into the fifth century, whereas in the sixth century there seems to be an increase of a low titanium glass. The seventh

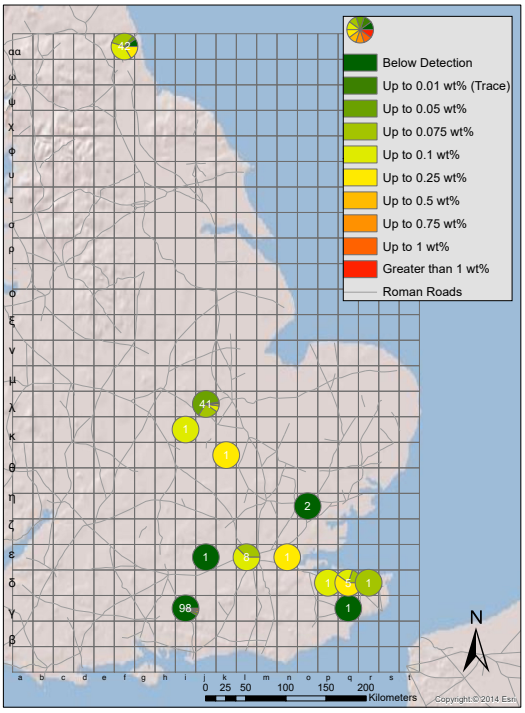

Figure 9.65: Map of Concentration of Titanium in Glass in Seventh Century in England

century is an increase of lower titanium glass, except from the sites for Jarrow, London and Lyminge (X, ϵl and γr).

9.8 Manganese Evidence

As titanium and iron, Manganese is usually linked to HIMT glasses. While it also acts as a purple or black colourant, there are few such glass in England. It predominately functions as a decolorant, but is present in sand. Manganese is usually around 0.55 wt% in blue-green glass, and much higher in HIMT glass. It is potentially added as a separate decolorant in such glasses.

The majority of the glass from the first century has low manganese, consistent with Levantine glasses [Figure 9.66]. There are, however, some notable examples at sites in London (ϵl) and Wroxeter which have greater than 0.6 wt%. In London, these are

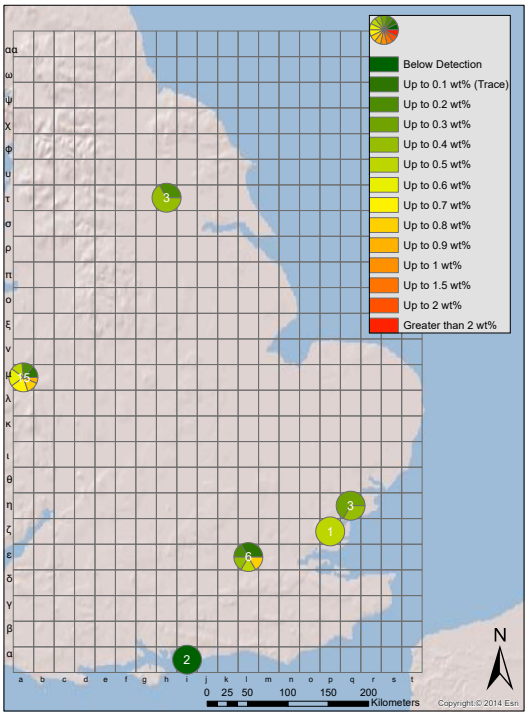

Figure 9.66: Map of Concentration of Manganese in Glass in First Century in England

3 blue cobalt glasses. Manganese is known to enhance the colour produced by cobalt so this might be a matter of deliberate choice. It is also a common trace in cobalt ores. Strangely, the Wroxeter glass is a mix of vessel cullet glass and manufacturing evidence, which contains this very high manganese. These are all naturally coloured which makes the high manganese more unusual.

In the second century, all glass with very high Mn is in enamels and tesserae [Figure 9.67]. The blue glasses again are among the highest in manganese, which is very likely related to the fact that it is commonly found in cobalt ores. However, London also has some high manganese glasses, which are manufacturing evidence, with no recorded colour. Finally York (τh) has a range of high manganese glass, the highest of which is yellow glass. The others, however, are blue-green, which only makes sense in context of mixing of this period.

In the third century, glass from Mancetter (λf), York and Dorchester (αb), as well

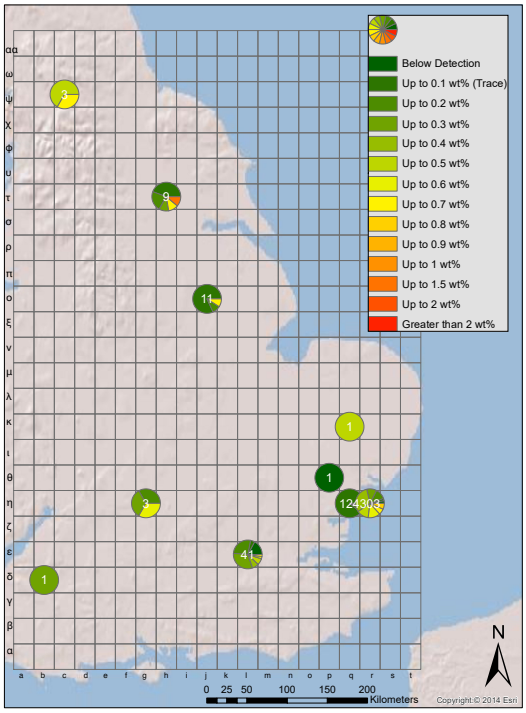

Figure 9.67: Map of Concentration of Manganese in Glass in Second Century in England

as a very small number of glasses from Worcester, all show higher manganese [Figure 9.68]. This is not seen anywhere else in England. These Western sites high have a stronger reliance on recycling in this century.

In the fourth century, there is an explosion of HIMT glasses [Figure 9.69]. The highest proportion of these glasses are seen near the Severn. Notable areas along the south coast, Kent and East Anglia all have considerably lower manganese, more consistent with the century previous. Beadlam villa (ϕh) again shows high HIMT glass than other Yorkshire sites, and Barton Court Farm (ζg) shows very high amount of manganese glass, but seemingly mixed with an earlier glass.

As seen for titanium, there was a significant rise in total manganese in the fifth century. There is an increase from an average of 0.74 wt% to 1.02 wt% [Figure 9.70]. The glasses from Uley (ζc) and in East Anglia again maintain an earlier signal, as seen in other HIT/HIMT indicators, as Kent, London and York.

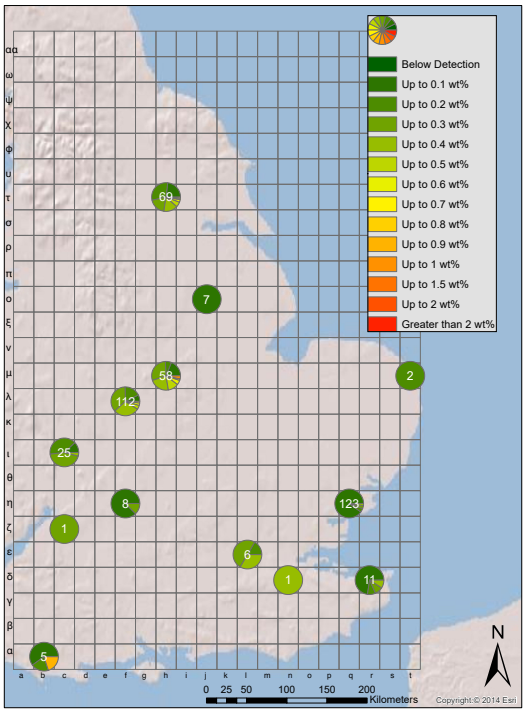

Figure 9.68: Map of Concentration of Manganese in Glass in Third Century in England

The sixth century is a departure back to a high proportion of recycled glass, though once again this could be related to typology [Figure 9.71]. The vast majority of assemblages are beads. The beads at Beckford (θd), as well as in East Anglia, all show a lower mangnesium, earlier Roman composition, mixed with HIMT glass. Unlike evidence from other elements, there isn't an appreciable difference between East Anglia and central English bead assemblages from cemeteries. The vessel glass from Cadbury Hill Congressbury is the south west has a varied but significantly higher amount of manganese. The other vessel glass spread across England are no where near as high, consistent with HIMT and Anglo-Saxon Period I and II, except for Lyminge (γr). Again, a great deal of earlier Roman glass is apparent here.

As with other elements, manganese in the seventh century indicates a flash of cleaner glass [Figure 9.72]. While high manganese remains in a few glasses, there is a much lower average. Jarrow ($\alpha\alpha$f) still shows some element of recycled HIMT glass,

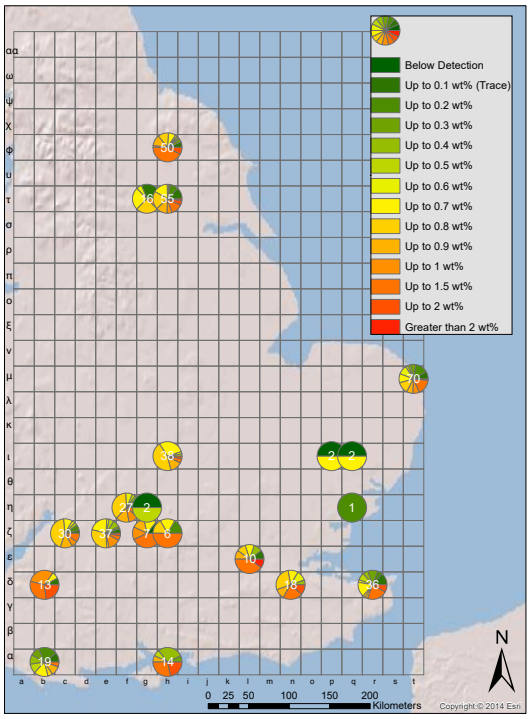

Figure 9.69: Map of Concentration of Manganese in Glass in Fourth Century in England

but it is far less obvious than when considering titanium. The other large collections of glass that show more mixed values of Mn are bead assemblages from Alton (γi) and Wakerley (λj).

The patterns seen in manganese are perhaps less marked than other elements, and more well understood. In the first two centuries, London shows elements of recycling. The fourth and third century also shows a high, mixed manganese in York, as well as Mancetter and Dorchester. There is a very marked change in the fourth century with the addition of HIMT glass, but East Anglia and the Southern coast shows a strange composition. While these are areas often associated with European trade, they are without this HIMT glass influx. The sixth century again has a strange composition on East Anglia, however the seventh century this changed, with what seems to be an influx of low manganese glass.

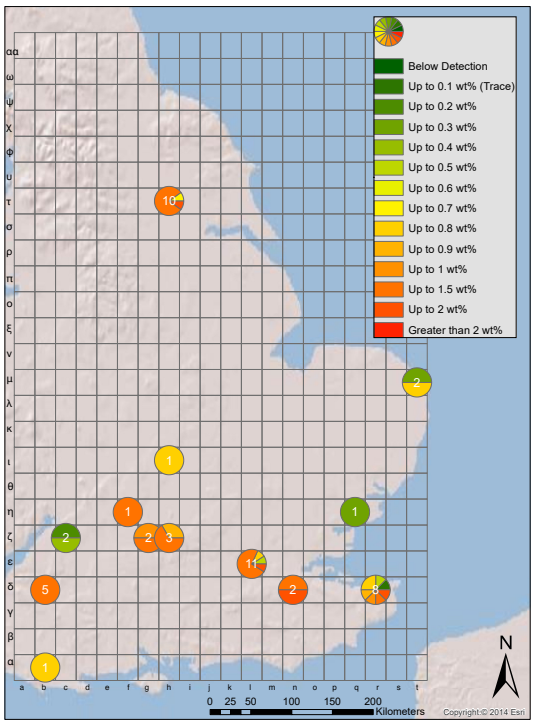

Figure 9.70: Map of Concentration of Manganese in Glass in Fifth Century in England

9.9 Aluminium and Calcium

It is difficult to draw much out of the the Al versus Ca plot, which is traditionally used to differentiate glass sands, particularly considering all centuries together [Figure 9.73]. Almost all glasses in the database have been analysed for these elements, yet the resolution of this data is not always fantastic, as indicated by the frequency of glasses at, for instance, Al2O3 2wt% and CaO 4 wt%. Due to the number of glasses, they will be considered in two sections.

When considering the first three centuries, there is some potential [Figure 9.74]. There are insufficient first century glass, but the vast majority of second century glasses plot very close together, with a few higher aluminium glasses. This doesn't seem a clear match for any glass group. The third century seems spread between the two extremes, as well as some higher calcium glasses. It seems heavily mixed between

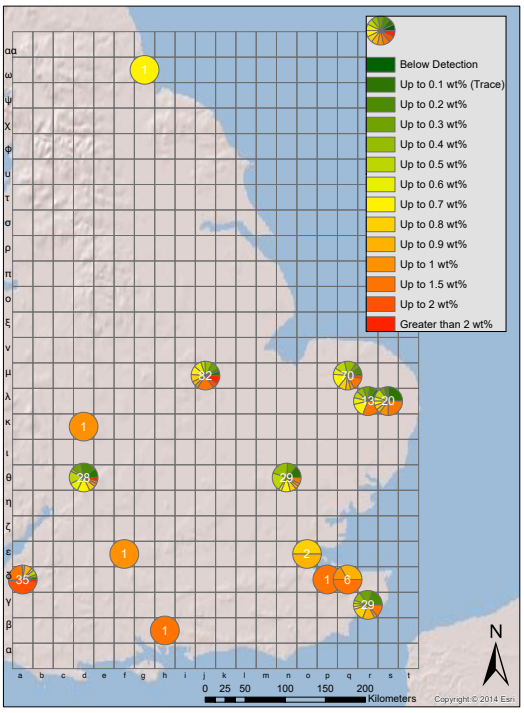

Figure 9.71: Map of Concentration of Manganese in Glass in Sixth Century in England

the existing second century glass and something new.

The fifth to seventh century glasses centres on this area of the second century glasses [Figure 9.75]. However, it also pulls up towards the values seen for third and fourth century Levantine glass. Once again, this seems to indicate the same pattern of perpetual recycling with additions continuing through the Early Medieval period.

9.10 Alkalis and Volatiles

The change in alkalis and volatiles over time have been suggested as a measure of recycling by multiple authors. Due to the complexities of multiple indicators, the lack of English based study, and the problem of resolution, these are considered without geographic information, only chronological.

First considering sodium and potassium, the general assumption for Roman glass

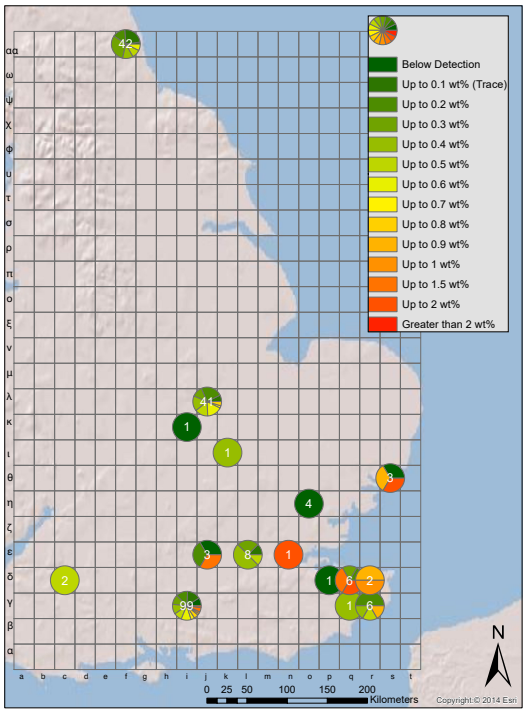

Figure 9.72: Map of Concentration of Manganese in Glass in Seventh Century in England

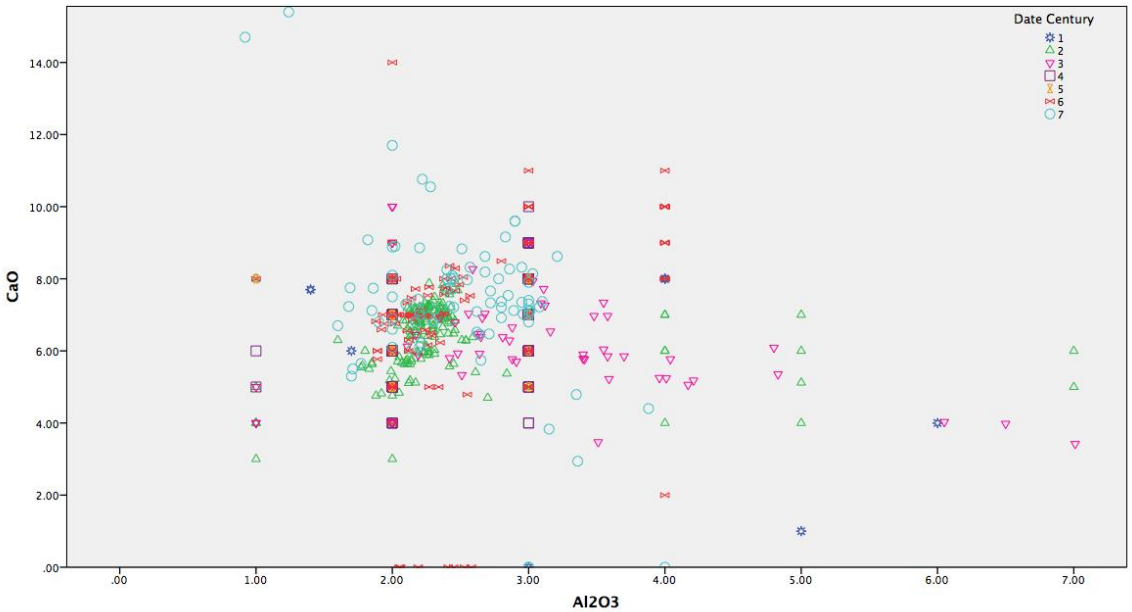

Figure 9.73: Aluminium versus calcium in British glass from the first to eigth centuries.

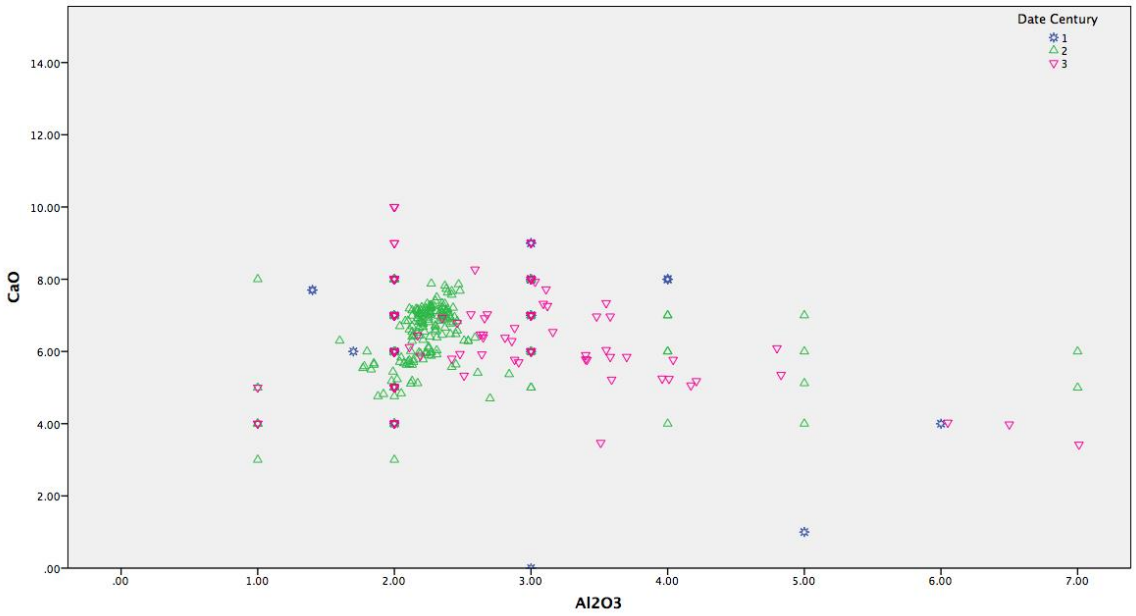

Figure 9.74: Aluminium versus calcium in British glass from the first to third centuries.

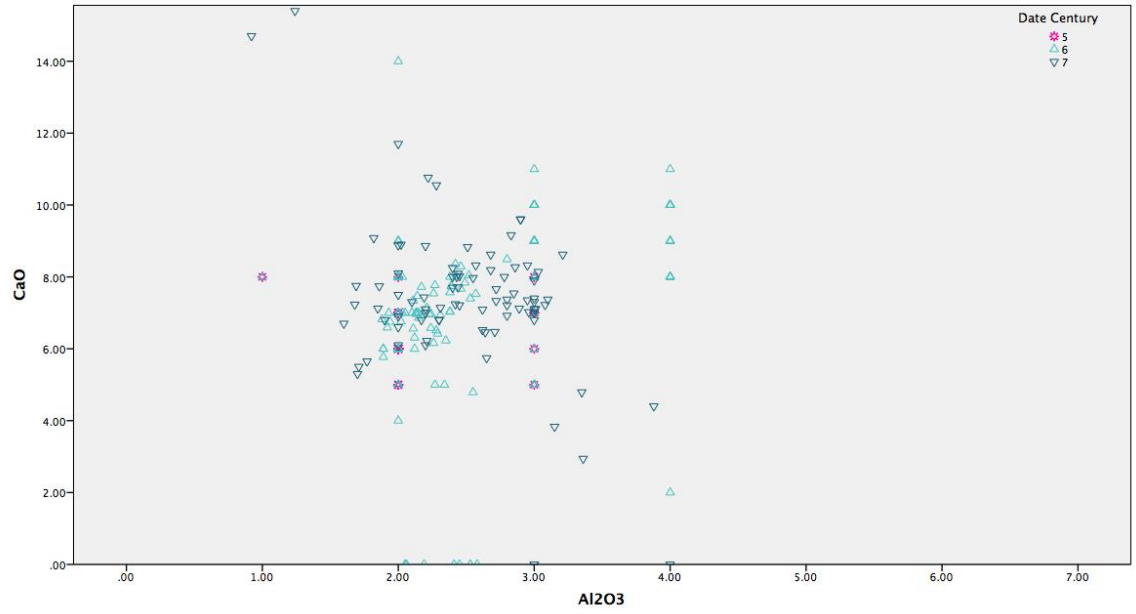

Figure 9.75: Aluminium versus calcium in British glass from the fifth to seventh centuries.

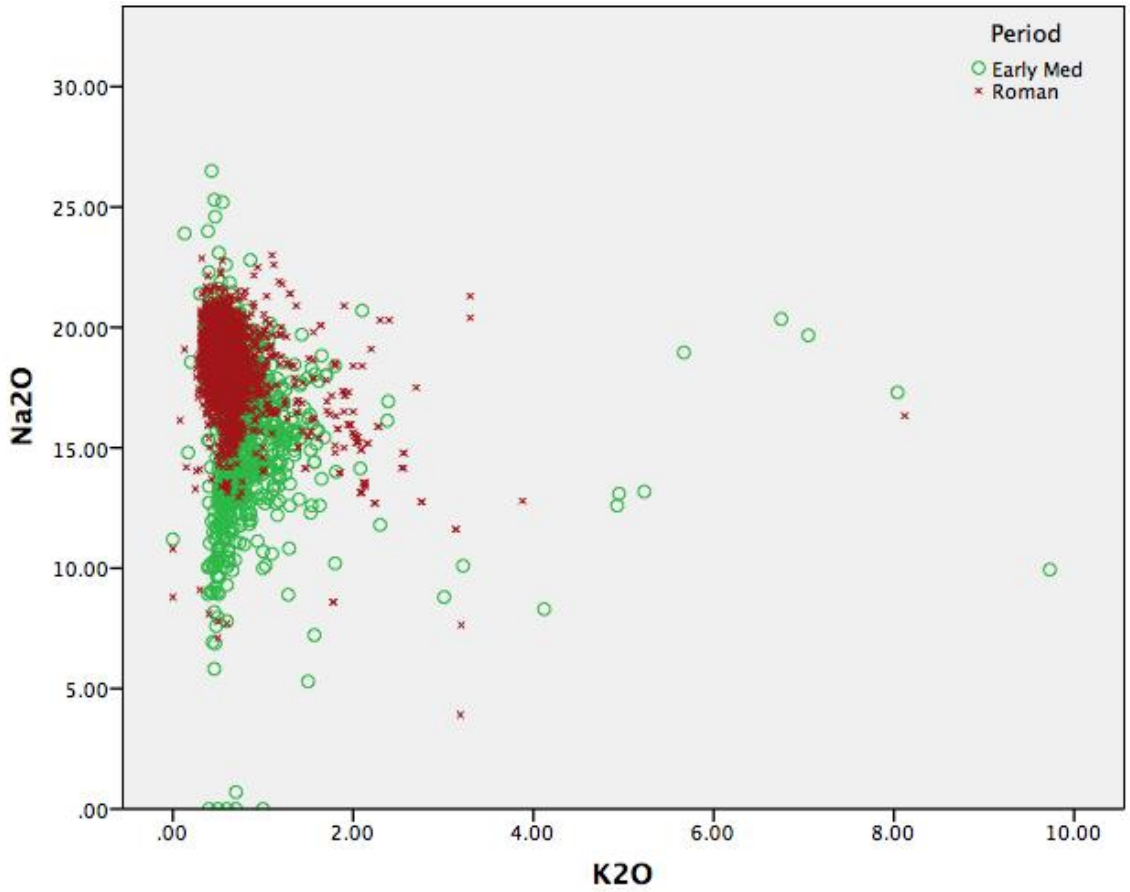

Figure 9.76: Concentration of Sodium Oxide versus Potassium Oxide in Glass in England, Differentiated by Period.

is that increased recycling will see a decrease in sodium. When glass is kept in a molten state, the sodium continues to react and burn off, making the glass increasingly viscous and difficult to work. Potassium has been observed to rise with successive remelting, either from ash from the furnace, or from the deliberate addition of wood ash to try and counteract this viscosity (Paynter and Jackson 2016, p. 6-7). When comparing Roman to Early Medieval glass, the decrease in sodium is particularly apparent, indicating a great deal of recycling [Figure 9.76].

The total amount of sodium is decreasing, but the spread of values notably increases. Many elements seem to show that what is occurring in England is periodic influxes of new glass, diluting a communal mass of glass. This patterning is a little more obvious when looking at glass which is dated to a single century [Figure 9.77].

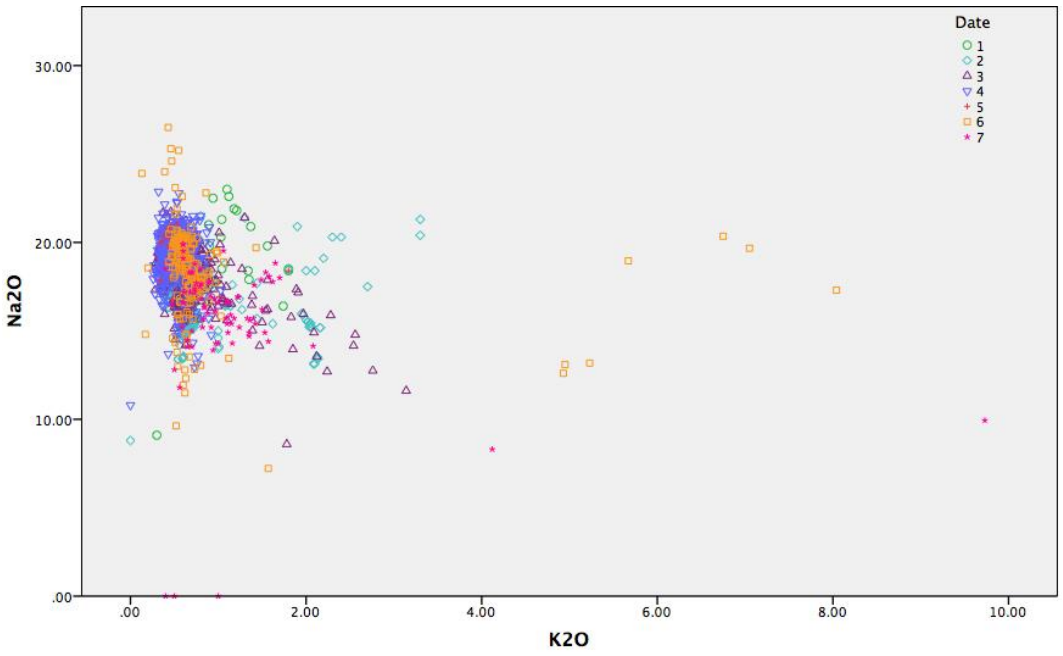

Figure 9.77: Concentration of Sodium Oxide versus Potassium Oxide in Glass in England, Differentiated by Century.

Looking first at only the glass from the Roman period, the fourth century is a far tighter group than any other century [Figure 9.78]. The first century shows consistently high sodium, but also high potassium. This is unique to England, but has been observed at Colchester (ηq), which is one of the largest collection of analyses in this period. The assumption is that this is partially plant ash glass. The difference of this glass to the third century glass is that they have, with a high amount of potassium, also a lower amount of sodium, which supports the idea that the elevated potassium seen here is an element of recycling.

What is particularly striking is that the fourth century, characterised in Britain by the influx of HIMT/HIT glasses, is very clear here. This glass, floods in, and seems to remain very clear in this fourth century. However, the fifth century glass, the small amount which is securely dates, mix of this glass and the existing Roman glass [Figure 9.79]. The sixth century glass, however, is notably different. it covers a much larger range of sodium, and while some glass contains the high potassium

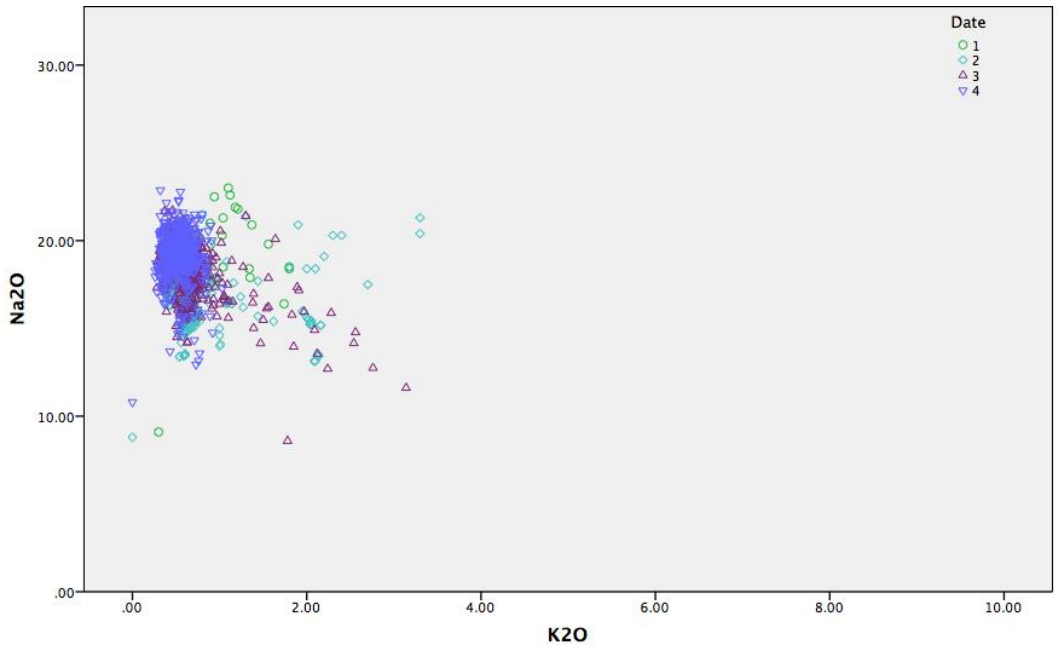

Figure 9.78: Concentration of Sodium Oxide versus Potassium Oxide in Glass in England, in First, Second, Third and Fourth Centuries.

trace of the addition of plant ash, it isn't the dominant glass. The seventh century, however, is consistent with this sixth century glass, with the addition of further plant ash. This acceleration of potassium in this period has also been shown in Freestone et al. 2008a.

The other consideration of volatile loss is the loss of chlorine and phosphorus in continually molten glass. Again, the range of glasses that have been analysed for both of these two elements is not sufficient for a detailed analysis. However, there is a clear difference between these two periods [Figure 9.80]. This is clearly further support of this continuous cycle of recycling.

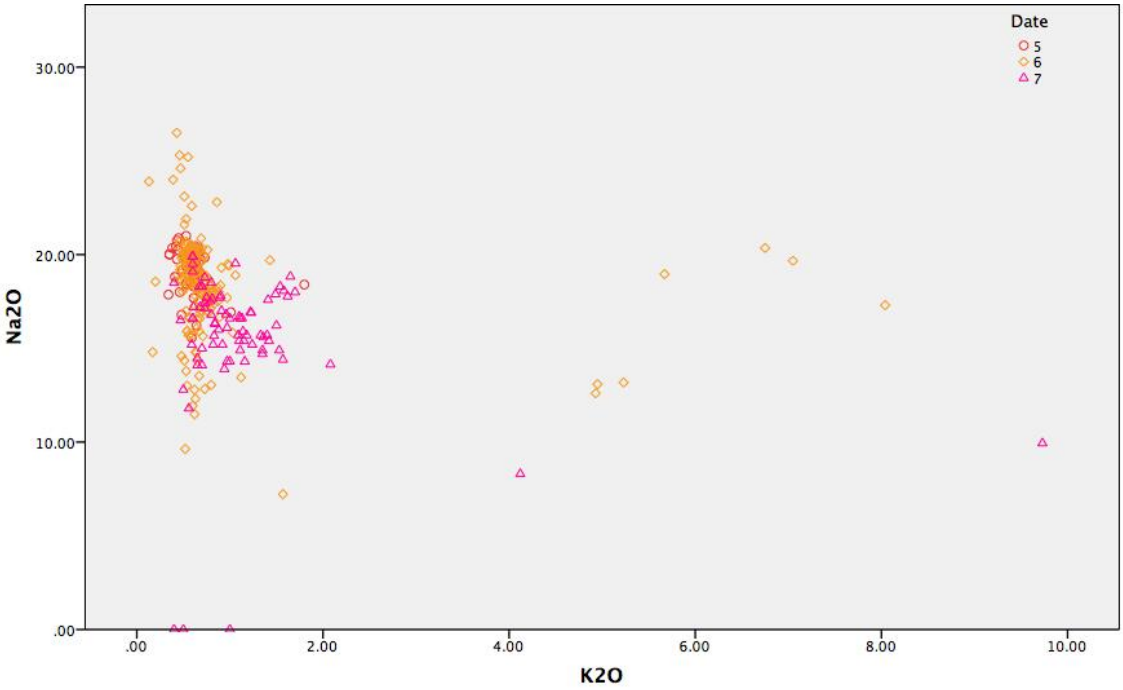

Figure 9.79: Concentration of Sodium Oxide versus Potassium Oxide in Glass in England, in Fifth, Sixth and Seventh Centuries.

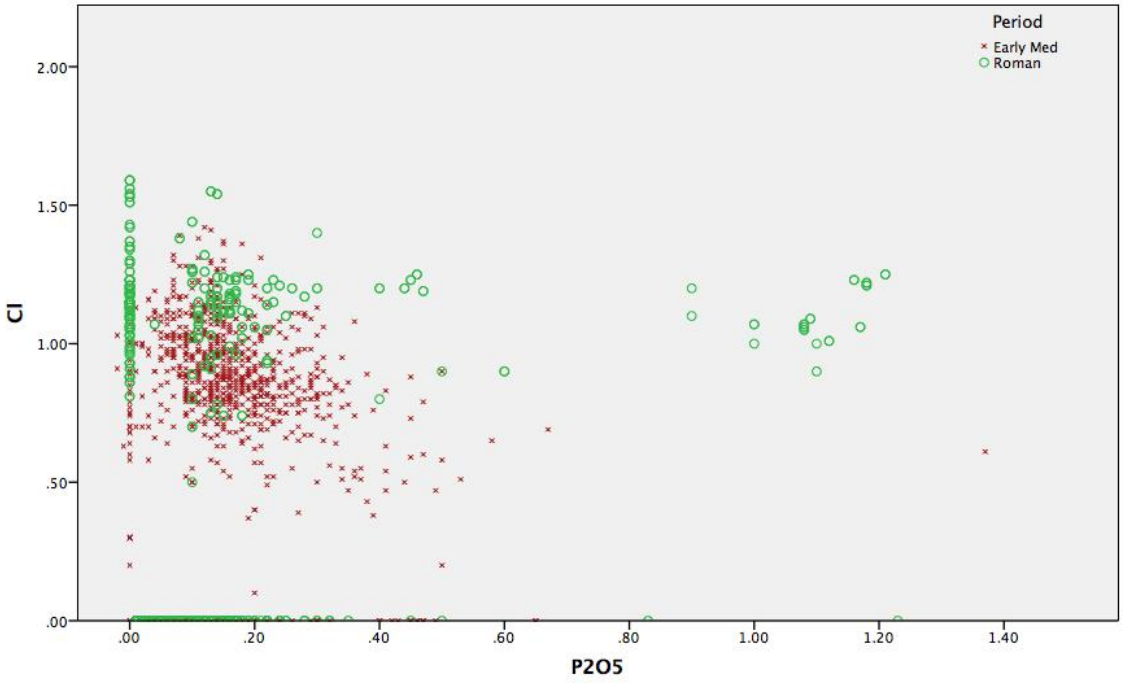

Figure 9.80: Concentration of Chlorine versus Phosphorus pentoxide in Glass in England, Differentiated by Period.

9.11 Summary of Evidence by century

9.11.1 First Century

Glass in the first century is less prevalent that the later centuries, and an even smaller proportion of it is analysed. Chemistry of first century glass is known from Fishbourne, York, London and Wroxeter, and there are clear differences between these glasses. The glass at the villa of Fishbourne is a colourless and coloured, high quality glass, with no evidence of recycling. York, at the other geographic extent, has variable amounts of elements relating to recycling, ie. copper and antimony. Interestingly, in terms of antimony, London has a higher proportion of 'clean' glasses to York. It seems these few glasses are less recycled.

While the very clean glass at Fishbourne might relate to the status of the site, the York and London glasses are from comparable settings, and thus likely implies that the North, or perhaps more military sites, are more reliant on recycling. Unfortunately the small number of both analyses and sites mean that all we can say so far is that they are different sites with different material. Due to the organisation of the Roman glass industry, this in itself is interesting.

The glass from Wroxeter has not been analysed for most of the elements used in the discussions here. However the Wroxeter glass has elevated compositions for manganese, and it also is high in potassium, with an average of 1.15 wt%. It is very possible that these belong to the very unusual group of Roman plant ash glasses, or glass made with a combination of plant ash and natron. As this material indicated production evidence, such results might even suggest a limited production of glass that is an intermediary between Iron Age and Roman glass. However, the sample size is such that any conclusions drawn are limited. The disjointed nature of the first century material that has been analysed reduces the ability to draw robust conclusions. However, this raises a possible future avenue of study.

9.11.2 Second Century

By the second century, a greater number of glasses appear in Britain, and a greater number have been analysed. This is the first century in which geographical patterning can be seen. First looking at the southern sites, London shows much evidence of recycling, with elevated copper, some of the highest in this century. It is also variable in antimony and glasses containing high cobalt and iron. While there is a variety of glasses analysed across the South, a great many of the samples are tesserae and enamels. The glasses in the South West, high in tin and lead, are mostly opaque but contain no antimony. It seems these two are forming the opacification.

The two East Anglian sites, West Clacton and Colchester, are different in composition and typology. Colchester glass, the majority of which was specifically chosen for analysis due to its very colourless appearance, does not show most elements of recycling. It is without high copper or iron, however, the antimony is higher than most other places and the glasses are a little higher in lead and much higher in cobalt. While the first set of evidence argues against recycling, the presence of cobalt implies something very different - that this high quality antimony decoloured material was carefully curated and recycled separately. That is, the very colourless glass was carefully recycled together to preserve its character, but a small amount of cobalt containing material, potentially decorative elements, entered the mix.

West Clacton, which is dominated by tesserae, instead shows very recycled material. This material is very mixed, containing high lead, unexpected titanium results, and variable antimony. West Clacton Villa lies less than half a days walk from Colchester, yet the recycling practices seem very different. However, as West Clacton is tesserae and Colchester vessel glass, this might not be surprising. This seems to indicate considered choice in recycling practices, relative to site and desired outcome. Tesserae glass, heavily coloured, can be recycled on mass, whereas if colourless glass is required, choices must be made.

Moving north, to Lincoln and York, these two sites are very different. York, like the proceeding century, has many patterns of elements that imply recycling. The glasses contain high and variable copper and manganese, though very little evidence of antimony. The glass in Lincoln, however, only shows a slight elevation in iron. It seems that the cities of London and York show much greater evidence of recycling and in a more chaotic approach than other settlements. The military site of Colchester shows some evidence of recycling, but much more closely curated than seen at the other large sites. This could be evidence of military controlled recycling, or biased by the glass typology chosen for analysis. It is clear in the second century, recycling patterns were diverse.

9.11.3 Third Century

In the third century, the evidence of long term endless cycling begins to be apparent. This is indicated by the fact that most elements related to recycling are higher than the centuries previously. To explain this, take the example of an antimony decoloured vessel, decorated with cobalt blue trails. If this is remelted, formed again as a decoloured vessel, it will contain cobalt from these trails. It this is again decorated with trails, and recycled again, there is twice as much cobalt in the resultant glass. Even on mass, such behaviours, continued for centuries, created observable traces.

Staring in the south, there are three sites, the western Dorchester and the eastern Lullingstone Villa and Canterbury. The site of Lullingstone villa is slightly higher in copper, and all glasses from these three sites have low but measurable cobalt. The coastal sites are otherwise broadly similar, though there is a notable glass in Dorchester that is high in Mn and Fe. It is difficult to ascertain how this vessel was dated and it might be an early example of HIMT. The next century shows that this southern coast is the entry point for such material. However, in the next century this material is far more common on eastern sites. It seems that southern sites are broadly

similar in glass sources. The presence of copper in Lullingstone only is interesting as one might expect cleaner glass at a villa site.

There is a single glass from London, which is black glass and high in practically every element, implying that it is very much a mixed batch. The solitary nature of this glass makes it unhelpful. Moving into East Anglia, the many analyses at Colchester are still low in copper, but elevated in cobalt. Now, however, a quarter have higher lead, and a smaller amount have high titanium. Again, it seems that a very specific approach to recycling is occurring at the site.

In Oxfordshire, the glasses are unremarkable, except that they are lower in lead than other glasses of the century. Above the Jurassic Ridge, however, there seems to be a lot more copper. Mancetter and Leicester both have high copper, but low antimony. Over three quarters of the glasses here are also high in iron and manganese. There is close relationship between these glasses, but Mancetter seems to have higher values of elements indicating recycling. Worcester is very similar, though not as closely related in base composition. Mancetter and Leicester are forts, where as Worcester is an urban settlement, so this might indicate two different flows of material, one domestic and one military.

Moving further north, Lincoln has high cobalt, though not as high as Mancetter and Leicester, and lower lead. It seems that these more central sites are more reliant on recycled material, which are then being recycled separately.

In this century, York remains a very mixed site. There is a great deal of copper, though the amount in each glass is variable, and the same is true for cobalt. For antimony, while amounts are still variable, it is much lower in all colours than the previous century. Lead, iron and titanium are also all high and variable. It is unfortunate that there is a lack of comparable material from London, but it seems heavy and indiscriminate recycling is occurring in these large urban centres in the third century.

9.11.4 Fourth Century

The fourth century glass, as so much in this century in Britain, is characterised by variability and change. This is the period at which HIT/HIMT glass is introduced, but the rate and proportion of introduction across the country is variable. While it is much more apparent in the south, with high iron and titanium clearly common. It does seem less present at Uley and Shakenoak, and invisible at Dorchester, implying that it is coming in from the East. Looking at analyses with just titanium, the sites of Asthall and Barnely Park Villa near Shakenoak also seem to be short of HIT/HIMT glass.

Most northern sites have very few glasses with notable titanium, with the exception of the villa at Beadlam. Beadlam villa has greater amounts of titanium, unlike glasses from nearby York or the villa at Dalton Parlours. What is interesting is that this divergence is not seen in all other elements. In fact, the villa at Beadlam and York are both otherwise similar, and notably different from Dalton Parlours. Both are higher in copper and cobalt, but low in antimony. Dalton Parlours has high antimony in colourless glass, but only slightly, and all glasses have higher lead. While the intramural sites in York are consistently the highest in copper and other traces related to recycling, the differences between the much closer villa of Dalton Parlours and Beadlam are interesting. Aside from the appearance of HIT glass at Beadlam, it would seem consistent with York, but Dalton Parlours seems wildly different. This will be interrogated further in the discussion.

As well as the introduction of this new glass type, there are also some other uniform changes across Britain. There is a significant increase in cobalt in non-blue glasses, but this is higher in the south. As discussed under cobalt (Chapter 9.3), this might not be related to more intensive recycling in the south but rather that cobalt was more commonly used as a colourant here. The general increase, however, implies a long term cyclical recycling, with ever more traces of cobalt glass being incorporated

within this material.

