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Exploring Value through Roman Glass from Karanis, Egypt

A dissertation submitted in partial satisfaction of the

requirements for the degree Doctor of Philosophy

in Near Eastern Languages and Cultures

by

Angela Pauline Susak Pitzer

2015

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ABSTRACT OF THE DISSERTATION

Exploring Value through Roman Glass from Karanis, Egypt

by

Angela Pauline Susak Pitzer

Doctor of Philosophy in Near Eastern Languages and Cultures

University of California, Los Angeles, 2015

Professor Willemina Z. Wendrich, Chair

In this multi-disciplinary study of Roman glass from Karanis, Egypt, I combine archaeological, chemical compositional data, ethnoarchaeology, and historical insights to assess how objects were valued in the ancient world. The series of physical actions carried out and decisions made during the production of an artifact, in short, the *chaîne opératoire,* reflect shared concepts of value. By considering an object not as an end product, but as the result of a *chaîne opératoire,* I have been able to intimate the social agency underwriting the production process. My ethnoarchaeological study of modern glass workers in Cairo and in Hampshire, UK helps to reconstruct the *chaîne opératoire* of glass manufacturing and identifies relationships between value and ancient technology. Following the *chaîne opératoire* of glass manufacturing informed by chemical, morphological, and contextual analyses, I reconstruct object biographies of recently excavated artifacts from Karanis dating primarily to the late Roman period (4th-6th centuries CE).

Through onsite portable X-ray fluorescence (pXRF) spectrometry analysis of recently excavated Karanis glass, I investigate the selection of raw materials. This research, combined with pXRF and electron probe micro-analysis (EPMA) of museum specimens from Karanis, helps distinguish glass compositional groups. These compositional groups are identified through quantitative analysis of these data and consideration of the detection and accuracy limitations of pXRF. At least two compositional groups identified most likely represent recycled glass due to the presence of both manganese and antimony above trace levels. This research contributes to the debate regarding the location, organization, and scale of glass manufacturing during the Roman period. The combination of analytical, historical, and archaeological evidence allows me to assemble the life history of certain glass vessel types--*unguentaria*, rectangular bottles, and oil flasks—demonstrating relationships among phases of the *chaîne opératoire* of glass manufacturing and the social function of objects.

In the late Roman period, an age when blown glass was commoditized and available to a broader demographic, only particular objects were considered luxury items. Karanidians tried to set themselves apart by using high-quality colorless oil flasks in the public sphere without ignoring the utility of glass as a container for oils and other commodities. For glass vessels that were most likely valued for the materials inside them rather than for the glass objects themselves, manufacturers preferred to use recycled glass. The diverse, yet complementary research techniques employed in this study expose the interplay between objects and social phenomena.

The dissertation of Angela Pauline Susak Pitzer is approved.

Kathlyn Cooney

Paul Nicholson

Dwight Read

David Scott

Willemina Z. Wendrich, Committee Chair

University of California, Los Angeles

2015

Dedicated to my parents, Gary and Linda Susak
and my loving family

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Chapter 1

Introduction and Theoretical Background

1.1 Introduction

This study investigates how we can assess value in the ancient world. To this end, I have embarked on archaeological, chemical, and morphological analyses of glass from Karanis, Egypt, augmented by ethnoarchaeological research and historical insights. This holistic approach exploits advancements in technology and analytical techniques that enable the exploration of new research questions about the Karanis glass assemblage that have wider implications to the location, organization, and scale of the Roman glass industry.

I examine a corpus of recently excavated glass from Karanis dating primarily to the Late Roman Period (4th-6th century CE), following the commoditization of blown glass vessels. By the 4th century CE, glass blowing and mold blowing were well-established technologies contributing to the mass production of glass vessels. Glass was no longer exclusively a luxury item, which only royalty and the elites could access or afford. Rather, mass production meant that glass became available to a much broader demographic.

By tracing the events in the lives of individual glass artifacts, starting from the selection of raw materials to discard, I expose the social agency underlying the entire production process. Secure archaeological context of these artifacts allows an in-depth contextual analysis using a unique set of analytical techniques that allows for the exploration of multiple typologies. I address how the commoditization of blown glass influenced the value of these objects. Did the commoditization of glass blowing change the nature of the social communication through material culture? If more people could afford or access glass, was this material still a suitable means of distinguishing oneself? Were certain types of glass objects still considered luxury

items? What objects were valued over others and why? By exploring these questions, we can begin to understand changes in the value of material culture as a result of well-established technological change. It will also allow us to trace shared conceptions in the Roman world that spill over into all areas of life, giving us a clearer picture of the society in which these artifacts were produced and used. Value studies help reconstruct the internal mechanisms of past societies, which can in turn enrich our understanding of the present (Dietler and Herbich 1998; Graeber 2001; Papadopoulos and Urton 2012).

1.2 Value Theory

Objects both reflect and shape our values as well as our perceptions of rank, power, and wealth. Since humans involve objects in almost all facets of social life, they inform us about the society and culture in which they are embedded (Dietler and Herbich 1998: 235). Objects enable communication, as the consumption and use of objects send social messages and also allow one to receive them (Appadurai 1986; Douglas and Isherwood 1979; Riegl 1903).

Value is a concept that is central to understanding a society and the role of material culture in it. It is, however, also an elusive concept, and there have been several theories on how to emically define, assess, and gauge value in the ancient world. Graeber published a synthesis of these various theories in his book, Towards an Anthropological Theory of Value (2001). His own theory of value builds upon three main streams of thought, which are all ultimately refractions of the same thing:

1. "values" in the sociological sense: conceptions of what is ultimately good, proper, or desirable in human life
2. "value" in the economic sense: the degree to which objects are desired, particularly, as measured by how much others are willing to give up to get them

3. and "value" in the linguistic sense, which goes back to the structural linguistics of Ferdinand de Saussure (1966), and might be more simply glossed as "meaningful difference" (Graeber 2001: 1-2).

Taking these multiple viewpoints into account, Papadopoulos and Urton suggest a more broad and "nuanced conception of value informed by anthropological, art historical, linguistic, and semiotic perspectives" (2012: 2). They define the concept of value as lying at "the intersection of individual and collective tastes, desires, sentiments, and attitudes that inform the ways people select or give priority to one thing over another" (Papadopoulos and Urton 2012: 2).

Anthropologists and archaeologists aim to answer a variety of questions through the study of value: How did people determine and negotiate value? Why are the same materials valued differently by different cultures? Is value inherent in the material itself? How does value contribute to social constructs (wealth, status, rank, power, authority)? How can value in the ancient world inform object value today? Value studies, however, do not often yield definitive answers to these questions. Value is a culturally assigned attribute, overwhelmed by paradox (Papadopoulos and Urton 2012). Value can often be fluid but sometimes absolute; it can be negotiable or intrinsic and it can be defiant or subject to quantitative measurements (Papadopoulos and Urton 2012). Objects can also move in and out of a commodity state (Appadurai 1986: 13). A further complication is that the value of an object may change many times throughout its lifetime: from precious novelty to damaged good; from commodity to treasured heirloom; or from discarded trash to coveted antiquity. Furthermore, objects take one new meanings in different contexts (Appadurai 1986; Caple 2000; Scott 2013).

Riegl (1982 [1903]) distinguishes three main categories of memory value when assessing monuments: "intentional commemorative-value", "historical-value", and "age-value." The first concept applies to intentional monuments, while the last two relate to unintentional monuments, meaning the choice of categorizing something as a monument can be a subjective preference (Arrhenius 2004; Riegl 1982 [1903]). "Historic value" places a single monument from the past

into the present (Papadopoulos and Urton 2012; Riegl 1982 [1903]), while "Age-value" means that any object, regardless of its original purpose, can accrue value as long as it is significantly old (Arrhenius 2004). "Intentional commemorative-value", on the other hand, attempts to preserve a moment in time for later generations (Papadopoulos and Urton 2012; Riegl 1982 [1903]).

1.3 Research Strategies

This multidisciplinary approach to studying value is motivated by three underlying strategies: object biographies (Appadurai 1986; Caple 2000), a life history approach (Kopytoff 1986), and a contextual approach (Lillios 1999: 239).

1.3.1 Object Biographies

Object biographies refer to "the way in which structured objects are used within a society" (Hurcombe 2007: 41). Objects have several types of biographies: economic, technical, and social (Kopytoff 1986: 68). Therefore, a biographical approach considers different moments of an object's biography--its production, exchange, consumption, and discard--along with its social contexts (Gosden and Marshall 1999: 169). Caple (2000) points out that although an object is an unbiased witness to all events during its life, not every "truth" about an object can be unveiled.

A culturally informed biographical approach recognizes an object as a "culturally constructed entity, endowed with culturally specific meanings, and classified and reclassified into culturally constituted categories" (Appadurai 1986: 68). Furthermore, an object's value is related to the ongoing negotiation of humans and objects throughout its lifetime and the reciprocal nature of these interactions (Hurcombe 2007: 41).

1.3.2 Life History Approach

Object biographies refer to those of *specific* objects as they move through time, different ownership, contexts, and uses. Life histories, in contrast, encompass classes or types of objects at a larger social scale and for longer periods of time. The meaning and value of object types may fluctuate over time, which is distinct from the biography of one member of a class or type of object (Appadurai 1986: 34). It is crucial to investigate object life histories in addition to biographies in order to adequately interrogate object value (Appadurai 1986; Gosden and Marshall 1999; Lillios 1999). "Objects can be understood only through looking at the cultural contexts which originally produced them and the new circumstances into which they are moved" (Gosden and Marshall 1999: 174).

1.3.3 Contextual Approach

After an object has been manufactured, the next phase in an object's life includes the exchange, use, and in some cases, reuse of the object. A contextual approach elucidates this phase through the identification and comparison of the various contexts in which the artifacts were found within the archaeological record (Lillios 1999: 240-241). Through contextual analysis, I investigate object function (literal, symbolical, and social) as well as inalienable objects, such as heirlooms, to help identify why some glass objects are valued differently than others.

Artifact provenience informs the manner of discard (and in some cases use), which is crucial for the interpretation of cultural material. Most glass objects recovered from Karanis are from domestic archaeological contexts, and this must also be taken into account when trying to assess the function of these objects. A possible ritual use of glass in temples or as funerary

goods, for instance, cannot be easily investigated given the context of the majority of glass artifacts found at Karanis. Also, since some of the recently excavated material is derived from refuse deposits, it can be difficult to infer function by this manner of discard.