There is a significant group of sites in Oxfordshire, Gloucester and Wiltshire that are comparatively higher in copper and cobalt. The glasses are, however, lower in antimony. These are sites with lower titanium and magnesium, but higher than most Roman glasses. It seems likely that, as a far smaller amount of the new HIT/HIMT glass is reaching this area, they are relying on a higher proportion of recycled, older Roman material, explaining the increasing copper and cobalt. The exception is Shakenoak, which has practically no evidence of HIT, but still low copper as in the previous century. Once again, this is a villa, whereas most other sites in this area are small towns and settlements. The status of Shakenoak might mean they have access to different material.

The nearby site of Bath seems to have the highest proportion of HIT glass in this century. This glass is high in copper and lead, but with very little antimony, so again it seems this material is instantly recycled in.

On the other side of the country, London shows a notable amount of HIT glass, but lower than Bath. These glasses also have low antimony, even in colourless glass. The only significantly eastern site is Caister-on-Sea, which has much lower HIT glass again, but is low in coper too.

The two East Anglian sites, Bury-St.-Edmunds and Brettenham, and Towcester in the Midlands all seem to have no glass high iron and titanium, though Towcester has moderately high magnesium. The Towcester glass, 37 sherds, is low in antimony and cobalt, as apposed to the high cobalt glasses of the other sites, totalling four. As in previous centuries, this cobalt might hace more to do with historical patterns. However, it is interesting that HIT/HIMT seems to travel along the roads connecting London and Bath, appearing at settlments here, but not reaching even slightly further north (Towchester), east (Bury-St.-Edmunds and Brettenham) or even along the southern coast (Dorchester).

9.11.5 Fifth Century

The fifth century seems to be very much a continuation of the fourth century, the significance of this will be discussed in the next chapter. Several indicators of recycling are common throughout this century. The low but omnipresent percentage of antimony and cobalt in the glass throughout this century is seem uniformly. As in the proceeding century, cobalt is slightly high in the south, and even more in the south west. However, the average values are lower than in the previous century. Similarly, antimony is low but present in all areas. Taken in conjunction with the fourth century, this indicates that while recycling is still occurring in this century, the majority of the glass has been recycled with a fresher glass.

The raised titanium and manganese in these glasses indicate the dominance of HIT/HIMT glass groups. The fact that this glass is much more apparent in the fifth century, as seen in Figures 9.81 and 9.82, than the third is interesting. Does this point towards a later influx of such glass that usually supposed, or that it can take up to a century for glass to be recycled? Given the archaeological evidence of increased recycling in the fourth century, ie. reduced large sherds, I would argue for the former.

However, HIT/HIMT is not the only clean glass seen. Both Bath and Towchester show a cleaner glass, which is not high in iron or titanium. While this material was apparent in Bath in the previous century, it doe not seem to be the dominate glass anymore. This glass is also seen at Uley, thought Uley also have clear examples of first to third century glass. This material is also still prevalent in Caister-on-Sea, on the other side of the country.

The other two sites with surprisingly low iron and titanium are York and London. While both sites seem to be recycling material with some proportion of HIT/HIMT glass, it accounts for a far lower percentage of the total material than at other sites (Assuming straightforward mixing as discussed in 6.1.2). In York, it seems such glass is accounting for significantly less of the batch, which on the whole is cleaner than the

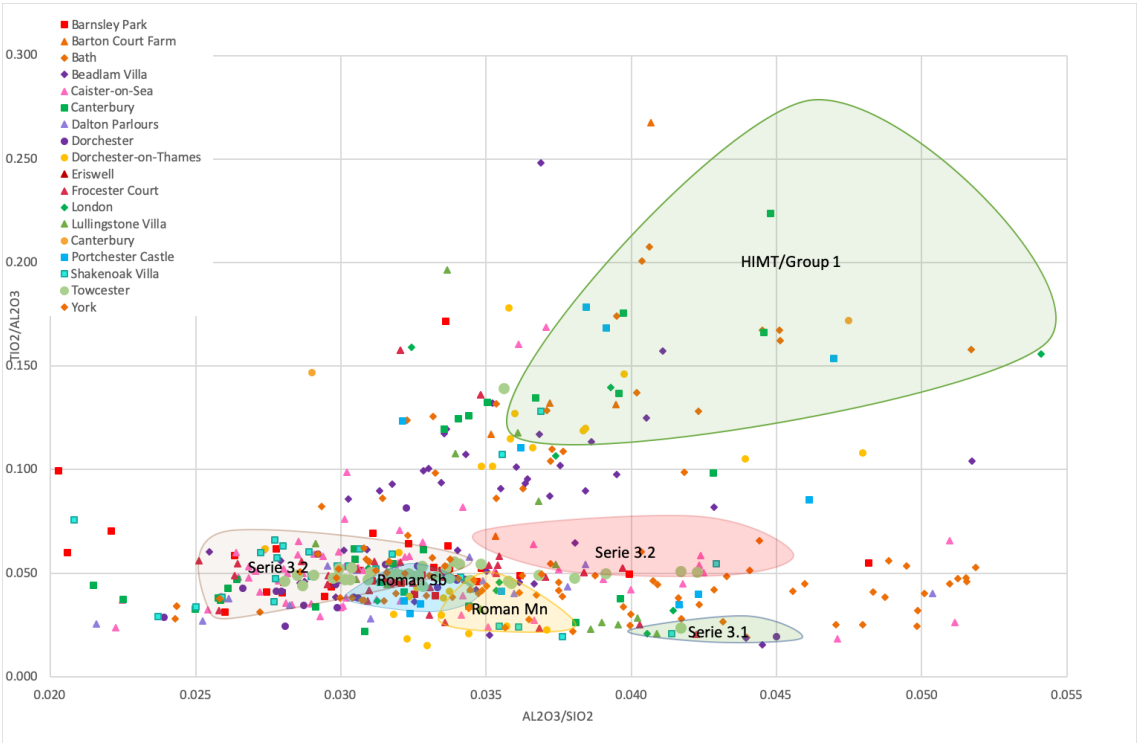

Figure 9.81: Glass groups in the fourth century, as indicated by Al_2O_3/SiO_2 vs TiO_2/Al_2O_3

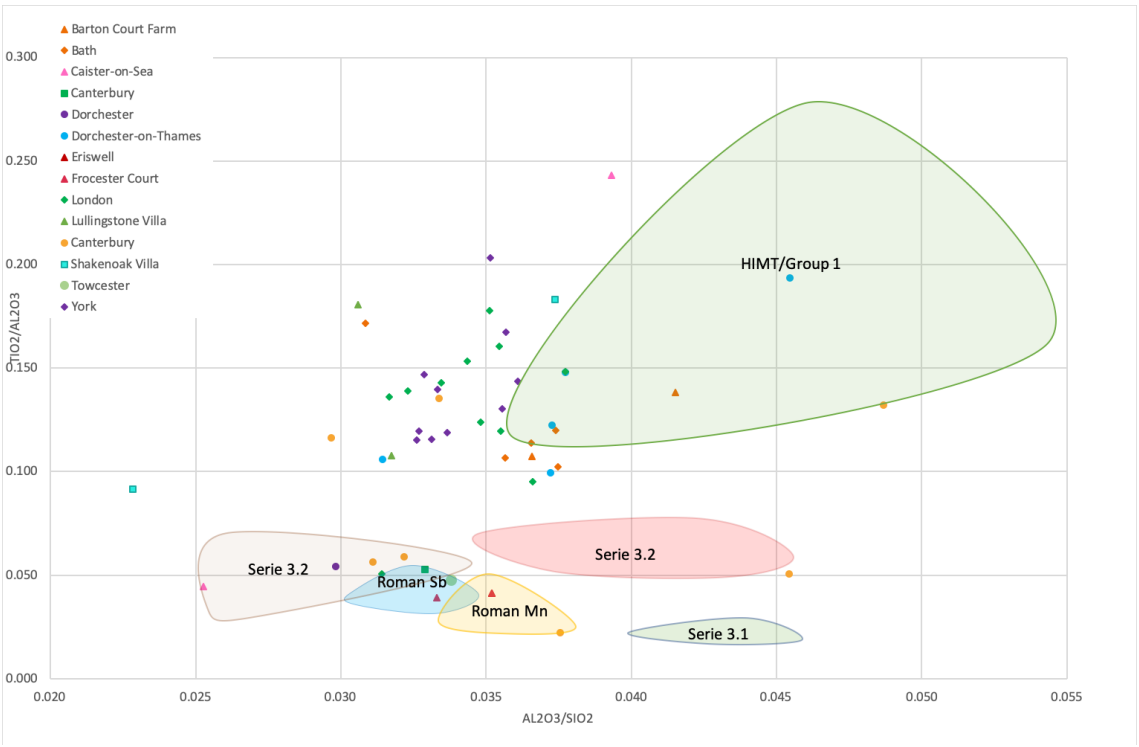

Figure 9.82: Glass groups in the fifth century, as indicated by Al_2O_3/SiO_2 vs TiO_2/Al_2O_3

previous centuries. The London glass, on the other hand, remains chaotic. It could be that a significant amount of glass, not HIT/HIMT glass, is reaching York, as it appears to be reaching other centres, yet this material is not present in the samples seen in London.

While the majority of sites in this period are dominated by the influx in HIT/HIMT glass, there are a few significant sites which buck these trends. There does not seem to be a clear geographical pattern to this, rather individual sites. It is not known whether the addition of further fifth century material, underrepresented here due to archaeological bias, would change this image. The overall picture implies that in this period, thought to be a period of isolation for Britain, both HIT glasses and another fresh glass seem to be making their way on to the island.

9.11.6 Sixth Century

In the sixth century, we are once again hampered by the nature of the material analysed. By far and away the majority of glass analysed from this period is bead glass. The reasons for this is discussed elsewhere, but can be summarised as an overrepresentation of graveyards. As such, this century will be considered firstly as sites with beads then as sites with vessel glass. The single site with both with be discussed with beads. It must be stressed that the lack of analyses does not mean that these sites, or their associated living sites for graveyards, were without such glass. As in a common theme, this thesis is hampered by the history of analyses. There is, however, an overwhelming pattern, of a shift away from HIT/HIMT glass.

Considering first the beads across all sites, they are often recycled. This is especially true of opaque glasses, but twenty percent of all coloured non-opaque glasses have antimony to levels consistent with Roman glasses, with a further 40% high enough to require deliberate addition at some point. As well as this, the base glass is predominately mix of HIT/HIMT glass, and earlier Roman compositions.

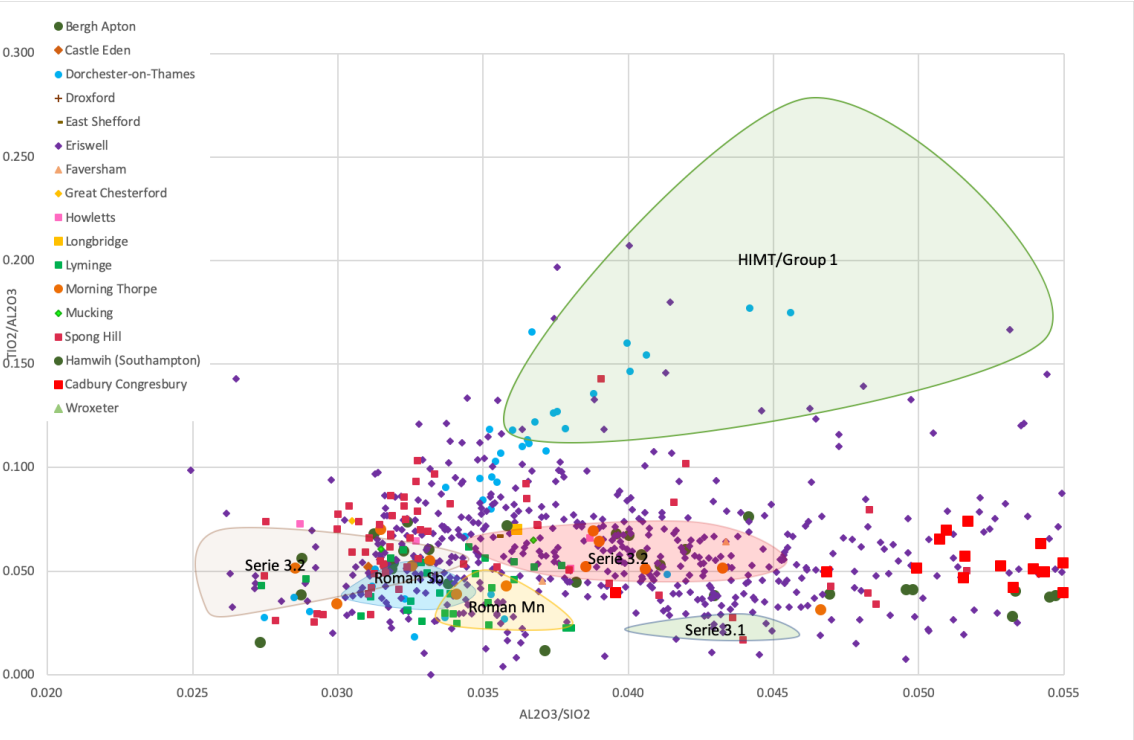

Figure 9.83: Glass groups in the sixth century, as indicated by Al_2O_3/SiO_2 vs TiO_2/Al_2O_3

There appears to be little to no broad pattern geographically, but this might be due to a lack of density in data. This said, there is a variance between sites, and a small group of East Anglian sites show data more closely grouped than elswhere. Beckford beads have no noticeable recycling evidence in copper and cobalt, and are in fact far more like the vessel glass from this century. Even in the opaque beads, only one eighth contain measurable antimony. At least one third of the beads from this site appear to be produced from clean glass.

This pattern does not continue in other sites. All glasses from Great Chesterford are high in copper, variable but many have in lead, and some of the highest tin measured in any glass in this study. Similarly, Empingham has very high copper, much higher than at the same site in the previous century. While antimony is still apparent here, it is only in half the opaque beads, and in far lower weight percent than in the beads from East Anglia. This theme is seen across all beads, with two

thirds of coloured translucent beads contain antimony, but much lower than the East Anglian equivalents. Taking the antimony, copper, and the high lead into account, it seems many of the beads are recycled from a mix of glasses, including early Roman material, but the East Anglian glass are using almost entirely first to third century glass.

There are three East Anglian sites with just beads analysed: Spong Hill, Morningthorne and Bergh Apton. All three sites have the same general patterns. All three have the highest antimony in beads in this century, though Spong Hill is slightly lower. All have the majority of glasses showing elevated cobalt, though Spong Hill is notably higher. All three are all also slightly high in tin, and lead. What is particularly interesting about these highly coloured beads is that the glass is very similar to that from West Clacton. Comparing rations of titanium, aluminium and silicon, this is clearly Roman period glass.

Only one site in this study has vessel glass analysed for trace elements and beads, Mucking. However, there is only one glass analysed, which is a coloured piece, with antimony high enough to need explanation, but is not among those very high glasses. The beads follow the patterns seen in all but the East Anglian sites, being high mixed.

Vessel glass analyses from this century are disparate due to the nature of the studies that created them. Unlike the bead studies, which were predominately done per excavation, the majority of the sites are accounted for by a single vessel. With the exception of the Lyminge material analysed for this study, the vessel glass almost entirely represents individual pieces from the British Museum's collection. That study included only 29 glasses, of which 14 were analysed for trace elements.

This means that the three cells with more than one vessel glass analysed are Lyminge, the combined cell of Faversham and Howletts, and Cadbury Hill Congressbury. The glass from Lyminge is discussed in detail elsewhere in this thesis, and thus only a few comments will be made. The glass from Lyminge is high in antimony,

copper and cobalt, and has no evidence of HIT/HIMT glass.

In contrast, the glass from Faversham and Howlets was uniformly low in copper, though it is present in all glasses. Both antimony and cobalt are also present in all glasses, but proportionally higher than copper. This seems to indicate that all three sites, Faversham, Howletts and Lyminge, are relying heavily on recycling. However, as discussed elsewhere, these sites are reliant on different base glass. This implies that the material recycled is not uniform across these sites, implying a potentially quite small operation.

The last site from the sixth century to comment on is Cadbury Hill Congressbury, which has glass spanning from the Roman period onwards, and usually assigned the cultural label 'sub-Roman'. This glass, analysed by XRF, is therefore lacking data for many of the elements used in discussions of recycling. However, these glasses show notably high Mn and Ti, consistent with HIT/HIMT glass, although the ratios of Al_2O_3/SiO_2 vs TiO_2/Al_2O_3 shows little to no concurrence with such glass. The alumina is significant, showing no concurrence with any glass groups in this study. This site is unique in its location on the Severn Estuary and we have little or no evidence of the Welsh glass of this period, which might explain this strange composition.

The bead glass of the sixth century is heavily recycled, with little care. While the vessel glass is also recycled, it does not seem unusual for this glass to be almost entirely first to third century compositions. This might imply that to create early medieval vessel glass, workers were scavenging older, disconnected Roman sites.

9.11.7 Seventh Century

In the seventh century, the final one considered in this thesis, a different pattern emerges. In fact, it might better be termed as the absence of pattern as there is less regional variation. All glass has evidence of at least some elevation in titanium and manganese, but much lower than in the glasses of the century before. It seems that

this glass is the result of six previous centuries, churned together, but also watered down with something new, and much cleaner. The glass does not seem to relate to the patterns of those areas in the previous centuries. This implies a large scale shift of industry.

As in the sixth century, glass of both bead and vessels are included. However, the beads are far more like the vessel glass in this century. As such, they will be considered together. Beginning in the North, the first site, Jarrow, is in fact the most like the previous centuries. There is variable copper across the non-blue glasses, but all are high. Seven of ten opaque glasses are antimony opacified and over three quarters of the coloured glass has very high levels of antimony. One fifth of the non-blue glasses have high cobalt, and many also have high tin. It seems that the glass of Jarrow is heavily recycled.

However, as we begin to move south, to Wakerley and the analysis of 41 beads, antimony was rarely present, even in the 7 colourless glasses (only 1 of 7). There is low cobalt, and moderately low copper. This is particularly interesting, as the beads are from 17 graves across the site, yet none show as much evidence of recycling as Jarrow. The glass from Jarrow, specifically commissioned for the windows of this monastery, is far less clean. It must be taken into account that the technical skill of production of windows far exceeds that of beads, and that this was potentially prised over fresh glass.

It is the pattern of the bead glass at Waklerly, rather than the vessels and windows of Jarrow, that seems to define the century. Neither the vessel glass at Broomfield, and at Taplow, have any noticeable trace of the antimony, an element that had been omnipresent over the previous six centuries. Taplow does, however, have a single moderately high copper glass, a yellow-green claw beaker. While the glasses from London are also higher in copper, antimony and cobalt than most of the other areas in the south, this glass is still unlike that seen at Jarrow.

Aside from London, Broomfield and Taplow, there are two other areas with multiple vessel glasses, Faversham/Howlets and Lyminge. The first accounts for two sites- The Anglo-Saxon cemetery of Howletts at Littlebourne, and the occupation site at Faversham. While these two sites are in fact near equidistant from both Lyminge and each other, they are mostly grouped in discussions in this thesis for two reasons. Firstly, they have very few glasses analysed each but they are broadly similar, and more pragmatically, they artificially fall into the same cell of the GIS Fishnet used for this analysis. The latter is clearly a methodological flaw, but it is hoped that the former counteracts this.

The notable assemblage from Alton, which has 99 analyses, is almost entirely beads. As discussed, while problematic to compare bead glass to vessel glass, in this period the glass does not appear. Of the small section of Alton glasses analysed for copper, they are all very low. What does stand out about this assemblage is that, of the 92 beads analysed for lead, just under three quarters contain measurable amounts. This is unlike most other glasses of the period, which have no measurable lead. Leaded glasses are not unknown in Britain, but are not the norm in this century. The window glass at Jarrow (0.5 wt%) and in inlays such as those at Sutton Hoo (2.5 wt%). However, single higher leaded glasses are seen at Lyminge, Faversham, Howlets, Taplow and Maiden Lane, London.

The relationship between inlay glass and vessel glass in this period is unknown. In the case of Sutton Hoo, the two opaque inlays are antimony opacified, which along with the high lead tends to indicate a mixed production. Similarly, a single inlay from Wingham shows the same. It might be that, like beads from the previous century, inlays are more likely to be produced from heavily recycled material. It seems like the high lead might be, like examples from ninth century Spain, used to stretch out the material.

To summarise again the seventh century Lyminge material, it is distributed be-

tween the glass seen in the previous century, and the other half as something new. That is, much appears very like the Roman material of the first to third centuries, expect much higher copper, antimony and cobalt in many glass types, though some seems much cleaner. In fact, the material at Lyminge has some of the strongest evidence of recycling. The nearby Faversham, is again dismilar, with little to no evidence of recycling.

The seventh century seems to indicate a shift in many areas in glass. A shift of production occurs, the once separate beads becoming more like vessel glass. A shift in both glass sourcing and recycling seems to occur. While some sites, such as Lyminge, retreat to an earlier glass, the majority of the country seems overwhelmed by a new, clean glass. The average values of copper and cobalt are greatly reduced, and there is no evidence of HIT/HIT glass. While it is difficult to assign clear groups with the range of different papers and techniques, it seems that the vast majority of material is consistent with either Roman material, or Foy's third century glass [Figure 9.84].

There are strong patterns, which can seen both regionally within each century, regionally across centuries, as well as generally per century. Each of these adds a great deal of understanding to the sourcing, consumption and manufacture of glass objects across Britain.

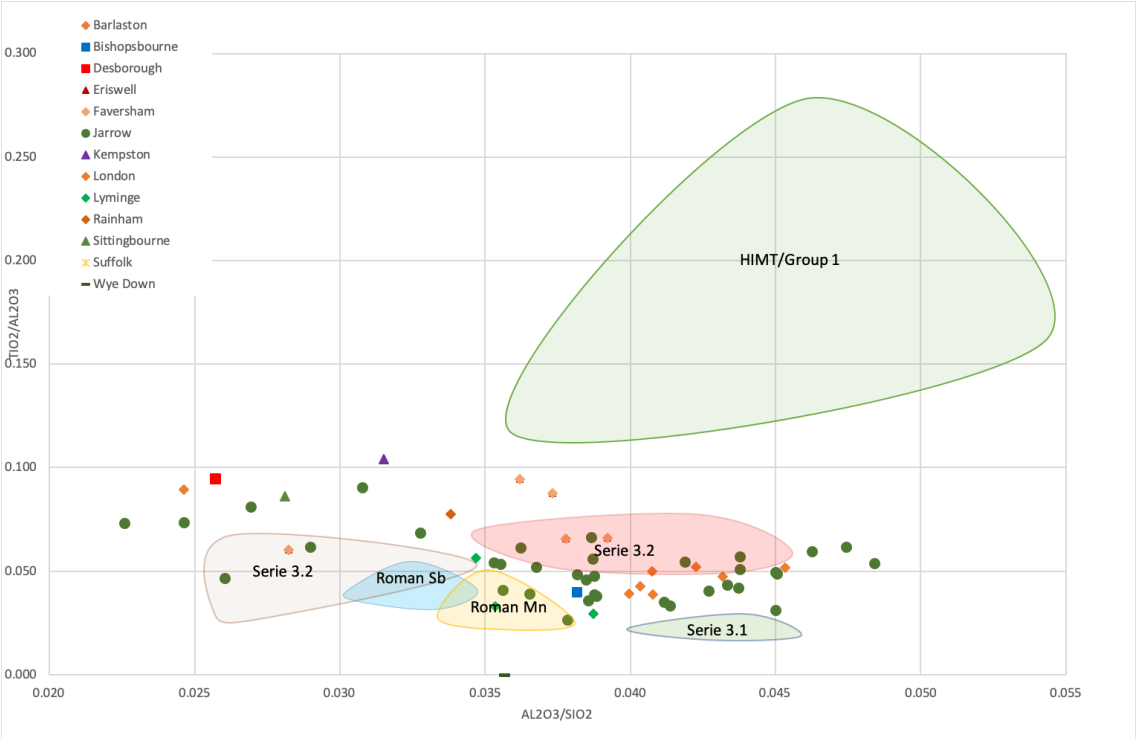

Figure 9.84: Glass groups in the seventh century, as indicated by Al_2O_3/SiO_2 vs TiO_2/Al_2O_3

Chapter 10

Glass in Britain in the First Millennium, A Discussion

The first and most striking element of this work is that the patterns of recycling seen in England seem unchanged across the majority of the period. That is, the relationship between regions remains constant, and there is a longstanding pattern of remelting. While there are large influxes of glass, seemingly in the first and second, fourth, and late sixth and seventh, there are also clear periods of stagnation, notably the third and fifth centuries. However, this importation of new glass does not seem to effect the way glass is recycled. This new glass is added to a longstanding, many cycling system of cullet material. While in some places this is done differently, which more or less care, its presence is constant. A notable proportion of the glass from the seventh century analysed, especially the vessel and window glass at Lyminge and the twin monasteries of Jarrow and Monkwearmouth, show a notable contribution of Roman material. This material, originally produced in the first to third century glass factories, finds itself on the tables and in the windows of peoples living half a millennium later. The significant contribution of copper in non-blue glasses, the absolute weight percentage of which increases over time, seems to imply that some

of this material has been in constant circulation across this whole period. However, some glasses are cleaner of elements of copper and cobalt, which might instead imply more recently scavenged Roman material, such as that seen at Sittingbourne and Lymine.

In the case of Jarrow, where we know a great deal about the glass, both the commissioning (Venerable Bede 1896, p. 368) and the composition (Freestone and Hughes 2006), it is interesting to see that production relied heavily on recycled Roman material. Lyminge, which might well be producing its own glass vessels on site, also seems to be exploiting already formed material.

It is quite clear that while the definitions in Chapter 4.1 are a useful heuristic tool, this approach only highlighted two types of recycling - cullet and incorporation. There is perhaps one or two elements of reforming in glass beads, where a single tesserae or glass sherd is made into a single object, but disentangling this from the constant ebb and flow of material across Britain does not currently seem a feasible prospect.

While many authors have looked for a relationship between typology and composition in Britain (eg. Heyworth et al. 1990; Paynter 2006), in these large overarching metrics, this doesn't seem apparent. While some forms, such as late beads, are clearly heavily recycled, where the typology of vessels are known, the chemistry of glass does not seem significant. As a unity of material has been shown in other typological studies, and in colours, it seems that this continuity is not the case over large areas or timeframes. This supports the idea that glass workers imported bulk material at various points, which overwhelmed the signature of glass at that place and time. This then persists until the next large import. Cullet collections such as that yet to be fully excavated at Lyminge seem to imply that a glass worker would not need access to a large supply of fresh raw material to produce a significant amount of objects. as well as this, choices made about what and where to recycle are a matter of degrees,

eg. separating a specific colour or type, and are not consistent across large areas of space and time.

Similarly, when looking at the relationship between the type of settlement, the composition of the glass, and the reliance on recycling, a clear pattern is not always apparent. While the villas of Fishbourne (total n = 14) and Dalton Parlours (n = 16) both show far less recycled material, or more carefully recycled material, leading to glass that is low in unexplained copper, cobalt and antimony. This is not true of other villas such a Beadlam (n = 50) and Shakenoak (n = 19). While the very clean glass at Fishbourne might be a factor of its early establishment, both Shakenoak and Dalton Parlours begin in the late first century, though the glass included in these analyses all dates from the fourth to fifth century. Therefore, while the early date might explain the Fishbourne glass, dating does not explain the contemporaneous Shakenoak and Dalton Parlours. At first glance, it appears that Shakenoak is relying on recycled material while the glass of Dalton Parlours is more primary. Beadlam is within two days walk of Dalton Parlours,[1] yet the glass seen here is wildly different in composition. All four of these villa sites have a range of typologically high status vessels, and yet no compositional pattern.

The other villas in this study are all also fourth to fifth century: Lullingstone Villa in Kent, Frocester Court and Barnsley Park in Gloucestershire. These analyses are predominately those of from Foster and Jackson 2009, 2010, and they are defined in these papers as Group 2a/b. When all these fourth and early fifth century high-status villa glasses are plotted together, there it is clear that there is something different about the glass at Beadlam Villa [Figure 10.1].

This very different glass shows two interesting things. Firstly, the majority of the villa material seem consistent with Roman glass, but not HIT/HIMT, with the exception being Beadlam. Beadlam, higher in elements related to recycling, is closer

[1] Assuming a walking speed of 30km per day, as used by ORBIS. These villas are approximately 45km apart, or around 75km by following the shortest known Roman road route.

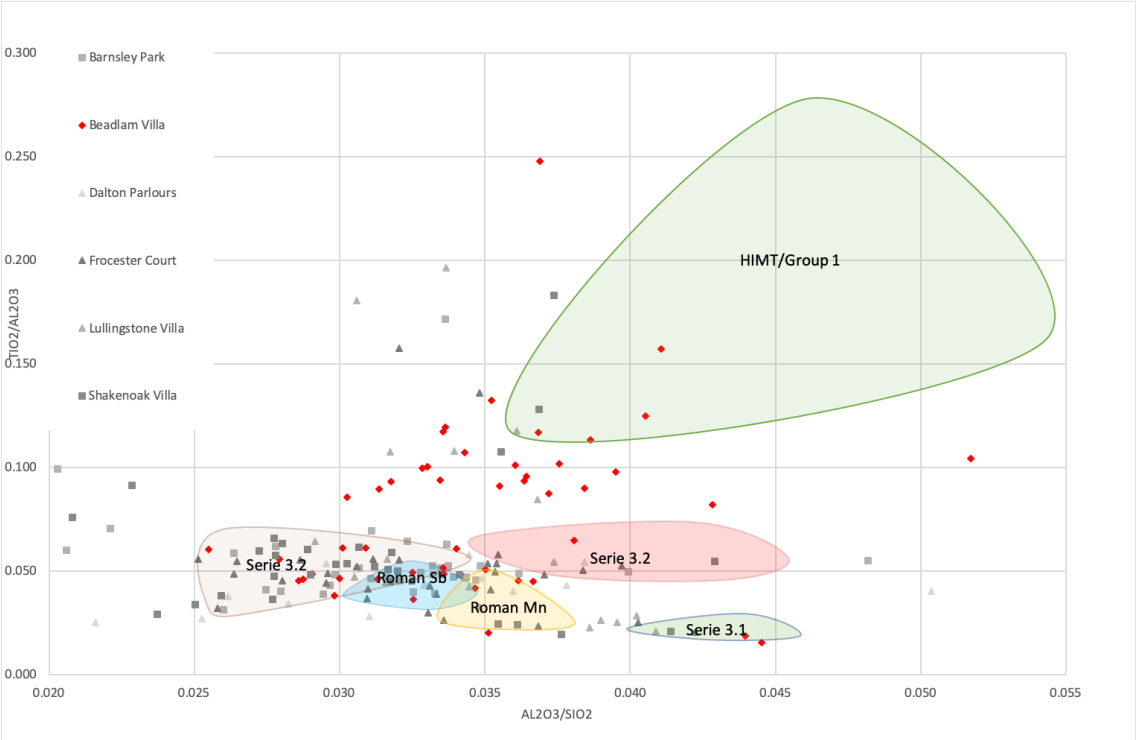

Figure 10.1: Glass groups in the villa glasses, as indicated by Al_2O_3/SiO_2 vs TiO_2/Al_2O_3, compared to glass groups

to HIT/HIMT glass, but falls on a mixing line between HIT and earlier glasses.

What this neatly highlights the presentist problem with imposing modern views of recycling, being an economic choice of the consumer or producer. While the vessels at many of these villas can be seen as comparable in terms of status, the material used to make them can be categorised as varying levels of 'new'. In a commodified system, as is assumed for much of the Roman period, the relationship between the consumer and producer, or source, could be very distant indeed. The very advantage of material like glass is that it can have been recycled with little or no indication of this in its visual appearance. In other words, those drinking from the vessels at Beadlam villa likely had no idea of the antiquity of the material used.

This same differential composition in similar sites is seen at the kingly halls of Lyminge compared to Faversham. Evidence shows that Anglo-Saxon occupation at both sites begun relatively early on in the period, were of a kingly status, and these

sites are within one days walk of one another.[2] Faversham is the assumed origin of Kempston beakers, yet the beakers of this type from Lyminge are of notably different compositions to those from Faversham. This variation raises many questions. In terms of Lyminge, this glass seems to show a greater evidence of recycling than glass from the nearby sites of Faversham and Howletts (Freestone et al. 2008a). Taking into account with the cullet pit (Thomas and Knox 2013), Lyminge could have been making its own beakers of this type, which means Lyminge could have been a significant producer of this vessel type. This difference of composition could be a way of indicating the workshop in other studied claw beakers. However, the glasses analysed from both Faversham and nearby Howletts were taken from the British Museum, and the samples are few. This study was of 2 Kempston and a further 19 other vessels, versus the Lyminge study of 3 Kempston and 27 other Anglo-Saxon vessels. These small numbers are such that conclusions drawn must be limited. It might be true that the case that Lyminge was more reliant on recycled glass, and the collection of cullet at this site certainly indicates recycling. Whether or not this means that Kempston beakers, or a variant of, were produced here, needs further exploration.

Returning to Roman period and a different site type. The *civitates* of York, London and Colchester are all comparable in many ways, yet there is a clear difference in their glass. London and York seem heavy recyclers through all periods, yet Colchester has far less evidence of this. As mixing is the main evidence used for recycling, and Colchester is not short of coloured, nor colourless glass, this is interesting (Cool and Price 1995, 10). Either recycling at this site is taking place in carefully organised and probably by military industrial manner, or it is just not common. There is some evidence of the former in that the Colchester glass does show a small amount of ev-

[2]Again, assuming 30km per day, as used by ORBIS. These towns are approximately 20km apart, or around 30km by following the shortest Roman road route. The continued use of these Roman roads is assumed for much of this period, shown by the correlation of finds to these roads (Reynolds 2011).

idence of recycling. The analyses from Colchester have a notable caveat in that the glasses analysed account for less than a tenth of minimum number of glasses excavated and were selected for their very decoloured nature, it seems plausible that recycling featured on this site. However, it is notable how effective this system of partitioned recycling seems to have been.

Such decoloured glass cullet seems to be one of the main sources of 'raw' glass in Britain (Cool and Price 1995, 6-7). The supposition that recycling could be taking place but with more caution is viable, but requires further study. In either case, such curated recycling is not the case in York and London.

York and London are not identical, and for this discussion it is worth considering the network of roads across Roman Britain. As iterated previously, until the third century, the glasses in both York and London seem very similar, relying on recycling. However, moving to the fourth century, this continues in York, with very little evidence of HIT/HIMT glass stirred in, whereas London shows a large influx of 'clean' HIT/HIMT glass. Spreading out from these sites, the network of Roman Roads seems key in whether or not sites have access to HIT/HIMT, and therefore whether or not it ends their recycling mix.

The roads linking London to Bath and Silchester appear to be key routes for this material. Unfortunately, the only analysis of glass from Silchester dates from the turn of the century and is limited. The addition of material from this city would provide a potentially more complete picture. As it stands, it seems that York, despite its significance as a civitas, even into this later Roman period, simply isn't as connected as these southern sites and thus the material they are recycling is more limited, and therefore the element patterns of recycling are different. As the varieties of primary glass coming into York were fewer than those available in the south, the various recycling possibilities were also fewer. The smaller quantities of material may also have increased the significance and necessity of glass recycling in general. If, as

the data amassed by this thesis seems to indicate, these southern and particularly southwestern roads are the main inroad of HIT/HIMT glass, this could also explain the lack of this glass in Kent and the rest of the southern coast. This paucity continues into the Early Medieval period, where the many sites recycling in this period are reliant on glass originally produced in the first to third centuries.

Both York and London have evidence of secondary workshops, as do other civitates across Britain. Some such sites we have material from are Wroxeter and Leicester. Unfortunately, the material from these sites is sporadic, with analyses from Wroxeter being only a small number of samples, from the workshop area. Leicester on the other hand is a large amount of glass from the third century, and very little from the fourth. This Leicester material shows no evidence of recycling looking at antimony, and a small degree looking at copper. This might mean that either they are not heavily recycling the material, or that like Colchester they are carefully curating it. In the case of Wroxeter, these very few glasses seem heavily recycled, and include production wasters. The civitates in this thesis with no present evidence of secondary workshops include as Dorchester, Canterbury, Winchester, Chichester, Cirenster and Lincoln. All of these sites, still occupied, are necessarily not excavated in their entirety so the lack of discovery does not imply that there was not glass working here.

Looking at these other cities, there is some interesting variation [Fig. 10.2. The material from Wroxeter looks a comparatively discrete, which is unsurprising giving its strange composition, discussed elsewhere. Leicester too seems relatively discrete in terms of glass group. Looking at recycling elements, this site seems very like Colchester. That is, that recycling is occurring, but in a very controlled group. Both Dorchester, and to a much greater degree Canterbury, show very mixed glass groups, far more like York. Canterbury stands out in terms of copper and antimony as well. Excavations at Canterbury indicate a town far less military in character than at Leicester. This all supports the supposition that large-scale, structured recycling is, if

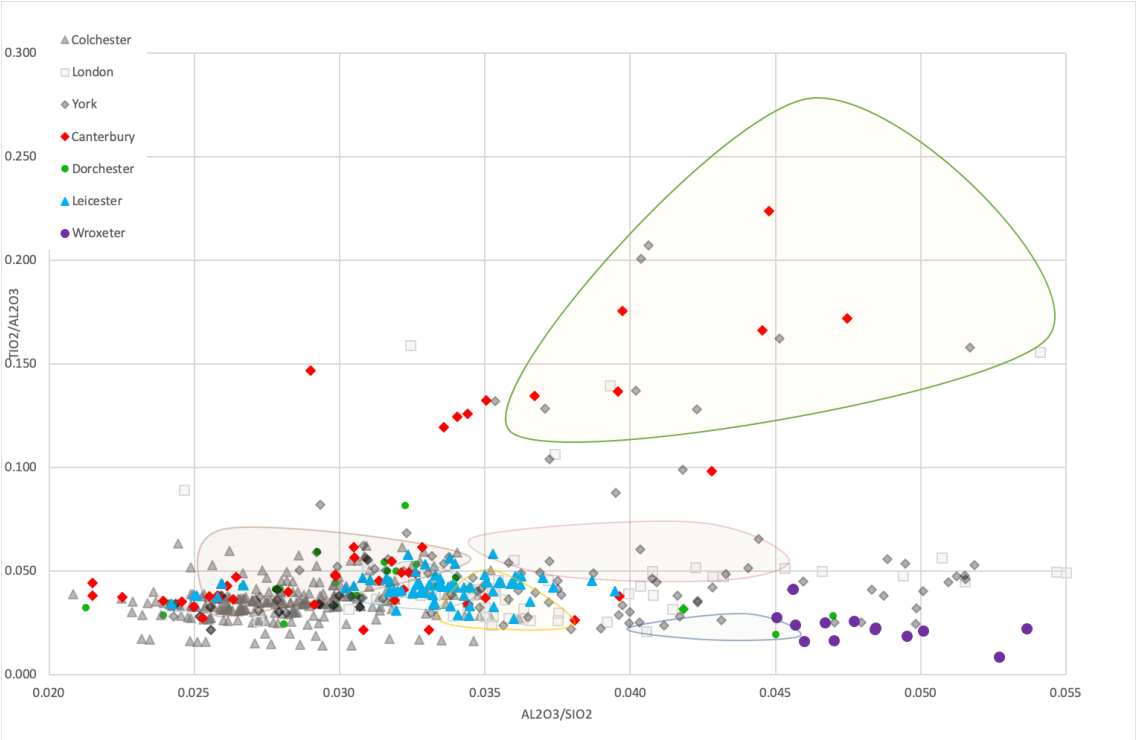

Figure 10.2: Glass groups in the Roman civitas glasses, as indicated by Al_2O_3/SiO_2 vs TiO_2/Al_2O_3, compared to glass groups

not directly military controlled, closely linked.

This thesis pulled together many small towns and rural sites, with the consideration that such would be particularly vital in looking at geographic patterns. However, a quirk of scholarship has meant something quite different. The vast majority of such sites analysed were all in one area, a small grouping of sites in Oxfordshire, Gloucestershire and Wiltshire. As discussed previously, these sites all show a different pattern to the rest of the country at any given period. This raises an interesting question. Is the glass available in these small towns different to that in larger towns and cities or is there something odd about these counties? That is, are these sites different due to their status, or their geography, or both? A study of two nearby civtates, one nearby and one within the study area would greatly add to our understanding. As discussed previously, understanding glass at Silchester itself, and the spread of

HIT/HIMT glass would be beneficial. If then this glass was compared to the glass excavated at Cirencester, this would be the first logical step to address this lack. This area has the greatest group of small town in this study, and a great range of unusual results. It is of particular interest as to whether Silchester and Cirencester are consistent or otherwise. The other comparative that would be very interesting for this is material from sites beyond the Severn. Looking at the location of these sites, this material might be indicative of a trade dominated by the known ports of the Severn estuary (Rippon 2008). As such, this might indicate the glass available in Roman Wales was disparate from that in the rest of Britain. Our understanding of glass in Roman Wales is paltry, and such data could only add to our understanding.

Turning to the early medieval period, it is both apparent that, while the recycling of Roman glass is important, it is not the only source of glass. It seems that the glass reaching different areas of Britain, however, is not uniform. The material at Jarrow, Lyminge and Cadbury Hill Congressbury all shows elements of recycled Roman material, but with potentially different end members. Freestone has discussed this in reference to Jarrow (Freestone and Hughes 2006, 152-153), the lack of comparative glass across England and Britain makes drawing any specific conclusions difficult.

It would be particularly interesting how the Cadbury Hill Congressbury glass compares to glass on the Atlantic facade of Britain. Yet, once again, we are sadly lacking in analyses of any such material. What we can say for certain about this period is that there seems to be a change in the sixth to seventh century, with bead glass becoming more like vessel glass as well as the introduction of a new glass source. It would be of great interest to ascertain what this glass is. Another area of study that would be of particular interest is a targeted analysis of Kempston beakers. It would be of interest if there are two clear chemical 'schools', connected to Lyminge and perhaps Faversham.

A brief comment will now be made on how Britain relates to the rest of Europe. What is interesting is that almost all European glass collated for this study shows a comparable level of recycling to that seen in Britain. Belgium and the Netherlands seem to consistently have glass in common with Britain. What is also interesting is that the most analysed country outside of Britain is, far in away, Italy. Yet, English glass has a surprising amount in common with even this glass. For example, when we consider the amount of antimony in Italian, Belgium, English and Dutch glass across the sample centuries, the pattern is consistent [Table 12]. This is a pattern that was repeated over and over again. It seems that despite being at the edge of the Empire, Britain's pattern of recycling is not significantly different from the centre. Does this mean that countries such as Italy were equally 'cut off' in the fourth century?

This returns us to the crux of the archeological question behind glass recycling- Comparing the nature of the glass industry in England during Roman Britain and the Early Medieval periods. The reason this was done was to try and address the nature of industry and trade in Early Medieval Britain, especially to asses whether recycling in this period indicated resilience of industry, or struggling collapse.

The frustrating lack of fifth century glass analyses has proven problematic. It seems both that very little 'fifth century' glass exists to be analysed. The reason for the lack is not necessarily real, as has been detailed about as discussed at length by Cool and others (eg. Campbell 1995; Cool 1995, 2000). Identifying fifth century sites is exceptionally problematic, before even considering the argument of small sherds discussed earlier (Chapter 3). However, if one assumes that this is simply due to a lack of glass in this century, which seems unlikely, then we will have to skip to the sixth century.

Studies of forms seem to show these as part of an evolution both in England and on the continent, and the same might be true of the glass itself. There is not a clear

dislocation in glass chemistry at any point, except perhaps the seventh century, but rather periodic floods of new material. The appearance of new material in England in the sixth century does seem to occur, such as at Lyminge, Bedford and Cadbury Hill Congressbury. However, all three of these glasses show different compositions appearing in the seventh century. At each of these sites any new glass still seems to be recycled with Roman glasses. This is particularly interesting when compared to studies such as Campbell (1995). Campbell found that material coming into Britain, especially pottery imports, showed a change in this period. Up to around 650 AD, the trade seems dominated by the Mediterraean, after which material is coming directly from the continent. Assuming this same parallels is occurring glass, not unlikely given the results of this thesis, this begs the question of what this glass is. Due to the scope of this thesis, European glass has not been closely interrogated. However, work currently being undertaken by a variety of colleagues across Europe means that the data set of 'dark age' glasses is set to grow. With such built, it is hoped that we might be able to understand where this new glass, or glasses, is coming from.

Recycling in this period also seems paralleled on the continent. All of these places have traditionally relied on the glass imported across the Mediterranean. The glass recycling of England seems to have no particular relation to its own membership of the Roman Empire, but is part of the endless ebb and flow of this material across the middle sea and Europe.

Comparing the outcomes of this thesis to the work done by other largescale data projects in Britain, there are some interesting correlations. While there has been no survey on glass at all, it features in other studies, to a much lesser degree. For instance, the Roman Rural Settlement project includes information on excavated evidence of Roman sites, other than major civitates. It is collected from both traditional site reports and the 'grey literature' that has proliferated since the 1990s and the in-

troduction of mandatory developer-funded excavation. The collation of this data as a reference has greatly added to our understanding of Roman Britain outside the cities.