By exploring the association of archaeological context to other variables, such as fabric type and morphology, I clarify how and why some glass objects are valued over others. I designed a database including several variables (e.g. archaeological context, morphological features, chemical composition, decoration) to enable me to identify and test various associations among variables.[1] For instance, I compare the fabric and morphological types of vessels found in hoards with those found in other contexts to establish a correlation of fabric and/or form and archaeological context. At least 14 glass hoards were found by the Michigan excavation team during the early 1920's. In fact, more than half of the total complete vessels were found in hoards (Harden 1936). Harden noted that certain fabrics were common among hoards, namely three wares representing "the best table ware of the well-to-do Karanidian resident of the fourth century" (1936: 37). Since these objects were protected and kept together in a specific location, they were probably valued differently than some of the ones found in refuse deposits. If they were heirlooms, their value may not have been dependent on the quality of the glass material or skill involved in making it; but rather, objects that are passed on between generations or presented as a gift often carry with them a part of the donor or forbear (Mauss 1990).

Spatial analysis of glass objects from Karanis as well as other types of artifacts intimates the social demographics of the town of Karanis. Areas of high affluence, for instance, contain high-quality glass, imported ceramics, and pig bone, while poorer areas contain few glass items and locally produced ceramic cooking pots, instead of imports. Furthermore, temporal variation in the types of glass consumed and used by inhabitants of Karanis, as well as the recycling of

[1] This is not an exhaustive list of variables as comprised in the database, which is available to colleagues upon request. See Appendix 3 for a list of measurments and data collected.

glass, corresponds to political, cultural, or economic factors, such as fluctuations in the overall economy of Karanis and/or the Roman Empire at large, or to transitions in the Roman glass industry.

Artifact provenience of recently excavated material from Karanis was recorded at the time of excavation. Artifacts are more generally sourced to the trench from which they were derived, and more specifically to a stratigraphic unit number. For recently excavated material, stratigraphic units were dated by the onsite pottery specialist, Sonali Gupta-agarwal, according to diagnostic pottery sherds present in each stratigraphic unit. Several stratigraphic units were also dated using C-14 analysis. Relying on pottery analysis and C-14 for the dating of stratigraphic units yields more accurate results than those obtained by Harden. The recently excavated material primarily dates to the late Roman period. Modern excavation methods enable the identification of a finely grained temporal sequence during this period. Furthermore, the types of deposits in which glass artifacts are found can also illuminate the nature of object use and discard at Karanis.

The dating of the Karanis glass excavated between 1924-1934 and published by Harden needs to be revised, because there are many dating inaccuracies due to both the excavation methods of the time and the reliance on coins and papyri for dating stratigraphic layers (1936). Harden recognized these limitations and disagreed with the dating conclusions published in the *Topological Report* of the University of Michigan Karanis excavations (Boak and Peterson 1931), especially the dates given for C-period houses and 5000 houses. He claimed that the coin and papyri dates published in Boak and Peterson (1931) were too early (Harden 1936: 32).

In addition to the spatial and temporal analyses of the archaeological context of artifacts, textual sources help identify events and circumstances that affected glass consumption as well as different glass types, their various functions (literal, symbolic, social, etc.), as well as their

exchange value. Textual sources include official documents issued by the Emperor, records and memoirs by historians and philosophers, and casual letters.

1.3.4 Ethnoarchaeology

Object biographies begin with the production phase. I will investigate the production of specific objects as well as object types through the analytical use of ethnoarchaeology, defined as the study of modern day society based on archaeological research questions (Wendrich 2013: 191).

> It is neither a theory nor a method, but rather a research strategy embodying a range of approaches to understanding the relationships of material culture to culture as a whole, both in the living context and as it enters the archaeological record, and to exploit such understandings in order to inform archaeological concepts and to improve interpretation (David and Kramer 2001: 2).

Although analogy plays a part in this research technique, the aim of ethnoarchaeology is not to observe contemporary cultures in order to draw direct parallels from modern practices to ancient ones. Wendrich (1999:16) defines analogous inference in archaeology as a comparison of two or more entities, ranging from elements of single objects to entire cultures. Analogous reasoning differs from a direct relation and should be done cautiously and within its proper context (Wendrich 2013: 192, after Hodder 1982). Rather than to merely identify situations that can be "'fitted' to the data", the goal of ethnoarchaeology is to reveal patterns in human behavior, environment, cultural identity, and/or social aspects that can be tested against the archaeological data (Tringham 1978 in: Gould 1978: 185; Wendrich 2002).

A common critique of ethnoarchaeological studies is that they often lack explicit theoretical and methodological frameworks (Stark 1993: 96; David and Kramer 2001: 33, 61); however, this does not mean that these publications are atheoretical (David and Kramer 2001:

33). Ethnoarchaeological studies are not always guided by or result in clear-cut theories or models concerning the past. Ethnoarchaeological research results in "interpretive cues, not certainties" (Cazella 2013: 6). By expanding his/her ethnographic background, "the archaeologist can become aware of alternative modes of behavior that would have been difficult to arrive at by logic alone" (Gould 1978: 254).

My ethnoarchaeological study serves two main goals: to identify how the final product might reflect the decisions artisans make while producing glass objects, and to explore possible relationships between glass value and technology. The subjects of this study include contemporary glass workers in Cairo, Egypt, a middleman in Egypt, and glass artists in Hampshire, UK, known as the Roman Glass Makers, who specialize in reproducing Roman vessels using reconstructed Roman methods and technology.

1.3.5 *Chaîne Opératoire*

I employ *chaîne opératoire* (Leroi-Gourhan *et al.* 1974; Lemonnier 1976; Lemonnier 1992) as an analytical framework to investigate the decisions made during the process of production that are informed by higher-level systems of meaning within Egyptian society during the Roman period. There are many choices outside of those dictated by the material properties or constraints of glass, which can reveal shared notions and values within a society.

My approach to studying material culture aims to intimate what Dobres refers to as "the social artifice and interpersonal relations of production by which they were made, used and given value" (2000:13). Using *chaîne opératoire* as a conceptual framework, one can explore the relationship between the physical and social behavior of the artisan and the life of the object created (Dobres 2000:7). As an analytic method, *chaîne opératoire* can assist in the

understanding of social agency underwriting the series of physical actions and choices comprising the entire production process. Technical processes involve "strategic moments" and "variants". By investigating the social control of "strategic moments" and "variants" comprising technical processes, the connectivity of technical and social phenomena can be revealed (Lemonnier 1976: 143-144; 1986: 155).

> As both an analytic methodology and a conceptual framework then, the study of sequential operational gestures, procedures, and judgments can bring to light material patterns capable of informing on social relations of production, meaningful interaction, and an agentive and embodied being-in-the-world that is the heart soul of ancient technological practice (Dobres 2000:7).

Chaîne opératoire accounts for the sequence of steps during the production of artifacts and also the relation between each of these steps and the conceptual framework guiding the decisions and actions of the artisan (Read 2007: 30). However, since fabrication of a single artifact can take place in stages at different and perhaps distant locales, the study of glass production is often complicated (Schiffer 1975). For example, colorizers can be added at a second time and location after the glass has already been made in one location. Ingots of glass could be transported to other locations, and these could be remelted to add colorizers, opacifiers, and other additives. Recycled glass (cullet) can also be remelted with a new batch of raw glass. Although some decorative techniques such as faceting, can only be done after the object has fully annealed, or slowly cooled down, other decorative techniques (e.g. trails of color, indentations, and applied decoration) can occur at various phases of production. Therefore, the employment of *chaîne opératoire* as a research method is crucial in identifying the possible choices one may have made during certain stages of the production process.

1.4 Classification of Karanis Glass: Theory and Methods

With explicit research questions in mind, classification enables the testing of hypotheses, which breeds new questions while continuously developing an explanatory narrative (Wendrich 1999: 11). Composing a typology is essential to exploring my research questions concerning value because "value is inherently contrastive" and "implies comparison" (Graeber 2001: 70, 42). Therefore, the value of one object can only be understood in relation to that of another. A typology, when composed using the appropriate analytical methods, can reveal how the society in which the object was embedded distinguished one object type from another.

A classification system should not be merely an imposed order, but instead, it should reflect the decisions artisans made during the manufacture and production of artifacts "using shared conceptualizations" (Read 2007: 11). Therefore, the *chaîne opératoire* of glass manufacturing, assembled from literature and my ethnoarchaeological research in Egypt and the UK, serves as the foundation for my typology of Karanis glass. The aim of a typology is to reveal through analytical methods the patterning imposed on archaeological material by the makers and users (Read 2007: 22). If one merely prescribes a classification system for an assemblage according to their own cultural biases or agenda, any patterns recognized would not be relevant to the society in question.

The analytical methods I employ to identify culturally salient types of Karanis glass are modeled after those in Read's publication, *Artifact Classification: A conceptual and methodological approach* (2007). Read stresses that composing a typology not only requires appropriate analytical methods, but also the "understanding of how the social and cultural context of artifact production frames and shapes the patterning arising when raw material is transformed into material objects by artisans who are part of a cultural and social system" (2007:

34-35). Culture cannot be equated to artifacts; rather, objects result from "culturally conditioned behavior" (Rouse 1939). And since culture is not one-dimensional (D'Andrade 2001; Leaf 2004), multiple cultural dimensions will dictate the relationship between culture and artifacts (Read 2007: 35).

This also means that each cultural dimension can form the foundation of a typology, and that the confluence of these typologies will help define new ways of characterizing types (Read 2007: 35). Therefore, multiple classifications of the same archaeological material can be valid (Brew 1946; Hill and Evans 1972), as long as they are modeled by the processes underlying the patterning in the data (Read 2007: 35). Culturally salient types relevant to the research question can only be defined by selecting the proper dimensions and analytical methods to create the classification.

Prior to dividing a corpus into types, it is ideal to have a well-defined data set. This means that outliers and objects irrelevant to the underlying process should be identified and removed prior to analysis in order to reveal dimensional patterning (Read 2007: 37; 2015). Otherwise, heterogeneous data may traverse different processes and obscure or hide patterning (Read 2007: 37; 2015). The initial step of forming a classification system, then, should involve homogenizing the data set by evaluating qualitative dimensions. Then one can establish patterning through quantitative variables. "Topological distinctions provide the broadest qualitative distinctions, followed by geometric distinctions, then bifurcated quantitative dimensions...and finally by qualitative distinctions based on nominalized metric dimensions--metric dimensions with a bi-or multimodal distribution (Read 2007: 38-39).

The first dimension on which I evaluate all objects is the fabric, as determined by chemical analysis. As mentioned, this represents the selection of raw materials, one of the

earliest stages of the *chaîne opératoire* of glass manufacturing. Once I identify fabric types primarily through quantitative analysis to establish compositional groups, these groups then become qualitative distinctions upon which I separate the glass corpus. I then continue to evaluate objects by additional dimensions in order of the sequence of decisions outlined in the *chaîne opératoire* of glass manufacturing.

I employ simple statistics, including frequency histograms and biplots, rather than multivariate statistics to conduct quantitative analysis of dimensions. Read (2007) cautions against the use of multivariate statistical methods, as the inclusion of irrelevant variables can hide the structure present in other variables if all variables are analyzed together, resulting in incorrect groupings. Furthermore, there are no statistical means to evaluate the veracity of results from methods such as cluster analysis (Read 2007). Detailed descriptions of Read's (2007; 2015) statistical methods I employ are in Chapters 3 and 4.