When looking at their sites that have identified any glass, there is a clear similarity with the glass we have analysed [Fig. 10.3.]. Of the 3478 of their sites fall within this study area, 30.9% (1076) contain glass vessel or objects. Of these, 877 (81.5%) of sites have glass as vessels, of which 33.8% (364) also contain other glass objects. Non-vessel glass objects are therefore present on 52.3% of sites. The systematic study of glass is usually focused on vessel glass, with beads only tending to become a focus in periods where vessel glass is less. Such numbers indicate that perhaps this is a mistake.

Looking at the breakdown of finds by county, these averages are maintained, (Vessel glass 47.0%, Glass objects 21.2% and both 31.7%). Using the regions defined in the RRSP study, there appears to be some correlation between region and type of glass vessel. While, for the most part, this averages over the whole region, the counties show something interesting. In particular, the sites to the west side of the central belt, which encompasses the area this thesis observed unusual data, seem to have a much higher quantity of sites with glass objects, other than vessels. While the value for just glass objects is close to average, a far greater number of sites have both glass objects and vessel glass. While the expected average of sites with glass objects totals 52.9%, yet in Somerset and Gloucestershire it is 57% and 64% respectively. The same pattern is not seen as one moves further east. This might be indicative of a different cultural preference in this region for non-vessel glass objects.

Whatever the cause, the fact that these areas stand out not just in chemistry but also typology is interesting.

Table 10.1: Data of the Roman Rural Settlement Project, showing count and percentage of sites containing glass vessel, objects, or both.

		Glass by numbers				Glass by percent		
County	**Region**	**Both**	**Objects**	**Vessels**	**Total**	**Both**	**Objects**	**Vessels**
Rutland	Central Belt	3	1	1	5	60%	20%	20%
Gloucestershire	Central Belt	37	10	36	83	45%	12%	43%
Somerset	Central Belt	23	11	19	53	43%	21%	36%
Hertfordshire	Central Belt	15	0	21	36	42%	0%	58%
Wiltshire	Central Belt	18	1	29	48	38%	2%	60%
Bedfordshire	Central Belt	13	2	25	40	33%	5%	63%
Oxfordshire	Central Belt	15	8	26	49	31%	16%	53%
Buckinghamshire	Central Belt	11	3	22	36	31%	8%	61%
Northamptonshire	Central Belt	11	5	20	36	31%	14%	56%
Worcestershire	Central Belt	4	5	7	16	25%	31%	44%
Lincolnshire	Central Belt	7	6	22	35	20%	17%	63%
Leicestershire	Central Belt	2	5	3	10	20%	50%	30%
Warwickshire	Central Belt	2	3	7	12	17%	25%	58%
Nottinghamshire	Central Belt	1	3	6	10	10%	30%	60%
Cheshire	Central West	5	0	1	6	83%	0%	17%
Greater Manchester	Central West	5	2	0	7	71%	29%	0%
Merseyside	Central West	1	0	2	3	33%	0%	67%
Staffordshire	Central West	2	1	4	7	29%	14%	57%
Shropshire	Central West	2	2	3	7	29%	29%	43%
Derbyshire	Central West	2	5	3	10	20%	50%	30%
West Midlands	Central West	0	0	1	1	0%	0%	100%
Norfolk	East	14	4	9	27	52%	15%	33%
Cambridgeshire	East	15	8	32	55	27%	15%	58%
Suffolk	East	4	4	11	19	21%	21%	58%
Lancashire	North	3	0	3	6	50%	0%	50%
Durham	North	6	5	5	16	38%	31%	31%
Cumbria	North	5	4	8	17	29%	24%	47%
Northumberland	North	4	15	1	20	20%	75%	5%
East Riding	North-East	9	7	5	21	43%	33%	24%
South Yorkshire	North-East	3	3	3	9	33%	33%	33%
North Yorkshire	North-East	9	9	10	28	32%	32%	36%
West Yorkshire	North-East	3	1	6	10	30%	10%	60%
City of York	North-East	0	1	2	3	0%	33%	67%
Dorset	South	16	5	12	33	48%	15%	36%
Surrey	South	11	2	11	24	46%	8%	46%
Essex	South	22	6	23	51	43%	12%	45%
Greater London	South	10	7	9	26	38%	27%	35%
East Sussex	South	5	2	7	14	36%	14%	50%
Kent	South	15	13	26	54	28%	24%	48%
West Sussex	South	8	7	16	31	26%	23%	52%
Hampshire	South	9	4	25	38	24%	11%	66%
Berkshire	South	2	2	6	10	20%	20%	60%
Isle of Wight	South	0	2	3	5	0%	40%	60%
Devon	South-West	5	3	8	16	31%	19%	50%
Cornwall	South-West	6	9	7	22	27%	41%	32%
Herefordshire	Upland Wales Marches	1	3	7	11	9%	27%	64%

Returning again to Figure 10.3, as commented it seems to show that glass is uncommon in much of the north west, and the north in general. Thus, the fact that this area is underrepresented in this study is of less concern. However, this is misleading. Iit is likely what they are actually showing is a lack of modern expansion and excavation.

As much of this excavation is developer funded, in areas without as much modern investment, many less interventions occur. As well as this, while the most councils have enforced guidance in policies such as PPG-16, requiring excavation prior to works, various northern county have chosen not to do this. In a recent discussion with the board of the Society of Museum Archaeologists, many members expressed their fear that this will exacerbate a historical lack of study in the north, outside Roman forts and Bronze Age settlements.

As part of the English Landscape and Identities Project, Dr Chris Green created a map of 'excavation affordance' [Fig 10.4]. This map shows the areas of England with high and low affordance; In other words, the extent to which any area in England has been explored by archaeological excavation, with remains dating from any period. This relied on all excavation recorded on the Historic England. As the Roman Rural Settlement project relied on meta-analysis of existing work, much as this thesis does, it means that it is bounded by these choices made. It is clear that everywhere explored, as show by excavation affordance, has glass.

In other words, the absence of evidence from these areas can not be interpreted as evidence of absence. Our understanding of material throughout Roman Britain is completely dependent on our history of excavation, which has been linked to areas that were either of excavated due to their perceived importance from historical or antiquarian reports, such as Colchester, or due to modern building work taking place, thanks to legislation such as PPG-16 required archaeological investigation. As has been discussed in great detail in both EngLAID and the RRSP, the legacy of data we

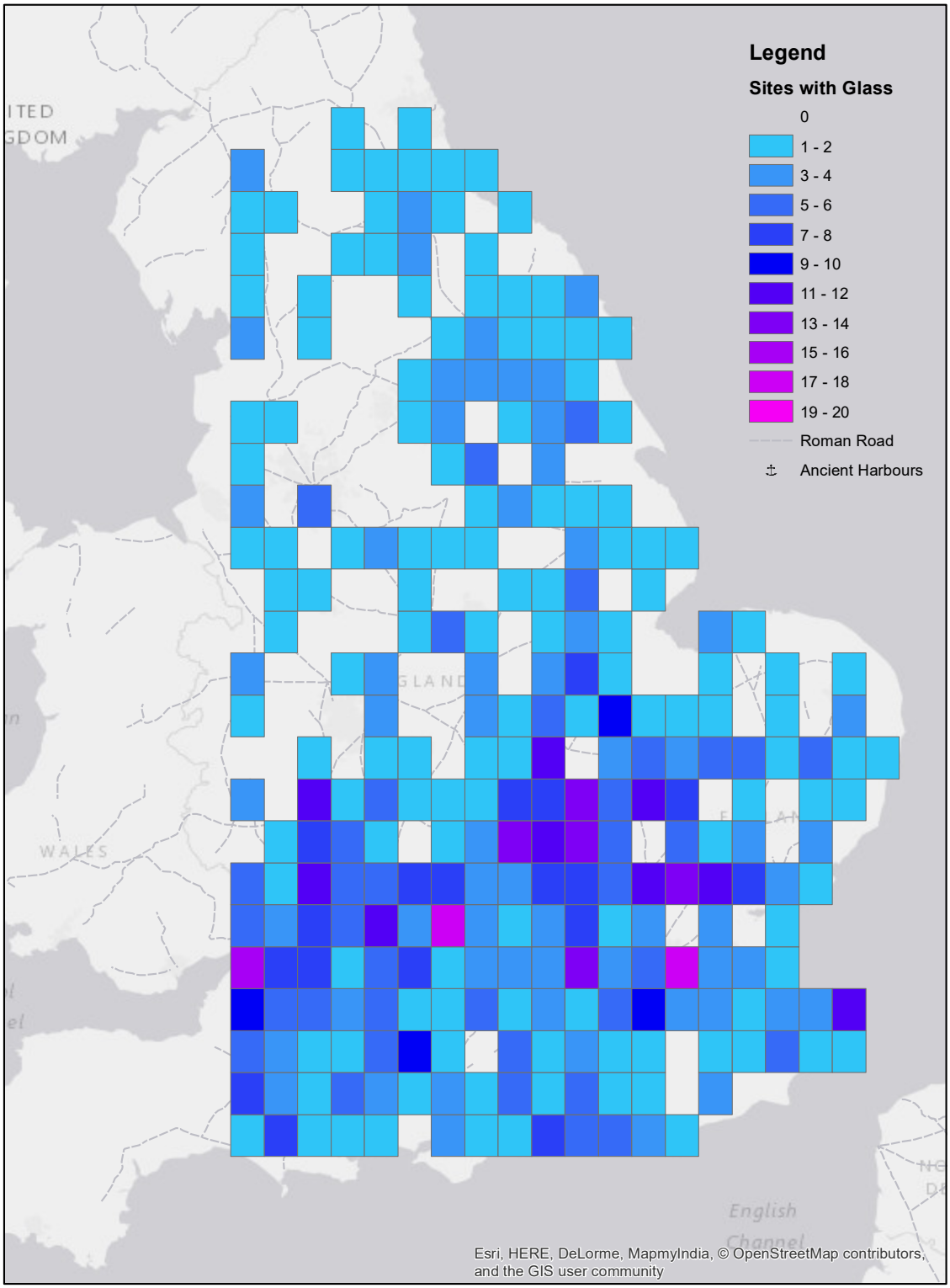

Figure 10.3: Map of Density of Excavations with Glass, recorded by the Roman Rural Settlement Project, at the University of Reading.

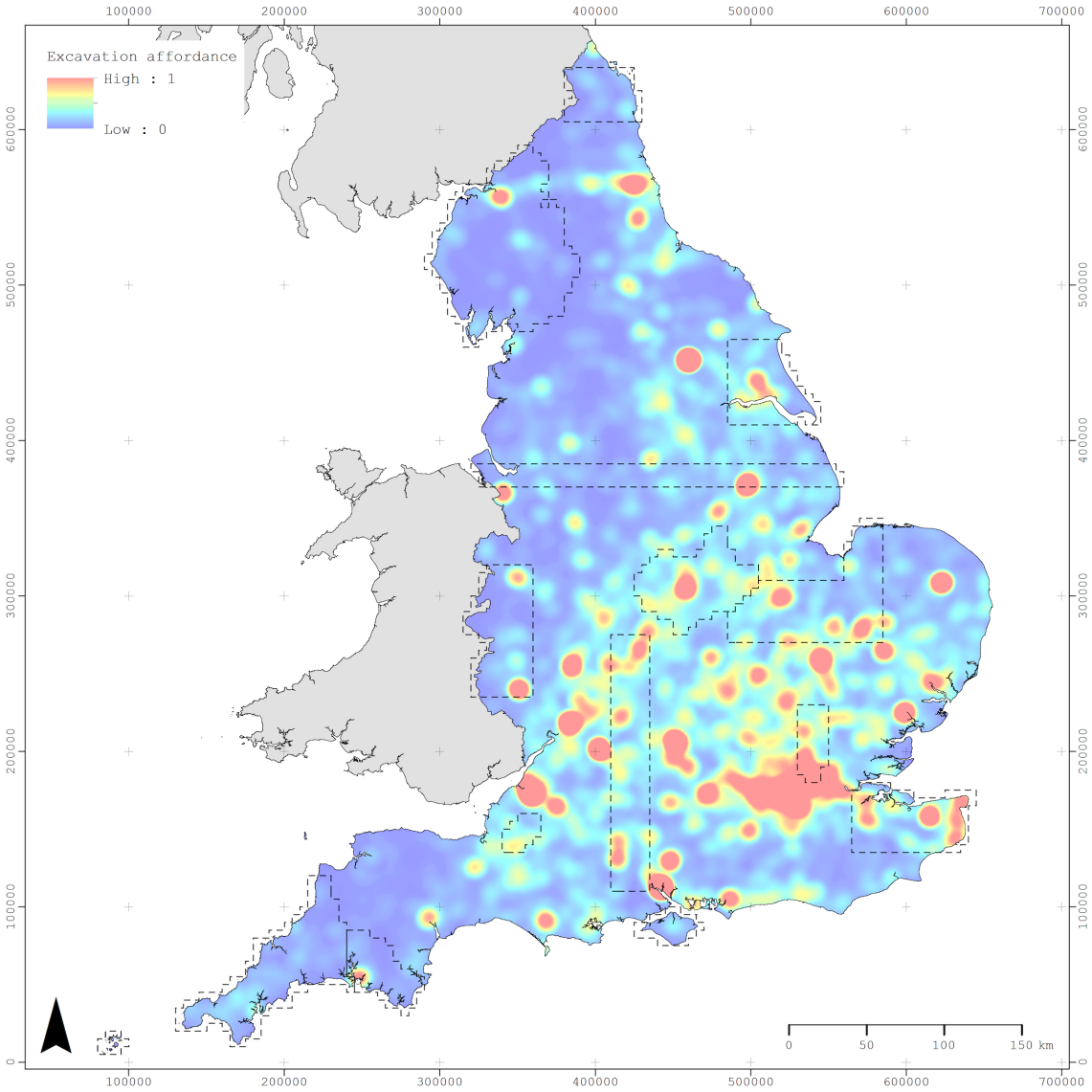

Figure 10.4: Map of Density of Excavations, using Historic England National Record of the Historic Environment, Excavation Index, from the English Landscape and Identities Produce, reproduced with kind permission of Dr Christopher Green.

are left with, while extensive, is thus biased.

What all of this seems to show is that glass, omnipresent in Roman Britain, is often heavily recycled. This recycling is periodically topped up with new material, entering the country though a variety of different routes. While some areas seem to stand out, and behave differently, there is an over arching pattern across Britain showing the same glass in use for over seven hundred years.

A final remark on the various elements used to discuss recycling in this thesis. As is perhaps not surprising, colourants often used indicated as evidence of cullet recycling, antimony, cobalt and copper, were all among the most useful elements in this study. However, what was particularly interesting was the potential for copper, and to a lesser degree manganese, to indicate potential successive recycling. This 'intensification' of unexplained copper was particularly useful in showing points where fresh glass was available, and when instead they relied on the majority of the batch being endlessly recycled. The potential of using cobalt in this way was stymied by what seems a region preference or differential availability of this material. Lead, often discussed relative to recycling, was of very little use here. This might have been improved with a more typologically split study due to its heavy use in beads and usefulness in cut glass. Tin was similarly problematic.

The elements related to glass type, iron, titanium, manganese etc, proved useful for showing large shifts of where fresh material came in or stagnated, but required these elements to be closely considered together. Of these, iron seemed the less useful due to its many possible origins, and titanium the most, though the majority of older papers do not routinely analyse for it. The shifting of glass groups proved a useful approach, though our lack of understanding of later glass groups in Europe was evident.

Conclusions

This thesis shows that the patterns of recycling in the Early Medieval period are not notably different to those in the Roman period. Fresh glass arrives in Britain in short flows, and is then mixed into the existing glass. There is, however, a significant shift in which areas of Britain receives this glass.

The first chapter presented and overview of the aims and scope of this thesis, and is followed by a chapter on methodology. The method taken in this thesis allowed a new way to address this problem of glass recycling. Looking at a large scale, chemical approach, with geographic considerations, allows glass recycling to be addressed. The advantage of such a technique is that it can utilise glass studies that already exist. This is important as the current academic climate is such that the funding requires more flexible approaches, and larger integrated projects are more popular. However, there are limitations in using such work. Areas of Britain that have not been heavily studied due to a variety of reasons are clearly missing from this assessment.

The next chapter showed that the changing situation in Britain across the first millennium was regional. Glass shifted in use and significance over time, some of which was related to politics and migration. The recycling of glass obscures our understanding of the amount of glass, and thus we must approach glass from more than just an archaeological approach. What is most clear is that there is a great deal more glass in Early Medieval England than traditionally thought.

Before approaching the data, Chapter Four considered what is meant by 'recy-

cling'. A schematic has been created to address different forms of recycling, particularly in terms of material studies approaches. The new terminology introduced showed the wide spread of behaviours that could loosely be termed 'recycling', and how economically, culturally and practically different they can be. The importance of this section is to raise the issue that recycling is so much more than is often thought. Cullet recycling is the most common form of recycling discussed in this thesis.

The next chapter dealt with the history of glass chemistry, both how it was conceived in the past, and the modern understanding of glass. Most ancient writings about glass are problematic, but worth consideration. In modern understandings, glass is a complex network structure which can include a great deal of additions, all of which require consideration. Moving into the seventh chapter, these modern understandings of glass are married with the history of their application to ancient glass; that is, archaeometric studies of glass. This also includes our chemical understanding of the Roman and Early Medieval glass industries.

This leads onto the chapter discussing how archaeometric results can be used to unpick recycling. This chapter discussed the three different areas of glass recycling: temporal changes in base glasses, deliberate and incidental additions and losses, and mixed provenance. This framework is drawn from many different studies addressing glass recycling. It has allowed this thesis to asses their practicality in application to a database and, based on this, choices were made of what elements were included in the geographical considerations of the next chapter. This chapter made clear that certain elements and certain types of recycling are more readily identifiable than others.

The next chapter, Seven, presents two new sets of glasses that were analysed. Both Dorchester-on-Thames and Lyminge are interesting sites as they add significant amounts of glass analyses that fall into the Early Medieval period., underrepresented in this thesis. These sites are also both very interesting in what they show about the 'end' of Roman Britain. The EMPA results are a significant addition, but show very

different results between these two sites.

The eighth chapter assesses the database that has been assembled. Nearly 3,300 British glasses were collated for this period, as well as 2,500 European glasses. While several different techniques are used the density of such data means that it is possible to ignore discrepancies, with the knowledge that the sheer volume of the data overwhelms them. As well as this, the geographic spread of techniques means that results from a single area of Britain are not noticeably biased by the use of only a single technique.

Chapter Nine went through elements individually, plotting how they were related to geography. Copper evidence showed a clear increase in recycling across the centuries, with a continuous pool of glass being added to over time, causing a slow and steady increase in otherwise inexplicable copper. The changeable nature of antimony is more difficult to read but still shows this continuation of material across time, with slightly different patterns seen in large urban centres. This same pattern is also seen in cobalt. Lead is more complicated, but does show Lyminge's recycling. Tin also shows a complicated but similar pattern. Iron, titanium and manganese are all related to the introduction of HIT/HIMT glasses. These show an increase of recycling in the third century onwards, with something strange occurring in the seventh century. Several other elements were also considered, but without their geographic relations. Aluminium and calcium show evidence of recycling from the second century onwards, and sodium and potassium show that a great deal of the Early Medieval glass is part of this continued mixing. This is also supported by the evidence given by chlorine and phosphorus. It ends in a survey of these analyses by century.

The tenth chapter has discussed what this all means, in the context of Roman and Early Medieval Britain. It showed that the periods in which recycling was most apparent in Britain was not directly linked to the 'fall' of Roman Britain. Rather, there were periodic influxes of glass, and centuries with very little new glass, such as

the fourth century. The patterns of glass recycling in Britain do not seem isolated as similarities are seen in glasses across the northwest provinces.

It is clear that Early Medieval glass in Britain is not simply an endless recycling of Roman glass. However, this material does feature. What is also clear is a great range of regional variation of what is occurring in Britain across the first millennium. While this thesis has begun to show some of this, it is clear that greater regional variation in glass studies is needed. Roman glass is found far beyond the areas that have been studied, and a great deal more detail could be added with further analyses of such glass. As well as this, variation of site type.

Variation is particularly pertinent when considering Wales and Scotland. The areas adjacent to Wales consistently showed different chemistry to the East of Britain, after the Roman period. As Atlantic Britain is known to have a different relationship to the wider world in this period, this is very suggestive (Campbell 2007). The addition of this area to these large-scale discussions would be invaluable. Similarly, there are less analysis of glasses from the fifth century onwards. As our awareness of the amount of this material is increasing, the systematic study of such material would greatly add to the work of this thesis.

The database created by this thesis will be made available online and it is hoped that by doing this, a greater amount of unpublished raw data will be contributed over time. Many authors do not make their raw data available, either due to funders' or publishers' restrictions, personal choice, or the study never reached a publishable stage. This means that a great deal of data that could contribute to this study, was not available for inclusion in this thesis. It is hoped that this will be improved over time.

This is particularly the case in the European data, which is part of the reason there is comparatively less analysis the originally envisioned for this project. While a comprehensive comparison to the limited European data was not possible in this

thesis due to necessary brevity, it will follow this thesis in a series of papers.

Roman and Early Medieval glasses stand out in many site assemblages due to their range of colours and forms. While they have been studied for centuries, the impact and importance of recycling has only recently begun to be assessed. This thesis is an important contribution to such work, for the first time beginning to linguistically unpick both what is meant by recycling and then, chemically, how this changes across Britain. This thesis has highlighted that the type of site can have a strong impact on the type of glass available, and thus the reliability of recycling. However, London and York have notably shown differences, likely to be related to locality.

The lack of change seen between the recycling practised across time supports the hypothesis that the Early Medieval glass industry was not notably different from that of the Roman period. Extrapolating further, it is clear that this period in Britain's history, where little or no outside trade is expected, is more complex than thought. The complete industry collapse posited relative to industries like pottery (Ward-Perkins 2005), is not supported here. Fresher levantine glass is used in the creation of technically exceptionally complex pieces, such as claw beakers (Chapter 7.2). This thesis has shown that recycling in Roman Britain, and especially Early Medieval Britain, can reveal information about both periods, which can then inform interpretations of glass on sites across the first millennium AD.

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Part I

Appendices

Chapter 1

Analyses of Glass from Dorchester-on-Thames and Lyminge

The calibrated EMPA results from all runs of from Dorchester-on-Thames and Lyminge glass. DOT indicates glass from Dorchester-on-Thames and Lym, Lyminge. 104 Dorchester glasses and 36 Lyminge glasses were analysed by wavelength-dispersive Jeol 8600 electron microprobe (EMPA) at the Research Laboratory for Archaeology and the History of Art, University of Oxford. An accelerating voltage of 15 kV, low beam current of 7.5 nA and a take-off angle of 40ere used in these analyses. An average of each sample was used, yet any analyses with less than 80% were discarded, which meant that only 103 Dorchester on Thames glasses were used.

Below are three tables, one showing the Raw Data, the second showing the values measured for Corning Glass standards, also indicating their location along the run, and the last showing the average values used in the analysis with their SFN added.

1.0.1 Raw Data from EMPA runs of Dorchester-on-Thames and Lyminge Glass

Label	No.	Date	Total	Na2O	MgO	Al2O3	SiO2	P2O5	Cl	K2O	CaO	TiO2	MnO	Fe2O3	CoO	CuO	SnO2	Sb2O5	PbO
DOT1.1_1	12	230215	100.3883	19.1488	0.6153	2.4237	68.1452	0.1346	1.4148	0.6705	6.0858	0.0928	0.5193	0.4633	0	0	0.0208	0.2556	0.0095
DOT1.1_2	13	230215	100.2597	18.8566	0.6709	2.4007	68.265	0.0658	1.4883	0.5518	6.2959	0.0997	0.5811	0.4663	0	0.0224	0.0281	0.2073	0
DOT1.1_3	14	230215	100.4486	18.8639	0.6483	2.3401	68.2369	0.0945	1.458	0.6421	6.2546	0.0886	0.527	0.5106	0.0141	0.0064	0.0598	0.2551	0
DOT1.1_4	15	230215	100.4073	18.8143	0.6406	2.4622	68.3192	0.1432	1.4445	0.6441	6.0746	0.0911	0.5952	0.5184	0	0.0224	0	0.2303	0
DOT1.2_1	16	230215	99.3641	19.8401	1.0745	2.3477	65.2699	0.0833	1.2771	0.6125	6.3228	0.2745	1.6481	1.2013	0	0.0081	0	0	0.0401
DOT1.2_2	17	230215	100.1531	19.6034	0.9558	2.2749	65.5623	0.0784	1.3292	0.6544	6.4321	0.28	1.654	1.0477	0.0185	0.0624	0	0.047	0
DOT1.2_3	18	230215	99.9115	19.3472	0.9648	2.3488	65.9056	0.0744	1.3381	0.6803	6.1889	0.2952	1.6832	1.0954	0	0	0	0.0245	0.0537
DOT1.2_5	19	230215	99.5648	19.5591	1.0468	2.2682	65.6125	0.1067	1.3345	0.5836	6.4801	0.2975	1.649	1.062	0	0	0	0	0
DOT1.2_6	20	230215	100.8054	19.7902	1.0308	2.3396	65.1166	0.048	1.2899	0.6386	6.2938	0.2697	1.6381	1.369	0	0.0985	0.0203	0.0353	0.0216
DOT1.3_1	21	230215	99.0971	1.9176	2.2657	4.888	61.0384	0.5445	0.3009	1.8455	24.4358	0.1964	0.0499	2.4032	0	0	0.0488	0	0.0653
DOT1.3_2	22	230215	98.7184	2.0361	2.3864	4.9086	60.8024	0.4644	0.2594	1.8389	24.63	0.2234	0.0605	2.3489	0.013	0	0	0	0.0282
DOT1.3_3	23	230215	98.8604	2.0965	2.3135	4.8193	60.8864	0.4834	0.2979	1.8908	24.4181	0.2181	0.0438	2.4637	0.0072	0.0614	0	0	0
DOT1.3_4	24	230215	99.137	1.9878	2.3446	4.9274	61.2523	0.5458	0.3117	1.8101	24.0834	0.2382	0.0684	2.384	0	0	0.0045	0.0246	0.0171
DOT1.4_1	25	230215	99.0414	4.7501	0.1533	6.2967	63.2705	0.0699	1.1724	0.3991	23.3344	0.075	0.0495	0.358	0.0086	0.0307	0.0192	0	0.0126
DOT1.4_2	26	230215	99.9061	4.7518	0.2097	6.401	63.5901	0.121	1.171	0.4206	22.8897	0.0559	0.0036	0.3857	0	0	0	0	0
DOT1.4_3	27	230215	98.9013	4.6199	0.1661	6.2843	63.7088	0.1013	1.1875	0.4234	23.1097	0.0428	0.0424	0.2835	0	0	0.0303	0	0
DOT1.4_4	28	230215	99.0594	4.6522	0.1346	6.2053	63.5917	0.1204	1.1093	0.4148	23.3315	0.0699	0.0108	0.3264	0	0	0.0332	0	0
DOT1.5_1	29	230215	100.0474	16.9102	0.6654	2.3444	68.8601	0.1427	1.0186	0.6284	7.0163	0.0716	0.4312	0.7211	0	0	0	0.3994	0.7907
DOT1.5_2	30	230215	100.389	16.9889	0.5932	2.3544	68.7736	0.1391	1.1096	0.6365	7.0362	0.079	0.3924	0.7973	0.0086	0	0.0182	0.3306	0.7424
DOT1.5_3	31	230215	99.9505	17.0266	0.6269	2.2589	68.57	0.0968	1.0712	0.6634	7.1363	0.0566	0.5235	0.7058	0	0.0112	0.0654	0.3611	0.826
DOT1.5_4	32	230215	100.4044	17.0371	0.6433	2.242	68.7514	0.088	1.0956	0.7173	7.0511	0.0763	0.4631	0.8087	0.0043	0.0159	0	0.3313	0.6746
DOT1.5_5	33	230215	99.7777	17.067	0.6038	2.228	68.8935	0.1383	1.0461	0.6285	6.9669	0.0736	0.4304	0.7883	0	0	0	0.3306	0.8051
DOT1.6_1	34	230215	100.1166	19.5084	1.0437	2.3869	65.5245	0.0751	1.3817	0.6244	6.3487	0.2896	1.5213	1.2639	0	0	0.0015	0.0132	0.0172
DOT1.6_2	35	230215	100.0176	19.5072	0.9505	2.4241	65.9116	0.0704	1.3008	0.6203	6.3917	0.2271	1.495	1.0101	0	0.0913	0	0	0
DOT1.6_3	36	230215	99.7421	19.0579	1.0585	2.5244	65.9676	0.1254	1.3224	0.5895	6.3013	0.2733	1.5782	1.0933	0	0.0176	0	0.0273	0.0633
DOT1.6_4	37	230215	99.6959	18.9643	1.0062	2.3872	66.4369	0.091	1.2674	0.6558	6.2893	0.2944	1.4406	1.0669	0	0.0337	0.0299	0.0365	0
DOT1.7_1	38	230215	99.5769	18.5381	0.5789	2.1306	68.5578	0.0716	1.2036	0.5854	6.3869	0.0927	0.2409	0.9699	0.0071	0.0467	0.0012	0.5438	0.0447
DOT1.7_2	39	230215	99.4557	18.4761	0.557	2.1411	68.9236	0.1128	1.0918	0.5318	6.2204	0.0862	0.3026	0.9983	0	0.0403	0.0095	0.5086	0
DOT1.7_3	40	230215	100.2543	18.3687	0.5414	2.1595	68.9196	0.1227	1.174	0.6038	6.1935	0.0882	0.2684	0.9988	0.0014	0.0224	0	0.5135	0.024
DOT1.7_4	41	230215	99.5553	18.2267	0.551	2.1573	68.9763	0.0923	1.2136	0.5891	6.234	0.0986	0.2211	1.0235	0	0	0	0.5292	0.0874
DOT1.8_1	42	230215	99.7994	19.4035	1.0192	2.4272	65.5882	0.0837	1.2661	0.6276	6.1809	0.3135	1.8219	1.1928	0.0257	0	0.0095	0.0403	0
DOT1.8_2	43	230215	100.1804	19.581	1.031	2.4373	65.6688	0.1043	1.265	0.6571	6.1872	0.2832	1.7142	1.0385	0.0199	0	0.0104	0.002	0
DOT1.8_3	44	230215	100.3907	19.4286	1.0813	2.4654	65.8024	0.1103	1.2115	0.6239	6.1086	0.2883	1.8082	1.0442	0	0	0	0.0274	0
DOT1.8_4	45	230215	99.5335	19.5349	0.9837	2.3416	65.8333	0.0817	1.2133	0.6612	6.2788	0.2963	1.6759	1.0671	0	0	0	0.0323	0

Label	No.	Date	Total	Na2O	MgO	Al2O3	SiO2	P2O5	Cl	K2O	CaO	TiO2	MnO	Fe2O3	CoO	CuO	SnO2	Sb2O5	PbO
DOT1.9_1	46	230215	98.9553	12.4545	1.4118	1.0607	70.8387	0	0.1105	0.4006	13.0242	0.0296	0.1815	0.3132	0.1039	0	0.0238	0.0176	0.0295
DOT1.9_2	47	230215	98.6796	12.799	1.3847	1.1195	70.3941	0.0634	0.1261	0.4002	13.0902	0.0442	0.0502	0.2451	0.0145	0.0179	0	0	0.2509
DOT1.9_3	48	230215	98.3925	12.636	1.426	1.0683	70.8884	0.0735	0.115	0.3612	12.8428	0.0384	0.1714	0.2903	0.045	0	0.0106	0	0.033
DOT1.9_4	49	230215	98.8079	12.6398	1.3564	1.0646	70.8644	0.0642	0.0941	0.39	12.7274	0.0424	0.1626	0.2908	0.0996	0.026	0.053	0.0086	0.1161
DOT1.10_1	50	230215	99.4868	14.1335	0.5442	2.4492	71.9326	0.0658	1.3607	0.4389	8.1626	0.021	0.5922	0.264	0.0258	0	0	0	0.0095
DOT1.10_2	51	230215	100.4246	14.2748	0.4702	2.4994	71.5879	0.1459	1.299	0.3885	8.3486	0.0698	0.4511	0.3666	0.0341	0	0.052	0	0.0122
DOT1.10_3	52	230215	99.9164	14.2215	0.5026	2.4186	71.8402	0.1305	1.3048	0.3911	8.2939	0.0611	0.4684	0.3173	0.0243	0.0097	0	0.016	0
DOT1.10_4	53	230215	94.328	14.2557	0.5158	2.5055	71.6483	0.12	1.3413	0.4915	8.2865	0.0531	0.4074	0.3395	0	0.0239	0.0117	0	0
DOT1.11_1	54	230215	99.4395	17.0273	0.3371	2.5085	69.8335	0.0829	1.5026	0.4836	7.6208	0.0403	0.1732	0.2789	0.0258	0.021	0	0.0075	0.0569
DOT1.11_2	55	230215	100.5136	17.1538	0.4162	2.4571	69.742	0.0991	1.5105	0.5006	7.4065	0.0514	0.2543	0.251	0.0057	0.0192	0	0.0292	0.1034
DOT1.11_3	56	230215	100.1426	16.7003	0.3941	2.6055	70.0805	0.1527	1.5083	0.5014	7.3979	0.0226	0.1605	0.3299	0.0243	0.0209	0	0.0226	0.0787
DOT1.11_4	57	230215	40.4625	18.6185	0.3972	2.2606	67.8436	0.127	1.7102	0.473	7.9118	0.0452	0.1624	0.3603	0.0069	0.0833	0	0	0
DOT9.1_1	58	230215	100.3812	16.4765	0.5664	2.5241	70.0048	0.0773	1.0804	0.7185	6.9103	0.0722	0.588	0.5275	0.0156	0.0368	0	0.3396	0.0621
DOT9.1_2	59	230215	100.7402	16.445	0.5735	2.5989	69.9188	0.1224	1.0949	0.7437	7.039	0.0869	0.5901	0.4676	0.0057	0.0159	0	0.2978	0
DOT9.1_3	60	230215	101.121	16.7476	0.5608	2.5469	69.5601	0.1458	1.1006	0.7366	6.9433	0.1087	0.5812	0.5893	0	0	0.0383	0.3409	0
DOT9.1_4	61	230215	100.6813	16.4016	0.5295	2.499	69.7679	0.1776	1.1211	0.7545	7.1738	0.0927	0.5206	0.5552	0.0071	0.0191	0.015	0.2797	0.0859
DOT9.2_1	62	230215	99.6558	8.8488	6.2625	1.5836	66.514	1.0483	0.5213	4.1125	10.253	0.0605	0.0705	0.5841	0.0028	0.0032	0	0.1116	0.0234
DOT9.2_2	63	230215	99.7017	8.8202	6.2854	1.5767	66.3998	1.1365	0.4943	4.094	10.3708	0.1034	0.0419	0.4671	0.0114	0.0064	0.0129	0.1311	0.0479
DOT9.2_3	64	230215	99.8723	8.8727	6.3034	1.512	66.7345	1.1217	0.5243	3.8854	10.0558	0.0922	0.0755	0.6941	0	0	0.0032	0.1251	0
DOT9.2_4	65	230215	84.8996	8.873	6.3647	1.5424	65.3407	1.1359	1.0084	4.3319	10.368	0.1551	0.0006	0.6333	0.057	0.1058	0.0016	0.0815	0
DOT9.3_4	66	230215	100.9256	15.8086	0.4346	2.1678	71.9937	0.0839	1.4862	0.4655	6.9668	0.0323	0.1586	0.3492	0	0	0.0527	0	0
DOT9.3_1	67	230215	101.4958	15.9983	0.5013	2.2275	71.4367	0.0962	1.4593	0.4231	7.1309	0.0485	0.1727	0.3015	0.0225	0.0744	0.0529	0.0272	0.0272
DOT9.3_2	68	230215	100.491	15.814	0.4366	2.2601	72.1768	0.0871	1.4728	0.4357	6.8651	0.0648	0.0893	0.2979	0	0	0	0	0
DOT9.3_3	69	230215	100.8543	15.7784	0.5423	2.1602	72.2044	0.1119	1.4645	0.3604	6.899	0.0614	0.0274	0.2945	0.0128	0.0414	0.0002	0	0.0412
DOT9.4_1	70	230215	100.5729	16.7048	0.5209	2.3002	70.1931	0.1294	1.2667	0.7252	6.7086	0.0911	0.4842	0.5128	0.0014	0.1309	0.0025	0.2093	0.019
DOT9.4_2	71	230215	100.8053	17.192	0.5841	2.4085	69.4529	0.2108	1.2107	0.7656	6.6901	0.0578	0.4425	0.5195	0	0.1209	0	0.2535	0.091
DOT9.4_3	72	230215	100.6077	16.9	0.5937	2.4242	69.7436	0.1892	1.2951	0.7464	6.5812	0.0977	0.4491	0.6147	0.0141	0.0367	0	0.2448	0.0697
DOT9.4_4	73	230215	101.3341	17.026	0.6189	2.3681	69.8294	0.1549	1.2146	0.7744	6.5869	0.0922	0.4802	0.5084	0.007	0.0397	0.0396	0.1992	0.0605
DOT9.5_1	74	230215	101.6584	17.8891	0.6101	2.1547	69.375	0.1109	1.1707	0.5722	6.2915	0.0797	0.2222	0.9759	0	0.0443	0	0.5038	0
DOT9.5_2	75	230215	100.5333	17.3666	0.5382	2.1954	70.09	0.0663	1.0863	0.5968	6.204	0.0737	0.1988	0.9731	0.0227	0	0	0.5282	0.0598
DOT9.5_3	76	230215	101.5331	17.8676	0.5304	2.1962	69.3464	0.0741	1.1975	0.5709	6.281	0.109	0.2338	0.9386	0	0	0	0.5708	0.0835
DOT9.5_4	77	230215	101.7002	17.9098	0.5565	2.2086	69.4467	0.0765	1.1586	0.5884	6.1552	0.0475	0.2083	1.0063	0.0085	0.0442	0	0.5417	0.0432
DOT9.5_5	78	230215	154.1799	0	5.9427	92.9881	0.0659	0	0.0243	0.0462	0.0891	0.0335	0.6005	0.0665	0	0.1119	0	0.0315	0
DOT9.6_1	79	230215	100.5346	18.0036	0.4995	1.9367	68.9533	0.0787	1.382	0.5258	6.0143	0.0621	0.2099	1.6092	0	0	0.0208	0.7041	0
DOT9.6_2	80	230215	100.8035	18.0984	0.5522	1.9739	68.5846	0.0694	1.3963	0.4985	5.9658	0.0297	0.306	1.7241	0	0.0541	0.0118	0.724	0.0112
DOT9.6_3	81	230215	100.819	17.783	0.4941	1.9524	69.2777	0.0494	1.3602	0.5263	6.0645	0.0728	0.2339	1.3877	0	0	0.028	0.7701	0

Label	No.	Date	Total	Na2O	MgO	Al2O3	SiO2	P2O5	Cl	K2O	CaO	TiO2	MnO	Fe2O3	CoO	CuO	SnO2	Sb2O5	PbO
DOT9.6_4	82	230215	101.4313	17.9162	0.4776	2.0484	68.7375	0.0903	1.3881	0.5635	6.0622	0.0476	0.2142	1.7573	0	0.0143	0.0155	0.659	0.0083
DOT9.7_1	83	230215	100.4962	18.3898	0.8886	2.4841	66.7626	0.0925	1.3336	0.745	6.5366	0.2182	1.4262	1.062	0	0.0431	0.0176	0	0
DOT9.7_2	84	230215	99.7445	18.5076	0.9454	2.4535	67.057	0.1167	1.2754	0.7284	6.3099	0.251	1.3674	0.8965	0	0.0322	0.0416	0.0174	0
DOT9.7_3	85	230215	100.7377	18.612	0.9557	2.4267	66.8251	0.1017	1.2715	0.7115	6.567	0.2432	1.2037	0.8556	0	0.0846	0.0408	0.0413	0.0597
DOT9.7_4	86	230215	63.8	17.8669	0.9629	2.3918	65.2202	0.0013	1.4342	0.7876	8.9368	0.2212	1.2368	0.9149	0	0	0	0	0.0254
DOT9.8_1	87	230215	100.5296	15.8489	0.4868	2.5101	70.5621	0.1668	1.3809	0.6943	7.5231	0.0707	0.3969	0.3278	0	0	0.0035	0.0076	0.0206
DOT9.8_2	88	230215	101.0783	15.9807	0.5904	2.568	70.2905	0.2082	1.411	0.6701	7.3351	0.0826	0.4409	0.3389	0	0.0175	0.0006	0.0063	0.0592
DOT9.8_3	89	230215	100.6619	16.1002	0.5064	2.4674	70.379	0.1528	1.3176	0.6642	7.5391	0.0581	0.4688	0.2904	0	0	0.0096	0.0286	0.0178
DOT9.8_4	90	230215	101.4522	16.0753	0.5325	2.5066	70.2048	0.203	1.2885	0.6788	7.6385	0.0322	0.428	0.2912	0	0.0381	0.042	0	0.0406
DOT9.10_1	91	230215	99.9333	11.371	0.9726	1.0034	72.5648	0.009	0.0896	0.4057	12.6908	0.0663	0.0987	0.3691	0	0.0547	0.0345	0.0169	0.2529
DOT9.11_1	92	230215	101.2862	17.7565	0.4602	1.9803	68.9641	0.019	1.5003	0.5075	5.8538	0.0633	0.2461	1.8567	0	0.0159	0	0.7192	0.0571
DOT9.11_2	93	230215	101.0929	18.0869	0.5285	2.045	68.6368	0.0621	1.4352	0.5228	6.0205	0.0569	0.1848	1.557	0	0.0302	0.0696	0.6559	0.1078
DOT9.11_3	94	230215	100.5844	18.1158	0.4983	1.9884	68.9714	0.083	1.4195	0.5442	5.977	0.067	0.2453	1.4099	0	0	0.0001	0.6801	0
DOT9.11_4	95	230215	100.2484	17.9223	0.481	1.9882	69.1519	0.0985	1.4067	0.5567	6.0677	0.0582	0.2451	1.4355	0	0	0.0139	0.5744	0
DOT9.10_2	96	230215	100.4663	11.647	0.9815	0.9748	72.506	0.0654	0.0669	0.4319	12.3104	0.0702	0.151	0.3837	0.0014	0	0	0	0.4099
DOT9.10_3	97	230215	100.4503	11.8361	0.9679	0.9898	72.1869	0.0815	0.0653	0.4247	12.4785	0.0467	0.164	0.354	0.017	0	0.0085	0.0465	0.3325
DOT9.10_4	98	230215	100.3817	11.4424	0.9415	1.0821	72.7069	0.0413	0.0788	0.4106	12.4153	0.0493	0.1115	0.4197	0	0	0	0	0.3006
DOT9.9_1	99	230215	101.0853	16.878	0.5984	2.189	68.4793	0.0747	1.2876	0.5838	6.6718	0.0871	0.4306	2.1869	0	0.0158	0.0121	0.382	0.123
DOT9.9_2	100	230215	100.8758	17.0187	0.5655	2.2206	68.5289	0.094	1.3175	0.684	6.5869	0.0939	0.3774	1.9942	0	0.0444	0.0189	0.4551	0
DOT9.9_3	101	230215	100.9145	16.9284	0.5531	2.2605	68.9955	0.0711	1.2677	0.6254	6.5368	0.0725	0.4116	1.8657	0	0	0	0.3457	0.0657
DOT9.9_4	102	230215	100.2813	16.934	0.5183	2.2071	68.8097	0.0983	1.2623	0.6276	6.623	0.073	0.3964	2.0122	0	0.0288	0	0.3751	0.034
DOT9.12_1	103	230215	100.6231	15.6283	0.6472	2.6458	69.5998	0.1367	1.0661	1.0111	6.7653	0.0976	0.2737	1.6083	0.0014	0.0143	0	0.3857	0.1187
DOT9.12_2	104	230215	100.173	15.8357	0.6069	2.5487	69.7929	0.1436	0.7805	1.0182	6.9499	0.0715	0.2735	1.4792	0	0	0.0119	0.3945	0.0929
DOT9.12_3	105	230215	101.7265	16.0398	0.5991	2.5689	69.3513	0.1394	1.1273	0.9968	6.7485	0.0672	0.2835	1.5803	0	0	0.0259	0.4212	0.0508
DOT9.12_4	106	230215	102.7178	13.8717	0.9901	10.7678	64.1525	0.1031	1.0466	0.8806	6.0565	0.1038	0.2987	1.3104	0.018	0.0172	0.0031	0.3801	0
DOT9.13_1	107	230215	100.2307	18.3427	0.6046	2.1382	69.1122	0.0528	1.4292	0.5686	6.1593	0.039	0.2926	0.4873	0.0071	0.0687	0.0294	0.5849	0.0835
DOT9.13_2	108	230215	100.8045	18.1004	0.7087	2.1103	68.9727	0.1402	1.4568	0.5673	6.3015	0.0842	0.3243	0.4358	0	0.0541	0	0.6364	0.1073
DOT9.13_3	109	230215	100.7703	18.2983	0.6743	2.1201	68.7923	0.1369	1.4936	0.6144	6.3955	0.0496	0.1925	0.572	0.0269	0.016	0.0011	0.6165	0
DOT9.13_4	110	230215	100.6712	18.4843	0.6335	2.1362	68.6462	0.0752	1.4802	0.5798	6.3778	0.0686	0.4116	0.481	0	0	0.0035	0.6027	0.0194
DOT6.1_1	114	230215	100.716	19.2642	0.9863	2.2439	65.3897	0.0697	1.4654	0.5375	6.9584	0.2695	1.5773	1.1895	0	0	0.0143	0.0344	0
DOT6.1_2	115	230215	100.2364	18.8667	0.8861	2.3109	66.2193	0.0649	1.342	0.6448	7.0288	0.1958	1.4673	0.9254	0.0256	0	0.0139	0.0084	0
DOT6.1_3	116	230215	100.2265	18.9028	0.81	2.347	66.1352	0.0859	1.3771	0.6021	7.0102	0.2249	1.4947	0.9526	0.0014	0.0561	0	0	0
DOT6.1_4	117	230215	100.4253	18.8415	0.9428	2.2887	66.0284	0.0503	1.4708	0.5703	6.8736	0.2444	1.6419	0.9868	0.0057	0	0	0.055	0
DOT6.2_1	118	230215	98.925	7.408	4.6074	2.5957	62.4966	1.4379	0.5458	6.5869	11.1067	0.1385	0.475	1.4102	0.0358	0	0	0.1735	0.9821
DOT6.2_2	119	230215	99.2404	7.3736	4.5298	2.5321	62.9786	1.4424	0.548	6.4698	10.9267	0.139	0.5106	1.4842	0	0.0032	0	0.2295	0.8325
DOT6.2_3	120	230215	99.35	7.2251	4.4903	2.587	62.8807	1.4401	0.5389	6.7137	10.9752	0.1303	0.5197	1.4384	0	0.0224	0	0.2319	0.8061