1.5 Concluding Remarks

Because value is inherently contrastive (Graeber 2001:70), the value of an object cannot be quantified and can only be understood in relation to that of another. By employing three main approaches--object biographies, archaeological context, and life history of Karanis glass--I identify glass types and compare their production, use, re-use, and discard. Through analytical methods such as ethnoarchaeology, *chaîne opératoire*, chemical analysis, and statistical methods, I compose multiple typologies of Karanis glass, which form the foundation for this study of value. By accounting for the social agency underwriting the actions and behaviors involved in glass production as well as the various stages in an object's life, I expose the interplay between objects and social phenomena.

Chapter 2

Historic and Archaeological Background

2.1 Karanis Background

The history of Karanis stretches over seven centuries, starting from around 250 BCE to the 6th century CE (Pollard 1998; Gupta-agarwal 2011, 2015). Karanis, known by its Arabic name as Kom Aushim, was built on a ridge rising approximately 12 meters above the surrounding plain. It was one of many towns established during the reign of Ptolemy II Philadelphus (285-247 BCE) in the Arsinoite nome of the Fayum (see Figure 2-1 below) (Wilfong 1999). The Fayum basin's fertile land encouraged the founding of several towns during the Greco-Roman Period where Greek mercenaries could settle and exploit these resources (Bagnall and Rathbone 2004; Wilfong 1999).

The Fayum region is a fertile lake district. Lake Moeris (modern name Birket el-Qarun) was fed by a branch of the Nile and fluctuated greatly due to Nile inundation levels. Engineers during the reign of Ptolemy I and II (310-350 CE) constructed a new and elaborate irrigation system and modified the Lahun dyke to help control the flooding of the Fayum and to reduce the water level of Lake Moeris (Bagnall and Rathbone 2004). This resulted in approximately three times the amount of cultivable area. Since the agricultural productivity of the region was dependent on these water systems, there were fluctuating periods of agricultural efficiency depending on the government's ability to maintain the irrigation system (Cook 2011; Gazda 2004).

Figure 2-1. Satellite image of Egypt showing location of Fayum and Karanis (Google Earth Images: 2015)



Wheat and olives were the main crops of Karanis, used to finance the allegiance of cities around the eastern Mediterranean to the Ptolemies. Local officials would ensure the security and transport of grain from Karanis to Alexandria on behalf of the imperial government, where it was stored and then shipped to Rome (Husselman 1952: 69-70). In the late first century, grain from Egypt supplied four-months of food to the city of Rome (Rickman 1980).

The Fayum experienced agricultural decline by the late Ptolemaic period, but was revived once Egypt was incorporated into the Roman Empire in 32 BC. Octavian's army restored the

canals and rebuilt the dikes (Gazda 2004). Karanis once again flourished and expanded the settlement towards the north (Boak 1933). The population at Karanis is projected to have been at least 4000 at its peak, but could have been up to three times larger. Karanis, like other regions of the empire, experienced significant recessions in the late second century and again in the later part of the third (Bagnall and Rathbone 2004: 131) The town was widely expanded during the fourth century, however, and managed to survive into the 6th century (Barnard *et al.* in press; Gupta-agarwal 2011, 2015).

2.2 Karanis Excavation History

The first excavations were carried out not by archaeologists, but rather, *sebbakhin*, usually farmers who removed *sebbakh* from various sites to use as fertilizer for agricultural purposes. The term *sebbakh* in Arabic refers to decomposed organic debris rich in nitrogen, and this resource was plentiful at Karanis. The systematic removal of sebbakh from ancient sites in Egypt was a common practice in the late nineteenth and early twentieth century. They even used a railway system to cart 200 m^3 of sebbakh a day out of the ancient town (Barnard *et al.* in press). As a result of their destructive activity, there is a huge gap in the middle of the town, leaving an incomplete picture of the layout, social demographics, and production sites at Karanis.

As the Sebbakhin worked, several valuable artifacts were removed and sold on the black market. Two major papyrus discoveries in the 1870s and 1880s increased the public awareness of the potential archaeological significance of the Fayum region (Wilfong 1999). Two English scholars, Bernard Pyne Grenfell (1869-1926), Arthur Surridge Hunt (1871-1934), and David Hogarth (1862-1927) arrived in 1895 and began the first archaeological investigation of the site. Unfortunately, they were not concerned with systematically recovering and recording

archaeological remains in detail like their contemporary, Sir Flinders Petrie (1853-1942); rather, they were primarily interested in finding and collecting papyri. Petrie visited Karanis in 1890, but did not do any significant work there (Husselman 1979).

Francis W. Kelsey (1858-1927) in 1920 was the next scholar to excavate Karanis after Grenfell, Hunt, and Hogarth. He also was motivated to collect papyri for the University of Michigan, where he was a professor of Latin Language and Literature. The University of Michigan began their excavation in 1924, directed first by James Starkey. Arthur Boak and Enoch Peterson continued the excavations from 1926-1934 and published a topographical and architectural report from the 1924-28 excavations (1931). Husselman later published a summary of the topography and architecture of the site based on the 1928-35 excavations (1979).

The team hoped to reconstruct the daily life environment of the Greco-Roman period and to focus on context and culture. They still managed to recover and preserve thousands of artifacts, 46,514 of which the Egyptian Department of Antiquities allocated to the University of Michigan and are now housed at the Kelsey Museum in Ann Arbor (Encina 2014). In addition, the University was allocated approximately 2,500 fragments of papyri, now part of the University of Michigan Papyrology Collection (Hyatt 2014). The remainder of artifacts recovered from the University of Michigan excavations was divided among the Egyptian Museum in Cairo, the Graeco-Roman Museum in Alexandria, and the Agricultural Museum in Dokki (Barnard *et al.* in press).

The University of Michigan's excavation methods and recording techniques, although advanced for the time, are not considered sufficient by today's standards. Boak and Peterson's team set up a grid, subdividing seven main areas of the town into a grid of 35 m squares (Boak and Peterson 1931). They seemed to have neglected the northeast and southwest portions of the

town, outside the main city center, as these areas are not sufficiently documented in their reports or plans (Barnard *et al.* in press). In the first few seasons, they divided the site into seven main areas (A-G) and excavated occupation layers according to a numbering system. Most recent (top level) layers were numbered 4000 and upward (100 and upward for Area B), second levels 5000 and upward, surface finds were designated as "X", and objects found below the surface but unconnected with any occupation layer were designated a number from 1 to 99. During the 1926-27 season, Boak and Peterson adopted a new numbering system for occupation levels in which the most recent levels were labelled "A period", followed by earlier layers called, "B period", "C period", and so on. Thus six occupation levels (A-F) were established, each structure was subdivided by room, and those were excavated separately according to occupation layers. In their new numbering system, Boak and Peterson also made distinctions between houses, open areas, and streets (1931; Harden 1936: 2-3).

During excavation, there were complications in determining the stratigraphy of the site. It was common practice in ancient villages to dispose of waste not only in abandoned houses but also in the streets. Therefore, there was a buildup of deposition over time and the street level continuously rose due to these discard habits as well as sand accumulation (Bagnall and Rathbone 2004). It was often necessary for people to abandon what used to be their ground-level floor and utilize it as a cellar instead.

In addition, the large gap in the middle of the site caused further difficulties in matching stratigraphic layers of occupation throughout the entire town. For instance, B layers in the north may not match up in occupation dates with the B layers in the south. Interpreting Michigan's stratigraphic assessments is further complicated by their use of two different numbering systems for the houses over their six years of excavation. The maps are exceedingly difficult to interpret

and to understand how they relate to one another. As a way to better understand what was actually represented in the Michigan reports, UCLA began a Karanis 3-D Virtual Reality Model project. The 3-D Virtual Reality model of the town shows occupation layers throughout the site by integrating all the Michigan maps (Cappers *et al.* 2013).

A joint project (1972-1975) between Cairo University and the Institut Français d'Archéologie Orientale (IFAO) was directed initially by A.A. Ali and then by S.A.A. El-Nassery. They worked primarily in the northwestern portion of Karanis, focusing on the decorated bath house and reported their work in two publications (El-Nassery and Wagner 1975; El-Nassery *et al.* 1976). Both expeditions, University of Michigan and the Cairo University/IFAO project, neglected to backfill after excavation, resulting in drastic degradation of the site due to erosion and exposure to the elements. They also left several large mounds of spoil, which still covers many areas of the site and blocks Karanis West and Karanis East from the original center of the site (Barnard *et al.* in press).

The URU (University of California Los Angeles, the Rijksuniversiteit Groningen (RUG, the Netherlands), and the University of Auckland) Project began in 2005 and continues to the present. The URU Project extends to other areas of the Fayum and is under the direction of Dr. Willeke Wendrich, Rene Cappers, and Simon Holdaway. In addition to extensive survey and excavation of Karanis, focus is also given to site conservation and to the restoration of the University of Michigan and Cairo University dig-house as a visitor's center. Archaeobotanical studies, as well as mud brick, canal, geological, and architectural surveys have also been conducted. A comprehensive survey of the entire site was conducted 2007-2011 utilizing a Topcon GTS-235W total station and a Trimble ProXRT DGPS receiver (Barnard *et al.* in press).

URU excavation techniques are more refined than that of previous expeditions at Karanis. The project uses a registrations system which is based on the Museum of London Archaeological Service (MOLAS) *Archaeological Site Manual* (1994). Trenches are excavated by stratigraphic unit and the relative sequence of events are recorded in the form of a Harris matrix. Dating of stratigraphic layers are determined by dating of pottery (as determined by Sonali Gupta-agarwal) and/or by C-14 dating of organic material present in the layers. All stratigraphic layers are drawn and recorded and plans are georeferenced and incorporated into the recent topographic and architectural survey plans (referenced above). Therefore, the context (relative sequence, date, and geographic location) has been carefully recorded. In East Karanis (KAE), recent excavations also employed total stations for the mapping and recording of stratigraphic units. Otherwise, plans were hand-drawn. Thirty-four trenches in total have been excavated at Karanis, some of which are ongoing, such as the trenches in Area G of the site (KAG) (see Chapter 7 for summary of site areas and trenches).

2.3 Ancient Glass

Prior to the invention of glass blowing, the glass industry in western Asia and Egypt had been well-established for almost 1,500 years, and had existed for close to 700 years in the eastern and central Mediterranean (Harden *et al.* 1987: 2). Glass was invented in the middle of the third millennium BCE in the region of modern Iraq and northern Syria (Tatton-Brown and Andrews 1991). According to Pliny the Elder, the discovery of glass occurred in the region of modern Syria along the shores of the Belus River:

> The story is, that a ship, laden with nitre (natron), being moored upon this spot, the merchants, while preparing their repast upon the sea-shore, finding no stones at hand for supporting their cauldrons, employed for the purpose some lumps of nitre which they had taken from the vessel. Upon its being subjected to the action of the fire, in combination

> with the sand of the sea-shore, they beheld transparent streams flowing forth of a liquid hitherto unknown: this, it is said, was the origin of glass (*Naturalis Historia*, Book 36, Ch. 65, trans. Bostock and Riley, 1855).

Soon after the discovery of glass, this technology spread to Egypt, presumably through Tuthmosis III's (1505-1450 BCE) conquest of this region (Tatton-Brown and Andrews 1991). Several techniques were employed to produce glass objects prior to the invention of glass blowing: core-forming, casting, grinding, and cold-cutting. Other techniques for decoration had also been developed. Such as trailing and cutting circular rods to make mosaic designs (Harden *et al.* 1987: 2). Core-forming was the earliest method of making glass vessels. There are also early examples of Egyptian vessels cast in molds dating to the 18th Dynasty, including a glass clam shell (British Museum Acc. 65774) and mosaic glass from el-Amarna (Brooklyn Museum Acc. 48.162) (Tatton-Brown and Andrews 1991:34-5). These techniques became more common by about the mid-second century BCE, when the Hellenistic glass industry was well established and prolific. "Cast" vessels, such as hemispheric bowls and dishes were produced and widely exported for almost a century (Tatton-Brown and Andrews 1991: 52-54). This technique involved slumping a flat disk of glass over a clay mold to form the vessel, whose surface would later be ground and polished. Mosaic glass is made by fusing rods of several colors of glass together, cutting them into small pellets once cold, and then fused them together to form a mosaic pattern (Tatton-Brown and Andrews 1991).

In the hundred or so years leading up to the invention of glass blowing (late second and early first centuries BCE), colorless glass was increasingly used for core-formed and cast vessels, as well as for handles and trailing. This clearer glass is more suitable for blowing delicate, clear vessels and was more commonly used by the earliest glass blowers to create blown vessels (Harden *et al.* 1987: 89). The late Hellenistic glass industry in Italy yielded many mosaic dishes and bowls, opaque and translucent monochrome vessels of various shapes – unguentaria,

bowls, dishes, jugs, bottles, and lidded boxes -- which continued to be produced during the early first century CE along with the earliest blown vessels and other monochrome table wares (Harden *et al.* 1987: 90). The level of expansion of the glass industry during the Hellenistic Period suggests that there may be other driving forces besides the invention of glass blowing which led to the scale of glass production known during the Roman Period (Larson, March 2014, Personal Communication). However, the impact this technological innovation had on the glass industry as a whole cannot be disputed.

Glass blowing was invented around the middle of the first century BC, somewhere on the eastern shore of the Mediterranean. Archaeological evidence of this important technological innovation includes a blown glass bottle in a Jewish cave-tomb from the site of Ein Gedi on the western shore of the Dead Sea, dating to the late second to first centuries BC) (Barag 1981; Avigad 1962: 183: Mazar and Dunayevsky 1964: 128).

Evidence from Jerusalem suggests that the invention of the blow pipe stemmed out of a previous innovation: the blowing of hollow tubes of glass after closing one end (Israeli 1991). In the Jewish Quarter of the Old City, a refuse heap from a glass workshop was found. The refuse included several glass tubes, some of which ended in drop-shaped oval bulbs (apparently "tub-blown"). Fragments of unquentaria (presumably made with a blow-pipe), glass waste products, and cullet were also found (Avigad 1972; Israeli 1991; Liardet 2011).

The technology of glass blowing began later in the western provinces, sometime during the reign of Augustus (27 BCE-14 CE) (Harden *et al.* 1987: 91; Tatton-Brown 1991). It is not yet evident how quickly the technology spread among eastern provinces. Although the earliest blown glass found in Cyprus, Syria, and Palestine can only be dated as precisely as the first century CE, it is presumed that glass blowing spread to the eastern provinces prior to its spread

to Italy (Harden *et al.* 1987: 91; Tatton-Brown 1991). It is also unclear exactly when mold-blowing was developed, but probably around 25 CE in both the eastern and western provinces (Harden *et al.* 1987:151; Tatton-Brown 1991). Cast vessels continue to dominate until late in the second quarter of the first century CE, when blowing became the primary method of making vessels (Grose 1983: 45; Harden *et al.* 1987: 90). Mold-blown vessels were also very popular at this time with the public of all classes throughout the entire empire (Harden *et al.* 1987: 152). Mold-blown circus cups, for instance, have been found in burials of middle and lower classes, while mold-blown objects signed by Ennion, a glass maker active in the second half of the first century CE, would have been valued higher and available to only the affluent members of society (Harden *et al.* 1987: 152; Tatton-Brown 1991).

Quickly after the invention of glass blowing, glass increased in popularity and the industry grew significantly in merely a few decades. Permanent glass factories were established throughout the Mediterranean and outlying provinces of the Roman Empire within fifty or a hundred years of the invention of glass blowing. Within the first thirty years of glass blowing, many of the techniques still used today had already been developed (Harden *et al.* 1987).

The invention of the blow pipe eventually lead to mass production of glass vessels. This is at least partly due to the fact that free-blown or mold-blown vessels generally take far less time to make than core-formed or cast vessels, and a wider range of forms and sizes can be created. "Thus glass production entered a new era of utility" and glass vessels went from being primarily luxuries consumed by only a small margin of society, to cheaper ordinary wares now available to a broader population (Harden *et al.* 1987). Mass production of glass vessels began in Egypt much later than the invention of glass blowing: the 3rd century and ending in the 5th (Harden 1936; Isings 1957). Consequently, few glass finds from Egypt are dated to the early Roman

Period. This is why Isings asserts, "the most important Egyptian glass finds come from Karanis, from the 2nd century AD onward" (1957:2).

By examining this late Roman (4th-6th centuries CE) glass corpus from Karanis, this study sheds light on this late onset of mass production of glass in Egypt as well as its impact on the value of glass objects.

2.4 Glass Production in Alexandria

In the late 1930s, Karanis had yielded more glass than any other single site in Egypt, including Hawara and Ehnasya, and glass from Karanis accounted for more than half of the Cairo Museum glass collection by the late 1930s. Without primary evidence for glass production at Karanis (glass kilns containing waste products), Harden assumes Karanis glass was produced in Alexandria, a known manufacturing site in Egypt (1936: 39). Textual evidence from Karanis attests to the fact that inhabitants of Karanis purchased at least some of their glass wares from Alexandria. A letter from a son living in Alexandria to his father in Karanis reads,

> Know, father, that I have received the things that you sent me...I thank you because you considered me worthy and have made me free from care. I have sent you, father...sets of glassware, two bowls of quinarius size, a dozen goblets...(P.Mich. inv. 5390, from Youtie and Winter 1951: 32).

The author, Strabo (3 BCE - 22 CE), claimed that during his time, there were two major centers of the glass industry in the eastern Mediterranean: Alexandria, Egypt and Sidon, on the Phoenician coast. Rome was the third major center (Harden *et al.* 1987: 88).

> I heard at Alexandria, from the glassworkers, that there was in Egypt a kind of vitreous earth without which many-colored and costly designs could not be executed, just as elsewhere different countries require different mixtures...(Strabo, *Geography* XVI.2.25, trans. Jones 1954).

Further textual evidence from Athenaeus of Naucratis (late 2nd to early 3rd century CE) attests to Alexandrian glass workshops:

> Athenaeus further says that the men of Alexandria make glass, working it into many varied shapes of cups, and copying the shape of every kind of pottery that is imported among them from everywhere (*The Deipnosophists*, XI.784, trans. Gulick 1980).

Although many scholars infer that Alexandria was an important glassmaking center, Meyer points out that there is still insufficient archaeological evidence to support this notion (1992). Lack of primary and secondary evidence of glass production may be at least partly due to the modern city obstructing or preventing the discovery of glass workshops in Alexandria.[2]

Despite these challenges, at least two primary glass workshops have been discovered near Lake Maryut near Alexandria. The first, was on the southern shore of the lake, excavated by A. de Cosson (de Cosson 1935). The second, was identified by Empereur and Picon at Taposiris Magna on the northern shore of the lake (Empereur and Picon 1998). At Taposiris Magna, glass kilns were found along with ceramic and metal kilns. In Marea, no kiln features were identified, but bricks with glass adhered to them were recovered, suggesting the presence of a primary glass workshop. Nearby, they also found some evidence for a secondary workshop. Chemical analysis of glass recovered from these four primary glass workshops in Egypt indicates that glass found in the western provinces of the Roman Empire differ in composition and most likely are derived from workshops in the Syria-Palestine region, rather than in Egypt (Nenna *et al.* 2000: 105).

At Kom el-Dikka in Alexandria, two glass furnaces were discovered just underneath the floor of Auditorium G, predating the structure, which dates to the Late Roman Period (Majcherek 2007: 33). Excavations in Area F of Kom el-Dikka have also yielded glass objects--

[2] Primary glass workshops are defined as those where raw glass is made, whereas secondary workshops refer to locations where glass is worked into objects, but not made onsite.

stone molds for shaping drawn collared beads, glass tubes, and beads of various shapes finished by hot-working--that suggest a secondary workshop onsite, where beads were manufactured (Kucharczyk 2008: 64). The same kind of workshop may have existed at the Theatre of Diane in Alexandria, based on remains recovered by the Center for Alexandrian Studies (CNRS) (Empereur 1997: Nenna *et al.* 2000: 110). Another primary glass workshop in the Wadi el-Natrun, near Alexandria, has also been discovered (Nenna *et al.* 2003, 2005).

The Alexandrine glass workshops most likely produced the majority of luxury wares in Egypt such as mold-cast, ground and polished, or engraved vessels. According to Strabo, the finest quality glassware in the world was produced in Alexandria and the properties of the glass used allowed the glass-blowers to achieve polychromatic affects that other glass workshops could only do by a blending process (*Geography*, 17.1.1, trans. Jones 1954). Morely generalizes that during the Roman period, a lack of mass demand as well as high costs of transport meant that most goods traded were "high-value, low-bulk luxuries for the wealthy elite and their dependents" (2007: 4).

Apparently, Alexandrian workshops also produced ordinary wares: thin, colorless, plain-blown bowls, beakers, and flasks (Harden 1936:40; Harden 1969: 47-48). They manufactured utilitarian green glass items like unguentaria, which may have been used as containers for oil-based perfumes and bath oils produced in Alexandria. Although Egypt probably only exported the luxury glass items, some ordinary wares serving as containers for perfumes and other liquids may also have been traded (Isings 1957: 3).

It is likely that Alexandria was a main glass manufacturing center, as it was an important manufacturing center of many products during the Roman Empire. While some goods arriving from the Red Sea trade were used in Alexandria to manufacture other products, many products

produced in Alexandria were exported through the Red Sea trade or Mediterranean trade (Young 2001). Because of its advantageous geographical location and nearby natural resources, Alexandria was a center for maritime trade with the Mediterranean and was also linked strongly to the Red Sea trade through the entrepot of Coptos (Bowman 1986). The port of Alexandria was where the goods of the Red Sea trade were brought after their travel down the Nile from Coptos (Young 2001).