Label	No.	Date	Total	Na2O	MgO	Al2O3	SiO2	P2O5	Cl	K2O	CaO	TiO2	MnO	Fe2O3	CoO	CuO	SnO2	Sb2O5	PbO
DOT6.2_4	121	230215	100.0442	7.3798	4.6702	2.6568	62.5666	1.478	0.5552	6.5645	10.9152	0.0961	0.5068	1.4715	0.0269	0	0	0.1938	0.9185
DOT6.3_1	122	230215	100.012	19.0446	1.0081	2.4451	65.4923	0.0405	1.3155	0.5306	6.502	0.3402	1.782	1.2587	0.0511	0.0176	0.0409	0.0224	0.1083
DOT6.3_2	123	230215	99.9329	18.8507	0.9779	2.4575	66.2519	0.0719	1.2875	0.6331	6.3466	0.2935	1.7236	1.0612	0	0.008	0	0.0271	0.0095
DOT6.3_3	124	230215	99.961	18.8551	0.8931	2.4726	66.1048	0.0655	1.2883	0.6298	6.4548	0.2727	1.7036	1.1168	0	0.0528	0	0.0174	0.0726
DOT6.3_4	125	230215	100.0315	18.7499	1.038	2.5325	66.0799	0.0399	1.3157	0.6297	6.3879	0.3512	1.6768	1.1343	0.0327	0.0144	0	0	0.0172
DOT6.4_1	126	230215	91.7645	18.423	1.0511	2.4157	66.4007	0.0947	1.5888	0.5521	6.6405	0.2322	1.5055	1.0538	0	0.0418	0	0	0
DOT6.4_2	127	230215	100.8416	19.3069	1.0435	2.2928	65.9539	0.0856	1.4348	0.5588	6.5279	0.2371	1.5382	0.9645	0.0183	0	0	0.0059	0.0317
DOT6.4_3	128	230215	100.7771	19.3509	1.0372	2.2574	65.8926	0.0873	1.3997	0.4889	6.591	0.2065	1.5103	1.0769	0	0.0381	0	0.0631	0
DOT6.4_4	129	230215	100.5075	19.0999	0.9832	2.3679	66.1612	0.0713	1.4319	0.5668	6.4735	0.2153	1.6493	0.9383	0.0099	0	0	0.0096	0.0217
DOT6.5_1	130	230215	101.0984	19.1015	1.0508	2.2993	65.9017	0.0598	1.4491	0.5073	6.6388	0.2471	1.6312	0.9855	0.0521	0.0286	0	0.0118	0.0354
DOT6.5_2	131	230215	100.4581	18.9954	1.1071	2.295	66.042	0.0644	1.437	0.5097	6.5822	0.2184	1.539	1.0523	0	0.0766	0	0.0261	0.0547
DOT6.5_3	132	230215	100.3911	18.8955	1.089	2.4157	65.7977	0.0879	1.4314	0.5492	6.6425	0.232	1.6276	1.0768	0	0.0558	0.0095	0	0.0895
DOT6.5_4	133	230215	100.3157	18.8729	1.0407	2.3249	65.967	0.1267	1.3804	0.555	6.7177	0.2595	1.5926	1.1255	0.0198	0	0.0086	0.0086	0
DOT6.5_5	134	230215	3.9957	18.4048	0.4505	1.6242	66.4414	0.0476	3.5438	0.8059	3.4162	0.3929	1.3665	2.1298	0	1.1212	0	0.2553	0
DOT6.6_1	135	230215	100.1596	2.2743	2.2622	5.536	59.3419	0.9782	0.4594	2.9743	24.0588	0.2045	0.2781	1.4927	0	0.0255	0	0.0726	0.0417
DOT6.6_2	136	230215	99.7739	2.2667	2.2208	5.4892	59.526	0.8611	0.4273	2.999	24.137	0.2303	0.2911	1.3598	0	0.099	0.0126	0.016	0.064
DOT6.6_3	137	230215	99.7024	2.3816	2.363	5.4775	58.9461	0.9107	0.4548	3.0315	24.3006	0.2373	0.1693	1.4032	0.0369	0.0256	0.0314	0.0754	0.1551
DOT6.6_4	138	230215	99.6024	2.2271	2.423	5.6183	59.3124	0.9467	0.4238	2.9341	24.0827	0.2121	0.2528	1.5348	0	0	0	0.0159	0.0164
DOT6.7_1	139	230215	100.273	18.6235	0.9162	2.3325	66.2645	0.099	1.3305	0.5741	6.8726	0.2542	1.465	1.0314	0	0.04	0.0554	0.0071	0.1339
DOT6.7_2	140	230215	100.536	18.8477	1.0599	2.3513	66.274	0.0263	1.3294	0.5748	6.6458	0.2087	1.513	0.9777	0	0	0.0497	0.0516	0.0902
DOT6.7_3	141	230215	100.6863	18.6415	1.013	2.3502	66.6533	0.0879	1.3266	0.5391	6.5421	0.2034	1.5339	1.0243	0	0.0095	0.02	0.0303	0.025
DOT6.7_4	142	230215	101.0383	18.9432	0.9965	2.2265	66.302	0.0848	1.3578	0.5643	6.719	0.2126	1.55	0.9376	0	0.0238	0.0226	0.0594	0
DOT6.8_1	143	230215	100.8203	18.8844	0.9862	2.3382	66.2706	0.1103	1.2771	0.6274	6.6084	0.2199	1.5582	1.0665	0.031	0.019	0.0028	0	0
DOT6.8_2	144	230215	100.2757	18.6138	0.9464	2.3825	66.6281	0.1265	1.3298	0.5621	6.5514	0.2142	1.5037	1.091	0	0.0287	0	0	0.0218
DOT6.8_3	145	230215	100.5217	18.6682	0.9763	2.3346	66.6838	0.0584	1.3518	0.5873	6.55	0.2385	1.4233	1.0325	0	0.0111	0	0.0116	0.0724
DOT6.8_4	146	230215	100.8419	18.8839	1.0089	2.3092	66.3435	0.1057	1.3135	0.5966	6.6385	0.2772	1.5367	0.9678	0.0127	0.0032	0.0028	0	0
DOT6.9_1	147	230215	100.1959	19.0733	1.0374	2.5733	65.4578	0.0274	1.3599	0.5769	6.3528	0.311	1.8963	1.1693	0	0.035	0.0104	0.0014	0.1179
DOT6.9_2	148	230215	100.7423	19.4217	1.0226	2.5376	65.2894	0.1028	1.2718	0.5807	6.411	0.2917	1.8081	1.1559	0	0.0238	0.0096	0	0.0733
DOT6.9_3	149	230215	100.5891	18.9077	1.0954	2.4931	65.8839	0.0784	1.2615	0.618	6.2909	0.3083	1.7878	1.2298	0.0169	0.0095	0	0.0072	0.0116
DOT6.9_4	150	230215	100.2797	19.1085	0.9572	2.4721	65.6183	0.1531	1.2953	0.6304	6.4151	0.2986	1.8158	1.1807	0	0	0	0	0.055
DOT6.10_1	151	230215	101.0265	18.8808	0.9153	2.3376	66.0199	0.0601	1.5052	0.5639	6.8355	0.2091	1.6072	0.9421	0.0211	0	0	0.0425	0.0597
DOT6.10_2	152	230215	101.3863	18.7025	0.9469	2.2161	66.2136	0.0887	1.4536	0.6005	6.948	0.2225	1.5359	0.9961	0.0266	0	0.0043	0	0.0447
DOT6.10_3	153	230215	101.0497	18.6583	0.9184	2.4033	66.4344	0.1096	1.5035	0.5666	6.8082	0.1856	1.4789	0.8643	0	0	0	0.0689	0
DOT6.10_4	154	230215	100.3999	18.4613	0.8811	2.3273	66.7492	0.0915	1.4828	0.5433	6.8731	0.1667	1.4523	0.8985	0	0	0	0.0592	0.0137
DOT6.11_1	155	230215	100.9125	19.2484	1.1631	2.1734	65.5966	0	1.5871	0.386	7.3423	0.1699	1.6303	0.6254	0.0155	0.0476	0	0.0145	0
DOT6.11_2	156	230215	100.6646	18.7759	1.0839	2.327	65.9905	0.0341	1.5593	0.4137	7.158	0.1426	1.6393	0.7462	0	0.0683	0.0022	0.0268	0.0321

Label	No.	Date	Total	Na2O	MgO	Al2O3	SiO2	P2O5	Cl	K2O	CaO	TiO2	MnO	Fe2O3	CoO	CuO	SnO2	Sb2O5	PbO
DOT6.11_3	157	230215	100.998	19.0768	1.1719	2.2153	65.7713	0.0388	1.7225	0.3819	7.1932	0.129	1.5885	0.6626	0.024	0.0032	0	0	0.021
DOT6.11_4	158	230215	101.5729	18.9716	1.114	2.2376	65.6877	0.037	1.5932	0.41	7.1674	0.1235	1.9	0.6756	0.0281	0	0.0312	0.0232	0
DOT6.12_1	159	230215	100.1257	18.776	0.9616	2.4248	66.4183	0.1092	1.2829	0.6065	6.4336	0.2679	1.6707	1.0235	0.0043	0.0208	0	0	0
DOT6.12_2	160	230215	100.2852	18.8255	0.9494	2.366	65.9634	0.0995	1.4238	0.6088	6.6453	0.2665	1.7154	1.0802	0	0	0	0.0561	0
DOT6.12_3	161	230215	100.3457	18.6624	1.0384	2.4829	66.1503	0.1568	1.1115	0.6234	6.5996	0.2866	1.5784	1.192	0	0.0542	0.0178	0.0456	0
DOT6.12_4	162	230215	100.5382	18.8733	0.9358	2.3913	66.0274	0.1319	1.1076	0.5857	6.6129	0.276	1.6449	1.2752	0	0.035	0.0204	0.0324	0.0499
DOT6.13_1	163	230215	88.737	0.7584	0.1149	0.137	0.4715	42.3269	0.4449	0.01	55.1804	0	0.0833	0.1926	0.0174	0.1502	0	0	0.1125
DOT6.13_2	164	230215	71.0768	0.3607	0.1028	0.0302	0.062	42.1825	0.5268	0.0346	56.4094	0	0.0049	0.178	0	0.1079	0	0	0
DOT6.13_3	165	230215	87.245	0.7008	0.1727	0.1593	0.6567	42.2984	0.4193	0.0049	55.0114	0	0.1009	0.2201	0.0562	0.1994	0	0	0
DOT6.13_4	166	230215	88.1169	0.7007	0.153	0.0743	0.3868	42.1294	0.3347	0.0108	55.7598	0.0348	0.0184	0.1671	0	0.2084	0	0	0.022
DOT6.13_5	167	230215	86.8415	0.6242	0.2593	0.0795	0.3194	42.2538	0.3448	0.0268	55.5368	0	0.0501	0.1834	0	0.2689	0	0	0.053
DOT6.14_1	168	230215	100.5736	19.338	0.9091	2.4216	66.0275	0.0981	1.3337	0.5977	6.3447	0.3029	1.4842	1.048	0.0255	0	0	0.0691	0
DOT6.14_2	169	230215	99.4269	18.9525	1.002	2.3446	66.3354	0.1162	1.3471	0.6332	6.4316	0.3031	1.4946	0.9523	0.0071	0.0338	0.004	0.0424	0
DOT6.14_3	170	230215	100.2542	18.8298	0.9255	2.3886	66.6858	0.0947	1.3585	0.5914	6.5154	0.235	1.4975	0.8771	0	0	0	0	0.0006
DOT6.14_4	171	230215	100.6794	18.9485	0.9773	2.355	66.3485	0.0985	1.3472	0.5985	6.4493	0.2532	1.5848	0.9808	0.0043	0	0.007	0.0471	0
DOT6.15_3	172	230215	100.0955	18.4799	1.2894	2.5884	64.4296	0.1049	1.295	0.4941	6.4676	0.3985	2.7427	1.6684	0	0	0.0247	0	0.0169
DOT6.15_4	173	230215	100.211	18.6953	1.248	2.5153	64.4727	0.0683	1.2575	0.4946	6.695	0.4029	2.6475	1.5002	0.0028	0	0	0	0
DOT6.15_1	174	230215	100.3879	18.3292	1.2355	2.513	64.4506	0.1091	1.3238	0.46	6.7018	0.4108	2.7243	1.7349	0.0071	0	0	0	0
DOT6.15_2	175	230215	99.4253	18.2517	1.4089	2.6807	64.4387	0.0681	1.2525	0.4746	6.416	0.4384	2.686	1.7687	0	0	0.0156	0.0423	0.0577
DOT6.16_1	176	230215	100.8771	18.5752	1.0059	2.6254	66.6773	0.0954	1.4633	0.444	5.7414	0.3017	1.8224	1.1256	0	0.0871	0.0354	0	0
DOT6.16_2	177	230215	100.9522	18.6046	1.0407	2.6481	66.4193	0.0581	1.4433	0.413	5.7575	0.3299	1.9202	1.3089	0	0.0222	0	0	0.0343
DOT6.16_3	178	230215	100.6297	18.5509	1.0227	2.5319	66.5953	0.0912	1.424	0.4143	5.776	0.3363	1.967	1.2356	0	0.0016	0.0147	0	0.0385
DOT6.16_4	179	230215	101.6047	18.7018	1.0273	2.5236	66.5802	0.0158	1.4819	0.4139	5.7715	0.2855	1.8626	1.2221	0.014	0.0647	0.0077	0.0197	0.0078
DOT7.1_1	184	230215	99.6346	17.2888	1.1214	2.9756	65.926	0.096	1.1908	0.4716	5.7771	0.5202	2.2811	2.328	0	0	0	0.0061	0.0174
DOT7.1_2	185	230215	100.2859	17.7363	1.1012	2.7399	65.7577	0.0944	1.1854	0.4581	6.0948	0.4989	2.378	1.8686	0.0226	0	0.0054	0.0588	0
DOT7.1_3	186	230215	99.2701	17.5165	1.087	2.928	65.5899	0.0002	1.2037	0.4581	6.0823	0.5064	2.3793	2.1524	0.03	0	0	0.0662	0
DOT7.1_4	187	230215	99.7666	17.3593	1.0569	2.9871	65.928	0.0193	1.2196	0.5862	5.6638	0.5335	2.5878	1.8686	0	0.0192	0.0639	0.1066	0
DOT7.2_1	188	230215	101.3153	19.0493	0.7918	1.9155	67.608	0.0774	1.562	0.2503	6.1914	0.1308	1.6376	0.7574	0	0	0	0.0117	0.0169
DOT7.2_2	189	230215	100.813	19.1936	0.7924	1.7778	67.8385	0.0572	1.5895	0.2747	6.1861	0.1046	1.3404	0.7373	0.0424	0.0541	0.0116	0	0
DOT7.2_3	190	230215	100.8226	18.9309	1.0397	1.8197	67.7927	0.0917	1.6509	0.269	6.0578	0.1233	1.4729	0.7005	0.0508	0	0	0	0
DOT7.2_4	191	230215	101.0373	19.2336	0.8738	1.8683	67.7285	0.0435	1.6075	0.278	6.1675	0.0845	1.4495	0.6478	0	0.0174	0	0	0
DOT7.3_1	192	230215	99.6572	16.8666	0.5971	2.359	69.5299	0.1912	1.2795	0.6913	6.9318	0.061	0.4436	0.5896	0	0.008	0.0327	0.3404	0.0783
DOT7.3_2	193	230215	100.2701	17.0141	0.6578	2.3376	69.09	0.1163	1.1538	0.7014	7.127	0.0964	0.4885	0.6026	0	0.048	0.0448	0.4092	0.1125
DOT7.3_3	194	230215	100.8206	17.0757	0.579	2.27	69.1469	0.1905	1.1644	0.6549	6.9567	0.0982	0.6651	0.6684	0	0	0.0604	0.4324	0.0373
DOT7.3_4	195	230215	100.9874	17.1593	0.6681	2.3169	68.9981	0.1879	1.2529	0.7132	7.0387	0.0966	0.4639	0.5474	0.0198	0	0.0812	0.3536	0.1023
DOT7.4_1	196	230215	101.2039	19.391	1.1991	2.3465	66.2972	0.059	1.373	0.4658	5.4858	0.4384	1.6653	1.2489	0	0	0.0301	0	0

Label	No.	Date	Total	Na2O	MgO	Al2O3	SiO2	P2O5	Cl	K2O	CaO	TiO2	MnO	Fe2O3	CoO	CuO	SnO2	Sb2O5	PbO
DOT7.4_2	197	230215	100.6407	19.1011	1.0408	2.3199	66.4072	0.0384	1.3918	0.4716	5.5903	0.3696	1.7584	1.3207	0.0141	0.0223	0.0435	0	0.1102
DOT7.4_3	198	230215	100.544	19.0267	1.2102	2.4082	66.5206	0.0312	1.424	0.4363	5.5691	0.4089	1.7952	1.1481	0	0	0	0.0215	0
DOT7.4_4	199	230215	100.0147	18.907	1.1953	2.4264	66.3337	0.0211	1.5272	0.4342	5.7234	0.4763	1.8683	1.0085	0.0257	0.0225	0	0.0303	0
DOT7.5_1	200	230215	100.3024	16.5171	1.2529	2.3947	67.2811	0.0582	1.4421	0.4012	6.1466	0.3415	2.8202	1.2587	0	0.0623	0	0	0.0234
DOT7.5_2	201	230215	99.6449	16.3347	1.3566	2.4308	67.0907	0.0564	1.4516	0.4058	6.0858	0.3986	2.829	1.3793	0.0014	0.1171	0.0045	0.002	0.0555
DOT7.5_3	202	230215	99.7538	16.8391	1.3034	2.3064	66.9971	0.1317	1.3943	0.3506	6.1423	0.376	2.8472	1.2609	0	0.0241	0	0	0.0269
DOT7.5_4	203	230215	99.6963	16.3402	1.3215	2.3596	67.2271	0.0931	1.3941	0.401	6.1271	0.3769	2.8871	1.4354	0	0.0321	0.0048	0	0
DOT7.6_1	204	230215	99.9163	20.4826	0.9075	2.3035	64.8678	0.1155	1.3002	0.5775	6.0256	0.2995	1.7176	1.1758	0	0.0674	0.1032	0.0362	0.0201
DOT7.6_2	205	230215	100.3042	19.7366	0.9589	2.2936	65.4274	0.0649	1.4264	0.6055	6.4562	0.2634	1.605	1.0987	0	0.0352	0	0.0129	0.0156
DOT7.6_3	206	230215	100.1626	19.8708	0.8856	2.3887	65.5042	0.1017	1.3244	0.6329	6.2119	0.2609	1.6299	1.1362	0.0299	0	0.008	0	0.015
DOT7.6_4	207	230215	100.1634	20.3123	0.9707	2.3991	64.7488	0.0643	1.3743	0.5894	6.2964	0.2851	1.6646	1.2226	0	0	0	0.0558	0.0166
DOT7.7_1	208	230215	100.5696	19.304	1.0947	2.3574	65.0074	0.1303	1.3766	0.5795	6.8866	0.2706	1.5717	1.2921	0	0.0334	0.0121	0.0036	0.08
DOT7.7_2	209	230215	98.2483	19.1125	0.9943	2.3319	65.7499	0.0631	1.303	0.4894	6.9965	0.2025	1.7135	1.0198	0	0	0	0.0235	0
DOT7.7_3	210	230215	99.9061	19.1955	1.1509	2.4318	65.5015	0.037	1.4463	0.5963	6.0994	0.3554	1.7595	1.3397	0.0014	0.0016	0.0012	0.0211	0.0615
DOT7.7_4	211	230215	100.1042	18.8219	1.1216	2.4502	66.1275	0.1048	1.3687	0.583	6.1704	0.312	1.6072	1.3015	0	0.0064	0	0.0248	0
DOT7.7_5	212	230215	1.4215	4.2631	14.4706	4.1435	21.1396	0	12.522	7.1966	15.5259	2.5536	2.617	5.8248	3.5033	3.9676	0.0141	0	2.2582
DOT7.8_1	213	230215	99.0848	20.9177	0.8768	2.5237	64.1084	0.0931	1.3682	0.7869	5.8254	0.3564	1.8734	1.1947	0.0388	0	0.0342	0	0.0022
DOT7.8_2	214	230215	99.4338	20.8735	0.9452	2.583	64.0535	0.073	1.2358	0.7674	5.9749	0.3959	1.81	1.1878	0	0	0.0347	0	0.0652
DOT7.8_3	215	230215	100.4995	21.3495	0.8575	2.5265	64.1308	0.0809	1.2198	0.634	5.88	0.3358	1.691	1.2942	0	0	0	0	0
DOT7.8_4	216	230215	101.0793	21.0408	0.9002	2.5521	63.8864	0.0522	1.2519	0.7444	5.8845	0.3992	1.8411	1.3053	0	0.0459	0	0.0961	0
DOT7.9_1	217	230215	100.1006	19.3602	0.9297	2.3173	66.3367	0.1166	1.3625	0.5001	6.4133	0.2085	1.4361	0.9105	0.0185	0.0304	0	0.0597	0
DOT7.9_2	218	230215	61.4083	17.0493	0.9793	2.6236	65.2843	0.1925	1.7252	1.2886	7.2463	0.8157	1.5755	0.9984	0.0555	0.0625	0.0236	0.0796	0
DOT7.9_3	219	230215	101.4596	19.193	0.9023	2.3358	66.8371	0.0985	1.3046	0.587	5.7043	0.2487	1.466	1.0557	0.0323	0	0	0.2341	0.0006
DOT7.9_4	220	230215	100.1252	18.9284	1.021	2.4334	66.3226	0.0496	1.2999	0.5996	6.0146	0.333	1.7124	1.2039	0.0085	0	0.0155	0.0337	0.0241
DOT7.10_1	221	230215	99.8628	17.4997	1.1049	3.0004	65.9559	0.093	1.2113	0.483	5.6265	0.5182	2.4963	1.9724	0	0.0384	0	0	0
DOT7.10_2	222	230215	99.9339	17.22	1.0657	2.9487	66.395	0.0984	1.236	0.5452	5.6745	0.5438	2.4142	1.839	0.0184	0	0.0012	0	0
DOT7.10_3	223	230215	100.7338	17.1969	1.0754	2.9843	65.9193	0.0874	1.2807	0.584	5.8351	0.5612	2.4108	2.0411	0	0.0238	0	0	0
DOT7.10_4	224	230215	100.847	17.1627	1.0521	2.8311	66.214	0.1173	1.2317	0.7126	5.9473	0.5396	2.2628	1.8157	0	0.0732	0.0399	0	0
DOT7.11_1	225	230215	99.747	18.9207	1.2527	2.9983	65.647	0.1188	1.3396	0.4231	5.4608	0.5738	1.5478	1.6652	0.0085	0.008	0	0	0.0358
DOT7.11_2	226	230215	99.7929	18.8188	1.2278	3.0761	66.0257	0.0192	1.2762	0.4244	5.3265	0.5926	1.5662	1.6264	0.0199	0	0	0	0
DOT7.11_3	227	230215	100.1996	19.2	1.1719	2.9829	65.9522	0.052	1.4321	0.3505	5.304	0.5681	1.5714	1.3926	0	0.0224	0	0	0
DOT7.11_4	228	230215	100.6269	18.8768	1.1774	2.9258	65.9605	0.0128	1.3106	0.4368	5.3357	0.585	1.5766	1.7738	0	0	0.0283	0	0
DOT7.12_1	229	230215	100.1554	19.2328	1.0071	2.1718	66.2608	0.0989	1.4839	0.5849	6.3904	0.2194	1.5522	0.8376	0.0369	0.0479	0.0252	0.0501	0
DOT7.12_2	230	230215	100.6744	19.259	0.9432	2.3083	66.3823	0.088	1.3663	0.5734	6.344	0.1913	1.5462	0.9526	0	0	0	0.0437	0.0016
DOT7.12_3	231	230215	101.1415	18.9367	0.9139	2.256	66.627	0.0384	1.3847	0.6174	6.295	0.2315	1.6426	0.9315	0.0197	0.0381	0	0.0677	0
DOT7.12_4	232	230215	100.5626	19.2088	1.0349	2.2191	66.4074	0.0845	1.2432	0.6085	6.3941	0.1666	1.4713	0.9273	0.0071	0.0366	0.0319	0.0769	0.0818

Label	No.	Date	Total	Na2O	MgO	Al2O3	SiO2	P2O5	Cl	K2O	CaO	TiO2	MnO	Fe2O3	CoO	CuO	SnO2	Sb2O5	PbO
DOT7.13_1	233	230215	100.0601	19.0137	0.9905	2.4182	66.123	0.1411	1.1617	0.6209	6.5622	0.2618	1.5752	1.0481	0	0.0464	0.0059	0.0314	0
DOT7.13_2	234	230215	99.6322	18.9069	0.9964	2.3903	66.092	0.0989	1.3171	0.653	6.6297	0.2571	1.5018	1.0804	0.0257	0	0.0299	0	0.0208
DOT7.13_3	235	230215	101.1643	19.1592	0.9488	2.4405	65.7804	0.1439	1.2873	0.7071	6.2817	0.2776	1.7118	1.1578	0.0098	0.0474	0.0468	0	0
DOT7.13_4	236	230215	99.8542	18.9005	1.0006	2.4149	66.171	0.0251	1.2362	0.5916	6.588	0.2826	1.5676	1.1565	0	0.0096	0	0.0381	0.0178
DOT7.14_1	237	230215	101.0618	19.0056	1.0828	2.3399	65.1069	0.1111	1.3763	0.4256	7.1926	0.2918	1.6946	1.3117	0	0.0507	0.0054	0.005	0
DOT7.14_2	238	230215	100.7047	19.2172	1.063	2.2917	64.8926	0.1515	1.3951	0.4456	7.1816	0.3372	1.7018	1.1743	0.0057	0	0.0212	0.0021	0.1196
DOT7.14_3	239	230215	100.5068	18.7904	1.0031	2.4001	65.2772	0.1561	1.3788	0.4381	7.28	0.2704	1.7776	1.2243	0	0	0.0039	0	0
DOT7.14_4	240	230215	100.6464	18.7963	1.0749	2.3373	65.1471	0.0908	1.3785	0.4433	7.3102	0.2905	1.8778	1.0765	0	0	0.0181	0.1044	0.0542
DOT7.15_1	241	230215	100.4439	19.4082	0.951	2.3628	65.947	0.0285	1.3303	0.5523	6.2847	0.2636	1.6035	1.1133	0	0	0.0342	0.0422	0.0784
DOT7.15_2	242	230215	100.3345	19.2274	0.9794	2.4299	66.2047	0.0402	1.3152	0.5292	6.21	0.268	1.7609	1.0286	0	0	0.0065	0	0
DOT7.15_3	243	230215	101.2238	19.3516	1.0081	2.436	65.9704	0.1006	1.4156	0.5177	6.217	0.2693	1.5185	1.1521	0	0.0253	0.018	0	0
DOT7.15_4	244	230215	100.6546	19.0048	0.9798	2.3837	66.2802	0.0573	1.4227	0.5288	6.3064	0.2601	1.7358	0.9791	0	0.0445	0	0.0167	0
DOT11.1_1	249	230215	7.3521	0	3.5051	2.383	11.4688	6.9626	0.627	0.5658	68.594	0.219	0.1836	4.343	0	0.3156	0	0	0.8324
DOT11.1_2	250	230215	14.6185	1.0877	2.7616	6.9138	28.3647	6.9686	0.602	1.4694	47.0028	0.1498	0.5308	3.6693	0	0.3434	0	0.1361	0
DOT11.1_3	251	230215	7.5809	0	3.7252	3.8267	13.2135	10.0529	0.9234	1.0817	61.498	0	0.2308	3.8505	0.1095	0.7783	0	0	0.7097
DOT11.1_4	252	230215	7.2481	0.7395	3.5044	1.9991	10.491	6.6279	0.8664	0.5946	68.618	0	1.0182	5.0662	0.1531	0.2566	0	0.0648	0
DOT11.2_1	253	230215	101.7768	0.9287	1.7086	22.6557	55.9732	0.4516	0.0124	2.8872	1.6388	1.0587	0.1825	12.3899	0.0028	0.0016	0	0.0693	0.0393
DOT11.2_2	254	230215	101.143	0.9323	2.0639	20.7132	55.8357	0.3911	0.0007	3.2904	1.3851	1.1388	0.1674	13.9299	0	0.0361	0	0.0539	0.0615
DOT11.2_3	255	230215	96.568	0.825	0.97	12.9171	72.0447	0.2672	0.0333	3.8544	0.9577	1.1772	0.0288	6.7642	0	0.0017	0.0266	0.1234	0.0087
DOT11.2_4	256	230215	101.6266	1.0096	2.0744	19.4321	54.5725	0.4706	0.0036	3.6075	1.2589	0.9728	0.1329	16.2612	0.0317	0.0436	0	0.0473	0.0812
DOT11.3_1	257	230215	100.4047	19.0531	0.9193	2.3953	66.1225	0.0995	1.2175	0.6158	6.268	0.2932	1.9047	1.0489	0.0269	0.0271	0	0	0.0083
DOT11.3_2	258	230215	100.6626	19.1315	0.9563	2.5762	65.6932	0.0999	1.4094	0.6192	6.0919	0.3548	1.8067	1.1739	0	0.027	0.0391	0.0079	0.0127
DOT11.3_3	259	230215	100.8393	19.0479	0.9544	2.4115	66.3943	0.0971	1.2323	0.6169	6.1748	0.2937	1.6384	1.0815	0.0239	0.0333	0	0	0
DOT11.3_4	260	230215	101.1244	18.9496	1.0613	2.5037	65.9614	0.1098	1.2948	0.6246	6.3882	0.3072	1.7517	1.0225	0.0225	0	0.0026	0	0
DOT11.4_1	261	230215	101.2166	17.476	0.5475	2.2676	69.779	0.1305	1.1542	0.5417	6.2766	0.0634	0.1504	0.954	0	0	0.004	0.5655	0.0896
DOT11.4_2	262	230215	100.9254	17.5891	0.5014	2.1559	69.6865	0.1174	1.1575	0.6107	6.3729	0.0741	0.2229	0.9181	0.0127	0.0159	0.0381	0.5123	0.0144
DOT11.4_3	263	230215	100.8685	17.5139	0.5701	2.2354	69.8349	0.1584	1.1507	0.5714	6.1504	0.0642	0.201	0.9759	0	0.0286	0	0.5451	0
DOT11.4_4	264	230215	101.2825	17.5836	0.599	2.2144	69.6941	0.0913	1.1415	0.5642	6.2485	0.0658	0.2861	0.8767	0.0084	0.027	0.0216	0.4881	0.0898
DOT11.5_1	265	230215	100.2218	18.4953	1.0087	2.4381	66.6429	0.1439	1.2482	0.5956	6.3487	0.2679	1.6527	1.0304	0.0525	0.0271	0	0	0.048
DOT11.5_2	266	230215	100.1171	18.3475	0.8999	2.3423	67.3621	0.0437	1.3437	0.6086	6.5789	0.2152	1.4281	0.7531	0.0099	0	0	0.0284	0.0385
DOT11.5_3	267	230215	100.3861	18.4209	0.9251	2.4102	66.7616	0.0948	1.2828	0.5223	6.469	0.2737	1.6435	1.12	0.0198	0.0526	0.0036	0	0
DOT11.5_4	268	230215	100.392	18.7022	0.978	2.3395	66.8356	0.0821	1.2649	0.5808	6.2211	0.2626	1.6924	0.9759	0	0.0128	0	0.0192	0.033
DOT11.6_1	269	230215	101.6671	18.9436	0.7675	2.0183	67.7967	0.1318	1.4176	0.6652	6.222	0.0849	0.9275	0.6459	0.0349	0.0567	0.064	0.1585	0.065
DOT11.6_2	270	230215	100.7581	18.3644	0.8469	2.539	68.2216	0.167	1.2022	0.6608	6.0891	0.1335	0.9371	0.6701	0	0	0	0.0893	0.079
DOT11.6_3	271	230215	93.998	3.3209	0.8501	2.923	81.3859	0.1649	1.5181	0.535	7.0819	0.15	1.116	0.7977	0	0.0445	0	0.0506	0.0614
DOT11.6_4	272	230215	101.2793	18.9283	0.8709	2.1427	67.866	0.1269	1.3586	0.7263	6.2063	0.0271	0.9872	0.6037	0	0.0016	0.0079	0.1134	0.0333

Label	No.	Date	Total	Na2O	MgO	Al2O3	SiO2	P2O5	Cl	K2O	CaO	TiO2	MnO	Fe2O3	CoO	CuO	SnO2	Sb2O5	PbO
DOT11.7_1	273	230215	100.2556	17.6512	0.0031	0.1877	74.665	0	0.3221	0.0442	6.7064	0.0325	0.1384	0.0072	0.0228	0	0.0055	0.214	0
DOT11.7_2	274	230215	99.3102	17.368	0.0473	0.1274	74.8578	0.0094	0.2906	0.0458	6.8658	0.0311	0.0806	0.028	0.0014	0	0	0.2081	0.0388
DOT11.7_3	275	230215	99.8072	17.5502	0.0216	0.239	74.7964	0	0.3088	0.0592	6.6427	0.0293	0.0343	0.0639	0.0043	0.0113	0.0133	0.2256	0
DOT11.7_4	276	230215	99.9707	17.6	0	0.1447	74.6212	0.0314	0.28	0.0595	6.7169	0.0551	0.1409	0.0807	0	0	0	0.25	0.0196
DOT11.8_1	277	230215	101.1048	18.0801	1.0468	2.4226	67.1165	0.0961	1.3738	0.5184	6.2292	0.2372	1.5722	1.1828	0.0084	0.0507	0	0.0157	0.0494
DOT11.8_2	278	230215	100.7057	18.4623	1.013	2.3985	66.983	0.068	1.3916	0.5658	6.2463	0.213	1.608	0.9213	0.0225	0.0461	0.0504	0.0102	0
DOT11.8_3	279	230215	101.4353	18.5937	0.9649	2.3156	67.1249	0.1248	1.4028	0.5555	6.182	0.2123	1.4889	1.0347	0	0	0	0	0
DOT11.8_4	280	230215	100.588	18.5452	0.9749	2.3728	66.8376	0.0808	1.3838	0.5695	6.3879	0.2207	1.626	0.8236	0	0	0.0591	0.0981	0.0201
DOT11.9_1	281	230215	100.9541	19.6598	0.8474	2.3777	66.3989	0.1196	1.327	0.468	6.5539	0.1447	1.2199	0.8012	0	0	0.0121	0.0239	0.046
DOT11.9_2	282	230215	101.0653	19.1859	1.0234	2.3963	66.4139	0.045	1.5778	0.4607	6.1496	0.2214	1.5008	0.9992	0	0	0	0	0.026
DOT11.9_3	283	230215	101.0746	19.9199	0.9765	2.2235	65.9358	0.0446	1.5556	0.5173	6.145	0.1736	1.5266	0.9417	0	0	0.0317	0	0.0082
DOT11.9_4	284	230215	100.5143	19.5881	0.9792	2.352	66.4165	0.0302	1.5812	0.4986	5.9289	0.2075	1.5436	0.8217	0	0	0	0.0303	0.0222
DOT11.10_1	285	230215	101.2917	19.2607	0.5387	1.8543	68.5569	0.045	1.4828	0.512	6.4604	0.1018	0.1534	0.42	0.0028	0	0.0082	0.5488	0.0542
DOT11.10_2	286	230215	101.5525	18.5669	0.5347	1.9728	69.0932	0.0952	1.3832	0.5288	6.4444	0.0894	0.1337	0.4674	0.0547	0	0	0.5549	0.0806
DOT11.10_3	287	230215	101.3025	19.1938	0.6062	2.0171	68.7635	0.0903	1.3765	0.4708	6.2387	0.0411	0.2141	0.4455	0	0.0016	0	0.5316	0.0093
DOT11.10_4	288	230215	101.5934	18.8985	0.5831	1.9903	68.5958	0.0052	1.4129	0.5493	6.4582	0.0597	0.1395	0.6182	0.0056	0	0.0143	0.5916	0.0778
DOT11.11_1	289	230215	100.9692	16.3797	0.5879	2.3764	69.6856	0.1654	1.2224	0.6906	7.1186	0.0824	0.4779	0.6863	0.0028	0.038	0	0.3832	0.1028
DOT11.11_2	290	230215	101.6396	16.5171	0.6123	2.5032	69.3185	0.177	1.107	0.7294	7.0266	0.0877	0.5767	0.8178	0.0014	0.0678	0.0536	0.3209	0.0831
DOT11.11_3	291	230215	100.9516	16.0268	0.6381	2.5352	70.1003	0.2155	1.0795	0.7121	6.9048	0.0777	0.5056	0.819	0	0.0255	0.0091	0.2979	0.0529
DOT11.11_4	292	230215	100.6001	16.2132	0.5934	2.4079	69.9222	0.1585	1.1523	0.6826	7.2913	0.053	0.4854	0.6172	0	0	0.0238	0.3239	0.0753
DOT11.12_1	293	230215	101.0543	18.8137	0.6117	2.2	68.1508	0.0931	1.4487	0.7579	6.3347	0.0897	0.0738	0.5075	0	0	0.0388	0.7948	0.0847
DOT11.12_2	294	230215	100.8589	18.8424	0.5654	2.2078	68.4207	0.1531	1.5034	0.792	5.9069	0.0776	0.0897	0.5107	0.0043	0	0	0.832	0.094
DOT11.12_3	295	230215	101.127	18.6057	0.5519	2.2224	68.3349	0.1247	1.4136	0.733	6.373	0.0848	0.0809	0.4818	0.045	0.0111	0	0.863	0.0744
DOT11.12_4	296	230215	101.2453	18.5019	0.632	2.21	68.3303	0.1292	1.4534	0.7784	6.3546	0.089	0.088	0.559	0	0	0.0395	0.808	0.0267
DOT11.13_1	297	230215	100.6762	19.691	0.8162	2.1199	66.6475	0	1.502	0.5059	6.5965	0.103	1.1809	0.7432	0.0014	0.0207	0.0137	0.0459	0.0122
DOT11.13_2	298	230215	101.3379	19.729	0.8521	2.1621	66.3747	0.0618	1.4999	0.5846	6.4508	0.1251	1.1381	0.7258	0.0014	0.0363	0.0283	0.1402	0.0898
DOT11.13_3	299	230215	100.6081	19.804	0.8631	2.2255	66.5034	0.0679	1.5161	0.5822	6.4971	0.1501	0.9681	0.7265	0	0.0716	0	0.0168	0.0079
DOT11.13_4	300	230215	100.8219	19.6198	0.8436	2.1915	66.9323	0.0836	1.4845	0.5513	6.2623	0.0948	1.0992	0.6629	0	0.0955	0.0206	0.0581	0
DOT11.14_1	301	230215	100.6095	18.5439	0.9934	2.3651	66.4805	0.1267	1.3993	0.6542	6.3379	0.2534	1.5165	1.1203	0.0098	0.0651	0	0.0679	0.0661
DOT11.14_2	302	230215	99.631	18.5955	0.9838	2.39	66.5977	0.1154	1.2766	0.7274	6.4995	0.2444	1.4943	1.0196	0.0114	0	0	0.0443	0
DOT11.14_3	303	230215	100.438	18.6041	1.051	2.3031	66.5262	0.101	1.3553	0.6926	6.3493	0.2605	1.5312	0.9522	0.0014	0.078	0.0143	0.0476	0.1323
DOT11.14_4	304	230215	100.6043	18.6269	1.0046	2.376	66.6509	0.0753	1.3652	0.6878	6.1775	0.2134	1.644	1.0162	0.0057	0.0588	0.0025	0.095	0
DOT11.15_1	305	230215	100.3414	14.5207	0.5437	2.5562	70.7396	0.2102	1.3038	0.6391	7.6746	0.0772	1.384	0.2683	0	0	0.035	0	0.0475
DOT11.15_2	306	230215	100.8801	14.0975	0.5771	2.5201	70.9834	0.1905	1.2699	0.8422	7.4835	0.0783	1.4332	0.3778	0.007	0.0397	0.0101	0.0159	0.0738
DOT11.15_3	307	230215	100.7301	14.2613	0.5601	2.5371	71.3092	0.184	1.2707	0.6277	7.5679	0.0702	1.3546	0.2053	0	0.0319	0	0	0.0201
DOT11.15_4	308	230215	99.4217	14.2623	0.5491	2.5604	71.6026	0.0696	1.2693	0.5718	7.4901	0.047	1.3299	0.135	0	0.0581	0.0202	0.0346	0