> ...the trade, not merely of islands, ports, a few straits and isthmuses, but of practically the whole world is yours. For Alexandria is situated, as it were, at the crossroads of the whole world, of even its most remote nations, as if it were a market serving a single city, bringing together all men into one place, displaying them to one another and, as far as possible, making them of the same race (*encomium of Dio of Prusa*, OR.32.36 in: Bowman 1986: 218).

Once the goods reached Alexandria, they were kept in public warehouses so that the government could draw its 25 percent tax, the tetarte (*P.Vindob*. G 40822 in: Young 2001), a key marker of luxury products. Alexandria thus became an important center for eastern luxury trade (Young 2001). Meyer points out that not all the export goods were produced in Alexandria; the items traded also varied from year to year and throughout time as availability and preferences changed (1992).

According to the main literary source for trade with the East written around the second half of the first century AD, the *Periplus Maris Erythraei*, glass manufactured in Egypt was a common export to the East (*Periplus* 6-7 in: Young 2001; Bowman 1986). Glass was also exported from Egypt into Italy and other areas of the West (Harden 1936: 44). Export of glass must have been considerable, since Emperor Aurelian imposed a tax on it (*S.H.A. Vita Aurelianus* XLV1), which Constantine later remitted (*Codex Theod*. 13, 4, 2) (Isings 1957:2; Wallace 1969).

During the first and second centuries, exports of fine glassware from Alexandria into the western provinces of the Roman Empire was common: to Italy, south Gaul, Britain, and Rhineland (Harden 1936:45). These exports dissipated in later periods, except for the cylindrical jugs and bottles with scratched decoration (Harden 1936: 45). Most of the exports from Alexandrian workshops to western provinces occurred via Syria and not direct. Since most of the glass from Karanis is utilitarian, or "ordinary wares", they are not among the types that would have been exported from Egypt to other provinces (Isings 1957).

There is no evidence that eastern provinces imported glass from the West (Harden 1936: 44). Therefore, any imports (meaning objects manufactured outside Egypt) found in the Karanis assemblage most likely came from eastern provinces. Harden asserts that if glass was imported into Egypt from other provinces, it was most likely for the contents of the vessel (liquids and unguents), rather than for the glass containers themselves (1936).

Even when the western glass workshops were capable of producing a sufficient number of luxury and utilitarian wares for the whole western market, "the eastern glass-works retained to the end of the Roman period, at least in part, that ascendancy in glass production which was so marked a feature of their earlier days (Harden 1936: 46). Harden attributes this to the western factories still depending on the eastern ones for ideas and perhaps even their personnel (1936: 46).

2.5 Other Glass Production Evidence in Egypt

At least two primary glass workshops have been identified in the region of the Wadi el-Natrun (Nenna *et al.* 2000, 2003). The Wadi el-Natrun is a depression, areas of which are below sea level, located between Cairo and Alexandria. A series of lakes in the Wadi el-Natrun are rich

in salt and natron, resources that were exploited throughout antiquity (Nenna *et al.* 2000: 99). Natron is the primary fluxing agent for glass made during the Roman Period. At the site of Beni Salama in the Wadi el-Natrun, remains of glass furnaces have been discovered, which were destroyed in antiquity after each glass batch was made. The glass batch cooled in a basin of the kiln and was broken into blocks to be transported to secondary glass workshops (Nenna *et al.* 2000: 99).

The site of Zakik, also in the Wadi el-Natrun, has yielded the same type of furnace remains as those of Beni Salama, as well as some evidence of secondary glass workshops, such as deformed glass fragments, and wasters. The glass found at the site appeared to have the same color and qualities of the glass found at Beni Salama. A few Zakik samples were analyzed, and appeared to be decolorized with manganese (Nenna *et al.* 2000: 102).

2.6 Local Origin of Karanis Glass?

Much of the glass found at Karanis could have been made locally, but no primary evidence of this (glass kilns) have been found. It is possible that glass kilns were located at the center of the site, which has been completely destroyed by sebbakhin activity. Most industrial activity, such as pottery and glass working, occurred on the outskirts of towns rather than in the center to avoid exposing inhabitants of the city to high levels of pollution (Fischer 2008?). Even historically in Cairo, permits to operate glass workshops were only allowed outside the main city boundaries (see below for further history of modern glass workshops in Egypt).

If not locally made, Karanis glass could have been made in the Fayum region, perhaps at Oxyrhynchus. This papyrus from the site references glass workers:

> (1st hand) In the consulship of our masters Constantinus Augustus for the seventh time and Constantinus the most illustrious Caesar for the first time. To Flavious Leucadius logistes of the Oxyrhynchite nome from the guild of glass-workers of the glorious and most glorious city of the Oxyrhynchites through me, Aurelius Zoilus....In response to your demand for an account of all the matters affecting our profession relating to the service of fitting out the warm baths in the public bath of the city, I have perforce drawn it up and submit it in order that your grace may be able to know. It is: for the work needed on the warm baths, x hundred pounds; for the work needed on the gymnasium, x hundred pounds; at a rate of 22 talents per hundred pounds. Total 6000 pounds, total 1320 talents. Which we accordingly report. In the aforementioned consulship, Epeiph...(2nd hand) I, Aureliius Zoilus, have presented this as set out above (Declaration by Glassworkers, *Collectanea Papyrologica* Part II, No. 81.3 1B.77/B(3)b. June/July AD 326, from Bowman *et al.* 1977).

The exact job the guild of glass workers was hired to carry out at the public bath is not clear from this text. However, given their needed expertise in building high temperature kilns, they were perhaps employed to help design, build, and/or maintain the furnace for the warm baths (Nicholson, April 2014, personal communication). The fact that there are several glass workers (forming a "guild" or union) suggests Oxyrhynchus may have had its own glass workshop. This most likely would have been a secondary manufacturing site, rather than glass making workshop, as there were most likely only a few glass making sites in the Roman Empire, given the homogeneity of Roman glass compositions (Foy *et al.* 2000; Freestone *et al.* 2000; Paynter 2006; Nenna 2007).

Further evidence of glass workers at Oxyrhynchus include the following description:

> And the crystal, as it tasted the heat of the fire, was softened by the strokes of Hephaistos like...He [the glassblower] blew in from his mouth a quick breath...like a man essaying the most delightful art of the flute...The glass received the force of his breath and became swollen out around itself like a sphere before it. It would receive another onslaught of the divine breath, for often swinging like an ox herd his crook he would breathe into...(Oxyrhynchus Papyrus 3536, Bowman 1983).

2.7 The Karanis Glass Assemblage

Donald B. Harden catalogued, classified, and published (1936) glass from the University of Michigan excavations at Karanis (1924-29). He examined over 150 complete vessels, several fragmented ones whose shape could be reconstructed, along with thousands of small fragments.

Harden's Karanis publication rapidly became a standard work. Revisiting the Karanis glass is imperative, however, not only because recent excavations provide better defined contexts and more secure dating of cultural material, but also because different research questions can be explored. Hayes critiques that the dating for Karanis finds is "open to question," as most of the "late" fabrics, which Harden dated to the fourth or early fifth century, were found in context with African Red Slip Ware (Late Roman B), which are dated elsewhere to the late fifth- to early sixth-century AD (1975: 2). The glass was dated according to the overall dates given to occupation levels of the site as determined by mainly coins and papyri. Hayes (1975) critiques that no coins were actually present in context with Karanis glass groups, or even in levels that had direct stratigraphic relationships to them; therefore, pottery dating will be the most accurate means for dating stratigraphic layers in which glass is found. Even Harden (1936: 24-25) acknowledges the inability to attribute definitive dates to finds, as he states that it is "only possible to make tentative suggestions as to the relative and absolute dates of any given series" of artifacts, given the challenges of establishing the sequence of stratigraphic layers (as mentioned above).

Harden also disagrees with the dates ascribed to 5000 and C-Period houses in the topographical and architectural report (see section 2.1.2) (Boak and Peterson 1931). Harden suspects them to have been dated too early (see Table 2-1). Boak and Peterson date the 5000 houses to the mid-first to early third century, and the C-Period houses to the early second to early

third century (1931). Harden, on the other hand, thinks that they are no earlier than 200 AD, and that their most common date is the first half of the third century. His assessment is based on the majority of papyri and ostraca found in these houses, which date to the third century (not second) as well as his general impressions of the stratification and architecture of these buildings (Harden 1936: 32). He explained the few examples of second-century papyri as safe-deposit documents kept over a long period of time. Similarly, he points out that the dating of glass artifacts presents additional challenges, since high-valued glass objects were often kept over long periods of time as heirlooms and are thus found in later contexts. Harden also asserts that at the time of publication, few glass finds from other sites in Egypt could be dated accurately and used as reference (1936: 33-34).

Table 2-1. Dating of Karanis houses excavated by University of Michigan (Harden 1936)

Excavation Date	Provenance	Date of House (Boak and Peterson 1931)	Date of House (Harden 1936)
1926-27	Houses B I – B25	early second to early third century	
1924-26	5000 Houses	mid-first to early third	late second to early third century
1927-29	C-Period Houses	early second to mid-third century	late second to mid-third century
1926-27	Houses B 26-B 59	late third to early fourth century	
1927-29	B-period Houses	mid-third to mid-fourth century	
1924-26	100 and 4000 Houses	fourth and fifth century	
1926-29	A-Period Houses	mid-fourth to mid-fifth century	

The latest date of occupation of the Karanis is debatable, but recent pottery analysis by Gupta-agarwal (2011, 2015) supports Pollard's (1998) assessment that the site was occupied well into the 6th century AD. Harden, however, asserts that there was little occupation after 400 AD, and no evidence for any occupation after 460 AD (1936: 33). So according to Harden, the date range of all glass found at Karanis is from 100 AD to the fifth century. No glass objects date earlier to 100 AD, so this corpus does not span the immediate time period following the invention of glass blowing around 50 BCE. This revolutionary change in technology was not solely responsible for mass production of glass objects, however. Political and economic forces also affected the glass industry. For instance, a remission of tax on glass workers by Constantine

(306-307) around the turn of the third and fourth centuries may have sparked mass production of glass products made with lower quality glass. Harden reports that vessels made from lower quality glass fabrics comprise the majority of glass objects found in large hoards at Karanis dating around the time of this tax remission (1936),

Other scholars besides Harden have also published on Karanis glass. While the IFAO/Cairo University expedition was exploring the furnace and area adjacent to the northern Roman bath of Karanis, they discovered what El-Nassery refers to as a "glass shop" a few feet from the southern boundary of the bath (1976: 232). There is no further description of this structure in the 1976 publication of these excavations. El-Nassery suggests that the area adjacent to the furnace of the northern bath was used in later periods as a "small factory of glass wares", and that the lower portion of the furnace was used as a kiln to fire terracottas (1976: 232). The only evidence mentioned to support these theories was the presence of terracottas and "glass knead" found near the furnace and nearby courtyard (El-Nassery 1976: 232).

Both Elizabeth Higashi and Robert Brill conducted chemical analysis of Karanis glass. Higashi conducted her research exclusively on conical vessels from the University of Michigan Karanis glass collection at the Kelsey Museum. She employed neutron activation analysis to further investigate fabric types as outlined by Harden (See Ch. 3) (Higashi 1990).

Brill conducted chemical analysis of surface finds from Karanis apart from the material previously evaluated by Harden (personal communication, November, 2010). These surface finds lack meaningful archaeological context, but offer valuable insight into the chemical composition of Karanis glass. The results are published in Chemical Analysis of Early Glasses (Brill 1999).

I evaluated Karanis glass from the Kelsey Museum of Archaeology as a reference collection. The author studied almost all objects analyzed and published by Harden to better understand his evaluations and criteria for determining fabric, morphology, and techniques. In addition, I measured and examined bowls from this collection to determine whether Harden's separation of bowls into shallow and deep categories should be maintained in the new classification of Karanis glass for this study (See Chapter 4).

In addition, thirty-five Karanis glass samples from the Kelsey museum were analyzed with pXRF in 2011. I emphasized the analysis of colorless glass, but most glass types were represented in this sample population[3]. Three of these same glass samples were chosen for electron microprobe analysis as well as one additional aqua-colored glass sample (see Chapter 3).

2.8 URU Fayum Project

The URU Project has recovered several thousand small glass fragments over ten seasons of excavation at Karanis thus far (2005-2014). I evaluated glass from seasons 2006-2010. All glass recovered from a given unit in a trench was bagged daily and given one registration number. All potentially diagnostic sherds recovered in 2006-2010 were given specialist identification numbers and bagged and labeled separately. Only a few small vessels were nearly whole; otherwise, the recently excavated material from Karanis is highly fragmentary. Many of these fragments are too small to determine the form of the original vessel. A random sample of these diagnostic sherds was chosen for portable X-ray fluorescence spectrometry (pXRF) analysis (see Chapter 3). Approximately 721 samples were analyzed over two excavation

[3] A few fabric types may not be represented in this sample population due to invalid spectral data.

seasons (2009 and 2010). To ensure the integrity and compatibility of the data, only 2010 data were used for the final quantitative analysis of pXRF results (n=464). All 721 samples were evaluated, photographed, drawn and/or sketched, and recorded in a database, created in Microsoft Access. The following criteria were recorded for each sample: maximum length, maximum width, maximum thickness, provenience, excavation year, registration ID, fabric type (according to Harden's criteria), morphological type (according to Harden's criteria), rim, base, handle, type (my own numbering system), color, decoration type, decoration color, portion(s) of vessel preserved, percentage of base or rim preserved (if applicable), parallels (in Harden's publication or elsewhere), estimated date of stratigraphic unit in which object was found, pXRF notes, and general notes. All analysis, drawings and sketches were done by the author. Photographs were taken by the author, the project photographers (Seppi Lehner, Christina Long, Jason Quinlan), and team members Rebecca Phillipps, and Joshua Emmitt.

Chapter 3

Background of Present Day Glass Workers

3.1 Introduction

In this section, I study modern glass workers in Cairo and in the UK to help identify the *chaîne opératoire* of manufacturing glass vessels. I also investigate how the use of recycled glass affects the production process as well as the final products, and how these glass objects are valued by their producers and consumers. I first visited Workshop 1 below in 2009. In 2010, Paul Nicholson and I conducted the bulk of our study, interviewing and observing artisans and documenting the manufacturing of several different vessel types with photography and video. In addition, I conducted follow-up interviews with both workshops in 2012 and interviewed a middleman who exports and sells glass products from Egypt.

This chapter includes background information about the subjects of this study. Including the geographic and cultural context of these subjects is important in understanding the ways in which they may serve as analogs to ancient glass workers. This background also assists in the interpretation of information gained by subjects and their behaviors.

3.2 Cairene Glass Workers

The geographic proximity of Cairene glass workers to Karanis does not, of course, imply a continuous line of tradition from ancient Roman times to that of the present. Societies continuously change, a process by which ideas, practices, and traditions are constantly redefined (Wendrich 2002: 8). However, these glass workers are suitable subjects for this ethnographic

study for two main reasons: they use traditional kilns and methods of production and they manufacture their products using recycled glass.

Since the glass making and working by traditional (i.e. non-mechanized) methods is now rare, ethnographic research of these workshops is essential (Nicholson 2002: 105). Despite changes in fuel, glass workshop owners claim to use the same kiln construction since the founding of their workshops over 100 years ago. Previous ethnographic studies of Cairene glass workshops all focus on what is referred to as Workshop 1 in the current study. Nessim Henein and Jean-Francois Gout (1974) studied this workshop in 1972. Alysia Fischer (2008) later conducted an ethnoarchaeological study of Workshop 1 in 1996. Paul Nicholson and Caroline Jackson also studied Workshop 1 in the late 1990s (n.p.).

Investigating the entire glass production process using the *chaîne opératoire* approach enables a better understanding of what the Roman procedure may have entailed, considering the traditional kilns of Cairene glass workshops provide a better analog to Roman kilns than an industrial glass bottle making factory, for instance (Wendrich 2013: 192).

Furthermore, economic factors, such as costs, distribution, and value, can be examined by studying the changes in the industry and its market over time in the present day workshop. There is archaeometric evidence from glass found in the northwestern provinces suggesting glass recycling was a common practice, especially during the Late Roman Period (Degryse *et al.* 2006; Foster and Jackson 2009, 2010; Huisman *et al.* 2009; Jackson 1996, 2005; Jackson and Foster 2014). Since modern Cairene workshops use recycled glass cullet to produce new glass objects, they offer unique insight into the glass industry during the Roman Period. Studying the effect recycling has on the properties and quality of their finished products aids in the identification of possible recycled glass products from the Roman Period.

Knowing the history and background of each workshop and the middleman is essential to understanding the cultural, social, and economic context of these Cairene glass workers. To preserve the anonymity of the interviewees, the workshops in this study will be referred to as Workshop 1 and Workshop 2. The names of the interviewees are pseudonyms.

3.2.1 Workshop 1

Location: near Bab el-Futuh

Participants:

Ahmed and Abdullah --shop owners, Mahmoud-- friend and owner of shop in Zamalek

Scale:

They have no functioning kiln at Bab el-Futuh, the area where most of the glass workers are based, but they claim to have a large factory in Giza (location unknown, approximately 3 glass workers at this location)

Products:

Lamps, tableware, candle holders, beads, vases, borosilicate glass (*Pyrex*) figurines, Christmas ornaments

History:

Ahmed and his son, Abdullah, own a glass shop near Bab el-Futuh that they say has been in their family for over 150 years. They proudly showed me several publications about their workshop. They framed and displayed some of them on the walls of their shop, while they kept other publications within reach to show tourists and other customers who visit the actual workshop. Most articles featured Ahmed, the owner of the shop.

Ahmed's father, grandfather, and uncle were all glass blowers and when his father died about 34 years ago, Ahmed took over the family business. Ahmed and his brother worked alongside each other for years, but his brother is now deceased. After working as a glass blower for about 50 years, Ahmed's eyes became damaged from extensive exposure to heat and flames from the kiln and he eventually had to stop producing glass himself. Abdullah, helps his father with marketing, expanding business, developing their website, and online orders, but he does not blow glass himself. Instead, Ahmed and Abdullah assert that they have a factory in Giza where three other glass workers trained by Ahmed now work. Nicholson and I requested on several occasions to visit this factory, but Ahmed and Abdullah were extremely reluctant to show us their Giza factory. Instead, Abdullah contacted the owner of Workshop 2, Mustafa, and helped arrange our visit to that workshop. Mustafa claims that Ahmed and Abdullah would not show us their Giza factory because they do not actually have a workshop there to show us.

Cairene glass workshops were commonly located on the outskirts of urban areas, because at one time, permits were not required in these areas. They were not allowed inside the walls of the Old City because glass workshops were thought to be fire hazards and irritating pollutants (Fischer 2008: 100). Although the government actually issued permits to operate glass factories, encouraging the construction of new factories and/or helping support existing ones, during the 1990s this situation drastically changed. New initiatives to limit the amount of pollution in urban areas resulted in more restrictive governmental regulations. Therefore, when Workshop 1's kiln, which had been running for the last century or so, stopped working about 14-19 years ago, Ahmed could not rebuild the kiln at its original location at Bab el-Futuh. In fact, the government prohibited the construction of any glass kilns within Cairo city limits and revoked all permits to existing glass factories. This may in part be due to the Energy Conservation and Environmental

Protection (ECEP) Program's initiative to heighten awareness in Egypt about industrial pollution as well as to implement measures to prevent this pollution. This was funded by the Cairo Mission of the U.S. Agency for International Development (USAID/Cairo) (Albertson *et al.* 1992; Mobarak 2001).

Apparently, Ahmed already had built a second factory in Giza by this time and was able to continue his glass production there after his first kiln broke. Ahmed supervises the work at the Giza factory and trained the three workers there prior to retiring from glass blowing.

Mahmud is a family friend of Ahmed's who was present during the interviews. As a shop owner (One Thousand Nights in Zamalek), he offered a unique outside perspective of the glass industry. He perceives Ahmed to be the "big boss" of glass in Cairo, and jokingly says, Abdullah "is the little boss." He buys glass from Workshop 1 to sell in his shop and sometimes alters glass pieces by painting various decorations on them. He also informed us that not all the glass sold at Workshop 1 is produced at Ahmed's workshop.

Mahmud has observed several changes in the industry over time. The dynamic among glass workshops has changed, for instance. Twenty years ago, all the factories knew and respected each other and were "as one." Now, "everyone from this business tries to say, 'I'm the boss.'" "Now all the glass workshops are private and separate. Because of money, they no longer get along. They get jealous of one another and no longer work together on anything or help each other with business. Now the different workshops don't show respect for one another."

Mahmud also commented on the changing number of workshops in Cairo. He estimated there are now only 3 or 5 glass workshops in Cairo due to the governmental regulations on glass factories to prevent pollution in urban areas. He postulates that there were approximately 10

glass factories about 10 years ago, 30 about 20 years ago, and as many as 50 glass workshops 30 years ago. Henein and Gout (1974) report only 5 glass blowing factories and only 10 glass workers in all of Egypt in 1972 when they conducted their study.

"I think after 10 years maximum, is coming one factory only because business is very simple for money--it doesn't give too much profit. So the rhythm of the life is very fast--in Egypt, in America, in Switzerland--it is very fast. So I hope from you to support this kind of work. Struggle to keep this life. This is please to you, I give you please. To do anything to help to leave this kind of work life. I think this kind of work after ten years, is going to end (gestures mean "to cease").