Label	No.	Date	Total	Na2O	MgO	Al2O3	SiO2	P2O5	Cl	K2O	CaO	TiO2	MnO	Fe2O3	CoO	CuO	SnO2	Sb2O5	PbO
DOT5.1_1	12	260215	100.0205	17.812	0.9227	2.2935	66.8543	0.0691	1.4138	2.1203	5.333	0.3522	1.3862	1.3111	0	0.0384	0.0375	0.0508	0.005
DOT5.1_2	13	260215	100.2455	19.0649	0.9722	2.3838	66.7947	0.0863	1.4715	0.4587	5.5857	0.3354	1.6152	1.18	0	0.0399	0	0	0.0117
DOT5.1_3	14	260215	100.3025	18.8956	1.0081	2.2803	66.6963	0.0156	1.4004	0.6648	5.5548	0.3219	1.6471	1.3749	0.017	0.0496	0.055	0.0184	0
DOT5.2_1	15	260215	100.9054	19.1387	1.2449	2.6439	65.0077	0.19	1.3164	0.5733	6.0334	0.4027	1.8604	1.5501	0.0084	0.0111	0.0111	0.008	0
DOT5.2_2	16	260215	100.1889	16.7828	0.9365	2.3296	64.4047	0.0714	1.2405	0.6885	6.1548	0.2955	1.5503	0.9215	0	4.5343	0.0288	0.0608	0
DOT5.2_3	17	260215	100.2031	19.1696	1.022	2.4011	65.9047	0.0961	1.3595	0.6216	6.1128	0.2731	1.5906	1.1824	0	0.0815	0.0446	0	0.1402
DOT5.3_1	18	260215	101.0935	20.7263	1.0755	2.2624	63.7567	0.0494	1.6048	0.3373	6.858	0.2694	1.7857	1.1869	0	0.0586	0	0	0.0292
DOT5.3_2	19	260215	0.3894	0.3852	6.8567	0	13.1741	0	39.2142	1.9517	8.3205	0	6.5742	13.9188	0	0	0	3.7494	5.8552
DOT5.3_3	20	260215	0.4069	0	0	0	1.9415	0	74.0477	2.6051	5.0135	1.5237	0	5.9966	2.8017	0	0.3686	1.45	4.2517
DOT5.4_1	21	260215	100.5686	20.607	1.119	2.2781	64.0515	0.0793	1.5372	0.3855	6.7153	0.2634	1.8067	1.0954	0	0.0398	0	0.0217	0
DOT5.4_2	22	260215	100.4182	20.4705	1.0783	2.2876	63.9944	0.075	1.6069	0.3831	6.8687	0.2638	1.7517	1.136	0.0283	0.0207	0.0195	0	0.0155
DOT5.4_3	23	260215	100.3765	20.1896	1.0179	2.2123	64.3922	0.0498	1.5404	0.4337	6.9443	0.2756	1.8063	1.0776	0.0184	0.0128	0	0.0293	0
DOT5.6_1	24	260215	100.3135	18.8838	1.0364	2.6062	66.079	0.1537	1.2811	0.6415	6.1545	0.287	1.5958	1.1378	0	0.0223	0.0212	0.0332	0.0664
DOT5.6_2	25	260215	100.2477	19.5689	0.9868	2.3645	65.8569	0.0981	1.1818	0.6571	6.1478	0.3128	1.5598	1.1398	0.0085	0.0463	0	0.071	0
DOT5.6_3	26	260215	99.0048	18.8257	0.9339	2.4827	65.9509	0.1106	1.3348	0.7675	6.3276	0.3205	1.6366	1.1961	0.0014	0.0517	0.0184	0.0253	0.0164
DOT5.5_1	27	260215	101.0726	19.4607	1.0379	2.4875	65.4843	0.0812	1.1729	0.7009	6.4382	0.2468	1.6381	1.0649	0	0.0712	0	0.0595	0.0559
DOT5.5_2	28	260215	100.4261	19.0254	1.0941	2.4795	65.8651	0.0974	1.295	0.6647	6.1776	0.3571	1.6365	1.1642	0	0.0016	0.02	0.0504	0.0713
DOT5.5_3	29	260215	100.9017	19.2274	1.0802	2.4927	65.8692	0.1545	1.2808	0.5598	6.178	0.2836	1.7241	1.1075	0	0	0	0.034	0.0083
DOT5.7_1	30	260215	100.4185	18.8866	1.2634	2.5287	65.8928	0.1135	1.3798	0.4882	6.5298	0.2485	1.7292	0.9267	0	0.0048	0.0081	0	0
DOT5.7_2	31	260215	100.8607	18.7215	1.0961	2.6274	66.0708	0.1123	1.1891	0.5138	6.4282	0.2431	1.7185	1.0967	0.0395	0.0111	0	0	0.1321
DOT5.7_3	32	260215	101.2099	19.0893	1.0555	2.2284	66.3893	0.1512	1.4296	0.4998	5.9686	0.2422	1.8531	1.0281	0	0.0063	0	0	0.0587
DOT5.8_1	33	260215	99.6181	2.3425	2.5464	3.3599	61.037	0.8274	0.9961	0.5685	26.2293	0.1791	0.0586	1.7988	0	0	0	0	0.0564
DOT5.8_2	34	260215	99.5231	2.3698	2.6349	3.4132	61.1365	0.8955	0.8966	0.5434	26.1516	0.188	0.0599	1.6846	0.0028	0.0048	0	0	0.0185
DOT5.8_3	35	260215	99.4353	2.2152	2.5967	3.4722	61.1107	0.8038	0.8908	0.6594	26.1948	0.185	0.0892	1.6616	0	0.069	0.039	0	0.0125
DOT5.9_1	36	260215	101.1268	18.7306	0.6102	2.2762	68.4241	0.1155	1.4072	0.6453	6.2002	0.0806	0.3103	0.5656	0	0.0665	0	0.5233	0.0443
DOT5.9_2	37	260215	100.5046	18.179	0.5906	2.2346	68.8456	0.1101	1.3216	0.582	6.4485	0.0976	0.3349	0.4883	0	0.0048	0.0458	0.6251	0.0914
DOT5.9_3	38	260215	100.6161	18.2038	0.5274	2.3885	68.6579	0.1266	1.3859	0.5773	6.3999	0.1247	0.3447	0.549	0.0028	0	0	0.6264	0.0851
DOT5.10_1	39	260215	99.9821	2.4437	2.6967	3.3485	61.1197	0.8815	0.9293	0.5838	26.0964	0.15	0.0753	1.6419	0	0.0096	0.0194	0	0.0042
DOT5.10_2	40	260215	100.0185	2.3223	2.6378	3.3309	61.2957	0.8341	0.9624	0.6271	25.9873	0.1338	0.0569	1.7761	0	0	0.0052	0	0.0305
DOT5.10_3	41	260215	100.3411	2.2798	2.6356	3.4321	60.8756	0.835	0.886	0.5865	26.1665	0.2056	0.1496	1.7538	0	0.1048	0	0	0.0891
DOT5.11_1	42	260215	101.2712	18.2596	0.5666	2.3162	68.6168	0.1645	1.4073	0.64	6.3433	0.0814	0.3614	0.5652	0.0155	0.0507	0	0.6116	0
DOT5.11_2	43	260215	101.6996	18.7729	0.591	2.2322	68.3023	0.1415	1.3828	0.6614	6.3948	0.0852	0.308	0.4664	0	0.0441	0.0013	0.603	0.0133
DOT5.11_3	44	260215	101.3455	18.6076	0.5237	2.2157	68.5078	0.0713	1.4298	0.6179	6.2737	0.0698	0.3902	0.5945	0.0449	0.03	0	0.5817	0.0415
DOT5.12_1	45	260215	101.3618	19.2051	0.8686	2.2021	67.4807	0.0795	1.3439	0.6856	6.1523	0.0764	1.0329	0.6642	0.0169	0.0427	0	0.1492	0
DOT5.12_2	46	260215	101.5601	19.203	0.8395	2.0672	67.8596	0.1057	1.4858	0.6579	5.6967	0.1324	1.2836	0.5486	0.0322	0.0142	0.0378	0.0356	0
DOT5.12_3	47	260215	100.3898	19.0768	0.961	2.0877	67.961	0.085	1.1622	0.7084	6.187	0.1151	1.1087	0.5173	0	0	0.0051	0.0249	0

Label	No.	Date	Total	Na2O	MgO	Al2O3	SiO2	P2O5	Cl	K2O	CaO	TiO2	MnO	Fe2O3	CoO	CuO	SnO2	Sb2O5	PbO
DOT5.13_1	48	260215	101.1615	20.6337	0.8254	2.29	65.4099	0.1415	1.5304	0.4822	6.3032	0.1593	1.3011	0.8795	0.0028	0.0206	0	0.003	0.0176
DOT5.13_2	49	260215	100.6304	21.0136	0.9165	2.2407	65.191	0.1215	1.6216	0.4965	6.2193	0.1203	1.2638	0.7094	0.0481	0.0334	0.0042	0	0
DOT5.13_3	50	260215	101.3146	20.9475	0.8574	2.2046	65.3722	0.0648	1.5899	0.5371	6.2117	0.1696	1.1347	0.7375	0	0	0.0095	0.1154	0.048
DOT5.14_1	51	260215	100.6171	19.8585	1.0619	2.3658	65.2096	0.1172	1.3475	0.5703	6.5751	0.1985	1.5899	0.9997	0.0368	0.0175	0.0118	0	0.04
DOT5.14_2	52	260215	101.2483	19.5702	1.0729	2.3393	65.4321	0.1309	1.3622	0.6412	6.5395	0.209	1.5736	0.9868	0	0.0491	0	0.0354	0.058
DOT5.14_3	53	260215	100.2761	19.8197	1.0447	2.3986	65.3329	0.1033	1.393	0.6101	6.3155	0.2015	1.7101	1.0519	0	0.016	0.0028	0	0
DOT5.15_1	54	260215	101.134	19.5541	1.0391	2.518	65.2438	0.1317	1.2664	0.5762	6.244	0.311	1.7516	1.2461	0.0056	0.019	0	0	0.0933
DOT5.15_2	55	260215	99.9438	19.1764	1.0513	2.5499	65.6137	0.1557	1.2722	0.6551	6.1511	0.3269	1.7238	1.2977	0	0.0016	0.0011	0.0236	0
DOT5.15_3	56	260215	100.4475	19.6741	1.0369	2.4526	65.3399	0.0713	1.2524	0.6457	6.134	0.2562	1.7064	1.4051	0	0.0256	0	0	0
Lym1b.1_1	57	260215	100.2841	19.0605	0.6109	2.256	67.7337	0.1425	1.4378	0.6928	6.3767	0.0996	0.2675	0.5996	0	0	0	0.662	0.0603
Lym1b.1_2	58	260215	100.4171	19.0072	0.6993	2.4039	67.5697	0.0898	1.3868	0.6332	6.4504	0.1135	0.2054	0.6645	0.0057	0.0207	0.0158	0.6643	0.0697
Lym1b.1_3	59	260215	100.5244	19.1845	0.6388	2.2045	67.5929	0.1501	1.4119	0.6501	6.4285	0.0638	0.2164	0.5836	0.0071	0	0	0.7687	0.0991
Lym1b.10_1	60	260215	100.0908	18.7187	0.976	2.161	65.8009	0.148	0.9677	0.7568	7.8792	0.1228	1.3846	0.9021	0	0	0.0097	0.1083	0.0641
Lym1b.10_2	61	260215	100.5524	19.2216	1.0064	2.2998	65.489	0.1696	0.9871	0.7043	7.8018	0.1398	1.2252	0.7721	0	0.0095	0.0419	0.0542	0.0775
Lym1b.10_3	62	260215	100.7059	18.5919	1.0749	2.3529	66.0131	0.0825	0.9641	0.703	7.6311	0.1472	1.3167	0.9008	0.0368	0.0223	0.0736	0.089	0
Lym1b.9_1	63	260215	99.6134	14.519	0.6115	2.4931	71.0106	0.1805	1.167	0.4272	8.8537	0.0579	0.303	0.3765	0	0	0	0	0
Lym1b.9_2	64	260215	100.5423	14.6407	0.6034	2.5796	71.0392	0.1679	1.2555	0.4982	8.4744	0.0498	0.2884	0.3901	0.0127	0	0	0	0
Lym1b.9_3	65	260215	100.2122	14.6116	0.5808	2.4373	71.046	0.261	1.1991	0.5294	8.5162	0.0651	0.2808	0.4328	0	0.0145	0.0014	0.024	0
Lym1a.2_1	69	260215	100.2709	17.2759	0.6065	2.2918	70.1621	0.1109	1.2299	0.6271	6.0127	0.1003	0.2224	0.7818	0.0212	0.0191	0.0029	0.4261	0.1092
Lym1a.2_2	70	260215	100.5485	17.9992	0.6315	2.2176	69.4484	0.1349	1.2665	0.6516	6.2068	0.0538	0.2281	0.5616	0.0227	0.0048	0	0.5239	0.0486
Lym1a.2_3	71	260215	100.3869	18.1052	0.5895	2.2842	68.9989	0.15	1.3829	0.6157	6.2511	0.078	0.2583	0.7043	0	0.0288	0	0.4977	0.0554
Lym1a.a_2	72	260215	99.8329	15.871	0.5776	2.6625	70.257	0.1757	1.3962	0.511	7.8147	0.0452	0.258	0.3778	0.0257	0	0	0	0.0275
Lym1a.a_3	73	260215	99.9052	15.8767	0.5795	2.6044	70.5281	0.1396	1.3608	0.5597	7.6449	0.0602	0.2417	0.3566	0.0285	0	0	0.0192	0
Lym1a.a_4	74	260215	100.3827	16.0545	0.5518	2.6992	70.0489	0.1415	1.334	0.558	7.8714	0.0857	0.1888	0.4154	0	0	0.051	0	0
Lym1a.b_1	75	260215	100.7252	17.0715	0.674	2.2678	68.8721	0.1968	1.3735	0.6304	6.9053	0.0545	0.6273	0.8871	0	0	0	0.3652	0.0746
Lym1a.b_2	76	260215	100.862	17.1634	0.6347	2.2216	68.7877	0.1796	1.3396	0.697	7.0619	0.1033	0.6537	0.8098	0.0099	0	0	0.3378	0
Lym1a.b_3	77	260215	100.6098	17.1023	0.5666	2.1993	68.9563	0.1745	1.3682	0.6539	6.9094	0.067	0.6405	0.8867	0.0127	0	0.0068	0.3861	0.0697
Lym1a.4_1	78	260215	100.4735	17.2302	0.558	2.3301	69.5219	0.1169	1.136	0.6334	6.4007	0.0629	0.3343	0.9009	0.0227	0.0511	0.0079	0.4968	0.1962
Lym1a.4_2	79	260215	100.2878	17.1775	0.5762	2.352	69.7879	0.1423	1.0239	0.6155	6.2599	0.0871	0.3204	0.9615	0	0.0591	0	0.5165	0.1202
Lym1a.4_3	80	260215	100.5555	17.3969	0.6302	2.354	69.899	0.1635	1.1054	0.5992	6.0323	0.0488	0.22	0.8316	0	0.1196	0.0021	0.4717	0.1258
Lym1a.5_1	81	260215	101.0809	17.5993	0.6107	2.218	69.029	0.1705	1.2954	0.6329	6.5716	0.1088	0.5141	0.6723	0.0056	0.0428	0.0441	0.3838	0.1011
Lym1a.5_2	82	260215	100.2884	17.49	0.584	2.1844	69.3747	0.1147	1.2988	0.6443	6.548	0.0506	0.482	0.6777	0.0043	0.0239	0	0.4549	0.0677
Lym1a.5_3	83	260215	100.7369	17.5765	0.6196	2.3096	69.0096	0.1522	1.2037	0.6997	6.6322	0.0529	0.4598	0.7355	0.0057	0.0095	0.0542	0.4647	0.0146
Lym1a.3_1	84	260215	100.3663	15.6887	0.5147	2.712	70.2856	0.1368	1.3871	0.5074	7.9851	0.0658	0.2086	0.3683	0.01	0.0848	0.0197	0.0254	0
Lym1a.3_2	85	260215	100.6156	15.9756	0.6122	2.6782	70.2405	0.1116	1.3246	0.5655	7.828	0.0541	0.1762	0.3293	0.0242	0.08	0	0	0
Lym1a.3_3	86	260215	100.5179	16.0529	0.4829	2.6095	70.0528	0.1893	1.3909	0.5374	7.9028	0.054	0.2509	0.3777	0.0029	0	0.0275	0.0055	0.0631

Label	No.	Date	Total	Na2O	MgO	Al2O3	SiO2	P2O5	Cl	K2O	CaO	TiO2	MnO	Fe2O3	CoO	CuO	SnO2	Sb2O5	PbO
Lym2.1_1	87	260215	100.696	20.1401	0.6339	2.0138	66.8839	0.0827	1.2637	0.4868	6.668	0.1139	1.0062	0.6098	0.0198	0	0.0088	0.0325	0.0361
Lym2.1_2	88	260215	99.9763	19.7855	0.6061	1.9421	67.3151	0.0881	1.2825	0.5308	6.822	0.0581	0.9932	0.5503	0.0242	0	0.0019	0	0
Lym2.1_3	89	260215	99.6979	19.9299	0.7181	1.8656	67.1453	0.0589	1.2853	0.4656	6.7678	0.0999	1.0207	0.577	0.0428	0	0	0	0.023
Lym2.2_1	90	260215	100.1416	19.3229	0.6931	2.1282	66.7442	0.0733	1.2691	0.6087	7.0415	0.1535	1.053	0.727	0	0.0592	0.0118	0.0669	0.0475
Lym2.2_2	91	260215	100.08	19.0567	0.7509	2.1615	67.187	0.1227	1.1378	0.6059	6.9101	0.0881	0.9794	0.6579	0	0	0.0711	0.1169	0.1541
Lym2.2_3	92	260215	99.8069	19.2751	0.7227	2.1143	66.8466	0.0894	1.1968	0.6698	6.9554	0.1197	1.0844	0.6643	0.0227	0.0705	0.0171	0.0452	0.1059
Lym2.3_1	93	260215	101.2086	18.1727	0.7585	2.3136	67.6255	0.1203	1.1307	0.6769	7.1384	0.0846	0.9389	0.6915	0	0.0253	0.0369	0.1927	0.0935
Lym2.3_2	94	260215	100.8939	18.3771	0.7464	2.2479	67.5718	0.0795	1.1101	0.6384	6.9652	0.1366	0.931	0.7302	0.0155	0.0856	0.0503	0.188	0.1264
Lym2.3_3	95	260215	100.5842	18.2007	0.7813	2.154	67.9398	0.1512	1.0822	0.6827	6.8115	0.1182	0.937	0.8208	0	0.0558	0	0.1728	0.092
Lym2.4_1	96	260215	100.8132	19.4712	0.5453	1.8589	67.8581	0.1152	1.2107	0.5108	6.6966	0.0933	1.0387	0.515	0	0.0398	0.0013	0.0452	0
Lym2.4_2	97	260215	100.6158	19.1968	0.706	1.8817	68.2213	0.0198	1.1632	0.4271	6.6201	0.0578	1.0198	0.6561	0	0	0.0303	0	0
Lym2.4_3	98	260215	100.3655	19.5653	0.6246	1.845	67.8916	0.069	1.1842	0.4707	6.7016	0.1001	1.0893	0.4066	0	0.0191	0.0307	0	0.0022
Lym2.5_1	99	260215	99.9523	18.6226	0.7008	2.1978	67.3222	0.1142	1.1207	0.6059	7.202	0.1097	1.0825	0.82	0	0.0032	0.0604	0.0379	0
Lym2.5_2	100	260215	99.6906	18.6347	0.7434	2.2545	67.1984	0.1328	1.1665	0.5711	7.1928	0.1199	0.8854	0.7631	0	0.061	0.0612	0.0583	0.1571
Lym2.5_3	101	260215	100.1304	18.8285	0.7803	2.1837	67.2272	0.1146	1.1075	0.5616	7.0144	0.1243	1.0076	0.6904	0.0128	0.115	0.0803	0.0389	0.113
Lym2.6_1	102	260215	100.4695	19.2008	1.0407	2.2621	65.6964	0.1145	1.2156	0.6897	7.3853	0.1636	1.1667	0.8406	0.0155	0.0366	0.017	0.1038	0.0512
Lym2.6_2	103	260215	100.7808	18.7308	0.8188	2.3425	67.0477	0.1702	1.1985	0.7584	6.9272	0.1064	0.8908	0.6982	0	0.0286	0.0585	0.2233	0
Lym2.6_3	104	260215	100.1002	18.4188	0.8885	2.3243	67.0824	0.1195	1.1519	0.7394	7.1005	0.1103	1.0607	0.6887	0.0242	0.0639	0.0529	0.1739	0
Lym2.7_1	105	260215	100.8113	17.4161	0.8312	2.4084	66.8187	0.1111	1.1085	0.7941	7.1285	0.0928	0.9206	0.7133	0	0	0.3037	0.2523	1.1008
Lym2.7_2	106	260215	99.9484	16.9416	0.7912	2.2632	66.0895	0.1842	1.0939	0.7664	7.0768	0.0788	0.9202	0.6953	0.0071	0.0492	2.0782	0.1811	0.7834
Lym2.7_3	107	260215	102.1867	16.6865	0.6985	2.2114	62.4219	0.0956	1.0753	0.7217	6.5598	0.0831	0.7961	0.5895	0.0478	0.0858	6.832	0.2073	0.8877
Lym2.8_1	108	260215	101.2238	17.0883	0.7851	2.2786	65.3833	0.15	1.0977	0.698	6.9553	0.1153	0.8439	0.8663	0	0.0986	2.6502	0.2169	0.7726
Lym2.8_2	109	260215	100.3618	19.3376	0.9897	2.3339	65.6773	0.1486	1.1942	0.7249	7.2735	0.1215	1.1377	0.8674	0.0198	0.0239	0.0027	0.1096	0.0379
Lym2.8_3	110	260215	100.2124	19.147	0.9551	2.2854	65.6832	0.114	1.2052	0.703	7.3901	0.1574	1.2444	0.8735	0.0213	0.0048	0.0176	0.1072	0.0909
Lym2.9_1	111	260215	100.3868	19.5612	0.9358	2.2362	65.8232	0.1448	1.1912	0.7181	7.3283	0.1149	1.0499	0.7283	0	0.0701	0	0.0846	0.0134
Lym2.9_2	112	260215	100.3898	19.4803	1.0858	2.2836	65.2938	0.1474	1.271	0.7168	7.2835	0.0701	1.2984	0.8433	0	0.0128	0.0668	0.1463	0
Lym2.9_3	113	260215	100.4949	19.9896	1.1376	2.2657	64.0529	0.1412	1.3081	0.6249	7.9994	0.1394	1.4986	0.7233	0	0.0556	0	0.0637	0
Lym2.10_1	114	260215	100.3812	18.6393	1.1063	2.4549	64.9499	0.11	1.1743	0.6683	8.1242	0.11	1.6973	0.8584	0	0.0223	0.0218	0.0341	0.0288
Lym2.10_2	115	260215	99.4419	18.3361	1.1934	2.3674	65.0528	0.1402	1.1368	0.6443	8.4826	0.1453	1.6373	0.7875	0.0272	0	0.0166	0	0.0325
Lym2.10_3	116	260215	99.0072	17.9301	1.0432	2.5536	65.7242	0.0839	0.977	0.7147	8.2549	0.134	1.7273	0.7893	0.0058	0	0	0.062	0
Lym2.11_1	117	260215	0.1544	0	0	0	13.5363	0	4.728	0	3.044	0	0	15.3497	0	20.0777	0	0	43.2642
Lym2.11_2	118	260215	0.0776	0	0	0	1.8041	0	10.567	8.1186	12.8866	5.6701	37.2423	9.1495	3.3505	11.2113	0	0	0
Lym2.11_3	119	260215	0.853	0	0	0	1.6178	0	91.1606	0	2.4971	1.313	2.7902	0.2345	0	0.3869	0	0	0
Lym2.13	120	260215	100.6949	17.2386	0.7784	2.1503	66.8015	0.1958	1.0836	0.7004	6.7213	0.0944	0.5342	0.8651	0	2.2251	0.2056	0.3041	0.1016
Lym2.14	121	260215	100.4814	16.8516	0.8115	2.2264	66.9735	0.1682	1.1079	0.7642	6.8959	0.1252	0.4687	0.8884	0	2.2483	0.2107	0.218	0.0416
Lym2.15	122	260215	100.4452	17.3154	0.8473	2.1263	66.5281	0.124	1.1893	0.7334	6.7856	0.1211	0.5028	0.8434	0.0014	2.1978	0.2579	0.2317	0.1944

Label	No.	Date	Total	Na2O	MgO	Al2O3	SiO2	P2O5	Cl	K2O	CaO	TiO2	MnO	Fe2O3	CoO	CuO	SnO2	Sb2O5	PbO
Lym2.14_1	123	260215	99.1439	16.681	0.8492	2.102	66.7218	0.2088	1.1334	0.7705	7.0326	0.1279	0.5017	0.8305	0.0185	2.4033	0.2665	0.194	0.1585
Lym2.14_2	124	260215	100.4501	17.0085	0.9068	2.1686	66.7172	0.1382	1.0902	0.7144	6.7773	0.1235	0.464	0.906	0	2.3905	0.2717	0.2645	0.0584
Lym2.14_3	125	260215	100.629	17.0304	0.8396	2.1648	66.5414	0.2283	1.0348	0.8283	6.7639	0.1438	0.4456	0.9734	0.0307	2.4033	0.2522	0.2508	0.0689
Lym2.15_1	126	260215	100.7867	16.995	0.7559	2.1592	66.9396	0.1531	1.0521	0.8112	6.6315	0.1149	0.5381	0.944	0.0139	2.3225	0.2424	0.25	0.0766
Lym2.15_2	127	260215	100.6013	17.0343	0.8296	2.106	67.1175	0.1396	1.0345	0.6981	6.8334	0.0584	0.6006	0.8611	0.0154	2.1523	0.1936	0.2582	0.0673
Lym2.15_3	128	260215	100.719	17.0171	0.7737	2.0946	66.9531	0.2038	1.1196	0.7597	6.8031	0.0996	0.5599	0.9127	0.0112	2.0625	0.1445	0.2611	0.2236
Lym2.16_1	129	260215	100.7098	14.4564	0.6786	2.7166	70.1588	0.1218	1.1439	0.7114	7.2848	0.1023	0.1126	0.6198	0.0098	1.6732	0.0679	0.0324	0.1097
Lym2.16_2	130	260215	100.132	14.497	0.6232	2.7246	70.2888	0.1255	1.1401	0.5881	7.3745	0.0621	0.1657	0.6899	0.0183	1.5988	0.0751	0.0284	0
Lym2.16_3	131	260215	0.4105	0	0	0	0	0	84.3362	0	0	0	7.6492	0	0	3.5566	0	0	4.458
Lym2.act.16_1	132	260215	100.5401	16.9481	1.2026	2.6065	67.294	0.1266	1.0417	0.9737	7.3584	0.1412	0.2484	1.1582	0.0874	0.1525	0	0.0289	0.6317
Lym2.act.16_2	133	260215	100.3693	16.5238	1.2717	2.6796	67.6038	0.2052	1.0605	0.9189	7.1521	0.1126	0.2586	1.1364	0.0763	0.1736	0	0.0577	0.7692
Lym2.act.16_3	134	260215	100.0268	16.9654	1.2248	2.6112	67.1335	0.2133	1.0893	0.978	7.4074	0.0954	0.2049	1.3467	0.0297	0.1164	0.0195	0	0.5644
Lym2.17_1	135	260215	100.0621	17.8573	1.035	2.3171	66.4515	0.0837	1.0154	0.8202	7.6466	0.1127	1.3497	1.1023	0	0.056	0.0345	0.1004	0.0177
Lym2.17_2	136	260215	100.9025	17.9585	1.0451	2.4314	65.9726	0.1595	1.0813	0.7547	7.7645	0.1592	1.4944	1.0204	0.0239	0.019	0.0207	0.0937	0.0012
Lym2.17_3	137	260215	100.4104	17.4702	1.0912	2.4353	66.3917	0.1838	0.9724	0.8013	7.8281	0.1189	1.3787	1.0875	0.0043	0.0845	0.0124	0.1344	0.0051
Lym2.18_1	138	260215	100.9914	18.0089	1.1011	2.4549	66.1757	0.1408	0.9986	0.7862	7.5826	0.1439	1.3365	1.0827	0.0226	0.0587	0.0181	0.0888	0
Lym2.18_2	139	260215	100.4968	17.6669	1.0423	2.3088	66.2026	0.1817	1.0517	0.7744	7.8509	0.0701	1.4533	1.1367	0.0169	0.0684	0.0654	0.0966	0.0134
Lym2.18_3	140	260215	100.4355	17.6015	1.0625	2.3984	66.3657	0.1264	0.9944	0.8455	7.7974	0.1048	1.3743	1.1301	0	0.0366	0.0551	0.0496	0.0576
Lym2.19_1	141	260215	100.8997	16.7109	0.9603	2.4362	67.653	0.06	0.8622	0.9289	7.7341	0.1259	1.0668	1.0114	0.0422	0.2632	0	0.1012	0.0437
Lym2.19_2	142	260215	100.8109	16.6478	0.833	2.4485	67.8046	0.1241	0.9483	0.8264	7.9541	0.1328	1.0849	0.871	0	0.2177	0.0192	0.0834	0.004
Lym2.19_3	143	260215	100.2704	16.6084	0.9731	2.5744	67.8232	0.0794	0.8557	0.9083	7.8451	0.1323	1.1432	0.8576	0	0.1993	0	0	0
Lym3.1_1	148	260215	101.0263	15.764	0.8195	2.5717	70.6893	0.2081	1.1325	0.8044	7.2107	0.0658	0.1467	0.5275	0	0	0.0126	0.0472	0
Lym3.1_2	149	260215	100.7244	15.6572	0.8404	2.5573	70.7646	0.1174	1.0632	0.8776	7.1333	0.0844	0.1682	0.6452	0.0014	0.0621	0	0.0276	0
Lym3.1_3	150	260215	100.7494	15.5897	0.8349	2.73	70.8931	0.1687	1.0093	0.8134	6.9313	0.0728	0.1647	0.5551	0.0113	0.0239	0	0.175	0.0267
Lym3.2_1	151	260215	100.5808	17.307	0.7097	2.2624	68.8516	0.0587	1.1966	0.7746	7.1654	0.047	0.6666	0.5904	0.0057	0.0859	0.042	0.1749	0.0617
Lym3.2_2	152	260215	101.3347	17.4865	0.7035	2.6492	68.1919	0.2311	0.8374	0.8419	7.423	0.0639	0.5521	0.7208	0	0.0758	0.0067	0.1361	0.0799
Lym3.2_3	153	260215	100.9038	17.7339	0.7256	2.3572	68.3997	0.1398	1.0415	0.7534	7.1246	0.1285	0.6805	0.6322	0	0.0048	0	0.2138	0.0644
Lym3.3_1	154	260215	100.5838	17.6669	0.8757	2.3563	67.432	0.1584	1.1257	0.7309	7.4134	0.1047	0.9284	0.829	0	0	0.0467	0.2187	0.1131
Lym3.3_2	155	260215	100.9977	17.8017	0.8531	2.3951	67.3306	0.1479	0.9113	0.7651	7.5775	0.0969	0.9889	0.794	0.0295	0.0396	0.0833	0.17	0.0154
Lym3.3_3	156	260215	99.959	17.1598	0.8876	2.3944	67.5685	0.1194	1.2092	0.7774	7.7137	0.1095	0.9597	0.7932	0	0.0863	0.0634	0.1544	0.0034
Lym3.4_1	157	260215	101.5565	18.808	0.6004	2.2502	67.8733	0.0718	1.3946	0.726	6.4983	0.104	0.1869	0.5953	0	0.0268	0	0.7958	0.0688
Lym3.4_2	158	260215	100.7479	18.5323	0.6379	2.3132	67.9943	0.1172	1.3485	0.6757	6.6136	0.0988	0.2337	0.7165	0.0112	0	0	0.707	0
Lym3.4_3	159	260215	100.704	18.3235	0.5815	2.2905	68.2605	0.056	1.421	0.7584	6.4315	0.0676	0.2023	0.7591	0.0098	0	0.0049	0.7957	0.0377
DOT12.1_1	160	260215	100.9566	17.8533	0.5663	2.3339	69.1509	0.0899	1.4399	0.6424	6.5601	0.0831	0.2608	0.5646	0.0056	0.0602	0.0106	0.3633	0.015
DOT12.1_2	161	260215	101.2229	18.1983	0.5658	2.3122	68.7855	0.1081	1.3464	0.6374	6.5453	0.0779	0.2957	0.5908	0	0.0174	0.0029	0.4993	0.0171
DOT12.1_4	162	260215	101.1669	18.1536	0.5665	2.3381	68.7889	0.1245	1.4011	0.59	6.6337	0.0633	0.343	0.5513	0	0.0063	0.039	0.4007	0

Label	No.	Date	Total	Na2O	MgO	Al2O3	SiO2	P2O5	Cl	K2O	CaO	TiO2	MnO	Fe2O3	CoO	CuO	SnO2	Sb2O5	PbO
DOT12.2_1	163	260215	97.505	0.1905	0	0.1087	53.1925	0	0	9.5636	0.034	0	0.0134	0.0442	0	0	0	0.3242	36.5289
DOT12.2_2	164	260215	97.7951	0.3457	0	0.1639	52.7537	0	0	9.5605	0.0732	0.004	0.0762	0.0495	0.0239	0.0139	0	0.4519	36.4836
DOT12.2_3	165	260215	97.4473	0.0248	0	0.0676	53.2634	0	0	8.8071	0.0783	0	0.0398	0.1199	0.0392	0.0195	0.0115	0.2839	37.245
DOT12.3_1	166	260215	100.5316	16.1914	0.4557	2.3696	70.3588	0.0922	1.5017	0.5221	7.8581	0.0191	0.2571	0.3229	0	0.0335	0.0086	0.0092	0
DOT12.3_2	167	260215	100.6829	16.397	0.4137	2.2522	70.4253	0.1261	1.5541	0.4342	7.7993	0.0637	0.2852	0.1906	0.0057	0.0159	0.0005	0.0176	0.019
DOT12.3_3	168	260215	100.7038	16.4298	0.4373	2.3275	70.0751	0.141	1.5004	0.5409	7.8419	0.0231	0.2321	0.3848	0	0	0.0209	0.0274	0.0178
DOT12.4_1	169	260215	100.6562	18.969	0.5204	2.0302	67.1355	0.1178	1.3897	0.404	5.0772	0.064	0.1245	0.3245	0.0042	2.2825	0.0056	1.496	0.055
DOT12.4_2	170	260215	100.9323	19.0489	0.518	1.7923	65.9419	0.0509	1.4826	0.4231	5.3683	0.0638	0.2494	0.3955	0.0028	1.8188	0.0167	2.7956	0.0314
DOT12.4_3	171	260215	101.0601	18.68	0.4974	1.6324	65.6158	0	1.3962	0.3902	5.4272	0.0221	0	0.3795	0	2.2938	0.014	3.5531	0.0985
DOT8.1_1	172	260215	100.3534	19.0015	1.0041	2.5345	66.2945	0.0923	1.2835	0.686	6.2261	0.2938	1.5066	1.0191	0.0071	0	0	0.0482	0.0028
DOT8.1_2	173	260215	100.328	18.7796	1.0248	2.5411	66.4815	0.1292	1.1498	0.6611	6.0573	0.3336	1.5239	1.1855	0.0439	0.0446	0	0.0229	0.0211
DOT8.1_3	174	260215	100.9206	18.9923	0.8992	2.5453	66.2535	0.1048	1.2538	0.6832	6.1433	0.237	1.4751	1.2284	0.0352	0.0602	0	0.0887	0
DOT8.2_1	175	260215	101.0728	18.7237	1.1443	2.5796	66.5361	0.0659	1.4302	0.3763	5.7578	0.3883	1.9044	1.0791	0	0.0142	0	0	0
DOT8.2_2	176	260215	100.6915	18.7623	1.1054	2.5649	66.3812	0.056	1.425	0.4253	5.9017	0.3263	1.9219	1.0579	0	0.0396	0	0.0326	0
DOT8.2_3	177	260215	100.8616	18.5886	1.0317	2.5797	66.1394	0.069	1.4623	0.3876	5.8621	0.3344	2.0781	1.2937	0.0295	0.0095	0.0457	0	0.0886
DOT8.3_1	178	260215	100.7864	17.5415	1.2115	2.9923	65.6794	0.0902	1.2812	0.4484	5.9665	0.5499	2.2989	1.8738	0.0112	0.0554	0	0	0
DOT8.3_2	179	260215	100.6043	17.4717	1.138	3.1126	65.6095	0.0632	1.2642	0.4751	6.0732	0.5043	2.3475	1.8864	0.0295	0.0032	0	0	0.0216
DOT8.3_3	180	260215	99.8139	17.4151	1.1124	2.9003	66.2203	0.1011	1.2032	0.4487	5.9491	0.519	2.2808	1.8178	0	0	0	0.017	0.0151
DOT8.4_1	181	260215	100.5533	19.0182	1.0001	2.4659	65.8953	0.1001	1.3282	0.5681	6.4946	0.2392	1.6354	1.1208	0.0127	0.027	0.0412	0.0009	0.0526
DOT8.4_2	182	260215	100.6633	18.8778	0.9312	2.3667	65.8768	0.0733	1.3421	0.538	6.726	0.2511	1.7738	1.0492	0.0169	0.065	0.0187	0.0391	0.0541
DOT8.4_3	183	260215	100.4347	18.9288	0.9805	2.3973	65.8824	0.075	1.3122	0.565	6.7064	0.2419	1.7466	1.036	0	0.1097	0	0.018	0
DOT8.5_1	184	260215	100.6575	18.5804	1.2221	2.5435	63.6753	0.1275	1.2601	0.4207	6.9452	0.3707	2.9043	1.861	0.0084	0.0682	0	0.0126	0
DOT8.5_2	190	260215	100.3712	18.791	1.2639	2.6027	63.8165	0.0457	1.3565	0.4637	6.6479	0.4068	2.7991	1.7479	0	0	0.0286	0.0296	0
DOT8.5_3	191	260215	100.3185	18.4863	1.3046	2.5315	64.1771	0.0246	1.3996	0.4975	6.5015	0.348	2.868	1.8002	0.0225	0.0111	0.0087	0.0187	0
DOT8.6_1	192	260215	101.0422	18.5492	1.0983	2.5645	66.3076	0.0233	1.4859	0.3766	5.9509	0.3263	1.9373	1.327	0.0028	0.0505	0	0	0
DOT8.6_2	193	260215	100.6627	18.7823	1.0451	2.5659	66.462	0.0437	1.5254	0.3994	5.8176	0.2944	1.8956	1.1369	0	0	0	0	0.0317
DOT8.6_3	194	260215	100.5052	18.5619	1.0429	2.6508	66.6528	0.0514	1.4987	0.3941	5.799	0.3118	1.7691	1.176	0.0126	0.0523	0.0249	0.0011	0.0005
DOT8.7_1	195	260215	101.0534	16.4512	0.5308	2.1981	69.9486	0.1342	1.5843	0.5085	7.7718	0.0683	0.2956	0.382	0.0141	0	0.0156	0	0.0969
DOT8.7_2	196	260215	100.6706	16.1464	0.4505	2.2975	70.4531	0.0917	1.534	0.5094	7.9542	0.0215	0.311	0.1574	0.0113	0.062	0	0	0
DOT8.7_3	197	260215	101.1653	16.1926	0.4849	2.3792	70.1945	0.1647	1.449	0.5547	7.9016	0.0371	0.233	0.2735	0.007	0	0.039	0.0035	0.0857
DOT8.8_1	198	260215	101.5208	19.112	0.8594	2.2137	67.2418	0.0891	1.3942	0.6132	6.616	0.0882	0.9685	0.6296	0.0167	0.0189	0.0381	0.0961	0.0043
DOT8.8_2	199	260215	100.7888	18.6961	0.845	2.177	67.6522	0.0622	1.4058	0.6468	6.5358	0.0722	1.0484	0.6914	0.0183	0	0	0.0971	0.0515
DOT8.8_3	200	260215	100.6942	19.2669	0.8829	2.2083	67.5366	0.0514	1.4523	0.5912	6.3587	0.1233	0.9679	0.4281	0	0	0.0114	0.0617	0.0593
DOT8.9_1	201	260215	101.1796	18.4215	0.5716	2.2871	68.6	0.1367	1.3846	0.6091	6.6351	0.0846	0.3816	0.4602	0.045	0	0.0305	0.3524	0
DOT8.9_2	202	260215	101.418	18.258	0.5981	2.3385	68.457	0.1525	1.4279	0.5847	6.6298	0.0647	0.47	0.4963	0	0	0.0817	0.3987	0.042
DOT8.9_3	203	260215	101.1722	18.1925	0.5394	2.3087	68.7711	0.1467	1.3807	0.5571	6.905	0.0427	0.2921	0.4631	0	0	0	0.401	0

Label	No.	Date	Total	Na2O	MgO	Al2O3	SiO2	P2O5	Cl	K2O	CaO	TiO2	MnO	Fe2O3	CoO	CuO	SnO2	Sb2O5	PbO
DOT8.10_1	204	260215	101.2074	18.6998	1.2825	2.568	63.9083	0.1471	1.35	0.4156	6.668	0.4068	2.7668	1.7362	0	0	0.0509	0	0
DOT8.10_2	205	260215	100.0379	18.2664	1.2957	2.6265	64.5166	0.0376	1.373	0.4746	6.5888	0.3866	2.6998	1.7217	0	0.0127	0	0	0
DOT8.10_3	206	260215	100.6698	18.6739	1.2979	2.6135	63.7793	0.0829	1.3122	0.4272	6.6242	0.4111	2.8956	1.8283	0	0.0537	0	0	0
DOT8.11_1	207	260215	100.8421	18.6215	1.0048	2.531	66.6553	0.0355	1.4821	0.4065	5.8299	0.3422	1.9255	1.1391	0	0.0111	0	0	0.0155
DOT8.11_2	208	260215	100.8391	18.8561	1.0344	2.5713	66.3316	0.0648	1.4395	0.4249	5.785	0.2943	1.8384	1.2719	0.0057	0.0537	0.0284	0	0
DOT8.11_3	209	260215	100.4009	18.8096	1.1137	2.4742	66.6436	0.0168	1.4862	0.4483	5.7995	0.3483	1.857	0.9545	0	0.0334	0	0	0.0149
DOT8.15_1	210	260215	101.5161	18.542	0.4979	2.256	68.6171	0.0603	1.382	0.585	6.531	0.0571	0.4943	0.4675	0.0041	0.0126	0	0.4468	0.0462
DOT8.15_2	211	260215	100.8498	18.5058	0.6142	2.2711	68.3024	0.0706	1.3599	0.5953	6.6927	0.0831	0.3951	0.4247	0.0211	0.0221	0.0808	0.4662	0.0947
DOT8.15_3	212	260215	101.6432	18.532	0.5564	2.3437	68.4987	0.0799	1.3218	0.5689	6.6549	0.0653	0.4666	0.4899	0.0279	0.0063	0	0.3805	0.0072
DOT8.14_1	213	260215	101.275	19.1281	0.8687	2.2422	67.4417	0.0795	1.33	0.5756	6.4668	0.0965	1.0151	0.6534	0	0.0315	0	0.0273	0.0436
DOT8.14_2	214	260215	101.1297	19.0583	0.8815	2.2201	67.1346	0.127	1.3743	0.6271	6.5658	0.0835	1.1021	0.5491	0	0.0379	0.0043	0.1297	0.1047
DOT8.14_3	215	260215	100.9099	19.2034	0.8498	2.1576	67.3123	0.1007	1.4218	0.6254	6.4574	0.1164	0.973	0.6839	0	0	0.009	0.061	0.0282
DOT8.13_1	216	260215	100.6488	16.0202	0.4944	2.2442	70.437	0.1056	1.5663	0.524	7.8858	0.0629	0.2378	0.3474	0	0	0.05	0.0243	0
DOT8.13_2	217	260215	100.8546	16.3654	0.4217	2.2914	70.2451	0.094	1.5267	0.4907	7.8555	0.0272	0.3321	0.2668	0	0	0.0381	0	0.0454
DOT8.13_3	218	260215	101.3772	16.5007	0.4269	2.2663	70.0788	0.1192	1.6146	0.588	7.6969	0.0335	0.2754	0.3589	0	0.0409	0	0	0
DOT8.X_1	219	260215	100.8759	19.2864	1.0001	2.4835	65.6845	0.0549	1.3343	0.5513	6.4613	0.274	1.6881	1.0805	0.0084	0.0332	0.0262	0.0332	0
DOT8.X_2	220	260215	99.9941	18.7725	0.9645	2.4354	66.284	0.0924	1.2069	0.5419	6.5445	0.2872	1.6867	1.0664	0	0.008	0.0282	0	0.0814
DOT8.X_3	221	260215	100.2734	18.8071	0.9597	2.4585	66.4872	0.0836	1.3264	0.5317	6.4427	0.2367	1.5527	1.0831	0.0085	0.016	0	0.0063	0
Lym1b.1_4	222	260215	0.2855	0	0	0	0	0.8406	82.627	0	0	3.1524	2.2767	0	3.1524	0	0	0	7.951
Lym1b.a_1	223	260215	100.0798	19.2423	0.656	2.1208	67.7959	0.1133	1.4505	0.5947	6.2224	0.086	0.305	0.5519	0.0241	0.0732	0.0037	0.714	0.0461
Lym1b.a_2	224	260215	100.1512	19.2922	0.6617	2.0948	67.9612	0.1246	1.3865	0.6641	6.4056	0.0953	0.2736	0.4244	0	0.0096	0	0.6036	0.0028
Lym1b.a_3	225	260215	100.0382	18.6637	0.6116	2.1307	68.5154	0.122	1.4235	0.6713	6.297	0.068	0.2258	0.5446	0	0.0255	0	0.668	0.033
Lym1b.b_1	226	260215	99.9541	16.5373	0.5773	2.3648	70.3361	0.1331	1.1744	0.5727	6.9507	0.0473	0.6397	0.36	0	0	0	0.2781	0.0286
Lym1b.b_2	227	260215	99.9699	16.5867	0.4437	2.3247	70.1811	0.1258	1.2763	0.558	7.0008	0.0763	0.7621	0.3768	0	0.0479	0	0.2397	0
Lym1b.b_3	228	260215	99.1776	16.7071	0.518	2.2547	70.2063	0.1663	1.3624	0.5681	6.8805	0.0443	0.5442	0.419	0	0.0322	0	0.297	0
Lym1b.c_1	229	260215	99.8323	18.5864	0.5186	2.1233	68.5128	0.1286	1.3692	0.5817	6.434	0.1022	0.2444	0.6385	0	0.0287	0.0159	0.5732	0.1426
Lym1b.c_2	230	260215	99.7167	18.4556	0.6335	2.1494	68.5177	0.1228	1.3982	0.5836	6.5628	0.0675	0.2227	0.575	0.0271	0.0417	0	0.519	0.1234
Lym1b.c_3	231	260215	99.8901	18.489	0.5915	2.0423	68.6056	0.0724	1.3711	0.6166	6.6942	0.0174	0.2363	0.6465	0.0099	0	0.0046	0.5411	0.0616
Lym1b.d_1	232	260215	100.0374	16.5622	0.5452	2.3917	69.8288	0.1694	1.3592	0.653	7.1098	0.0457	0.4174	0.5515	0	0.0224	0.0029	0.2496	0.0912
Lym1b.d_2	233	260215	100.0992	16.4274	0.5536	2.389	70.2389	0.1042	1.2863	0.6453	6.9952	0.0664	0.4148	0.5359	0	0	0	0.2848	0.0582
Lym1b.d_3	234	260215	100.1012	16.7003	0.5435	2.3627	70.0725	0.1232	1.2471	0.6527	6.9934	0.0887	0.5319	0.3462	0.0028	0.0192	0.0128	0.2873	0.0156
Lym1b.e_1	235	260215	99.3403	14.4161	0.6441	2.3688	71.2783	0.1628	1.267	0.5398	8.459	0.0762	0.3096	0.3875	0.01	0.0403	0.0292	0	0.0114
Lym1b.e_2	236	260215	99.5409	14.3474	0.5558	2.4231	71.2617	0.1172	1.1896	0.5298	8.7118	0.0436	0.2741	0.4688	0	0.0548	0	0.0174	0.0051
Lym1b.e_3	237	260215	99.9137	14.2893	0.616	2.4991	71.2169	0.1297	1.1755	0.4494	8.6322	0.06	0.3256	0.4216	0.0327	0.0048	0.0482	0.0244	0.0746