3.2.2 Workshop 2

Location:

Northern Cemetery (aka "City of the Dead" or "City of the Mamluks") in Cairo, next to Qaitbay Mosque

Interview Participants:

Mustafa, two sons Karim and Mukhtar, and Mustafa's wife

Scale:

Two main workers blow glass: Mustafa (Hassan) and Amr (Ahmed), his nephew. Mustafa's two sons, Karim and Mukhtar also work in the shop and sometimes blow glass. His wife and three daughters decorate certain vessels (usually hand-painting them) and also construct mosaic lamps and beaded lamps. We can confirm one operating kiln, where only one person can work at any given time. Mustafa claims to also have a second factory with a kiln that can accommodate three people working at once. They only operate this factory when they have orders.

Products:

lamps, tableware (bowls, dishes, plates, cups, chalices), candle holders, beads, vases, tea pots, beaded lamps, ceiling lamps, metal and glass lamps, light stands, jugs. Borosilicate glass ("Pyrex") figurines are sometimes sold at the shop, but these are made in another factory, most likely by other workers (so outsourced products).

History:

According to Mustafa, one can trace glass blowing back multiple generations, a tradition lasting over 200 years in his family. His family history of glass blowers is "older than America," he jests. During Mustafa's lifetime, he has gained much fame and recognition for his skill in glass blowing. He proudly displays several certificates, pictures, and publications throughout his workshop, and during interviews, showed us several magazines and books in which either he or his father has been featured.

Workshop 2 is located in the Northern Cemetery, a 4-mile-long area in southeastern Cairo comprising densely populated mausoleums and tombs. It is a unique setting, where the living currently reside alongside the deceased. Among mosques and businesses are families who have repurposed mausoleums as their homes. Workshop 2 is an ancient structure, comprising a rectangular room with a barrel-vaulted ceiling. These architectural features suggest the building was once a mausoleum or tomb, but Mustafa denies this possibility and says that it was most likely an old stable for horses or animals. Ashraf (see Methods section below) translates Mustafa's description of the workshop, "fifty years ago, there was no honor for this place. It was an archaeological site, made of limestone and plaster." The workshop is situated next to Qaitbay Mosque. Mustafa boasts that several generations of his family have helped decorate and restore

portions of Qaitbay Mosque among many other mosques and churches in Cairo. Among lamps and other decorations, Mustafa's father also produced stained glass windows for mosques and churches in Egypt.

Mustafa's father began teaching him the trade of glass blowing when Mustafa was 7 years old. At the age of 58 at the time of the interview (2012), Mustafa has been blowing glass for over 52 years. Mustafa left primary school to work at his father's shop. He later took up boxing, but ultimately gave up his boxing career to return to his family tradition of glass blowing. He made these sacrifices because loves what he does and takes great pride in his work.

Although Mustafa says that he often creates new forms that he designs, he explains that he also produces the same shapes that his father and grandfather manufactured, using the same techniques. Mustafa stresses that his family tradition has even older roots. For instance, the name of his workshop implies their glass is derived from a Mamluk tradition. On his business card, Mustafa even links his work to "the Pharohinic (sic) glasses". Pharaonic glass in Egypt was not blown, however, it was mostly core-formed, which is a drastic difference in manufacturing techniques.

These attestations seem to function as a marketing tool, targeting tourists whose fascination with pharaonic Egypt most likely compelled them to visit the country. Another marketing tactic Mustafa and his family pursued was the internet. They apparently created a website that may have functioned at one time, but is currently no longer in service. To further market their products, Workshop 2 printed brochures through the assistance of the USAID (U.S. Agency for International Development). In it, they claim that they are "our last surviving blown glass workshop" which is "what makes our company designs unique and differentiated." He also

showed us a recently published magazine article, which declares him as, “the last king of glassblowing in Egypt”.

Since I had already visited Workshop 1 (2009 and 2010), I challenged Mustafa’s assertion that his workshop was the only functioning glass workshop in Egypt. When I mentioned Workshop 1 to Mustafa, he said that this shop, like all the others, sells glass, but they do not make it. He claims they all buy glass he produces at his workshops. Because they buy in large numbers, they purchase glass from him at a discounted price and sell it for profit in their own shops. According to Mustafa, Workshop 1 had a functioning kiln prior to 10 or 15 years ago, but they have not produced glass since then. He negates their claim of owning a workshop in Giza where they produce their own glass. He adds that his father used to work at their previous workshop near Bab el-Futuh and also lived in the area while doing so. About 40 years ago, however, he stopped working there and moved to the current location of Workshop 2 in the Northern Cemetery.

Not only does Mustafa’s statement that Workshop 2 is the last functioning workshop in Cairo conflict with claims made by Workshop 1 owners, it also contradicts information the middleman, Hammam, provided in 2012. According to Hammam, a middleman who exports Egyptian glass, there are at least three workshops, one of which is owned by Mustafa’s brother, Muftah Khelid. Hammam describes the relationship of these two brothers as quite hostile: “They are brothers who really hate each other. They’d kill each other. They are competing and fighting.” Hammam said that this shop is located within steps of Mustafa’s shop in the Northern Cemetery. Hammam was not aware that Mustafa had a second workshop outside Cairo and thought it very unlikely. During Mustafa’s interview, however, he specifically mentioned that he would not tell any middleman about his second workshop. The reasoning behind this secrecy is

not readily apparent. If anything, knowing about a second workshop would boost a middleman's confidence in the production capacity and reliability of a given glass business. If he does, indeed, have a second workshop, perhaps there are legal reasons to withhold that information from middlemen or other people whom Mustafa does not trust.

3.3 Middleman

Location: 6 October City, near Mall of Arabia

Participant: Hammam

History:

Hammam has been in logistics and business related to export for 10 years. He started his export company in 2003, but only recently (since 2009) did he start exporting glass and working with Mustafa and Muftah. Hammam now only buys from Mustafa's brother, Muftah. Hammam dealt with Mustafa initially when he started exporting Egyptian glass for the first time (around 2009), but that he chose not to work with Mustafa after he created problems for him.

Middlemen, such as Hammam, are called "shimsar" in Egyptian Arabic. Ashraf translates this term as "commissioner" or "middleman". In short, a middleman secures orders abroad, pays vendors to produce orders, and then exports these products to foreign countries. Hammam explains, however, that his company does much more than this and importers have strong advantages of employing his services. For instance, his company designs new products to be manufactured by glass workshops. Sometimes customers request these designs and provide Hammam with drawings or pictures, but his company also comes up with their own original designs to market abroad. Another advantageous service his company provides is quality control. They follow up with the producers and inspect all products to be exported. If they are

not satisfied with the quality of the products, they deal with the producers to solve the problem. They also assist with all the documentation and certificates needed to successfully export the materials out of Egypt. In addition, they may make shipping arrangements for their clients and replace or refund any items that break before the customer receives them. For all of these services, Hammam's company charges its customers 25-30% in addition to the price of the glass.

3.4 Roman Glassmakers (now trading also as the Georgian Glassmakers)

Location: Quarley, Andover, Hampshire, UK

Participants: Mark Taylor and David Hill

Scale: One glass studio with one large modern furnace, one portable glory hole (also used as a furnace for small pots of glass), and cold-working equipment. Taylor is the main glass blower, while Hill periodically assists and also produces molds for mold-blown glass.

Products: Various Roman glass forms: skyphos, circus cups, jugs, bowls, "cast" bowls, mosaic bowls, bottles, bath flasks, conical vessels, mold-blown cups and flasks, flasks, etc. They also produce replicas of Georgian glass (17th-18th Cent. AD): goblets, tumblers, bottles.

History:

Taylor and Hill have called their company the "Roman Glassmakers", as they reproduce Roman vessels using traditional methods, techniques, tools, equipment, and glass compositions based on modern analysis of ancient glass. They started their business with the intention of selling to museums and later expanded their market to include independent collectors.

Taylor has a background in archaeology and both he and Hill employ an academic approach to their profession. In 2005 and 2006, they conducted extensive experimental archaeological studies of Roman glass furnaces. In 2005, they reconstructed two Roman

furnaces in 2005, a tank furnace and a smaller dome-shaped furnace, based on archaeological remains of Roman glass furnaces from various sites. These furnaces were fueled with wood and operated 24 hours a day for several weeks. In 2006, they reconstructed the smaller furnace and built a separate annealing oven. Subsequent to the operation of these furnaces, they have continually monitored the deterioration of these furnaces (http://www.romanglassmakers.co.uk). They also recently participated in the Roman Glass Project at the Villa Borg in Germany, another experimental archaeological study involving the reconstruction of Roman glass furnaces and replication of Roman glass forms using these furnaces (www.glasofenexperiment.de).

The practical experience of these artists in replicating Roman vessels is unparalleled and their insight into the process of making Roman vessels, Roman furnace construction, Roman glass recipes, and working with recycled glass is integral to reconstructing the entire chain of events involved in producing a Roman vessel. Knowing this sequence of steps is a crucial component of constructing a typology for Karanis glass that reflects these decisions artisans made during glass manufacturing.

Chapter 4

Ethnoarchaeology and the *Chaîne Opératoire* of Glass Manufacturing

4.1 Introduction

By studying modern glass workers in Cairo and in the UK, I investigate the *chaîne opératoire* of glass manufacturing. This ethnoarchaeogical study helps me identify important decisions artisans made during the production process and the general sequence of events. In addition to this study, I took several training courses in glass blowing so that I could better understand this *chaîne opératoire* for various kinds of vessels as well as the challenges of working with glass. As a novice, I was able to see how my lack of skill and intuition affected the end result. Bubbles, for instance, can be introduced into the object unintentionally during several phases of the process, and unskilled use of tools always translates to the final product. Glass is an extremely unforgiving medium, requiring not only fine motor skills, stamina, and concentration, but also a good understanding of the chemical properties of the glass and how it behaves in certain conditions. It requires deliberate but fluid movements, and most often it requires extensive forethought in the design and execution of the object. It is clearly a craft that cannot be mastered in a few days, and due in part to the cost of fuel, it is expensive.

4.2 Ethnoarchaeological Study: Cairene Glass Workers

4.2.1 Methods and Data Collection

> The nature of the research project will affect the ways in which observations are made and data collected, as well as the quality, quantity, and seasonality of those data (David and Kramer 2001: 64).

In 2010, Dr. Paul Nicholson of Cardiff University and I collaborated on an ethnoarchaeological study of glass workshops in Cairo. We conducted video-recorded interviews and observations of glass workers and owners of Workshop 1 and Workshop 2. In addition, I interviewed a middleman who sells Cairene glass to glass importers in 2012 to gain a broader perspective of the glass industry in Cairo. Prior to conducting interviews, we verbally communicated the aim of the study and obtained each subject's verbal consent to participate in the study. All requirements for the Institutional Review Board (IRB) of the Office of the Human Research Protection Program (OHRPP) at UCLA were fulfilled and permissions granted prior to us conducting these interviews in 2010.