Run Name	Runs	SFN	Na2O	MgO	Al2O3	SiO2	P2O5	Cl	K2O	CaO	TiO2	MnO	Fe2O3	CoO	CuO	SnO2	Sb2O5	PbO
DOT1.1	4		18.9209	0.6438	2.4067	68.2416	0.1095	1.4514	0.6271	6.1777	0.0931	0.5557	0.4897	0.0035	0.0128	0.0272	0.2371	0.0024
DOT1.2	5		19.6280	1.0145	2.3158	65.4934	0.0782	1.3138	0.6339	6.3435	0.2834	1.6545	1.1551	0.0037	0.0338	0.0041	0.0214	0.0231
DOT1.3	4		2.0095	2.3276	4.8858	60.9949	0.5095	0.2925	1.8463	24.3918	0.2190	0.0557	2.4000	0.0051	0.0154	0.0133	0.0062	0.0277
DOT1.4	4		4.6935	0.1659	6.2968	63.5403	0.1032	1.1601	0.4145	23.1663	0.0609	0.0266	0.3384	0.0022	0.0077	0.0207	0.0000	0.0032
DOT1.5	5		17.0060	0.6265	2.2855	68.7697	0.1210	1.0682	0.6548	7.0414	0.0714	0.4481	0.7642	0.0026	0.0054	0.0167	0.3506	0.7678
DOT1.6	4		19.2595	1.0147	2.4307	65.9602	0.0905	1.3181	0.6225	6.3328	0.2711	1.5088	1.1086	0.0000	0.0357	0.0079	0.0193	0.0201
DOT1.7	4		18.4024	0.5571	2.1471	68.8443	0.0999	1.1708	0.5775	6.2587	0.0914	0.2583	0.9976	0.0021	0.0274	0.0027	0.5238	0.0390
DOT1.8	4		19.4870	1.0288	2.4179	65.7232	0.0950	1.2390	0.6425	6.1889	0.2953	1.7551	1.0857	0.0114	0.0000	0.0050	0.0255	0.0000
DOT1.9	4		12.6323	1.3947	1.0783	70.7464	0.0503	0.1114	0.3880	12.9212	0.0387	0.1414	0.2849	0.0658	0.0110	0.0219	0.0066	0.1074
DOT1.10	4		14.2214	0.5082	2.4682	71.7523	0.1156	1.3265	0.4275	8.2729	0.0513	0.4798	0.3219	0.0211	0.0084	0.0159	0.0040	0.0054
DOT1.11	4		17.3750	0.3862	2.4579	69.3749	0.1154	1.5579	0.4897	7.5843	0.0399	0.1876	0.3050	0.0157	0.0361	0.0000	0.0148	0.0598
DOT9.1	4		16.5177	0.5576	2.5422	69.8129	0.1308	1.0993	0.7383	7.0166	0.0901	0.5700	0.5349	0.0071	0.0180	0.0133	0.3145	0.0370
DOT9.2	4		8.8537	6.3040	1.5537	66.2473	1.1106	0.6371	4.1060	10.2619	0.1028	0.0471	0.5947	0.0178	0.0289	0.0044	0.1123	0.0178
DOT9.3	4		15.8498	0.4787	2.2039	71.9529	0.0948	1.4707	0.4212	6.9655	0.0518	0.1120	0.3108	0.0088	0.0290	0.0265	0.0068	0.0171
DOT9.4	4		16.9557	0.5794	2.3753	69.8048	0.1711	1.2468	0.7529	6.6417	0.0847	0.4640	0.5389	0.0056	0.0821	0.0105	0.2267	0.0601
DOT9.5	5		14.2066	1.6356	20.3486	55.6648	0.0656	0.9275	0.4749	5.0042	0.0687	0.2927	0.7921	0.0062	0.0401	0.0000	0.4352	0.0373
DOT9.6	4		17.9503	0.5059	1.9779	68.8883	0.0720	1.3817	0.5285	6.0267	0.0531	0.2410	1.6196	0.0000	0.0171	0.0190	0.7143	0.0049
DOT9.7	4		18.3441	0.9382	2.4390	66.4662	0.0781	1.3287	0.7431	7.0876	0.2334	1.3085	0.9323	0.0000	0.0400	0.0250	0.0147	0.0213
DOT9.8	4		16.0013	0.5290	2.5130	70.3591	0.1827	1.3495	0.6769	7.5090	0.0609	0.4337	0.3121	0.0000	0.0139	0.0139	0.0106	0.0346
DOT9.10	4		11.5741	0.9659	1.0125	72.4912	0.0493	0.0752	0.4182	12.4738	0.0581	0.1313	0.3816	0.0046	0.0137	0.0108	0.0159	0.3240
DOT9.11	4		17.9704	0.4920	2.0005	68.9311	0.0657	1.4404	0.5328	5.9798	0.0614	0.2303	1.5648	0.0000	0.0115	0.0209	0.6574	0.0412
DOT9.9	4		16.9398	0.5588	2.2193	68.7034	0.0845	1.2838	0.6302	6.6046	0.0816	0.4040	2.0148	0.0000	0.0223	0.0078	0.3895	0.0557
DOT9.12	4		15.3439	0.7108	4.6328	68.2241	0.1307	1.0051	0.9767	6.6301	0.0850	0.2824	1.4946	0.0049	0.0079	0.0102	0.3954	0.0656
DOT9.13	4		18.3064	0.6553	2.1262	68.8809	0.1013	1.4650	0.5825	6.3085	0.0604	0.3053	0.4940	0.0085	0.0347	0.0085	0.6101	0.0526
DOT6.1	4		18.9688	0.9063	2.2976	65.9432	0.0677	1.4138	0.5887	6.9678	0.2337	1.5453	1.0136	0.0082	0.0140	0.0071	0.0245	0.0000
DOT6.2	4		7.3466	4.5744	2.5929	62.7306	1.4496	0.5470	6.5837	10.9810	0.1260	0.5030	1.4511	0.0157	0.0064	0.0000	0.2072	0.8848
DOT6.3	4		18.8751	0.9793	2.4769	65.9822	0.0545	1.3018	0.6058	6.4228	0.3144	1.7215	1.1428	0.0210	0.0232	0.0102	0.0167	0.0519
DOT6.4	4		19.0452	1.0288	2.3335	66.1021	0.0847	1.4638	0.5417	6.5582	0.2228	1.5508	1.0084	0.0071	0.0200	0.0000	0.0197	0.0134
DOT6.5	5		18.8540	0.9476	2.1918	66.0300	0.0773	1.8483	0.5854	5.9995	0.2700	1.5514	1.2740	0.0144	0.2564	0.0036	0.0604	0.0359
DOT6.6	4		2.2874	2.3173	5.5303	59.2816	0.9242	0.4413	2.9847	24.1448	0.2211	0.2478	1.4476	0.0092	0.0375	0.0110	0.0450	0.0693
DOT6.7	4		18.7640	0.9964	2.3151	66.3735	0.0745	1.3361	0.5631	6.6949	0.2197	1.5155	0.9928	0.0000	0.0183	0.0369	0.0371	0.0623
DOT6.8	4		18.7626	0.9795	2.3411	66.4815	0.1002	1.3181	0.5934	6.5871	0.2375	1.5055	1.0395	0.0109	0.0155	0.0014	0.0029	0.0236
DOT6.9	4		19.1278	1.0282	2.5190	65.5624	0.0904	1.2971	0.6015	6.3675	0.3024	1.8270	1.1839	0.0042	0.0171	0.0050	0.0022	0.0645
DOT6.10	4		18.6757	0.9154	2.3211	66.3543	0.0875	1.4863	0.5686	6.8662	0.1960	1.5186	0.9253	0.0119	0.0000	0.0011	0.0427	0.0295
DOT6.11	4		19.0182	1.1332	2.2383	65.7615	0.0275	1.6155	0.3979	7.2152	0.1413	1.6895	0.6775	0.0169	0.0298	0.0084	0.0161	0.0133
DOT6.12	4		18.7843	0.9713	2.4163	66.1399	0.1244	1.2315	0.6061	6.5729	0.2743	1.6524	1.1427	0.0011	0.0275	0.0096	0.0335	0.0125

Run Name	Runs	SFN	Na2O	MgO	Al2O3	SiO2	P2O5	Cl	K2O	CaO	TiO2	MnO	Fe2O3	CoO	CuO	SnO2	Sb2O5	PbO
DOT6.13	5		0.6290	0.1605	0.0961	0.3793	42.2382	0.4141	0.0174	55.5796	0.0070	0.0515	0.1882	0.0147	0.1870	0.0000	0.0000	0.0375
DOT6.14	4		19.0172	0.9535	2.3775	66.3493	0.1019	1.3466	0.6052	6.4353	0.2736	1.5153	0.9646	0.0092	0.0085	0.0028	0.0397	0.0002
DOT6.15	4		18.4390	1.2955	2.5744	64.4479	0.0876	1.2822	0.4808	6.5701	0.4127	2.7001	1.6681	0.0025	0.0000	0.0101	0.0106	0.0187
DOT6.16	4		18.6081	1.0242	2.5823	66.5680	0.0651	1.4531	0.4213	5.7616	0.3134	1.8931	1.2231	0.0035	0.0439	0.0145	0.0049	0.0202
DOT7.1	4		17.4752	1.0916	2.9077	65.8004	0.0525	1.1999	0.4935	5.9045	0.5148	2.4066	2.0544	0.0132	0.0048	0.0173	0.0594	0.0044
DOT7.2	4		19.1019	0.8744	1.8453	67.7419	0.0675	1.6025	0.2680	6.1507	0.1108	1.4751	0.7108	0.0233	0.0179	0.0029	0.0029	0.0042
DOT7.3	4		17.0289	0.6255	2.3209	69.1912	0.1715	1.2127	0.6902	7.0136	0.0881	0.5153	0.6020	0.0050	0.0140	0.0548	0.3839	0.0826
DOT7.4	4		19.1065	1.1614	2.3753	66.3897	0.0374	1.4290	0.4520	5.5922	0.4233	1.7718	1.1816	0.0100	0.0112	0.0184	0.0130	0.0276
DOT7.5	4		16.5078	1.3086	2.3729	67.1490	0.0849	1.4205	0.3897	6.1255	0.3733	2.8459	1.3336	0.0004	0.0589	0.0023	0.0005	0.0265
DOT7.6	4		20.1006	0.9307	2.3462	65.1371	0.0866	1.3563	0.6013	6.2475	0.2772	1.6543	1.1583	0.0075	0.0257	0.0278	0.0262	0.0168
DOT7.7	5		16.1394	3.7664	2.7430	56.7052	0.0670	3.6033	1.8890	8.3358	0.7388	1.8538	2.1556	0.7009	0.8018	0.0055	0.0146	0.4799
DOT7.8	4		21.0454	0.8949	2.5463	64.0448	0.0748	1.2689	0.7332	5.8912	0.3718	1.8039	1.2455	0.0097	0.0115	0.0172	0.0240	0.0169
DOT7.9	4		18.6327	0.9581	2.4275	66.1952	0.1143	1.4231	0.7438	6.3446	0.4015	1.5475	1.0421	0.0287	0.0232	0.0098	0.1018	0.0062
DOT7.10	4		17.2698	1.0745	2.9411	66.1211	0.0990	1.2399	0.5812	5.7709	0.5407	2.3960	1.9171	0.0046	0.0339	0.0103	0.0000	0.0000
DOT7.11	4		18.9541	1.2075	2.9958	65.8964	0.0507	1.3396	0.4087	5.3568	0.5799	1.5655	1.6145	0.0071	0.0076	0.0071	0.0000	0.0090
DOT7.12	4		19.1593	0.9748	2.2388	66.4194	0.0775	1.3695	0.5961	6.3559	0.2022	1.5531	0.9123	0.0159	0.0307	0.0143	0.0596	0.0209
DOT7.13	4		18.9951	0.9841	2.4160	66.0416	0.1023	1.2506	0.6432	6.5154	0.2698	1.5891	1.1107	0.0089	0.0259	0.0207	0.0174	0.0097
DOT7.14	4		18.9524	1.0560	2.3423	65.1060	0.1274	1.3822	0.4382	7.2411	0.2975	1.7630	1.1967	0.0014	0.0127	0.0122	0.0279	0.0435
DOT7.15	4		19.2480	0.9796	2.4031	66.1006	0.0567	1.3710	0.5320	6.2545	0.2653	1.6547	1.0683	0.0000	0.0175	0.0147	0.0147	0.0196
DOT11.1	4		0.4568	3.3741	3.7807	15.8845	7.6530	0.7547	0.9279	61.4282	0.0922	0.4909	4.2323	0.0657	0.4235	0.0000	0.0502	0.3855
DOT11.2	4		0.9239	1.7042	18.9295	59.6065	0.3951	0.0125	3.4099	1.3101	1.0869	0.1279	12.3363	0.0086	0.0208	0.0067	0.0735	0.0477
DOT11.3	4		19.0455	0.9728	2.4717	66.0429	0.1016	1.2885	0.6191	6.2307	0.3122	1.7754	1.0817	0.0183	0.0219	0.0104	0.0020	0.0053
DOT11.4	4		17.5407	0.5545	2.2183	69.7486	0.1244	1.1510	0.5720	6.2621	0.0669	0.2151	0.9312	0.0053	0.0179	0.0159	0.5278	0.0485
DOT11.5	4		18.4915	0.9529	2.3825	66.9006	0.0911	1.2849	0.5768	6.4044	0.2549	1.6042	0.9699	0.0206	0.0231	0.0009	0.0119	0.0299
DOT11.6	4		14.8893	0.8339	2.4058	71.3176	0.1477	1.3741	0.6468	6.3998	0.0989	0.9920	0.6794	0.0087	0.0257	0.0180	0.1030	0.0597
DOT11.7	4		17.5424	0.0180	0.1747	74.7351	0.0102	0.3004	0.0522	6.7330	0.0370	0.0986	0.0450	0.0071	0.0028	0.0047	0.2244	0.0146
DOT11.8	4		18.4203	0.9999	2.3774	67.0155	0.0924	1.3880	0.5523	6.2614	0.2208	1.5738	0.9906	0.0077	0.0242	0.0274	0.0310	0.0174
DOT11.9	4		19.5884	0.9566	2.3374	66.2913	0.0599	1.5104	0.4862	6.1944	0.1868	1.4477	0.8910	0.0000	0.0000	0.0110	0.0136	0.0256
DOT11.10	4		18.9800	0.5657	1.9586	68.7524	0.0589	1.4139	0.5152	6.4004	0.0730	0.1602	0.4878	0.0158	0.0004	0.0056	0.5567	0.0555
DOT11.11	4		16.2842	0.6079	2.4557	69.7567	0.1791	1.1403	0.7037	7.0853	0.0752	0.5114	0.7351	0.0011	0.0328	0.0216	0.3315	0.0785
DOT11.12	4		18.6909	0.5903	2.2101	68.3092	0.1250	1.4548	0.7653	6.2423	0.0853	0.0831	0.5148	0.0123	0.0028	0.0196	0.8245	0.0700
DOT11.13	4		19.7110	0.8438	2.1748	66.6145	0.0533	1.5006	0.5560	6.4517	0.1183	1.0966	0.7146	0.0007	0.0560	0.0157	0.0653	0.0275
DOT11.14	4		18.5926	1.0082	2.3586	66.5638	0.1046	1.3491	0.6905	6.3411	0.2429	1.5465	1.0271	0.0071	0.0505	0.0042	0.0637	0.0496
DOT11.15	4		14.2855	0.5575	2.5435	71.1587	0.1636	1.2784	0.6702	7.5540	0.0682	1.3754	0.2466	0.0018	0.0324	0.0163	0.0126	0.0354
DOT5.1	3		18.5908	0.9677	2.3192	66.7818	0.0570	1.4286	1.0813	5.4912	0.3365	1.5495	1.2887	0.0057	0.0426	0.0308	0.0231	0.0056
DOT5.2	3		18.3637	1.0678	2.4582	65.1057	0.1192	1.3055	0.6278	6.1003	0.3238	1.6671	1.2180	0.0028	1.5423	0.0282	0.0229	0.0467

Run Name	Runs	SFN	Na2O	MgO	Al2O3	SiO2	P2O5	Cl	K2O	CaO	TiO2	MnO	Fe2O3	CoO	CuO	SnO2	Sb2O5	PbO
DOT5.3	3		7.0372	2.6441	0.7541	26.2908	0.0165	38.2889	1.6314	6.7307	0.5977	2.7866	7.0341	0.9339	0.0195	0.1229	1.7331	3.3787
DOT5.4	3		20.4224	1.0717	2.2593	64.1460	0.0680	1.5615	0.4008	6.8428	0.2676	1.7882	1.1030	0.0156	0.0244	0.0065	0.0170	0.0052
DOT5.6	3		19.0928	0.9857	2.4845	65.9623	0.1208	1.2659	0.6887	6.2100	0.3068	1.5974	1.1579	0.0033	0.0401	0.0132	0.0432	0.0276
DOT5.5	3		19.2378	1.0707	2.4866	65.7395	0.1110	1.2496	0.6418	6.2646	0.2958	1.6662	1.1122	0.0000	0.0243	0.0067	0.0480	0.0452
DOT5.7	3		18.8991	1.1383	2.4615	66.1176	0.1257	1.3328	0.5006	6.3089	0.2446	1.7669	1.0172	0.0132	0.0074	0.0027	0.0000	0.0636
DOT5.8	3		2.3092	2.5927	3.4151	61.0947	0.8422	0.9278	0.5904	26.1919	0.1840	0.0692	1.7150	0.0009	0.0246	0.0130	0.0000	0.0291
DOT5.9	3		18.3711	0.5761	2.2998	68.6425	0.1174	1.3716	0.6015	6.3495	0.1010	0.3300	0.5343	0.0009	0.0238	0.0153	0.5916	0.0736
DOT5.10	3		2.3486	2.6567	3.3705	61.0970	0.8502	0.9259	0.5991	26.0834	0.1631	0.0939	1.7239	0.0000	0.0381	0.0082	0.0000	0.0413
DOT5.11	3		18.5467	0.5604	2.2547	68.4756	0.1258	1.4066	0.6398	6.3373	0.0788	0.3532	0.5420	0.0201	0.0416	0.0004	0.5988	0.0183
DOT5.12	3		19.1616	0.8897	2.1190	67.7671	0.0901	1.3306	0.6840	6.0120	0.1080	1.1417	0.5767	0.0164	0.0190	0.0143	0.0699	0.0000
DOT5.13	3		20.8649	0.8664	2.2451	65.3244	0.1093	1.5806	0.5053	6.2447	0.1497	1.2332	0.7755	0.0170	0.0180	0.0046	0.0395	0.0219
DOT5.14	3		19.7495	1.0598	2.3679	65.3249	0.1171	1.3676	0.6072	6.4767	0.2030	1.6245	1.0128	0.0123	0.0275	0.0049	0.0118	0.0327
DOT5.15	3		19.4682	1.0424	2.5068	65.3991	0.1196	1.2637	0.6257	6.1764	0.2980	1.7273	1.3163	0.0019	0.0154	0.0004	0.0079	0.0311
Lym1b.1	4		14.3131	0.4873	1.7161	50.7241	0.3058	21.7159	0.4940	4.8139	0.8573	0.7415	0.4619	0.7913	0.0052	0.0040	0.5238	2.0450
Lym1b.10	3		18.8441	1.0191	2.2712	65.7677	0.1334	0.9730	0.7214	7.7707	0.1366	1.3088	0.8583	0.0123	0.0106	0.0417	0.0838	0.0472
Lym1b.9	3		14.5904	0.5986	2.5033	71.0319	0.2031	1.2072	0.4849	8.6148	0.0576	0.2907	0.3998	0.0042	0.0048	0.0005	0.0080	0.0000
Lym1a.2	3		17.7934	0.6092	2.2645	69.5365	0.1319	1.2931	0.6315	6.1569	0.0774	0.2363	0.6826	0.0146	0.0176	0.0010	0.4826	0.0711
Lym1a.a	3		15.9341	0.5696	2.6554	70.2780	0.1523	1.3637	0.5429	7.7770	0.0637	0.2295	0.3833	0.0181	0.0000	0.0170	0.0064	0.0092
Lym1a.b	3		17.1124	0.6251	2.2296	68.8720	0.1836	1.3604	0.6604	6.9589	0.0749	0.6405	0.8612	0.0075	0.0000	0.0023	0.3630	0.0481
Lym1a.4	3		17.2682	0.5881	2.3454	69.7363	0.1409	1.0884	0.6160	6.2310	0.0663	0.2916	0.8980	0.0076	0.0766	0.0033	0.4950	0.1474
Lym1a.5	3		17.5553	0.6048	2.2373	69.1378	0.1458	1.2660	0.6590	6.5839	0.0708	0.4853	0.6952	0.0052	0.0254	0.0328	0.4345	0.0611
Lym1a.3	3		15.9057	0.5366	2.6666	70.1930	0.1459	1.3675	0.5368	7.9053	0.0580	0.2119	0.3584	0.0124	0.0549	0.0157	0.0103	0.0210
Lym2.1	3		19.9518	0.6527	1.9405	67.1148	0.0766	1.2772	0.4944	6.7526	0.0906	1.0067	0.5790	0.0289	0.0000	0.0036	0.0108	0.0197
Lym2.2	3		19.2182	0.7222	2.1347	66.9259	0.0951	1.2012	0.6281	6.9690	0.1204	1.0389	0.6831	0.0076	0.0432	0.0333	0.0763	0.1025
Lym2.3	3		18.2502	0.7621	2.2385	67.7124	0.1170	1.1077	0.6660	6.9717	0.1131	0.9356	0.7475	0.0052	0.0556	0.0291	0.1845	0.1040
Lym2.4	3		19.4111	0.6253	1.8619	67.9903	0.0680	1.1860	0.4695	6.6728	0.0837	1.0493	0.5259	0.0000	0.0196	0.0208	0.0151	0.0007
Lym2.5	3		18.6953	0.7415	2.2120	67.2493	0.1205	1.1316	0.5795	7.1364	0.1180	0.9918	0.7578	0.0043	0.0597	0.0673	0.0450	0.0900
Lym2.6	3		18.7835	0.9160	2.3096	66.6088	0.1347	1.1887	0.7292	7.1377	0.1268	1.0394	0.7425	0.0132	0.0430	0.0428	0.1670	0.0171
Lym2.7	3		17.0147	0.7736	2.2943	65.1100	0.1303	1.0926	0.7607	6.9217	0.0849	0.8790	0.6660	0.0183	0.0450	3.0713	0.2136	0.9240
Lym2.8	3		18.5243	0.9100	2.2993	65.5813	0.1375	1.1657	0.7086	7.2063	0.1314	1.0753	0.8691	0.0137	0.0424	0.8902	0.1446	0.3005
Lym2.9	3		19.6770	1.0531	2.2618	65.0566	0.1445	1.2568	0.6866	7.5371	0.1081	1.2823	0.7650	0.0000	0.0462	0.0223	0.0982	0.0045
Lym2.10	3		18.3018	1.1143	2.4586	65.2423	0.1114	1.0960	0.6758	8.2872	0.1298	1.6873	0.8117	0.0110	0.0074	0.0128	0.0320	0.0204
Lym2.11	3		0.0000	0.0000	0.0000	5.6527	0.0000	35.4852	2.7062	6.1426	2.3277	13.3442	8.2446	1.1168	10.5586	0.0000	0.0000	14.4214
Lym2.13	3		17.1352	0.8124	2.1677	66.7677	0.1627	1.1269	0.7327	6.8009	0.1136	0.5019	0.8656	0.0005	2.2237	0.2247	0.2513	0.1125
Lym2.14	3		16.9066	0.8652	2.1451	66.6601	0.1918	1.0861	0.7711	6.8579	0.1317	0.4704	0.9033	0.0164	2.3990	0.2635	0.2364	0.0953
Lym2.15	3		17.0155	0.7864	2.1199	67.0034	0.1655	1.0687	0.7563	6.7560	0.0910	0.5662	0.9059	0.0135	2.1791	0.1935	0.2564	0.1225

Run Name	Runs	SFN	Na2O	MgO	Al2O3	SiO2	P2O5	Cl	K2O	CaO	TiO2	MnO	Fe2O3	CoO	CuO	SnO2	Sb2O5	PbO
Lym2.16	3		9.6511	0.4339	1.8137	46.8159	0.0824	28.8734	0.4332	4.8864	0.0548	2.6425	0.4366	0.0094	2.2762	0.0477	0.0203	1.5226
Lym2.act.16	3		16.8124	1.2330	2.6324	67.3438	0.1817	1.0638	0.9569	7.3060	0.1164	0.2373	1.2138	0.0645	0.1475	0.0065	0.0289	0.6551
Lym2.17	3		17.7620	1.0571	2.3946	66.2719	0.1423	1.0230	0.7921	7.7464	0.1303	1.4076	1.0701	0.0094	0.0532	0.0225	0.1095	0.0080
Lym2.18	3		17.7591	1.0686	2.3874	66.2480	0.1496	1.0149	0.8020	7.7436	0.1063	1.3880	1.1165	0.0132	0.0546	0.0462	0.0783	0.0237
Lym2.19	3		16.6557	0.9221	2.4864	67.7603	0.0878	0.8887	0.8879	7.8444	0.1303	1.0983	0.9133	0.0141	0.2267	0.0064	0.0615	0.0159
Lym3.1	3		15.6703	0.8316	2.6197	70.7823	0.1647	1.0683	0.8318	7.0918	0.0743	0.1599	0.5759	0.0042	0.0287	0.0042	0.0833	0.0089
Lym3.2	3		17.5091	0.7129	2.4229	68.4811	0.1432	1.0252	0.7900	7.2377	0.0798	0.6331	0.6478	0.0019	0.0555	0.0162	0.1749	0.0687
Lym3.3	3		17.5428	0.8721	2.3819	67.4437	0.1419	1.0821	0.7578	7.5682	0.1037	0.9590	0.8054	0.0098	0.0420	0.0645	0.1810	0.0440
Lym3.4	3		18.5546	0.6066	2.2846	68.0427	0.0817	1.3880	0.7200	6.5145	0.0901	0.2076	0.6903	0.0070	0.0089	0.0016	0.7662	0.0355
DOT12.1	3		18.0684	0.5662	2.3281	68.9084	0.1075	1.3958	0.6233	6.5797	0.0748	0.2998	0.5689	0.0019	0.0280	0.0175	0.4211	0.0107
DOT12.2	3		0.1870	0.0000	0.1134	53.0699	0.0000	0.0000	9.3104	0.0618	0.0013	0.0431	0.0712	0.0210	0.0111	0.0038	0.3533	36.7525
DOT12.3	3		16.3394	0.4356	2.3164	70.2864	0.1198	1.5187	0.4991	7.8331	0.0353	0.2581	0.2994	0.0019	0.0165	0.0100	0.0181	0.0123
DOT12.4	3		18.8993	0.5119	1.8183	66.2311	0.0562	1.4228	0.4058	5.2909	0.0500	0.1246	0.3665	0.0023	2.1317	0.0121	2.6149	0.0616
DOT8.1	3		18.9245	0.9760	2.5403	66.3432	0.1088	1.2290	0.6768	6.1422	0.2881	1.5019	1.1443	0.0287	0.0349	0.0000	0.0533	0.0080
DOT8.2	3		18.6915	1.0938	2.5747	66.3522	0.0636	1.4392	0.3964	5.8405	0.3497	1.9681	1.1436	0.0098	0.0211	0.0152	0.0109	0.0295
DOT8.3	3		17.4761	1.1540	3.0017	65.8364	0.0848	1.2495	0.4574	5.9963	0.5244	2.3091	1.8593	0.0136	0.0195	0.0000	0.0057	0.0122
DOT8.4	3		18.9416	0.9706	2.4100	65.8848	0.0828	1.3275	0.5570	6.6423	0.2441	1.7186	1.0687	0.0099	0.0672	0.0200	0.0193	0.0356
DOT8.5	3		18.6192	1.2635	2.5592	63.8896	0.0659	1.3387	0.4606	6.6982	0.3752	2.8571	1.8030	0.0103	0.0264	0.0124	0.0203	0.0000
DOT8.6	3		18.6311	1.0621	2.5937	66.4741	0.0395	1.5033	0.3900	5.8558	0.3108	1.8673	1.2133	0.0051	0.0343	0.0083	0.0004	0.0107
DOT8.7	3		16.2634	0.4887	2.2916	70.1987	0.1302	1.5224	0.5242	7.8759	0.0423	0.2799	0.2710	0.0108	0.0207	0.0182	0.0012	0.0609
DOT8.8	3		19.0250	0.8624	2.1997	67.4769	0.0676	1.4174	0.6171	6.5035	0.0946	0.9949	0.5830	0.0117	0.0063	0.0165	0.0850	0.0384
DOT8.9	3		18.2907	0.5697	2.3114	68.6094	0.1453	1.3977	0.5836	6.7233	0.0640	0.3812	0.4732	0.0150	0.0000	0.0374	0.3840	0.0140
DOT8.10	3		18.5467	1.2920	2.6027	64.0681	0.0892	1.3451	0.4391	6.6270	0.4015	2.7874	1.7621	0.0000	0.0221	0.0170	0.0000	0.0000
DOT8.11	3		18.7624	1.0510	2.5255	66.5435	0.0390	1.4693	0.4266	5.8048	0.3283	1.8736	1.1218	0.0019	0.0327	0.0095	0.0000	0.0101
DOT8.15	3		18.5266	0.5562	2.2903	68.4727	0.0703	1.3546	0.5831	6.6262	0.0685	0.4520	0.4607	0.0177	0.0137	0.0269	0.4312	0.0494
DOT8.14	3		19.1299	0.8667	2.2066	67.2962	0.1024	1.3754	0.6094	6.4967	0.0988	1.0301	0.6288	0.0000	0.0231	0.0044	0.0727	0.0588
DOT8.13	3		16.2954	0.4477	2.2673	70.2536	0.1063	1.5692	0.5342	7.8127	0.0412	0.2818	0.3244	0.0000	0.0136	0.0294	0.0081	0.0151
DOT8.X	3		18.9553	0.9748	2.4591	66.1519	0.0770	1.2892	0.5416	6.4828	0.2660	1.6425	1.0767	0.0056	0.0191	0.0181	0.0132	0.0271
Lym1b.1	4		14.3131	0.4873	1.7161	50.7241	0.3058	21.7159	0.4940	4.8139	0.8573	0.7415	0.4619	0.7913	0.0052	0.0040	0.5238	2.0450
Lym1b.a	3		19.0661	0.6431	2.1154	68.0908	0.1200	1.4202	0.6434	6.3083	0.0831	0.2681	0.5070	0.0080	0.0361	0.0012	0.6619	0.0273
Lym1b.b	3		16.6104	0.5130	2.3147	70.2412	0.1417	1.2710	0.5663	6.9440	0.0560	0.6487	0.3853	0.0000	0.0267	0.0000	0.2716	0.0095
Lym1b.c	3		18.5103	0.5812	2.1050	68.5454	0.1079	1.3795	0.5940	6.5637	0.0624	0.2345	0.6200	0.0123	0.0235	0.0068	0.5444	0.1092
Lym1b.d	3		16.5633	0.5474	2.3811	70.0467	0.1323	1.2975	0.6503	7.0328	0.0669	0.4547	0.4779	0.0009	0.0139	0.0052	0.2739	0.0550
Lym1b.e	3		14.3509	0.6053	2.4303	71.2523	0.1366	1.2107	0.5063	8.6010	0.0599	0.3031	0.4260	0.0142	0.0333	0.0258	0.0139	0.0304

1.0.2 Corning Museum of Glass EMPA Results

Analysis No.	No.	Na2O	MgO	Al2O3	SiO2	P2O5	Cl	K2O	CaO	TiO2	MnO	Fe2O3	CoO	CuO	SnO2	Sb2O5	PbO	Date
Brill A-1	1	14.33	2.57	0.92	65.51	0.13	0.10	2.86	4.95	0.69	0.96	0.95	0.26	1.13	0.18	2.00	0.01	2/23/15
Brill A-2	2	14.13	2.63	0.87	66.32	0.06	0.13	2.90	4.93	0.69	0.99	0.82	0.19	1.28	0.23	2.01	0.07	2/23/15
Brill A-3	3	13.90	2.74	0.81	66.15	0.08	0.12	2.88	5.09	0.67	1.01	0.97	0.21	1.20	0.18	1.87	0.13	2/23/15
Brill A-5	111	14.23	2.63	0.85	66.21	0.12	0.12	2.98	4.92	0.64	0.98	0.94	0.18	1.21	0.22	1.99	0.08	2/23/15
Brill A-4	183	13.88	2.61	0.90	66.45	0.15	0.13	2.93	4.98	0.76	1.03	1.06	0.22	1.23	0.20	2.02	0.03	2/23/15
Brill A-6	246	13.45	2.73	0.91	67.05	0.14	0.10	2.92	5.06	0.68	0.99	0.93	0.14	1.22	0.20	1.90	0.16	2/23/15
Brill A-7	313	14.04	2.78	0.79	66.58	0.13	0.13	2.95	5.02	0.71	1.05	1.11	0.12	1.18	0.23	1.96	0.05	2/23/15
Brill A-8	314	14.41	2.75	0.86	66.16	0.11	0.11	2.90	4.96	0.70	1.03	0.96	0.12	1.27	0.22	1.98	0.06	2/23/15
Brill A-1	1	14.40	2.72	0.84	66.69	0.16	0.11	2.86	4.97	0.73	0.99	0.96	0.15	1.33	0.21	2.03	0.11	2/26/15
Brill A-2	2	13.98	2.63	0.92	66.73	0.15	0.09	2.92	5.02	0.66	0.95	0.98	0.15	1.23	0.25	2.07	0.05	2/26/15
Brill A-7	3	14.03	2.73	0.87	67.05	0.10	0.10	2.92	5.07	0.65	0.99	0.87	0.21	1.29	0.20	1.97	0.00	2/26/15
Brill A-3	66	14.12	2.71	0.97	66.84	0.17	0.11	2.78	4.93	0.66	1.03	0.88	0.15	1.21	0.24	1.95	0.14	2/26/15
Brill A-6	145	13.88	2.64	0.85	66.91	0.06	0.07	2.89	5.00	0.68	1.09	0.98	0.22	1.31	0.20	2.01	0.08	2/26/15
Brill A-4	147	14.05	2.58	0.90	67.16	0.11	0.09	2.90	4.98	0.68	1.07	1.02	0.13	1.32	0.18	1.90	0.07	2/26/15
Brill A-5	185	14.16	2.61	0.92	66.40	0.13	0.08	2.92	5.21	0.67	0.95	1.02	0.19	1.32	0.18	1.94	0.03	2/26/15
Brill A-8	238	14.41	2.63	0.86	66.94	0.17	0.09	2.83	4.90	0.72	1.02	0.95	0.16	1.21	0.17	1.87	0.07	2/26/15
Brill A	**AVERAGE**	**14.09**	**2.67**	**0.88**	**66.57**	**0.12**	**0.10**	**2.90**	**5.00**	**0.69**	**1.01**	**0.96**	**0.17**	**1.25**	**0.21**	**1.97**	**0.07**	
Brill A	**ST DEV**	**0.25**	**0.07**	**0.05**	**0.44**	**0.03**	**0.02**	**0.05**	**0.08**	**0.03**	**0.04**	**0.07**	**0.04**	**0.06**	**0.02**	**0.06**	**0.05**	
Brill B-1	10	16.92	0.98	3.97	61.21	0.82	0.23	1.13	8.67	0.11	0.21	0.33	0.00	3.03	0.08	0.47	0.49	2/23/15
Brill B-2	11	17.46	0.98	4.08	61.32	0.89	0.22	1.03	8.73	0.10	0.29	0.39	0.02	3.04	0.04	0.48	0.56	2/23/15
Brill B-3	180	16.84	1.05	4.03	62.18	0.86	0.25	1.07	8.76	0.07	0.26	0.29	0.09	2.93	0.04	0.54	0.45	2/23/15
Brill B-4	245	16.88	1.09	4.20	62.41	0.83	0.22	1.06	8.77	0.11	0.23	0.31	0.02	2.86	0.03	0.56	0.55	2/23/15
Brill B-5	309	16.46	1.04	4.13	62.32	0.95	0.25	0.99	8.49	0.09	0.25	0.29	0.06	2.85	0.05	0.48	0.47	2/23/15
Brill B-6	310	16.77	1.00	4.22	62.08	0.87	0.20	0.99	8.85	0.07	0.22	0.30	0.04	2.99	0.00	0.53	0.50	2/23/15
Brill B-1	4	16.86	1.02	3.99	61.71	0.87	0.22	1.04	8.66	0.12	0.22	0.28	0.06	2.97	0.05	0.48	0.60	2/26/15
Brill B-5	5	16.73	1.11	4.32	61.18	0.92	0.26	1.04	8.72	0.10	0.24	0.24	0.09	2.89	0.04	0.48	0.45	2/26/15
Brill B-8	6	17.00	1.02	4.17	61.82	0.90	0.21	0.99	8.94	0.13	0.26	0.26	0.05	2.99	0.05	0.54	0.50	2/26/15
Brill B-2	67	16.89	1.01	4.18	62.06	0.85	0.19	1.04	8.51	0.06	0.24	0.31	0.03	2.88	0.02	0.46	0.52	2/26/15
Brill B-4	187	17.07	1.08	4.15	61.61	0.83	0.25	0.99	8.65	0.12	0.22	0.32	0.04	2.86	0.00	0.56	0.51	2/26/15
Brill B-7	188	17.20	1.07	4.13	62.34	0.80	0.23	1.07	8.66	0.08	0.30	0.34	0.02	2.99	0.01	0.49	0.50	2/26/15
Brill B-3	239	16.66	1.01	4.17	61.96	0.89	0.22	1.04	8.86	0.08	0.28	0.34	0.01	2.89	0.01	0.57	0.64	2/26/15
Brill B-6	240	17.17	1.08	4.21	61.77	0.84	0.23	0.98	8.54	0.08	0.26	0.25	0.06	3.00	0.00	0.48	0.55	2/26/15
Brill B	**AVERAGE**	**16.92**	**1.04**	**4.14**	**61.86**	**0.87**	**0.23**	**1.03**	**8.70**	**0.09**	**0.25**	**0.30**	**0.04**	**2.94**	**0.03**	**0.51**	**0.52**	
Brill B	**ST DEV**	**0.25**	**0.04**	**0.10**	**0.41**	**0.04**	**0.02**	**0.04**	**0.13**	**0.02**	**0.03**	**0.04**	**0.03**	**0.07**	**0.02**	**0.04**	**0.05**	

Analysis No.	No.	Na2O	MgO	Al2O3	SiO2	P2O5	Cl	K2O	CaO	TiO2	MnO	Fe2O3	CoO	CuO	SnO2	Sb2O5	PbO	Date
Brill C-1	4	1.27	2.26	0.69	32.82	0.13	0.00	2.90	5.23	0.71	0.01	0.30	0.20	1.25	0.21	0.08	38.01	2/23/15
Brill C-2	5	0.90	2.26	0.66	32.95	0.09	0.00	2.92	4.88	0.75	0.00	0.38	0.18	1.15	0.17	0.03	37.38	2/23/15
Brill C-3	6	0.91	2.36	0.67	32.96	0.06	0.00	2.85	4.93	0.77	0.00	0.34	0.16	1.11	0.18	0.12	37.98	2/23/15
Brill C-5	112	1.26	2.31	0.59	32.52	0.04	0.00	2.91	5.08	0.79	0.00	0.30	0.23	1.14	0.19	0.02	37.77	2/23/15
Brill C-4	182	1.06	2.41	0.73	32.82	0.02	0.00	2.78	5.02	0.70	0.00	0.29	0.19	1.13	0.21	0.08	38.38	2/23/15
Brill C-6	247	1.00	2.37	0.70	33.18	0.10	0.00	2.95	5.10	0.77	0.00	0.27	0.14	1.12	0.20	0.04	38.43	2/23/15
Brill C-7	311	1.04	2.38	0.67	33.05	0.14	0.00	2.81	4.98	0.73	0.00	0.22	0.19	1.13	0.18	0.03	38.28	2/23/15
Brill C-8	312	1.08	2.22	0.58	33.06	0.13	0.00	2.83	5.04	0.74	0.00	0.37	0.10	1.10	0.16	0.05	38.08	2/23/15
Brill C-1	7	1.12	2.28	0.71	32.57	0.18	0.00	2.92	5.03	0.67	0.03	0.31	0.23	1.21	0.23	0.07	38.54	2/26/15
Brill C-5	8	1.05	2.34	0.67	32.79	0.09	0.00	2.96	4.98	0.76	0.00	0.38	0.24	1.09	0.19	0.10	38.08	2/26/15
Brill C-8	9	1.09	2.36	0.62	32.55	0.12	0.00	2.90	4.99	0.72	0.01	0.34	0.15	1.17	0.25	0.01	37.81	2/26/15
Brill C-4	144	1.08	2.33	0.70	32.66	0.09	0.00	2.81	5.05	0.71	0.00	0.35	0.21	1.10	0.16	0.02	38.06	2/26/15
Brill C-7	189	0.90	2.26	0.69	32.56	0.08	0.00	2.93	5.02	0.78	0.02	0.24	0.16	1.28	0.19	0.06	37.95	2/26/15
Brill C-2	241	1.03	2.33	0.50	32.63	0.11	0.00	2.81	5.10	0.73	0.00	0.30	0.14	1.14	0.16	0.04	38.85	2/26/15
Brill C-6	242	0.98	2.29	0.74	32.68	0.11	0.00	2.87	5.05	0.64	0.00	0.27	0.16	1.15	0.18	0.09	37.67	2/26/15
Brill C-3	243	0.95	2.37	0.54	32.67	0.03	0.00	2.87	5.02	0.67	0.00	0.21	0.14	1.17	0.20	0.07	38.26	2/26/15
Brill C	**AVERAGE**	**1.05**	**2.32**	**0.65**	**32.78**	**0.10**	**0.00**	**2.88**	**5.03**	**0.73**	**0.00**	**0.31**	**0.18**	**1.15**	**0.19**	**0.06**	**38.10**	
Brill C	**ST DEV**	**0.11**	**0.05**	**0.07**	**0.21**	**0.04**	**0.00**	**0.06**	**0.08**	**0.04**	**0.01**	**0.05**	**0.04**	**0.05**	**0.03**	**0.03**	**0.36**	
Brill D-1	7	1.44	3.79	4.99	54.20	4.15	0.24	11.60	14.62	0.31	0.65	0.45	0.02	0.46	0.10	1.24	0.17	2/23/15
Brill D-2	8	1.29	3.89	4.96	54.64	4.15	0.21	11.32	14.64	0.30	0.57	0.50	0.04	0.38	0.09	1.36	0.31	2/23/15
Brill D-3	9	1.27	3.91	4.96	54.66	4.07	0.22	11.27	14.58	0.36	0.51	0.39	0.02	0.39	0.15	1.25	0.28	2/23/15
Brill D-4	113	1.32	3.81	5.03	55.54	4.23	0.21	11.51	14.72	0.34	0.55	0.44	0.04	0.41	0.11	1.46	0.24	2/23/15
Brill D-5	181	1.26	3.71	5.30	55.54	4.23	0.19	11.43	14.73	0.34	0.50	0.35	0.02	0.47	0.14	1.34	0.27	2/23/15
Brill D-6	248	1.30	3.92	5.01	55.48	4.19	0.18	11.57	14.52	0.33	0.52	0.47	0.05	0.42	0.10	1.44	0.30	2/23/15
Brill D-7	315	1.27	3.89	5.12	55.01	4.12	0.19	11.37	14.65	0.38	0.52	0.54	0.00	0.41	0.09	1.42	0.25	2/23/15
Brill D-8	316	1.26	3.89	5.10	55.10	4.28	0.18	11.36	14.69	0.35	0.63	0.49	0.00	0.39	0.13	1.43	0.26	2/23/15
Brill D-1	10	1.33	3.81	5.01	54.97	4.26	0.22	11.49	14.69	0.30	0.48	0.36	0.01	0.43	0.07	1.32	0.23	2/26/15
Brill D-3	11	1.29	3.88	4.98	55.08	4.36	0.24	11.48	14.60	0.34	0.57	0.47	0.02	0.33	0.07	1.34	0.25	2/26/15
Brill D-6	68	1.30	3.87	5.03	54.76	4.29	0.21	11.27	14.30	0.33	0.55	0.42	0.05	0.35	0.10	1.42	0.28	2/26/15
Brill D-5	146	1.42	3.87	5.10	54.58	4.13	0.22	11.48	14.37	0.31	0.53	0.40	0.03	0.39	0.08	1.35	0.26	2/26/15
Brill D-4	186	1.38	3.87	5.09	55.19	4.12	0.21	11.18	14.82	0.34	0.58	0.47	0.02	0.36	0.06	1.35	0.16	2/26/15
Brill D-8	244	1.33	3.85	5.14	55.09	4.15	0.20	11.32	14.62	0.26	0.55	0.36	0.02	0.40	0.10	1.41	0.24	2/26/15
Brill D-2	245	1.41	3.87	5.00	55.10	4.10	0.22	11.31	14.76	0.35	0.60	0.46	0.03	0.36	0.06	1.21	0.31	2/26/15
Brill D-7	246	1.24	3.83	4.96	55.02	4.24	0.23	11.29	14.43	0.33	0.68	0.50	0.06	0.29	0.08	1.40	0.26	2/26/15
Brill D	**AVERAGE**	**1.32**	**3.85**	**5.05**	**55.00**	**4.19**	**0.21**	**11.39**	**14.61**	**0.33**	**0.56**	**0.44**	**0.03**	**0.39**	**0.10**	**1.36**	**0.25**	
Brill D	**ST DEV**	**0.06**	**0.05**	**0.09**	**0.37**	**0.08**	**0.02**	**0.12**	**0.14**	**0.03**	**0.06**	**0.05**	**0.02**	**0.05**	**0.03**	**0.08**	**0.04**	

1.0.3 Average EMPA data from Dorchester-on-Thames and Lyminge Glass

Analysis No.	SFN.	Na2O	MgO	Al2O3	SiO2	P2O5	Cl	K2O	CaO	TiO2	MnO	Fe2O3	CoO	CuO	SnO2	Sb2O5	PbO
Dorchester-on-Thames Glass																	
DOT1.1	3093	18.92	0.64	2.41	68.24	0.11	1.45	0.63	6.18	0.09	0.56	0.49	0.00	0.01	0.03	0.24	0.00
DOT1.2	3131	19.63	1.01	2.32	65.49	0.08	1.31	0.63	6.34	0.28	1.65	1.16	0.00	0.03	0.00	0.02	0.02
DOT1.3	3486	2.01	2.33	4.89	60.99	0.51	0.29	1.85	24.39	0.22	0.06	2.40	0.01	0.02	0.01	0.01	0.03
DOT1.4	3788	4.69	0.17	6.30	63.54	0.10	1.16	0.41	23.17	0.06	0.03	0.34	0.00	0.01	0.02	0.00	0.00
DOT1.5	4213	17.01	0.63	2.29	68.77	0.12	1.07	0.65	7.04	0.07	0.45	0.76	0.00	0.01	0.02	0.35	0.77
DOT1.6	4605	19.26	1.01	2.43	65.96	0.09	1.32	0.62	6.33	0.27	1.51	1.11	0.00	0.04	0.01	0.02	0.02
DOT1.7	8535	18.40	0.56	2.15	68.84	0.10	1.17	0.58	6.26	0.09	0.26	1.00	0.00	0.03	0.00	0.52	0.04
DOT1.8	8583	19.49	1.03	2.42	65.72	0.10	1.24	0.64	6.19	0.30	1.76	1.09	0.01	0.00	0.00	0.03	0.00
DOT1.9	8592	12.63	1.39	1.08	70.75	0.05	0.11	0.39	12.92	0.04	0.14	0.28	0.07	0.01	0.02	0.01	0.11
DOT1.10	8901	14.22	0.51	2.47	71.75	0.12	1.33	0.43	8.27	0.05	0.48	0.32	0.02	0.01	0.02	0.00	0.01
DOT1.11	9023	17.37	0.39	2.46	69.37	0.12	1.56	0.49	7.58	0.04	0.19	0.31	0.02	0.04	0.00	0.01	0.06
DOT11.1	9132	0.46	3.37	3.78	15.88	7.65	0.75	0.93	61.43	0.09	0.49	4.23	0.07	0.42	0.00	0.05	0.39
DOT11.2	9509	0.92	1.70	18.93	59.61	0.40	0.01	3.41	1.31	1.09	0.13	12.34	0.01	0.02	0.01	0.07	0.05
DOT11.3	3053	19.05	0.97	2.47	66.04	0.10	1.29	0.62	6.23	0.31	1.78	1.08	0.02	0.02	0.01	0.00	0.01
DOT11.4	3054	17.54	0.55	2.22	69.75	0.12	1.15	0.57	6.26	0.07	0.22	0.93	0.01	0.02	0.02	0.53	0.05
DOT11.5	9746	18.49	0.95	2.38	66.90	0.09	1.28	0.58	6.40	0.25	1.60	0.97	0.02	0.02	0.00	0.01	0.03
DOT11.6	3371	14.89	0.83	2.41	71.32	0.15	1.37	0.65	6.40	0.10	0.99	0.68	0.01	0.03	0.02	0.10	0.06
DOT11.7	3699	17.54	0.02	0.17	74.74	0.01	0.30	0.05	6.73	0.04	0.10	0.04	0.01	0.00	0.00	0.22	0.01
DOT11.8	3903	18.42	1.00	2.38	67.02	0.09	1.39	0.55	6.26	0.22	1.57	0.99	0.01	0.02	0.03	0.03	0.02
DOT11.9	4009	19.59	0.96	2.34	66.29	0.06	1.51	0.49	6.19	0.19	1.45	0.89	0.00	0.00	0.01	0.01	0.03
DOT11.10	4283	18.98	0.57	1.96	68.75	0.06	1.41	0.52	6.40	0.07	0.16	0.49	0.02	0.00	0.01	0.56	0.06
DOT11.11	4333	16.28	0.61	2.46	69.76	0.18	1.14	0.70	7.09	0.08	0.51	0.74	0.00	0.03	0.02	0.33	0.08
DOT11.12	4475	18.69	0.59	2.21	68.31	0.13	1.45	0.77	6.24	0.09	0.08	0.51	0.01	0.00	0.02	0.82	0.07
DOT11.13	4537	19.71	0.84	2.17	66.61	0.05	1.50	0.56	6.45	0.12	1.10	0.71	0.00	0.06	0.02	0.07	0.03
DOT11.14	4604	18.59	1.01	2.36	66.56	0.10	1.35	0.69	6.34	0.24	1.55	1.03	0.01	0.05	0.00	0.06	0.05
DOT11.15	4753	14.29	0.56	2.54	71.16	0.16	1.28	0.67	7.55	0.07	1.38	0.25	0.00	0.03	0.02	0.01	0.04
DOT12.1	9069	18.07	0.57	2.33	68.91	0.11	1.40	0.62	6.58	0.07	0.30	0.57	0.00	0.03	0.02	0.42	0.01
DOT12.2	9199	0.19	0.00	0.11	53.07	0.00	0.00	9.31	0.06	0.00	0.04	0.07	0.02	0.01	0.00	0.35	36.75
DOT12.3	9573	16.34	0.44	2.32	70.29	0.12	1.52	0.50	7.83	0.04	0.26	0.30	0.00	0.02	0.01	0.02	0.01
DOT12.4	9716	18.90	0.51	1.82	66.23	0.06	1.42	0.41	5.29	0.05	0.12	0.37	0.00	2.13	0.01	2.61	0.06
DOT5.1	3177	18.59	0.97	2.32	66.78	0.06	1.43	1.08	5.49	0.34	1.55	1.29	0.01	0.04	0.03	0.02	0.01
DOT5.2	3188	18.36	1.07	2.46	65.11	0.12	1.31	0.63	6.10	0.32	1.67	1.22	0.00	1.54	0.03	0.02	0.05
DOT5.3	3254	20.73	1.08	2.26	63.76	0.05	1.60	0.34	6.86	0.27	1.79	1.19	0.00	0.06	0.00	0.00	0.03

Analysis No.	SFN.	Na2O	MgO	Al2O3	SiO2	P2O5	Cl	K2O	CaO	TiO2	MnO	Fe2O3	CoO	CuO	SnO2	Sb2O5	PbO
DOT5.4	3271	20.42	1.07	2.26	64.15	0.07	1.56	0.40	6.84	0.27	1.79	1.10	0.02	0.02	0.01	0.02	0.01
DOT5.5	3332	19.24	1.07	2.49	65.74	0.11	1.25	0.64	6.26	0.30	1.67	1.11	0.00	0.02	0.01	0.05	0.05
DOT5.6	3357	19.09	0.99	2.48	65.96	0.12	1.27	0.69	6.21	0.31	1.60	1.16	0.00	0.04	0.01	0.04	0.03
DOT5.7	3435	18.90	1.14	2.46	66.12	0.13	1.33	0.50	6.31	0.24	1.77	1.02	0.01	0.01	0.00	0.00	0.06
DOT5.8	3439	2.31	2.59	3.42	61.09	0.84	0.93	0.59	26.19	0.18	0.07	1.72	0.00	0.02	0.01	0.00	0.03
DOT5.9	3501	18.37	0.58	2.30	68.64	0.12	1.37	0.60	6.35	0.10	0.33	0.53	0.00	0.02	0.02	0.59	0.07
DOT5.10	3518	2.35	2.66	3.37	61.10	0.85	0.93	0.60	26.08	0.16	0.09	1.72	0.00	0.04	0.01	0.00	0.04
DOT5.11	3524	18.55	0.56	2.25	68.48	0.13	1.41	0.64	6.34	0.08	0.35	0.54	0.02	0.04	0.00	0.60	0.02
DOT5.12	3556	19.16	0.89	2.12	67.77	0.09	1.33	0.68	6.01	0.11	1.14	0.58	0.02	0.02	0.01	0.07	0.00
DOT5.13	3584	20.86	0.87	2.25	65.32	0.11	1.58	0.51	6.24	0.15	1.23	0.78	0.02	0.02	0.00	0.04	0.02
DOT5.14	3597	19.75	1.06	2.37	65.32	0.12	1.37	0.61	6.48	0.20	1.62	1.01	0.01	0.03	0.00	0.01	0.03
DOT5.15	3640	19.47	1.04	2.51	65.40	0.12	1.26	0.63	6.18	0.30	1.73	1.32	0.00	0.02	0.00	0.01	0.03
DOT6.1	3643	18.97	0.91	2.30	65.94	0.07	1.41	0.59	6.97	0.23	1.55	1.01	0.01	0.01	0.01	0.02	0.00
DOT6.2	3656	7.35	4.57	2.59	62.73	1.45	0.55	6.58	10.98	0.13	0.50	1.45	0.02	0.01	0.00	0.21	0.88
DOT6.3	3658	18.88	0.98	2.48	65.98	0.05	1.30	0.61	6.42	0.31	1.72	1.14	0.02	0.02	0.01	0.02	0.05
DOT6.4	3711	19.05	1.03	2.33	66.10	0.08	1.46	0.54	6.56	0.22	1.55	1.01	0.01	0.02	0.00	0.02	0.01
DOT6.5	3719	18.85	0.95	2.19	66.03	0.08	1.85	0.59	6.00	0.27	1.55	1.27	0.01	0.26	0.00	0.06	0.04
DOT6.6	3779	2.29	2.32	5.53	59.28	0.92	0.44	2.98	24.14	0.22	0.25	1.45	0.01	0.04	0.01	0.04	0.07
DOT6.7	3819	18.76	1.00	2.32	66.37	0.07	1.34	0.56	6.69	0.22	1.52	0.99	0.00	0.02	0.04	0.04	0.06
DOT6.8	3986	18.76	0.98	2.34	66.48	0.10	1.32	0.59	6.59	0.24	1.51	1.04	0.01	0.02	0.00	0.00	0.02
DOT6.9	4006	19.13	1.03	2.52	65.56	0.09	1.30	0.60	6.37	0.30	1.83	1.18	0.00	0.02	0.01	0.00	0.06
DOT6.10	4041	18.68	0.92	2.32	66.35	0.09	1.49	0.57	6.87	0.20	1.52	0.93	0.01	0.00	0.00	0.04	0.03
DOT6.11	4122	19.02	1.13	2.24	65.76	0.03	1.62	0.40	7.22	0.14	1.69	0.68	0.02	0.03	0.01	0.02	0.01
DOT6.12	4136	18.78	0.97	2.42	66.14	0.12	1.23	0.61	6.57	0.27	1.65	1.14	0.00	0.03	0.01	0.03	0.01
DOT6.13	4136	0.63	0.16	0.10	0.38	42.24	0.41	0.02	55.58	0.01	0.05	0.19	0.01	0.19	0.00	0.00	0.04
DOT6.14	4174	19.02	0.95	2.38	66.35	0.10	1.35	0.61	6.44	0.27	1.52	0.96	0.01	0.01	0.00	0.04	0.00
DOT6.15	4196	18.44	1.30	2.57	64.45	0.09	1.28	0.48	6.57	0.41	2.70	1.67	0.00	0.00	0.01	0.01	0.02
DOT6.16	4210	18.61	1.02	2.58	66.57	0.07	1.45	0.42	5.76	0.31	1.89	1.22	0.00	0.04	0.01	0.00	0.02
DOT7.1	4288	17.48	1.09	2.91	65.80	0.05	1.20	0.49	5.90	0.51	2.41	2.05	0.01	0.00	0.02	0.06	0.00
DOT7.2	4328	19.10	0.87	1.85	67.74	0.07	1.60	0.27	6.15	0.11	1.48	0.71	0.02	0.02	0.00	0.00	0.00
DOT7.3	4363	17.03	0.63	2.32	69.19	0.17	1.21	0.69	7.01	0.09	0.52	0.60	0.00	0.01	0.05	0.38	0.08
DOT7.4	4387	19.11	1.16	2.38	66.39	0.04	1.43	0.45	5.59	0.42	1.77	1.18	0.01	0.01	0.02	0.01	0.03
DOT7.5	4415	16.51	1.31	2.37	67.15	0.08	1.42	0.39	6.13	0.37	2.85	1.33	0.00	0.06	0.00	0.00	0.03
DOT7.6	4437	20.10	0.93	2.35	65.14	0.09	1.36	0.60	6.25	0.28	1.65	1.16	0.01	0.03	0.03	0.03	0.02
DOT7.7	4455	16.14	3.77	2.74	56.71	0.07	3.60	1.89	8.34	0.74	1.85	2.16	0.70	0.80	0.01	0.01	0.48
DOT7.8	4518	21.05	0.89	2.55	64.04	0.07	1.27	0.73	5.89	0.37	1.80	1.25	0.01	0.01	0.02	0.02	0.02

Analysis No.	SFN.	Na2O	MgO	Al2O3	SiO2	P2O5	Cl	K2O	CaO	TiO2	MnO	Fe2O3	CoO	CuO	SnO2	Sb2O5	PbO
DOT7.9	4597	18.63	0.96	2.43	66.20	0.11	1.42	0.74	6.34	0.40	1.55	1.04	0.03	0.02	0.01	0.10	0.01
DOT7.10	4617	17.27	1.07	2.94	66.12	0.10	1.24	0.58	5.77	0.54	2.40	1.92	0.00	0.03	0.01	0.00	0.00
DOT7.11	4644	18.95	1.21	3.00	65.90	0.05	1.34	0.41	5.36	0.58	1.57	1.61	0.01	0.01	0.01	0.00	0.01
DOT7.12	4650	19.16	0.97	2.24	66.42	0.08	1.37	0.60	6.36	0.20	1.55	0.91	0.02	0.03	0.01	0.06	0.02
DOT7.13	4738	19.00	0.98	2.42	66.04	0.10	1.25	0.64	6.52	0.27	1.59	1.11	0.01	0.03	0.02	0.02	0.01
DOT7.14	4740	18.95	1.06	2.34	65.11	0.13	1.38	0.44	7.24	0.30	1.76	1.20	0.00	0.01	0.01	0.03	0.04
DOT7.15	4752	19.25	0.98	2.40	66.10	0.06	1.37	0.53	6.25	0.27	1.65	1.07	0.00	0.02	0.01	0.01	0.02
DOT8.1	4751	18.92	0.98	2.54	66.34	0.11	1.23	0.68	6.14	0.29	1.50	1.14	0.03	0.03	0.00	0.05	0.01
DOT8.2	8473	18.69	1.09	2.57	66.35	0.06	1.44	0.40	5.84	0.35	1.97	1.14	0.01	0.02	0.02	0.01	0.03
DOT8.3	8506	17.48	1.15	3.00	65.84	0.08	1.25	0.46	6.00	0.52	2.31	1.86	0.01	0.02	0.00	0.01	0.01
DOT8.4	8548	18.94	0.97	2.41	65.88	0.08	1.33	0.56	6.64	0.24	1.72	1.07	0.01	0.07	0.02	0.02	0.04
DOT8.5	8593	18.62	1.26	2.56	63.89	0.07	1.34	0.46	6.70	0.38	2.86	1.80	0.01	0.03	0.01	0.02	0.00
DOT8.6	8651	18.63	1.06	2.59	66.47	0.04	1.50	0.39	5.86	0.31	1.87	1.21	0.01	0.03	0.01	0.00	0.01
DOT8.7	8720	16.26	0.49	2.29	70.20	0.13	1.52	0.52	7.88	0.04	0.28	0.27	0.01	0.02	0.02	0.00	0.06
DOT8.8	8913	19.03	0.86	2.20	67.48	0.07	1.42	0.62	6.50	0.09	0.99	0.58	0.01	0.01	0.02	0.08	0.04
DOT8.9	9079	18.29	0.57	2.31	68.61	0.15	1.40	0.58	6.72	0.06	0.38	0.47	0.02	0.00	0.04	0.38	0.01
DOT8.10	9257	18.55	1.29	2.60	64.07	0.09	1.35	0.44	6.63	0.40	2.79	1.76	0.00	0.02	0.02	0.00	0.00
DOT8.11	9260	18.76	1.05	2.53	66.54	0.04	1.47	0.43	5.80	0.33	1.87	1.12	0.00	0.03	0.01	0.00	0.01
DOT8.13	9290	16.30	0.45	2.27	70.25	0.11	1.57	0.53	7.81	0.04	0.28	0.32	0.00	0.01	0.03	0.01	0.02
DOT8.14	9408	19.13	0.87	2.21	67.30	0.10	1.38	0.61	6.50	0.10	1.03	0.63	0.00	0.02	0.00	0.07	0.06
DOT8.15	9481	18.53	0.56	2.29	68.47	0.07	1.35	0.58	6.63	0.07	0.45	0.46	0.02	0.01	0.03	0.43	0.05
DOT8.16	9553	18.96	0.97	2.46	66.15	0.08	1.29	0.54	6.48	0.27	1.64	1.08	0.01	0.02	0.02	0.01	0.03
DOT9.1	3040	16.52	0.56	2.54	69.81	0.13	1.10	0.74	7.02	0.09	0.57	0.53	0.01	0.02	0.01	0.31	0.04
DOT9.2	3279	8.85	6.30	1.55	66.25	1.11	0.64	4.11	10.26	0.10	0.05	0.59	0.02	0.03	0.00	0.11	0.02
DOT9.3	3361	15.85	0.48	2.20	71.95	0.09	1.47	0.42	6.97	0.05	0.11	0.31	0.01	0.03	0.03	0.01	0.02
DOT9.4	3436	16.96	0.58	2.38	69.80	0.17	1.25	0.75	6.64	0.08	0.46	0.54	0.01	0.08	0.01	0.23	0.06
DOT9.5	3531	14.21	1.64	20.35	55.66	0.07	0.93	0.47	5.00	0.07	0.29	0.79	0.01	0.04	0.00	0.44	0.04
DOT9.6	3745	17.95	0.51	1.98	68.89	0.07	1.38	0.53	6.03	0.05	0.24	1.62	0.00	0.02	0.02	0.71	0.00
DOT9.7	3756	18.34	0.94	2.44	66.47	0.08	1.33	0.74	7.09	0.23	1.31	0.93	0.00	0.04	0.03	0.01	0.02
DOT9.8	3771	16.00	0.53	2.51	70.36	0.18	1.35	0.68	7.51	0.06	0.43	0.31	0.00	0.01	0.01	0.01	0.03
DOT9.9	3872	16.94	0.56	2.22	68.70	0.08	1.28	0.63	6.60	0.08	0.40	2.01	0.00	0.02	0.01	0.39	0.06
DOT9.10	4049	11.57	0.97	1.01	72.49	0.05	0.08	0.42	12.47	0.06	0.13	0.38	0.00	0.01	0.01	0.02	0.32
DOT9.11	4096	17.97	0.49	2.00	68.93	0.07	1.44	0.53	5.98	0.06	0.23	1.56	0.00	0.01	0.02	0.66	0.04
DOT9.12	4100	15.34	0.71	4.63	68.22	0.13	1.01	0.98	6.63	0.09	0.28	1.49	0.00	0.01	0.01	0.40	0.07
DOT9.13	4265	18.31	0.66	2.13	68.88	0.10	1.46	0.58	6.31	0.06	0.31	0.49	0.01	0.03	0.01	0.61	0.05

Lyminge Glass

Analysis No.	**SFN.**	**Na2O**	**MgO**	**Al2O3**	**SiO2**	**P2O5**	**Cl**	**K2O**	**CaO**	**TiO2**	**MnO**	**Fe2O3**	**CoO**	**CuO**	**SnO2**	**Sb2O5**	**PbO**
Analysis No.	SFN	Na2O	MgO	Al2O3	SiO2	P2O5	Cl	K2O	CaO	TiO2	MnO	Fe2O3	CoO	CuO	SnO2	Sb2O5	PbO
Lym1a.1	555	2.26	69.54	0.13	1.29	0.63	6.16	0.08	0.24	0.68	0.01	0.02	0.00	0.48	0.07	0.40	0.00
Lym1a.2	358	2.66	70.24	0.15	1.37	0.54	7.84	0.06	0.22	0.37	0.02	0.03	0.02	0.01	0.02	0.27	0.00
Lym1a.3	380	2.23	68.87	0.18	1.36	0.66	6.96	0.07	0.64	0.86	0.01	0.00	0.00	0.36	0.05	0.73	0.00
Lym1a.4	157	2.35	69.74	0.14	1.09	0.62	6.23	0.07	0.29	0.90	0.01	0.08	0.00	0.50	0.15	0.44	0.00
Lym1a.5	312	2.24	69.14	0.15	1.27	0.66	6.58	0.07	0.49	0.70	0.01	0.03	0.03	0.43	0.06	0.70	0.00
Lym1b.1	501	2.29	67.63	0.13	1.41	0.66	6.42	0.09	0.23	0.62	0.00	0.01	0.01	0.70	0.08	0.41	0.00
Lym1b.2	454	2.12	68.09	0.12	1.42	0.64	6.31	0.08	0.27	0.51	0.01	0.04	0.00	0.66	0.03	0.09	0.00
Lym1b.3	208								FAIL								
Lym1b.4	699	2.31	70.24	0.14	1.27	0.57	6.94	0.06	0.65	0.39	0.00	0.03	0.00	0.27	0.01	0.30	0.00
Lym1b.5	275								FAIL								
Lym1b.6	550								FAIL								
Lym1b.7	594	2.38	70.05	0.13	1.30	0.65	7.03	0.07	0.45	0.48	0.00	0.01	0.01	0.27	0.06	0.08	0.00
Lym1b.8	799	2.11	68.55	0.11	1.38	0.59	6.56	0.06	0.23	0.62	0.01	0.02	0.01	0.54	0.11	0.19	0.00
Lym1b.9	520	2.47	71.14	0.17	1.21	0.50	8.61	0.06	0.30	0.41	0.01	0.02	0.01	0.01	0.02	0.14	0.00
Lym1b.10	689	2.27	65.77	0.13	0.97	0.72	7.77	0.14	1.31	0.86	0.01	0.01	0.04	0.08	0.05	0.45	0.00
Lym2.1	2.105	1.94	67.11	0.08	1.28	0.49	6.75	0.09	1.01	0.58	0.03	0.00	0.00	0.01	0.02	0.12	0.00
Lym2.2	2.192	2.13	66.93	0.10	1.20	0.63	6.97	0.12	1.04	0.68	0.01	0.04	0.03	0.08	0.10	0.01	0.00
Lym2.3	23	2.24	67.71	0.12	1.11	0.67	6.97	0.11	0.94	0.75	0.01	0.06	0.03	0.18	0.10	0.90	0.00
Lym2.4	42	1.86	67.99	0.07	1.19	0.47	6.67	0.08	1.05	0.53	0.00	0.02	0.02	0.02	0.00	0.60	0.00
Lym2.5	348	2.21	67.25	0.12	1.13	0.58	7.14	0.12	0.99	0.76	0.00	0.06	0.07	0.05	0.09	0.08	0.00
Lym2.6	634	2.31	66.61	0.13	1.19	0.73	7.14	0.13	1.04	0.74	0.01	0.04	0.04	0.17	0.02	0.45	0.00
Lym2.7	458	2.29	65.11	0.13	1.09	0.76	6.92	0.08	0.88	0.67	0.02	0.05	3.07	0.21	0.92	0.98	0.00
Lym2.8	458	2.30	65.58	0.14	1.17	0.71	7.21	0.13	1.08	0.87	0.01	0.04	0.89	0.14	0.30	0.60	0.00
Lym2.9	463	2.26	65.06	0.14	1.26	0.69	7.54	0.11	1.28	0.76	0.00	0.05	0.02	0.10	0.00	0.42	0.00
Lym2.10	404	2.46	65.24	0.11	1.10	0.68	8.29	0.13	1.69	0.81	0.01	0.01	0.01	0.03	0.02	0.39	0.00
Lym2.11	107								FAIL								
Lym2.12	935	2.17	66.77	0.16	1.13	0.73	6.80	0.11	0.50	0.87	0.00	2.22	0.22	0.25	0.11	0.54	0.00
Lym2.13	631	2.15	66.66	0.19	1.09	0.77	6.86	0.13	0.47	0.90	0.02	2.40	0.26	0.24	0.10	0.07	0.00
Lym2.14	134	2.12	67.00	0.17	1.07	0.76	6.76	0.09	0.57	0.91	0.01	2.18	0.19	0.26	0.12	0.70	0.00
Lym2.15	278	2.72	70.22	0.12	1.14	0.65	7.33	0.08	0.14	0.65	0.01	1.64	0.07	0.03	0.05	0.42	0.00
Lym2.16	43	2.63	67.34	0.18	1.06	0.96	7.31	0.12	0.24	1.21	0.06	0.15	0.01	0.03	0.66	0.31	0.00
Lym2.17	483	2.39	66.27	0.14	1.02	0.79	7.75	0.13	1.41	1.07	0.01	0.05	0.02	0.11	0.01	0.46	0.00
Lym2.18	678	2.39	66.25	0.15	1.01	0.80	7.74	0.11	1.39	1.12	0.01	0.05	0.05	0.08	0.02	0.64	0.00
Lym2.19	306	2.49	67.76	0.09	0.89	0.89	7.84	0.13	1.10	0.91	0.01	0.23	0.01	0.06	0.02	0.66	0.00
Lym3.1	59	2.62	70.78	0.16	1.07	0.83	7.09	0.07	0.16	0.58	0.00	0.03	0.00	0.08	0.01	0.83	0.00

Analysis No.	SFN.	Na2O	MgO	Al2O3	SiO2	P2O5	Cl	K2O	CaO	TiO2	MnO	Fe2O3	CoO	CuO	SnO2	Sb2O5	PbO
Lym3.2	457	2.42	68.48	0.14	1.03	0.79	7.24	0.08	0.63	0.65	0.00	0.06	0.02	0.17	0.07	0.94	0.00
Lym3.3	412	2.38	67.44	0.14	1.08	0.76	7.57	0.10	0.96	0.81	0.01	0.04	0.06	0.18	0.04	0.51	0.00
Lym3.4	697	2.28	68.04	0.08	1.39	0.72	6.51	0.09	0.21	0.69	0.01	0.01	0.00	0.77	0.04	1.00	0.00

Chapter 2

A Database of Comparative European Glasses

Amrein, Burkhardt and Stern, 1995

This paper analysed 82 glasses vessels and raw glass, from Aventicum (Avenches) on of the major Roman cities in Switzerland. Both ED-XRF and WD-XRF were performed, on these many coloured glass, which all date from the first to third century. There is much evidence of a glass-workshop there, but the glass is contiguous with other Roman glass.

Arletti, Giordani, Tarpini and Vezzalini, 2005

Arletti and colleagues have generated an extensive series of analyses of glass from Italy and southern Switzerland. This paper includes 79 analyses of glasses from a variety of sites in the western half of Emilia-Romagna in Italy, these were analysed by EMPA.

Arletti, Ciarallo, Quartieri, Sabatino and Vezzalini, 2006

This paper is a study of a mixture of opaque and translucent glass from Pompeii, particularly focused on comparing gaming counters to vessel glass and mosacis. The glass was examined by EMPA and WDS-XRF. The paper hypotheses melted tesserae as the origin of opaque counters.

Arletti, Dalconi, Quartieri, Triscari and Vezzalini, 2006

This paper includes another 4 glasses from the Campaignian site of Pompeii, as well as a further 5 from Sicily. The glass are predominately opaque and are a combintion of tesserae, counters and vessel glass. These samples were analysed by WDS-EMPA.

Arletti, Quartieri and Vezzalini, 2006c

A further 9 analyses by Arletti and collegeues on glass tesserae from Pompeii. They were analysed for composition by EMPA and examined under SEM-BSE and -EDS, to analyse production technology and heterogeneity. Only the microprobe analyses were retained for the database.

Arletti, Vezzalini, Biaggio Simona and Maselli Scotti, 2008

This paper was an exploration of remains of possible glass-working in Canto Tincino, Switzerland, and comparing it to the Roman glass in Italy, across the Alps. 11 glass from Northern Italy and 30 from Switzerland were examined by predominately WDS-XRF, though with some EMPA. It is interesting that these Swiss glasses do not show the common shift expected at the introduction of HIT-style glasses. These glass were again only recorded by Isings numbers.

Arletti, Giacobbe, Quartieri, Sabatino, Tigano, Triscari and Vezzalini,2010

This paper includes 8 post-Roman lamps from Sicily, which were predominately examined with EMPA, though LA-ICP-MS is also used for trace analysis. At least two clear types of glass are here, which makes sense as Sicily is in a strategic trading position.

Arletti, Vezzalini, Benati, Mazzeo Saracino and Gamberini, 2010

A further paper of Italian glasses by Arletti and colleagues, analysed by a combination of WDS-XRF and EMPA. These window glasses come from two sites in the Emilia-Romagna region, 23 glasses, and one site in Marche, 15 glasses. While there is a correlation between different technologies and compositions, but the authors attribute this to chronology rather than any specific choices.

Barbarea, Barone, Crupi, Longo, Majolino, Mazzoleni, Sabatino, Tanasi and Venuti, 2012

This paper is primarily concerned with degradation of Late Roman and Byzantine (from 2nd to 8th century) glass from Catania, in Sicily. These 15 shards of vessel glass were analysed by SEM-EDS, as well as FT-IR, though only the former is relevant to this database.

Bezborodov, 1975

This paper by the Russian archaeologist is one of the few that covered what were USSR territories. An extensive work, it was unclear what technique was used, but 762 pieces were analysed from across Europe and the Near East, spanning from Roman to the Middle Ages.

Bezborodov and Abdurazakov, 1964

This paper is an analysis of 5 glasses from the Ukraine, analysed by XRF. Little information is included in this brief paper.

Boon, 1966

A breif spectrographic paper of four analyses on a single cut vessel glass from Caerleon in Welsh.

Brill, 1964

Brill was able to analyse three of the rare diatreta, or cage cups. 5 analyses were done at the Corning Museums, 2 each on of the colours of the Corinth Cage Cup and Athenian Cage Cup, and one on an unknown fragment of cage cup.

Cagno, Favaretto, Mendera, Izmer, Vanhaecke and Janssens, 2012

Cagno and colleagues analysed 37 glasses, typologically dated to the early medieval period, due to problematic stratigraphy at site. The all come from San Genesio in Tuscany, and were analysed by ICP. A large range of colours were analysed. This paper confirmed the vast majority of glasses were soda ash glasses, though some compositions were more unstable.

Cavalieri and Giumlia-Mair, 2009

This paper is rare study of Lombardic glass. Due to the requirement to be non-destructive, XRF was used on 40 samples, compared to Roman glass standards that had been measured by ICP-OES. There is clear evidence of tesserae recycling at this site, which is a Late Antique villa, with a several later workshops atop it. Unfortunately the relative error in some samples, such as the necklace beads, was as high as

25%. However, each piece was analysed at a minimum of three different spots to try and minimise this.

The evidence of recycling is clear at this site, but it is clear that the glass workshop is part of a large system. The gold glass tesserae are mixed with lead for cuppulation, so used as a source of gold rather than glass, and the refractory clays used match other reworking at the site. The villa is clearly being used as a resource source.

Ceglia, Meulebroeck, Cosyns, Nys, Terryn and Thienpont, 2013

Ceglia and colleagues looked at 16 glasses from the Roman Villa Treignes, Belgium, to look at predominately ionic states. The question was about how technology and colour were connected. The bulk chemistry was done by SEM-EDS, though this paper was focused on the potential of UV-Vis-NIR, for colour.

Cole, 1966

A rare spectrographic paper of Welsh glass. These are early Roman window glasses and not much more is recorded.

DaCruz, 2009

DaCruz is undertaking a large amount of study of Spanish Roman glass, though very little of this has been published thus far. This paper includes the analyses of three late Roman bracelets, which are black. A larger study on dark glass is still forthcoming. Unfortunately, the technique used was not recorded. While it is like to LA-ICP-MS, due to the analyst, this isn't recorded.

Freestone, Ponting and Hughes, 2002

19 sherds of vessel and lamp glass were analysed from the sixth-seventh century church, located at Maroni Petra, in Cyprus. The analysis was SEM-EDX for bulk

chemistry, and ICP-MS for trace. This paper was concerned with where glass in the very central island of Cyprus was coming from.

The glass was predominately Levantine, but with some HIMT glass too, which probably originated in Egypt. This paper also discusses various possible workshop organisations. There is little evidence of recycling here, though there is some. Due to Cyprus' position in the Mediterranean, this is not too surprising.

Gaitzsch, Follmann-Schulz, Wedepohl, Hartmann and Tegtmeier, 2000

This paper is one of two large-scale reports on the excavation of the Hambacher Forst (Hambach Forest) glasshouses. This extensive report covers the organisation of the workshops, furnaces, the typology of the sherds and vessels found, and the EMPA analysis of a subsection of this. 85 sherds sherds were analysed, including production drops and manufacturing waste, the predominance of which was naturally coloured. This paper was focused on the potential for German primary production of glass, as well as the well known vessel production.

Gallo and Silvestri, 2012

38 medieval glass samples from Rocca di Asolo in Italy were analysed for this paper to better understand raw materials and relationship to contemporaneous glass from the Mediterranean area. Only 8 of these pieces date from the seventh century, the rest extending up to the tenth century. All the early glasses are windows.

Of these early glasses, all are still soda ash, and seeming Levantine. They are consistent with Roman and Late Antique glasses, 6 seemingly HIMT and 2 Roman recycled glass.

Ganio, Boyen, Fenn, Scott, Vanhoutte, Gimeno and Degryse, 2012

This paper is looking for compositional and isotopic relationships of glass across the Roman Empire and how this relates to glass sourcing. For this paper 114 glasses form the first to fifth century were analysed for composition, and 87 for isotopes, across multiple institutions.

Samples from the Iulia Felix shipwreck were analysed at the University of Padova by X-ray fluorescence. The Univeristy of Leuven analysed samples from the Embiez shipwreck by ICP-OES. This same technique was used by the University of Torino for the Augusta Praetoria samples. They also analysed the Tienen samples were determined by a combination of the AES and AAS. Samples from Barcino, Oudenburg, Petra, Barsinia and Gonio were analysed by EMPA at University of Salzburg.

The combination of these analyses, and the isotopic work, highlights only a few large factories, though they are not solely in the Near East.

Gliozzo, Santagostino Barbone, D'Acapito, Turchiano, Memmi Turbanti and Volpe, 2010

This paper shows three sectilia panels, analysed multiple times by ICP-OES, ICP-MS and then SEM-EDS for textural observations. These were taken from the Late Antique villa site of Faragola, in Ascoli Satriano, Italy. They formed an elaborate mosaic in the *cenatio*. A variety of natural and synthetic standards were used to track consistency, but no values were published.

This paper was concerned with colouration, but also whether these sectilia plates were imported as finished productions, or a local production from raw glass. This paper was unable to solve this.

Gliozzo, Santagostino Barbone, Turchiano, Memmi and Volpe, 2012

The villa at Faragola is also the focus of the analysis in this paper. The large bath-house underwent heavy modification in the late antique period, specifically the fifth century. 26 glass tesserae from the vault, which collapsed into the frigidarium, were collected and analysed. They were analysed by ICP-MS, ICP-OES and SEM-EDS. A variety of natural and synthetic materials were used as primary and quality control standards, but the results were not published.

This paper was looking at the range of colours and how they were formed. There is evidence of a secondary workshop at Farafola and it is supposed that either finished objects and recycled materials were reformed into new tesserae in situ, or brought by ad hoc itinerant glassworkers.

Henderson1999

This brief report by Henderson formed part of the excavation report in Wijnaldum, in Friesland. While there was some Roman glass analysed, the vast majority dated fro the Early Medieval period. 38 analyses of glasses were performed by SEM and EMPA. (Henderson 1999)

Hulinsky and Cerna, 2003

A rare study of glass from the Czech Republic, this brief paper covers 85 samples of glass from the sixth to twelfth century. EMPA and SEM analyses were performed on these samples, which are predominantly beads and rings, though also some window glass and hollow vessel glass.

This paper was trying to analyse how this early medieval glass fit into the story of European glass, showing that this glass was not all Levantine, but also related to Russian glass.

Mirti, Casoli and Appolonia 1993

Augusta Praetoria was a Roman colonia in Italy, modern day Aosta, with an Augustan formation. Due to its northern position, it quickly fell in the fifth century. As such, the samples analysed were 55 fragments of Roman glass, from the Augustan period to the fourth century. They were analysed by ICP-OES.

This paper used various statistical methods to try and find a correlation between the form of an object and the composition of the glass used. None was identified.

Mirti, Lepora and Saguì, 2000

Between this paper and Mirti et al. 2001, 64 fragments from the Crypta Balbi were analysed, as well as three tesserae. The excavation of this central block of Rome yielded more than 10,500 sherds of glass from the late seventh century alone.

Of the 64 analysed, 40 are seventh-century fragments, reported in this paper, and 24 are eighth-century fragments, reported in the following paper. Of the early samples, thirty two samples are coloured vessel glass, seven are colourless, or lightly coloured window panes, five are fragments of brightly coloured decorative inlays and the last four manufacturing samples.

They were analysed by plasma emission spectroscopy, reflectance spectroscopy and X-ray diffraction. A multi-element standard was analysed every five samples to limit effects such as machine drift. The results of these were not reported.

Mirti, Davit, Gulmini and Saguì, 2001

The samples in this paper are the eighth century samples analysed during the same run as Mirti et al. 2000. The eighth century glasses include fragments of 15 vessel, 2 window panes, 7 pieces of manufacturing material and 3 potentially earlier tesserae.

Compared to the early samples, these glasses have high copper, generally associated with high antimony and lead. This has been interpreted as greater use of

recycled glass.

Moncke et al 2014

23 Roman and Protobyzantine glass samples from Messene in Greece were analysed by OES and SEM-AES. A standardless internal correction was used. The glasses were drawn from both the urban centre at the site and the supposed glass workshop, including chunks, droplets and test pieces, along with vessels and windows.

This paper is primarily about colour formation and intentionality, which is why optical spectroscopy was chosen, to better understand technological aspects such as redox conditions, and ligand coordination.

Rech, 1982

This paper was the first published data from the Hambach glass workshops, published in more detail in later works such as Gaitzsch et al. 2000. This paper included microprobe analysis of 8 production samples, taken from glasshouse 75.

Santagostino Barbone, Gliozzo, D'Acapito, Memmi Turbanti, Turchiano and Volpe, 2008

8 analyses were done on three sections of sectilia panels, of red, orange and yellow, also taken from the villa in Faragola. These were analysed by a variety of techniques, SEM-EDS, EMPA, ICP-MS, ICP-OES as well as XAS to determine the chemical state of copper.

This paper is focused on how these glasses were coloured, and the chemical composition of the Faragola samples did not clearly match any province groups.

Schibille and Freestone, 2013

The ninth-century Italian monastery of San Vincenzo, and its attached glass workshop, yielded many samples from excavation. 136 glasses glasses were analysed by electron microprobe WDS, and a smaller subset of these were also analysed by SEM-EDXA. Corning Museum Ancient Glass Standards were used, but no calibrations or corrections were deemed necessary, and the results of these standards was not recorded.

This study showed that it was likely that the weakly-coloured glasses are produced from Roman window glass, though coloured glasses were produced by melting and mixing tesserae. It seems that the bulk of the glass was taken from the windows and tesserae of a large Roman building.

Silvestri, Molin and Salviulo, 2005

81 fragments of Roman and medieval glass from Italy were analysed for this paper. They were from the Province of Naples, Veneto and Friuli-Venezia Giulia, dating from the first to fourteenth century. They were analysed by both XRF and EMPA. The glasses were sorted by hierarchical cluster analysis, which identified six groups, related to chronology. This paper also showed clear evidence of early plant ash glasses.

Geological standards were used for calibration, the calibrations were included however the raw results for these standards were not results.

Silvestri, 2008

This paper, and its companion paper Silvestri et al. 2008, are analyses of glass from the Iulia Felix, or Grado, shipwreck. Barrels with over 11,000 sherds of cullet dating from the third century were found in this shipwreck and 88 of the coloured sherds were analyses by XRF and EMPA for this study. No data about standards was included.

The glasses were characterised by hierarchical cluster analysis. It was noted that

antimony was present, an indication of recycling and thus Silvestri tried to create a recycling index to determine how recycled it was, mentioned elsewhere in this thesis.

Silvestri, Molin, and Salviulo, 2008

This paper by Silvestri and colleagues, focused on the colourless, rather than the coloured glass from the Iulia Felix shipwreck. 85 sherds were analysed, by XRF and EMPA. No data about standards was included.

This paper was able to tell that were were at least two different composition styles of glass in this assemblage, implying several large glasshouses were at work at the time.

Silvestri, Tonietto and Molin, 2011

A paper reporting the analysis of 96 polychrome tesserae from the sixth century palaeo-Christian glass mosaic, located in what is now St. Prosdocimus, Padova, Italy. The glasses were first analysed by EMPA and then LA-ICP-MS for greater accuracy and precision on trace elements.

Velde and Gendron, 1980

A large survey of 56 Gallo-Roman blown glass samples taken from central-western France were analysed. They date from the first to the fifth centuries. Being an early paper, this was looking at the consistency of the composition of this glass. It found whether window mater, decorative or utilitarian houseware, the glass was all very standardised and contained little obvious contaminant. Velde and Gendron were also concerned about possible sources for the alumina, though they did not suggest sources.

The analyses were done by microprobe.

Velde and Sennequier, 1985

This early paper by Velde and Sennequier was an analysis of Gallo-Roman and Frankish glass, from predominately France. 44 French and 4 German glasses were analysed. (Velde and Sennequier 1985)

Wedepohl, Pirling and Hartman, 1997

This paper is an analysis of the Roman and early medieval (Frankish) glass from the graveyard in Krefeld-Gellep, North Rhine-Westphalia, the Roman town of Gelduba. There were analysed by microprobe analysis.

Wolf, Kessler, Stern and Gerber, 2005

This analysis by Wolf and colleagues encompasses 40 window sherds and 3 samples of production waste, selected from the excavation of a single fifth to sixth century Christian cemetery church in Sion, Valais, Switzerland. The analyses are done by WDS-XRF, to discover if these coloured, decorative triangles of window glass were still produced in the Roman fashion. Corning B, C and D were used as standards for calibration, however the results were not reported. The glass was consistent with Roman glass.

List of Tables

7.3 Glass from Lyminge, arranged by glass group, and the typology of the vessels. Vessels identified as Roman by typology or colour have been highlighted grey.
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Table 1: Elements typically analysed for in glass, as well as their manufacturing sources and uses in glass. 'Contaminant' indicates a part of the salt (natron or plant ash), sand or colourant, which was not one of the main elements of that ingredient.

Chemical	**Sources**	**Uses**
Aluminium	Sand contaminants	Contaminant
Antimony	Deliberate addition: likely predominantly as stibnite (Sb_2S_3)	Colourant: opaque yellow, decolourant, opacifier. Fining agent.
Arsenic	Deliberate addition	Colourant
Barium	Sand contaminants Colorant contaminants	Contaminant
Beryllium	Sand contaminants	Contaminant
Bismuth	Salt contaminants	Contaminant
Boron	Salt contaminant Sand contaminant	Contaminant
Bromine	Salt contaminant	Contaminant
Caesium	Sand contaminants	Contaminant
Cadmium	Deliberate addition	Colourant
Calcium	Salt additions: plant ash. Stabiliser: seashells, limestone, perhaps incidental	Flux. Contaminants: Shell in sand.
Cerium	Sand contaminants	Contaminant
Chlorine	Salt contaminant	Contaminant
Chromium	Sand contaminant	Contaminant
Cobalt	Deliberate addition: Cobalt ores, likely traces of Mn, Pb, Sb, Ni, Zn, Bi and Fe.	Strong blue colourant.
Copper	Deliberate addition: smelted copper	Colourant: blue, green, opaque red.
Dysprosium	Sand contaminants	Contaminant
Erbium	Sand contaminants	Contaminant
Europium	Sand contaminants	Contaminant
Fluorine	Salt contaminant	Contaminant
Gadolinium	Sand contaminants	Contaminant
Germanium	Sand contaminants	Contaminant
Gold	Deliberate addition	Colourant: dichromic effects.
Hafnium	Sand contaminants	Contaminant
Holmium	Sand contaminants	Contaminant
Indium	Deliberate addition	Colourant
Iron	Sand contaminants Deliberate addition:	Colourant: 'black', blue, green. Contaminants.
Lead	Deliberate addition: metallic lead or galena, scrap leaded copper alloys Salt additions: plant ash. Sand contaminants	Colourant: opaque white, opaque yellow. Contaminants
Lanthanum	Sand contaminants	Contaminant
Lithium	Sand contaminants	Contaminant
Lutetium	Sand contaminants	Contaminant
Magnesium	Deliberate addition	Flux.
Manganese	Deliberate addition: likely predominantly pyrolusite (MnO_2). Sand contaminants.	Colourant: 'black', purple, decolourant. Contaminants.

Table 1: Elements found in glass, their sources and uses, *continued*.

Chemical	**Sources**	**Uses**
Mercury	Contaminants in deliberate addition	Colourants
Molybdenum	Sand contaminants	Contaminant
Neodymium	Sand contaminants	Contaminant
Nickel	Deliberate addition	Colourants
Niobium	Sand contaminants	Contaminant
Phosphorus	Salt contaminant Sand contaminant	Contaminant
Potassium	Deliberate addition	Flux.
Praseodymium	Sand contaminants	Contaminant
Rubidium	Sand contaminants	Contaminant
Samarium	Sand contaminants	Contaminant
Scandium	Sand contaminants	Contaminant
Silicon	Sand	Main network former
Silver	Deliberate addition	Colourant
Sodium	Salt additions: plant ash, natron ($Na_2CO_3{\cdot}NaHCO_3{\cdot}2H_2O$). Sand contaminants.	Flux. Contaminants.
Strontium	Sand contaminant Lime contaminant	Contaminant
Sulphur	Salt contaminant	Contaminant
Tantalum	Sand contaminants	Contaminant
Tellurium	Sand contaminants	Contaminant
Terbium	Sand contaminants	Contaminant
Thallium	Sand contaminants	Contaminant
Thorium	Sand contaminants	Contaminant
Thulium	Sand contaminants	Contaminant
Tin	Deliberate additions	Colourant and opacifier
Titanium	Sand contaminants	Contaminant
Tungsten	Sand contaminants	Contaminant
Uranium	Salt contaminant Salt contaminant	Contaminant
Vanadium	Sand contaminants	Contaminant
Ytterbium	Sand contaminants	Contaminant
Yttrium	Sand contaminants	Contaminant
Zinc	Deliberate addition	Colourants
Zirconium	Sand contaminants	Contaminant

Table 2: Periodic Table Marking Elements with Notations Related to Recycling

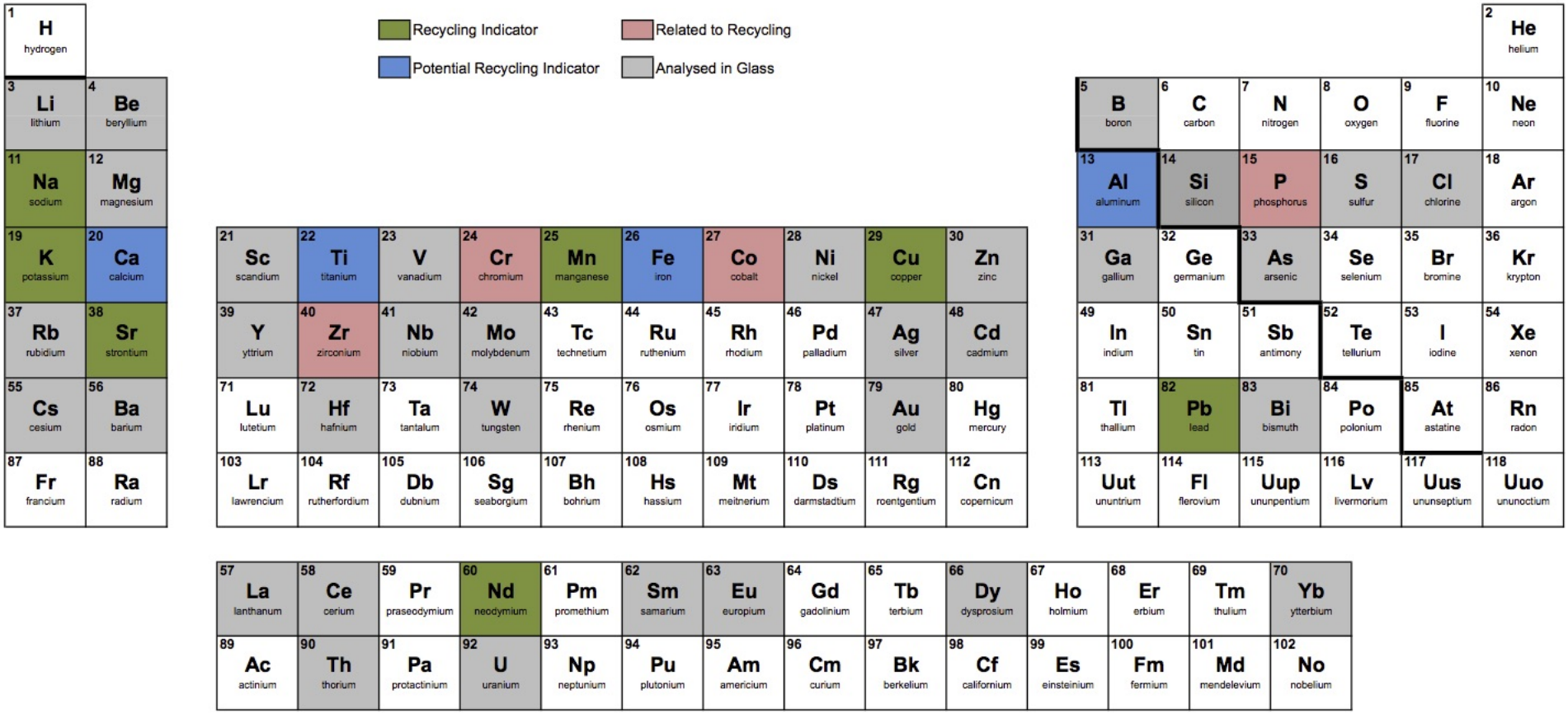

Table 3: Variously Identified Traditional Glass Groups, observed at multiple sites. Many of these are in reality overlapping productions.

References	Name	Site	Date	SiO_2	NaO	CaO	Al_2O	K_2O	MgO	Fe_2O_3	TiO_2	MnO	Sb_2O_3	P_2O	PbO	Ba (ppm)	Cu (ppm)	SO_3	CI
Gallo et al 2013	ADN1	Adria, Italy	1st	69.02	17.55	7.71	2.51	0.64	0.51	0.40	0.06	0.50	0.06	0.13	61 ppm	nm	98	0.20	1.40
Jackson et al. 2009	Plant Ash	Colchester	1st	63.06	16.54	6.96	2.14	1.73	1.84	1.44	0.19	0.79	0.34	0.77	0.49	600	16720	0.24	0.90
Baxter et al. 2005	Facet-cut	Across UK	1st-2nd	nm	17.77	3.96	1.30	0.58	0.43	0.51	0.09	0.05	2.20	0.06	0.44	87	33*	nm	nm
Foy et al. 2004	Group 4	Egypt, France	1st-3rd	71.00	19.05	5.56	1.94	0.42	0.43	0.34	0.06	0.02	0.63	0.02	nm	nm	nm	nm	nm
Paynter 2006	Antimony only	Binchester, Colchester	1st-3rd	nm	18.90	5.67	2.01	0.43	0.41	0.37	0.06	0.02	0.43	0.05	0.04	148	12	nm	nm
Jackson 2005	Group 1a	York. Mancetterr	1st-4th (2nd-3rd)	nm	19.34	5.63	1.91	0.50	0.45	0.35	0.07	0.04	0.50	0.04	0.04	148	17	nm	nm
Jackson 1992	Group 2b	Coppergate	1st-4th (2nd-3rd)	nm	16.85	8.24	2.86	0.65	0.60	0.44	0.08	1.07	0.03	0.12	0.01	406	17	nm	nm
Gallo et al. 2013	N2	Adria, Italy	2nd	69.20	18.84	5.44	1.87	0.46	0.51	0.40	0.08	0.09	0.53	0.04	<0.01	134	9	0.31	1.60
Gallo et al. 2013	N2	Adria, Italy 2nd	2nd	70.25	17.13	4.22	1.48	0.75	0.44	0.51	0.10	0.16	1.14	0.04	0.11	<10	151	nm	nm
Jackson 2005	2a	York	2nd-3rd	nm	19.25	6.10	2.28	0.71	0.56	0.54	0.10	0.34	0.46	0.10	0.07	207	116	nm	nm
Ganio et al. 2012	CL2	Embiez	2nd-early 3rd	65.27	15.55	8.44	2.26	0.54	0.45	0.28	0.05	1.35	0.16	0.16	nm	433	nm	nm	nm
Silvestri et al. 2008	CL1	lulia Felix	3rd	70.15	19.80	4.80	2.00	0.40	0.40	0.40	0.07	bd	0.80	0.03	<0.01	118	18	0.30	1.40
Silvestri et al. 2008	CL2	lulia Felix	3rd	70.29	15.20	7.80	2.60	0.50	0.60	0.20	0.07	1.40	bd	0.14	21 ppm	369	17	0.10	1.20
Silvestri et al. 2008	Cl1/2	lulia Felix	3rd	69.13	19.02	5.64	2.14	0.54	0.66	0.64	0.12	0.19	0.79	0.07	83 ppm	144	24	0.28	1.30
Jackson and Price 2012	Colourless	South Shields	3rd-4th	nm	18.93	5.62	1.79	0.42	0.51	0.39	0.07	0.03	0.46	0.02	bd	138	23	nm	nm
Foster and Jackson 2010	Colourless 1	UK various	3rd-4th	nm	18.99	5.74	1.90	0.39	0.49	0.40	0.06	0.04	0.35	0.02	0.01	148	23	nm	nm
Meek 2013	2a	?	3rd-7th	67.42	18.81	6.41	2.36	0.53	0.73	0.63	0.09	0.97	nm	nm	nm	nm	nm	nm	1.30
Foster and Jackson 2009	HIMT2	UK	4th	nm	19.65	6.00	2.25	0.58	0.76	0.72	0.12	0.98	0.11	0.05	0.02	290	105	nm	nm
Foster and Jackson 2009	Levantine 1a	UK various	4th	nm	15.55	8.45	2.81	0.60	0.59	0.42	0.07	1.23	0.06	0.09	<0.01	383	20	nm	nm
Foster and Jackson 2010	2a	UK	4th	nm	18.46	5.77	1.81	0.29	0.67	0.48	0.09	1.14	0.06	0.03	bd	199	14	nm	nm
Foster and Jackson 2010	Colourless 3	Uk various	4th	nm	19.48	6.12	2.08	0.53	0.59	0.55	0.09	0.35	0.04	0.05	0.07	219	121	nm	nm
Foster and Jackson 2009	Levantine lb	Various UK	4th	nm	14.56	8.55	2.93	0.72	0.45	0.33	0.06	0.10	0.06	0.08	0.02	254	15	nm	nm
Foster and Jackson 2009	HIMT1	UK	4th	nm	19.11	6.08	2.49	0.50	0.98	1.36	0.33	1.71	0.05	0.05	0.01	600	91	nm	nm
Freestone et al. 2005	HIMT London	London	4th	66.38	18.54	5.99	2.47	0.57	0.92	1.28	0.33	1.90	nm	nm	nm	nm	nm	nm	nm
Freestone et al. 2005	HIMT Carthage	Carthage	4th	64.77	18.74	5.24	3.18	0.44	1.29	2.30	0.68	2.66	nm	nm	nm	nm	nm	nm	nm
Foy et al.2003	Group 3.2	France	4th-5th	68.07	18.79	7.05	1.92	0.44	0.65	0.70	0.09	0.89	18.00	0.08	179 ppm	243	25	nm	nm
Meek 2013	2b	UK	4th-7th	70.10	15.67	8.70	3.02	0.67	0.65	0.44	0.06	1.17	nm	nm	nm	bm	nm	nm	nm
Schibille et al. 2012	Petra 2	Petra	4th	68.45	16.13	8.16	2.73	1.04	0.46	0.36	0.07	1.08	0.02	0.15	<0.01	308	59	0.17	0.90
Foy et al. 2003	Group 1	France, Tunisia	5th	64.50	19.10	6.22	2.88	0.41	1.23	2.28	0.49	2.02	7 ppm	0.11	63 ppm	654	79	nm	nm
Freestone et al 2000	Levantine	Dor, Appolonia	6th-7th	69.01	15.98	9.06	2.99	0.83	0.63	0.42	0.12	nm	nm	0.14	nm	223	nm	0.30	0.90
Foy et al. 2004	Lot A	Carthage and France	hellenistic	74.70	18.00	4.09	1.12	0.56	0.55	0.40	0.08	bd	2.97	bd	1.30	nm	nm	nm	nm
Foy et al. 2000	Group 3			69.80	17.00	8.01	2.54	0.61	0.61	0.54	0.06	0.63	nm	0.23	nm	nm	nm	nm	nm
Wedepohl et al. 1997		Frankish Krefeld-Gellep		68.49	16.37	7.18	2.37	0.68	0.88	1.05	0.13	0.86							
Velde 1990		Merovingian Vicq		67.63	18.07	7.67	2.38	0.76	1.02	0.82	nm	1.43							
Mirti et al. 2000		Crypta Balbi, Rome	7th c	67.26	17.3	7.21	2.37	0.6	0.83	0.85	0.14	0.69							
Freestone et al. 2008a	Anglo-Saxon Period I	UK		66.6	18.55	7.52	2.31	0.71	0.9	0.81	0.13	1.22		<0.1					

Table 3: Traditional Glass Groups, *continued*.

References	Name	Site	Date	SiO_2	NaO	CaO	Al_2O	K_2O	MgO	Fe_2O_3	TiO_2	MnO	Sb_2O_3	P_2O	PbO	Ba (ppm)	Cu (ppm)	SO_3	Cl
Freestone et al. 2008a	Anglo-Saxon Period II (Low Mg)	UK		67.6	17.8	7.5	2.5	0.7	0.8	0.9	<0.10	0.1	0.0	0.1	<0.10			0.1	0.4
Freestone et al. 2008a	Anglo-Saxon Period II (High Mg, low Mn)	UK		65.2	18.6	8.0	2.0	1.5	1.8	1.0	0.2	0.2	bd	0.3	0.2			0.5	0.7
Freestone et al. 2008a	Anglo-Saxon Period II (High Mg, high Mn)	UK		63.4	16.8	9.5	2.2	1.6	1.9	1.2	0.2	1.8	0.0	0.3	<0.2			0.5	0.7

Table 4: Types of Analysis used on glass, including detection limits and other factors governing selection.

	SEM-EDS	**ED-XRF**	**ICP-AES**	**LA-ICP-MS**	**EMPA**
Sample Destruction?	Maybe: Polishing (Preferably cross-section mounting)	Maybe: Polishing	Yes: Complete dissolution.	Minor (laser damage).	Mounting
General Detection Limit	0.1wt %, but improving	1wt %	typically 50ppm	1ppm	0.1wt% minimum
Sample Preparation?	Mounting and polishing	Polishing	Acid dilution	None (Occurs with laser ablation)	Mounting and polishing
Required Sample Size	5 mg	10 mg	10 mg	> 50 μg	5 mg
Precision	Fair	Fair	excellent	Very good	Very good
Accuracy	Fair	Fair	excellent	Very good	Very good
Multi-elements?	Low	Low	Medium	High	High

Table 5: Glasses selected for analysis from Dorchester-on-Thames.

SF No	Context	Description	Colour	Date
3040	3000	fragment, flat and thick	Blue-green	Unknown
3053	3000	fragment	Green	Unknown
3054	3052	fragment	Green	Unknown
3093	3000	fragment	Green	Unknown
3131	3000	fragment, melted	Green	Unknown
3174	3020	fragment	Nearly Colourless	Early Med
3188	3019	fragment, trail decoration	Green	Unknown
3254	3029	fragment, rim open vessel	Green	Unknown
3271	3029	fragment, melted, two	Green	Unknown
3279	3029	fragment	Blue-green	Unknown
3332	3020	fragment, cracked off rim?	Green	Unknown
3357	3028	droplet	Green	Unknown
3361	3028	fragment	Blue-green	Unknown
3371	3028	fragment	Nearly Colourless	Unknown
3435	3033	fragment, heavily scratched, potentially wheel abraided	Green	Unknown
3436	3033	fragment	Blue-green	Unknown
3439	3051	fragment	Green	Unknown
3486	3030	fragment	Yellow	Unknown
3501	3053	fragment, flat and thick	Green	Early Med
3518	3053	fragment	Green	Unknown
3524	3051	fragment, thick	Green	Unknown
3531	3053	fragment	Blue-green	Unknown
3556	3032	fragment, folded rim open vessel	Green	Unknown
3584	3055	fragment, wheel abraided decoration	Green	Unknown
3597	3055	fragment	Green	Unknown
3640	3055	fragment, rim open vessel	Green	Unknown
3643	3068	fragment	Green	Early Med
3656	3068	fragment	Green	Early Med
3658	3055	fragment, possibly melted	Green	Unknown
3699	3034	fragment	Nearly Colourless	Unknown
3711	3034	fragment	Green	Unknown
3719	3057	fragment	Green	Unknown
3745	3063	fragment	Blue-green	Unknown
3756	3057	fragment, thick	Blue-green	Unknown
3771	3066	fragment, flat	Blue-green	Early Med
3779	3062	fragment	Green	Unknown
3788	3064	Fragment, likely shoulder	Nearly Colourless	Unknown
3819	3102	fragment, cracked off rim?	Green	Fifth century
3872	3096	Ring base	Blue-green	Sixth century
3903	3091	fragment	Nearly Colourless	Sixth century
3986	3099	fragment, rim open vessel	Green	Sixth century
4006	3055	fragment, melted	Green	Unknown
4009	3098	fragment	Nearly Colourless	Sixth century
4041	3099	fragment	Green	Sixth century
4049	3052	fragment	Blue-green	Unknown
4096	3067	fragment, rim open vessel	Blue-green	Early Med
4100	3099	fragment	Blue-green	Sixth century
4122	3099	fragment	Green	Sixth century
4136	3098	fragments, three, trail decorated	Green	Sixth century

Table 5: Glasses selected for analysis from Dorchester-on-Thames, *continued*.

SF No	Context	Description	Colour	Date
4174	3093	fragment	Green	Sixth century
4196	3093	fragment	Green	Sixth century
4210	3092	fragment	Green	Sixth century
4213	3092	fragment	Blue-green	Sixth century
4265	3093	fragment	Blue-green	Sixth century
4283	3093	fragment	Nearly Colourless	Sixth century
4288	3024	fragment, melted	Green	Unknown
4328	3127	fragment	Green	Sixth century
4333	3127	fragment	Nearly Colourless	Sixth century
4363	3157	fragment	Green	Sixth century
4387	3161	fragment, trail decoration	Green	Sixth century
4415	3161	fragment	Green	Sixth century
4437	3161	fragment	Green	Sixth century
4455	3167	fragment	Green	Sixth century
4475	3160	fragment	Nearly Colourless	Sixth century
4518	3091	fragments, many	Green	Sixth century
4537	3097	fragment	Nearly Colourless	Sixth century
4597	3097	fragment, melted	Green	Sixth century
4604	3179	fragment	Nearly Colourless	Sixth century
4605	3091	fragment, trail decoration	Green	Sixth century
4617	3097	fragment	Green	Sixth century
4644	3097	fragment, melted	Green	Sixth century
4650	3182	fragment	Green	Sixth century
4738	3066	fragment, base	Green	Early Med
4740	3092	fragment, rim open vessel	Green	Sixth century
4751	3098	fragment, cracked off rim?	Green	Sixth century
4752	3098	fragment, flat	Green	Sixth century
4753	3056	fragment, thick	Nearly Colourless	Unknown
8473	3377	fragment, trail decoration	Green	Fifth century
8506	3530	fragment, rim open vessel	Green	Roman
8534	3564	fragment, base	Blue-green	Roman
8548	3546	fragment, cracked off rim	Green	Roman
8583	3574	fragment	Green	Roman
8592	3540	fragment	Blue	Roman
8593	3581	fragment, flat	Green	Roman
8651	3570	cullet	Green	Roman
8720	3593	fragment	Green	Roman
8901	3533	window glass	Nearly Colourless	Fourth century
8913	3611	fragment	Green	Roman
9023	3629	fragment	Nearly Colourless	Roman
9069	3604	fragment	Blue-green	Roman
9079	3604	fragment	Green	Roman
9132	3555	Slag	Slag	Roman
9199	3627	fragment, rim or maybe base	Nearly Colourless	Roman
9257	3563	fragment, rim open vessel	Green	Roman
9290	3658	fragment	Green	Roman
9408	3658	fragment, decorated	Green	Roman
9481	3673	fragment	Green	Fourth century
9509	3683	Slag	Slag	Early Med
9522	3533	fragment	Nearly Colourless	Fourth century
9553	3695	fragment	Green	Third century

Table 5: Glasses selected for analysis from Dorchester-on-Thames, *continued*.

SF No	Context	Description	Colour	Date
9573	3658	fragment	Green	Roman
9716	3579	fragment	Blue	Roman
9746	3623	fragment, flat	Green	Roman

Table 6: Glasses selected for analysis from Lyminge.

SF No	Context	Description	Colour	Period
555	6277	window glass	blue-green	Roman
358	6661	square bottle fragment	blue-green	Roman
380	6661	window glass	blue-green	Roman
275	6902	Frontius bottle	blue-green	Roman
550	99051	fragment	blue-green	Roman
208	99071	fragment, flat	blue-green	Roman
157	99086	fragment	blue-green	Roman
312	99121	fragment	blue-green	Roman
501	99125	fragment	blue-green	Roman
454	99201	Thick handle	blue-green	Roman
520	99204	window glass	blue-green	Roman
594	99250	thick fragment	blue-green	Roman
699	99256	shoulder of a handled square bottle	blue-green	Roman
689	99261	handle	green	Roman
799	99279	shoulder of a handled square bottle	blue-green	Roman
2.105	2541 C	Kempston beaker fragment	nearly colourless	Anglo-Saxon
2.192	2570 C	Kempston beaker fragment	nearly colourless	Anglo-Saxon
43	3101	fragment	dark blue	Anglo-Saxon
134	3302	fragment with fine trail	blue-green	Anglo-Saxon
278	3306	fragment	turquoise	Anglo-Saxon
631	3404	fragment	blue-green	Anglo-Saxon
935	3909	fragment	blue-green	Anglo-Saxon
107	6300	fragment	dark blue	Anglo-Saxon
457	7012	possible moil with iron-scale	blue-green	Anglo-Saxon
59	9290	molten possible drop	green	Anglo-Saxon
42	99002	fragment	green	Anglo-Saxon
23	99009	fine regular trails	yellow	Anglo-Saxon
306	99109	fragment	smokey green	Anglo-Saxon
348	99148	fragment	green	Anglo-Saxon
412	99174	fragment	green	Anglo-Saxon
483	99177	fragment with fine trails	amber	Anglo-Saxon
404	99178	fragment of a claw	yellow	Anglo-Saxon
458	99198	fragment with white opaque trails	nearly colourless	Anglo-Saxon
463	99212	fragment with white opaque trails	nearly colourless	Anglo-Saxon
678	99250	fragment of a claw	amber	Anglo-Saxon
634	99250	Kempston beaker fragment	nearly colourless	Anglo-Saxon
697	99264	raw glass multiple sherds with pottery sherd	blue-green	Anglo-Saxon

Table 7: Distribution of Colours in Dorchester-on-Thames Glass.

Colour	**Total Roman**	**Total Late and Post-Roman**	**Analysed Roman**	**Analysed Late and Post-Roman**
Green	26	160	15	50
Nearly Colourless	52	41	15	19
Blue-green	14	36	10	20
Yellow	1	7	1	6
Blue	2	4	2	0
Too weathered	1	4	0	0
Slag	6	2	3	1
Brown	2	2	2	2
White	0	2	0	0
Colourless	0	1	0	1
Black	2	0	2	0

Table 8: Summary of papers containing analytical data of glass from other European sites from the same period including the administrative region and country, as well as the analytical technique.

Paper	**Count**	**Region and Country**	**Technique**
Amrein et al. 1995	82	Vaud, Switzerland	ED-XRF WD-XRF
Arletti et al. 2005	79	Emilia-Romagna, Italy	EMPA XRF
Arletti et al. 2006a	23	Campania, Italy	XRF EMPA
Arletti et al. 2006b	9	Campania, Italy (4) Sicily, Italy (5)	WDS-EMPA
Arletti et al. 2006c	9	Campania, Italy	EMPA
Arletti et al. 2008b	41	Friuli-Venezia Giulia, Italy (11) Ticino, Switzerland (30)	WDS-XRF EMPA
Arletti et al. 2010a	8	Sicily, Italy	EPMA LA-CP-MS
Arletti et al. 2010b	38	Emilia-Romagna, Italy (23) Marche, Italy (15)	WDS-XRF EMPA
Bayley 4183	4 *part*	Tuscany, Italy (2) County Dublin, Ireland (2) *As reported in Table 8.1*	ED-XRF
Barbera et al. 2012	15	Sicily, Italy	SEM-EDS

Table 8: Summary of papers containing analytical data from other European glass, *continued*.

Paper	**Count**	**Region and Country**	**Technique**
Bezborodov 1975	463 *& 299*	Kyyivs'ka Oblast', Ukraine (65) Unknown, Unknown (64) Rheinland-Pfalz, Germany (19) Wojewodztwo Kujawsko-Pomorskie, Poland (19) Vinnyts'ka Oblast', Ukraine (19) Oblast Shumen, Bulgaria (16) Avtonomna Respublika Krym, Ukraine (13) Brestskaya Voblasts', Belarus (11) Minskaya Voblasts', Belarus (11) Provincia di Udine, Italy (11) Land Nordrhein-Westfalen, Germany (10) Wojewodztwo Zachodniopomorskie, Poland (10) Land Hessen, Germany (9) Wojewodztwo Opolskie, Poland (9) Belgorodskaya Oblast', Russia (9) Leningradskaya Oblast', Russia (9) Oblast Veliko Turnovo, Bulgaria (8) Splitsko-Dalmatinska Zupanija, Croatia (8) Homyel'skaya Voblasts', Belarus (7) Vitsyebskaya Voblasts', Belarus (7) Kralovehradecky kraj, Czech Republic (7) Departement de l'Aisne, France (7) Fejer Megye, Hungary (7) Vladimirskaya Oblast', Russia (7) Hlavni Mesto Praha, Czech Republic (6) Chernihivs'ka Oblast', Ukraine (6)	

Table 8: Summary of papers containing analytical data from other European glass, *continued*.

Paper	Count	Region and Country	Technique
		Yerevan, Armenia (5)	
		Hrodzyenskaya Voblasts', Belarus (5)	
		Land Niedersachsen, Germany (5)	
		Provincia di Venezia, Italy (5)	
		Departement de la Marne, France (4)	
		Unknown, Hungary (4)	
		Wojewodztwo Lubuskie, Poland (4)	
		Smolenskaya Oblast', Russia (4)	
		Ivano-Frankivs'ka Oblast', Ukraine (4)	
		Provincia di Napoli, Italy (3)	
		Wojewodztwo Malopolskie, Poland (3)	
		Kaliningradskaya Oblast', Russia (3)	
		Tambovskaya Oblast', Russia (3)	
		L'vivs'ka Oblast', Ukraine (3)	
		Zlinsky Kraj, Czech Republic (2)	
		Departement des Bouches-du-Rhone, France (2)	
		Unknown, Italy (2)	
		Unknown, Poland (2)	
		Bryanskaya Oblast', Russia (2)	
		Kabardino-Balkarskaya Respublika, Russia (2)	
		Ryazanskaya Oblast', Russia (2)	
		Yaroslavskaya Oblast', Russia (2)	
		Jihomoravsky Kraj, Czech Republic (1)	
		Unknown, Czech Republic (1)	
		Lazio, Italy (1)	
		Livorno, Italy (1)	
		Unknown, Lithuania (1)	
		Mi?dzyrzecz County, Poland (1)	
		Wojewodztwo Dolnoslaskie, Poland (1)	
		Wojewodztwo Wielkopolskie, Poland (1)	
		Ivanovskaya Oblast', Russia (1)	
		Kaluzhskaya Oblast', Russia (1)	
		Kostromskaya Oblast', Russia (1)	
		Kyyivs'ka Oblast', Russia (1)	
		Novgorodskaya Oblast', Russia (1)	
		Respublika Kareliya, Russia (1)	
		Unknown, Russia (1)	
		Unknown, Slovakia (1)	
		Kharkivs'ka Oblast', Ukraine (1)	
		Sums'ka Oblast', Ukraine (1)	
		Uzbekistan (88)	
		Egypt (45)	
		Georgia (45)	
		India (29)	
		Iraq (19)	
		Azerbaijan (12)	
		Pakistan (10)	
		Kyrgyzstan (9)	
		Turkmenistan (9)	

Table 8: Summary of papers containing analytical data from other European glass, *continued.*

Paper	**Count**	**Region and Country**	**Technique**
		Tajikistan (8) *Indonesia (6)* *Japan (6)* *Tanzania (6)* *Armenia (3)* *Turkey (3)* *Malaysia (1)*	NAA
Bezborodov and Abdurazakov 1964	5	Dniester, Ukraine	XRF
Boon 1968	4	Monmouthshire, Wales	Spectrographic
Brill 1964	5	Athens, Greece Corinth, Greece Unknown	?
Brill 1999	201 & *part*	Grosseto, Italy (48) Veneto, Italy (26) Ravenna, Italy (21) Split-Dalmatia County, Croatia (19) Gelderland, Netherlands (12) South Jutland County, Denmark (10) Primorje-Gorski Kotar, Republic of Croatia (7) Condeixa-a-Nova, Portugal (5) Attica, Greece (4) Monmouthshire, Wales (4) Province of Siena, Italy (4) Newport, Wales (3) Livorno, Italy (2) North Rhine-Westphalia, Germany (2) Republika Srpska, Bosnia and Herzegovina (2) Rhineland-Palatinate, Germany (2) County Meath, Ireland (1) Fribourg, Switzerland (1) Limburg, Belgium (1)	
Cagno et al. 2012b	37	Tuscany, Italy	SEM-EDX LA-ICP-MS
Cagno et al. 2013	379 *part*	Where	SEM-EDX LA-ICP-MS
Cagno et al. 2014	31 *part*	Vaud, Switzerland (6) Basel-Landschaft, Switzerland (8) Limburg, Netherlands (10) Namur, Belgium (7) *As reported in Table 8.1*	SEM-EDX LA-ICP-MS
Cavalieri and Giumlia-Mair 2009	40	Tuscany, Italy	XRF
Ceglia et al. 2013	16	Namur, Belgium	SEM-EDS
Cole 1966	3	Monmouthshire, Wales	Spectrographic
da Cruz 2009	3	Minho Province, Portugal	Spectrographic

Table 8: Summary of papers containing analytical data from other European glass, *continued*.

Paper	**Count**	**Region and Country**	**Technique**
Freestone et al. 2002	19	Larnaca District, Cyprus	SEM-EDXA ICP-MS
Gaitzsch et al. 2000	85	North Rhine-Westphalia, Germany	EPMA
Gallo and Silvestri 2012	38	Veneto, Italy	EPMA
Ganio et al. 2012	104 *& 10*	Catalonia, Spain (19) Var, France (18) Aosta Valley, Italy (18) West Flanders, Belgium (16) Friuli-Venezia Giulia, Italy (14) Flemish Brabant, Belgium (11) Adjara, Georgia (8) *Jerash Governorate, Jordan (8)* *Ma'an Governorate, Jordan(2)*	XRF ICP-OES AES AAS EMPA
Gliozzo et al. 2010	13	Foggia, Italy	SEM-EDS EMPA ICP-MS
Henderson 1999	38	Freisland, Netherlands	SEM EMPA
Hulínskỳ and Černá 2003	85	Where	EMPA SEM
Mirti et al. 1993	58	Aosta Valley, Italy	ICP-OES
Mirti et al. 2000	40	Lazio, Italy	ICP-OES
Mirti et al. 2001	27	Lazio, Italy	ICP-OES
Möncke et al. 2014	23	Peloponnese, Greece	SEM
Rech 1982	8	North Rhine-Westphalia, Germany	EMPA
Santagostino Barbone et al. 2008	8	Foggia, Italy	SEM-EDS EMPA ICP-MS ICP-OES
Silvestri et al. 2005	81	Friuli-Venezia Giulia, Italy	XRF EMPA
Silvestri et al. 2008	88	Friuli-Venezia Giulia, Italy	XRF EMPA
Silvestri et al. 2011	96	Veneto, Italy	EMPA LA-ICP-MS
Velde and Gendron 1980	59	Aquitaine-Limousin-Poitou-Charentes, France	EPMA
Velde and Sennequier 1985	48	Normandy, France (33) Bourgogne-Franche-Comté, France (6) Nord-Pas-de-Calais-Picardie, France (3) Unknown, France (2) Rhineland-Palatinate, Germany (2) North Rhine-Westphalia, Germany (1) Trier-Saarburg, Germany (1)	
Wedepohl et al. 1997	28	North Rhine-Westphalia, Germany	EMPA
Wolf et al. 2005	43	Valais, Switzerland	XRD-WDS

Table 9: Results from analyses of Corning A and B, including the papers that have recorded these values, this thesis, and the two commonly accepted literature values from Schibille, 2011 and Vicenzi et al., 2002.

Reference	Glass Type	Analysis	Na2C	MgO	Al2O	K2O	CaO	TiO2	MnO	Fe2O3	Sb2O	Sb2O5	Cu	CuO	Co	CoO	P2O5	PbO
Mortimer, 1996b	**Corning A**	SEM-EDX	13.60	2.80	0.90	3.00	5.10	0.80	1.10	1.00	1.70	-	-	1.20	-	0.20	0.00	0.10
Paynter, 2006	**Corning A**	ICP-AES	14.27	2.80	1.01	2.88	5.04	0.80	1.01	1.09	-	1.69	-	1.25	-	0.15	¡0.1	0.05
Sainsbury	**Corning A**	EMPA	14.09	2.67	0.88	2.90	5.00	0.69	1.01	0.96	-	1.97	-	1.25	-	0.17	0.12	0.07
(Schibille 2011)	**Corning A**		14.34	2.59	0.90	2.89	5.30	0.82	1.08	1.03		1.97		1.27	0.18		0.12	0.08
(Vicenzi et al. 2002)	**Corning A**		14.30	2.66	1.00	2.87	5.03	0.79	1.00	1.09		1.75		1.17	0.17		0.13	0.10
Foster and Jackson, 2010	**Corning B**	ICP-AES	17.20	1.04	4.30	1.05	8.69	0.08	0.35	0.34	-	-	1.89	-	0.03	-	0.75	0.41
Foster and Jackson, 2010	**Corning B**	ICP-AES	17.20	1.04	4.30	1.05	8.69	0.08	0.35	0.34	-	-	1.89	-	0.03	-	0.75	0.41
Mortimer, 1996b	**Corning B**	SEM-EDX	16.20	1.10	4.30	1.10	8.40	0.10	0.30	0.30	0.60	-	-	2.70	-	0.10	0.90	0.30
Sainsbury	**Corning B**	EMPA	16.92	1.04	4.14	1.03	8.70	0.09	0.25	0.30		0.51		2.94		0.04	0.87	0.52
(Schibille 2011)	**Corning B**		17.12	1.01	4.11	1.04	9.42	0.10	0.29	0.35		0.49		2.91	0.04		0.88	0.54
(Vicenzi et al. 2002)	**Corning B**		17.00	1.03	4.36	1.00	8.56	0.09	0.25	0.34		0.46		2.66	0.05		0.82	0.61

Table 10: List of all sites included in the thesis, with site type as recorded in the publication and the period given for the glass.

Alton, Hampshire	Cemetery	Early Medieval
Appleton, Oxfordshire	Stray find	Roman
Asthall, Oxfordshire	Stray find	Roman
Bardwell, Suffolk	Stray find	Roman
Barlaston, Staffordshire		
Barnsley Park, Gloucestershire	Rural Villa (and field system)	Roman
Barrington, Cambridgeshire	Cemetery	Early Medieval
Barton Court Farm, Oxfordshire	Rural Villa	Roman
Bath, Somerset	Temple (and field systems)	Roman
Beadlam Villa, North Yorkshire	Rural Villa	Roman
Beckford, Worcestershire	Cemetery	Early Medieval
Bergh Apton, Norfolk	Cemetery	Early Medieval
Binchester, Durham	Fort	Roman
Bishopsbourne , Kent	Cemetery	Early Medieval
Brettenham, Suffolk	Stray find	Roman
Broomfield, Essex	Cemetery (single burial)	Early Medieval
Brough, Cumbria	Stray find	Roman
Bury-St.-Edmunds, Suffolk	Stray find	Roman
Cadbury Congress, Bristol	Settlement	Post-Roman
Caister-on-Sea, Norfolk	Fort	Late-Roman
Campsfield, Oxfordshire	Stray find	Roman
Canterbury, Kent	Urban (some extramural)	Roman
Carisbrooke Castle, Isle of Wight	Settlement (with burials)	Early Medieval
Castle Eden, Durham	Cemetery (single burial)	Early Medieval
Castleford, West Yorkshire	Fort and Urban	Roman
Chichester, West Sussex	Urban	Roman
Chiddingfold, Sussex	Workshop	Early Medieval
Colchester, Essex	Urban	Roman
Coppergate, North Yorkshire	Workshop	Roman
Dalton Parlours, West Yorkshire	Villa	Roman
Desborough, Northamptonshire	Cemetery (single burial)	Early Medieval
Ditchley, Oxfordshire	Stray find	Roman
Dorchester-on-Thames, Oxfordshire	Urban	Roman and Early Medieval
Dorchester, Dorset	Urban	Roman
Dover, Kent	Cemetery	Early Medieval
Droxford, Hampshire	Cemetery	Early Medieval
East Shefford, Berkshire	Cemetery	Early Medieval
Empingham, Leicestershire	Settlement	Early Medieval
Eriswell, Suffolk	Cemetery	Early Medieval
Faversham and Howletts, Kent	Cemetery	Early Medieval
Finglesham, Kent	Cemetery	Early Medieval
Fishbourne Villa, West Sussex	Villa	Roman
Frocester Court, Gloucestershire	Villa	Roman
Great Bently, Essex	Field system	Roman
Great Chesterford, Essex	Cemetery	Early Medieval
Great Waldingfield, Suffolk	Stray find	Roman
Heybridge, Essex	Unknown	Roman
Icklingham, Suffolk	Stray find	Roman
Ipswich, Suffolk	Settlement	Early Medieval
Ixworth, Suffolk	Stray find	Roman

Jarrow and Monkwearmouth, Tyne and Wear	Monestary	Early Medieval
Kempston, Bedfordshire	Cemetery	Early Medieval
Lancing Down, Sussex	Stray find	Roman
Leicester, Leicestershire	Urban	Roman
Lincoln, Lincolnshire	Fort and Urban	Roman
London (incl. Maiden Lane, Winetavern St, Watling House, Moorgate, Copthall Avenue, Norton Folgate, Tower of London, Bedfordbury, National Gallery, Westminster Abbey)	Urban (some extramural)	Roman and Early Medieval
Longbridge, West Midlands	Cemetery	Early Medieval
Lullingstone Villa, Kent	Villa	Roman
Lyminge	Settlement	Early Medieval
Mancetter, North Warwickshire	Fort	Roman
Morningthorpe, Norfolk		Early Medieval
Mucking, Essex	Cemetery	Early Medieval
Portchester Castle, Hampshire	Fort	Roman
Rainham, Greater London	Cemetery	Early Medieval
Repton, Derbyshire	Monestary	Early Medieval
Salisbury (Old Sarum), Wiltshire	Urban	Early Medieval
Shakenoak Villa, Oxfordshire	Villa	Roman
Sittingbourne, Kent	Cemetery	Early Medieval
Southampton (Hamwih), Hampshire	Urban (some extramural)	Early Medieval
Spong Hill, Norfolk	Cemetery	Early Medieval
Sproughton, Suffolk		
Sutton Hoo, East Anglia	Cemetery (single burial)	Early Medieval
Taplow, Buckinhamshire	Cemetery	Early Medieval
Towcester, Northampton	Fort and Urban	Roman
Trowbridge, Wiltshire	Monestary	Early Medieval
Uley, Gloucestershire	Temple	Roman and Early Medieval
Wakerley, Northamptonshire	Cemetery	Early Medieval
West Clacton Reservoir, Essex	Villa	Roman
Wharram Percy, Yorkshire	Settlement	Early Medieval
Whitby, Yorkshire	Cemetery	Early Med
Windchester, Hampshire	Settlement	Early Medieval
Wingham, Kent	Cemetery	Early Medieval
Woodeaton, Oxforshire	Stray find	Roman
Worcester, Worcestershire	Urban	Roman
Wroxeter, Shropshire	Urban	Roman
Wye Down, Kent	Cemetery	Early Medieval
York (inclinding York Fortress, York Minster, Wellington Row, Fishergate), North Yorkshire	Urban (some extramural)	Roman and Early Medieval

Term	Definition	Weight	Chemistry	Object Type	Colour
Reuse					
Finishing	Completing the production of an object after producing a 'rough' shape.	Same	Bulk same, with possible additions	Same	Bulk same, with possible additions
Reclamation	The reuse of an old object without physical alteration but obviously in a new social world.	Same	Same	Same	Same
Repair					
Ressamble	The repairing of an object, to its original form, with or without the addition of further material.	Bulk same	Bulk same, with possible additions	Same	Same
Reworking	Simple alteration in the solid state to transform an object into a new class, typically for a new role.	Possible increase	Same	Change	Same
Remelting					
Reforming	Forming of an object into a new shape, with or without a change of object type, through a liquid state.	Same	Possible Change	Change or same	May change
Recycling - consolidation	Taking a number of objects and melting them to cast a single larger new object.	Increase	Change	Change or same	May change
Recycling - division	Melting a large object and casting an increased number of new objects.	Decrease	Possible Change	Change or same	Same
Cullet	Melting multiple units, from which a number of cast objects are derived.	Same	Change	Change or same	May change
Incorporation	Small amounts of recycled colourant, added to a fresh melt.	Increase	Change	Change or same	Change

Table 11: Summary of definitions of glass recycling

Table 12: Concentration of Antimony in Glasses from Italy, Belgium, Netherlands, France and England, from First to Seventh Centuries.

Country	Century	Below Detection	<0.001 wt%	0.005 wt%	0.01 wt%	0.05 wt%	0.1 wt%	0.5 wt%	1 wt%	2 wt%	>2 wt%	TOTAL
Italy	1	2	2	3	2	7	3	47	11	5	0	82
Italy	2	5	1	5	1	8	5	60	7	0	0	92
Italy	3	0	2	0	0	5	5	66	6	0	0	84
Italy	4	2	7	3	0	0	0	18	3	5	0	38
Italy	5	0	0	2	2	9	1	1	0	0	1	16
Italy	6	9	16	4	5	15	3	41	11	2	0	106
Italy	7	8	10	0	0	14	0	21	22	6	3	84
Belgium	1	0	0	0	0	1	0	8	2	0	0	11
Belgium	2	0	0	0	0	3	0	8	0	0	0	11
Belgium	3	0	0	0	0	1	0	6	5	0	0	12
Belgium	4	0	0	0	1	3	0	6	5	1	0	16
Belgium	5	0	0	0	0	0	0	7	3	1	0	11
Belgium	6	0	0	0	0	0	0	0	0	0	0	0
Belgium	7	0	0	0	0	0	0	0	0	0	0	0
Netherlands	1	0	0	0	0	0	0	0	0	0	0	0
Netherlands	2	0	0	0	0	0	0	1	0	0	0	1
Netherlands	3	0	0	0	0	0	0	4	0	0	0	4
Netherlands	4	0	0	0	0	0	0	0	0	0	0	0
Netherlands	5	1	0	0	0	0	1	0	1	0	0	3
Netherlands	6	2	0	0	0	0	1	0	0	0	0	3
Netherlands	7	1	0	0	0	0	0	0	0	0	0	1
France	1	0	0	0	0	0	0	0	0	0	0	0
France	2	0	0	0	0	0	0	0	0	0	0	0
France	3	0	0	0	0	0	0	37	0	0	0	37

France	4	0	0	0	0	0	0	0	0	0	0	0
France	5	0	0	0	0	0	0	0	0	0	0	0
France	6	0	0	0	0	0	0	0	0	0	0	0
France	7	0	0	0	0	0	0	0	0	0	0	0
England	1	5	0	0	0	3	1	3	0	0	0	12
England	2	11	0	1	3	4	1	120	20	2	0	162
England	3	1	0	0	44	11	8	323	27	2	0	416
England	4	32	0	0	16	86	132	176	2	0	0	444
England	5	2	0	0	4	24	12	7	0	0	0	49
England	6	23	0	0	17	29	42	25	2	0	0	138
England	7	48	0	0	0	14	4	19	3	0	1	97