Although we offered to conduct the interviews individually in a private setting, all participants preferred that the interviews take place among family and/or friends in the casual setting of their workshop or storefront. Interview questions included the following subject matters: work organization, work experience and training, types of vessels/objects produced at the workshop, raw material acquisition, distribution of final products, the techniques employed to produce certain vessels, the furnace construction at this workshop, the advantages and limitations of these furnaces, number of people glass working at one time, work schedules, maintenance of furnaces and workshop, glass recycling, challenges of glass making, qualities the participant values in his products, methods or logic in determining the selling price for each vessel, materials or techniques contributing to a vessel's value (See Appendix 1 for a complete list of interview questions).

Ashraf Sohby acted as translator for the interviews Dr. Paul Nicholson and I conducted at Workshop 2 in 2010. I conducted a short interview with Workshop 1 independently in 2009 and Dr. Nicholson and I also did not use an interpreter when we completed our 2010 interviews

with Workshop 1. Dr. Nicholson and I communicated with subjects in Egyptian Arabic and I translated video-recorded responses. In 2012, Ashraf Sohby acted as translator for the follow-up interview I conducted at Workshop 2. All interviews were video-recorded and I transcribed these interviews to carry out analysis of these data.

4.2.2 Challenges and Biases

"The observer's presence affects what is observed, and the researcher must take account of this in evaluating his or her observations" (David and Kramer 2001: 76). This principle is crucial when evaluating the information collected in these interviews and observations. Workshop 2, for instance, usually does not operate their traditional furnace located within the shop unless they are fulfilling an order or a group of tourists requests a visit through a tourism company or through the shop directly. The shop owner, Mustafa, typically charges the tourists a large fee to observe glass blowing in their shop in addition to their cost of firing up and operating the furnace for the day. On top of this fee, tourists usually buy glass from their shop, further increasing the workshop owner's profit. These visits are quite lucrative for the owner, so even though we explained that we are not tourists and do not expect to pay for him to operate his furnace, the shop owner had a difficult time letting go of these expectations. Nonetheless, he fired up his furnace the day we visited at our request, not to fill a normal work order. Therefore, the owner's motivations in operating the furnace that day may have affected several aspects of the work such as: the type of glass being produced, the glass worker chosen to work, the speed at which he worked, and the quality of the finished product. Our observations, then, may not closely represent a typical day of glass manufacturing at the shop for export, but rather, the procedures and events during a live demonstration of glass blowing for tourists. This possible

effect of our presence at the shop should be taken into account when comparing data with that of Henein and Gout as well as with Nicholson's previous ethnographic studies.

Furthermore, our interpreter, Ashraf, and I emphasized to the workers that this project was strictly academic for the purpose of learning more about the past through observation of the present. Despite these explanations, all glass workers seemed to view this project as a possible means for monetary gain. This impression was obvious, when Mustafa almost refused to let us video and observe his worker blowing glass in his shop without first paying 1000 Egyptian pounds. Dr. Nicholson and I refused to pay anything for their interviews and for observations, but assured him that we would purchase some glass after we finished. Nicholson and I agreed that paying the workers for the opportunity to observe and interview them would further encourage them to equate us as a means of monetary gain. This attitude would potentially further motivate them to exaggerate or lie during interviews to be in line with what they perceive to be a tourist's or foreigner's desire. Mustafa refused to allow us to observe the glass blowing in his shop unless we paid this large fee. To ameliorate the situation, Ashraf and I talked with Mustafa, Karim, and Mukhtar outside Workshop 2 and we initiated a friendly conversation. After gaining some of Mustafa's trust, he warmed up to the idea of us video recording our conversation and eventually, he acquiesced and gave us permission to video record his worker producing vessels. Regardless, Mustafa seemed to hold onto the idea that somehow this study would increase his profits. After showing me numerous publications in which he and his shop featured, it was clear that he viewed this study as another opportunity to benefit from exposure and publicity.

4.2.3 Deceptions to Impress

With the above biases in mind, information provided by subjects must be critically evaluated since subjects may be motivated to lie and/or exaggerate during interviews. For instance, Mustafa claimed the Egyptian movie, Kaboria ("Crabs"), made in 1990, was based on his life, and that the famous actor, Omar Sharif, is somehow involved in the film. The main actor in this film is actually Ahmed Zaky, so perhaps Mustafa confused the two actors. The film is about a boxer who later works as an entertainer for elite parties. If the movie is, indeed, based on his life, it does not explore his glass blowing career. (Link to movie on youtube: http://www.youtube.com/watch?v=ywP2fO9nlE0).

Mustafa also blatantly exaggerated, perhaps with the mentality that when something is published, it becomes true. At least two magazine articles Mustafa showed us published that Mustafa's workshop is the only functioning glass factory in Egypt. Ashraf translates one article:

> Each piece he makes as kind of art or music he plays. He is the last one of the glass makers in Egypt and the one who keeps the secrets of the natural color oxides, not only in Egypt, but the whole world. He is an artist and can play like a musician and can play with fire. You should know this man.

Contrary to what is published above, I visited at least two other workshops in Cairo, one of which most likely still produces glass. Hammam, the middleman I later interviewed, also knew of at least two other glass workshops other than Workshop 2. One of these workshops, located in the same neighborhood as Mustafa's workshop, is actually owned and operated by Mustafa's brother. He is Hammam's lead manufacturer of the glass he exports. Hammam says these two brothers despise each other and are fierce competitors. Even though Mustafa's claim to be the only operating glass workshop in Cairo is verifiably false, it testifies to this contentious relationship and to his disregard for all other competitors, family or not.

There is now a clear rivalry within the community of glass workers. A shop owner and friend of Workshop 1 owner, Mahmud, described the current relationship between all glass workshops as contentious. They once worked together as friends and family, he claimed, but now this camaraderie within the glass industry has drastically diminished over time, overcome by competition.

Both Workshop 1 and 2 claim to not only be the oldest workshop in Cairo, but Workshop 2 also claims their tradition can be traced back to those of the Mamluks (as hinted in their workshop name) and even pharaonic times. Both Workshop 1 and 2 owners seem to perceive this long history of tradition as desirable to tourists, who are often compelled to visit Egypt by their fascination with ancient Egypt and its monuments. These glass workers strive to link themselves with this ancient culture to elevate their mystique and to appeal to the average tourist.

Along with this claim of being the first workshop in Cairo comes an attestation that they taught all other glass workshop owners/operators most everything they know about glass blowing. For instance, Ahmed claimed that he taught Mustafa how to blow glass while he was an apprentice in his shop prior to opening up his own. Mustafa denies this and says that he, in fact, first taught Ahmed how to blow glass. Several pictures of a man of similar appearance to Mustafa in Fischer's study of Workshop 1 provides tentative evidence that Mustafa was indeed an apprentice at Workshop 1 in the 1990's (Fischer 2008: 103, 116, 117).

If these interviews with Cairene glass workers contain numerous conflicting statements, what is their value for the purpose of my research? Willeke Wendrich encouraged me focus on the message sent by these statements, rather than on the veracity of each claim. She pointed out that "truth" has different meaning in many cultures, and that my "Western concept of truth" does not often exist in other cultures (Wendrich, personal communication 2010). The concept of truth

and deception can differ according to sociocultural norms and customs (Sweetser 1987). More recent studies have shown cultural variance in how people assess the veracity and falsehood of various messages (Fu et. al. 2001; Yeung and Nishiyama 1999).

> The anthropologist, then, should search for the reasons underlying lies and treat each lie as a sociocultural datum. The lie should be an impetus to further study rather than an end to a relationship. Lies, in short, are a form of communication, not its negation. Investigation of lies leads to the discovery of cultural values (Salamone 1977: 121). It may potentially result in a deeper understanding of the dynamic nature of social organization (Salamone 1977: 121 after Firth 1951).

Truth may be what one perceives is the desired reality, or in the case of an interview, what the interviewee perceives is the ideal answer for the question. That may include the interviewee's perception of what the interviewer wants to hear, or his or her response may reflect the interviewee's ideal reality (not the "Western" concept of reality).

> However, whether in lying he is protecting an established identity that is threatened in a given kind of situation or staking out a claim to a new identity, the lying itself is a significant datum, for in any case, he is presenting himself as a particular kind of person (Salamone 1977: 122).

Kobben (1967), for instance, conducted a census among the Djuka of Surinam and found that mothers deliberately reduced the number of children they claimed had died at a young age. After investigating the sociocultural influences underlying these lies, he discovered that the Djuka believe women who have children that die during childbirth or at an early age are witches. Therefore, lying about the number of children they lost allowed Djuka women to deny themselves being identified as witches.

Therefore, underlying messages, often not explicitly voiced and open to interpretation, are essential to the understanding of the current Cairene glass industry and its workers. Mustafa's testimony that he has the only surviving workshop in Egypt, for instance, reflects his desire to be the only glass factory as well as his perception that once written down and published, this ideal becomes a reality, whether or not it is true in the "Western" sense of the word.

But how does one filter these statements to extract the reality from the ideal? How may one trust what each subject has claimed? Interpretation of interviews necessitates selectivity in information used to formulate generalizations about the industry and cross-checking of information through different sources. Cross-checking informant statements has been emphasized by Chagnon (1968: 10-11) and Dean and Whyte (1958).

Hammam provides an excellent means of cross-checking information, as he presumably has little motivation to obscure the facts about each of these workshops. He seems the least likely to benefit from false statements about the workshops. No translator was necessary during his interview, as his English proficiency was quite high. He clearly understood that my project was strictly academic and that he did not stand to benefit from the study in any way. Mustafa explicitly advised me not to speak to this particular middleman, however, saying that he is a bad man. They obviously had disagreements in the past and perhaps Mustafa was also concerned that this middleman would give a negative impression of him. Perhaps a fear that his ideal image would be tainted by the words of this middleman motivated Mustafa to dissuade me from conducting an interview with Hammam. Hammam, on the other hand, warns, "Do not trust these guys."

4.2.4 Results: *Chaîne Opératoire*, Cairene Glass Workers

The strategic moments and decisions made during the manufacturing process of glass objects are identified through interviews and observations of Cairene glass workers. However, not all steps of the production process could be observed during the duration of our visits to the workshops. Therefore, previous studies of Workshop 1, such as those done by Nicholson

(unpublished), Henein and Gout (1974), and Fischer (2008) are used to supplement our own observations and data from the Cairene glass workshops.

Henein and Gout (1974) describe the furnace construction in detail but they do not include the sequence of events required to build the furnace. They do, however, include a detailed description of furnace maintenance and preparation, as does Fischer (2008). Nicholson also observed the maintenance of Workshop 1's furnace while it was still in operating condition in the late 1990s.

1. Furnace Construction

I will rely on the data from the Roman Glass Makers (below) for the *chaîne opératoire* of furnace building.

2. Furnace Maintenance and Preparation

    a. reline the glass tank [note: wood fueled furnace requires relining once a month, while motor oil fueled furnace requires relining once a week] (Fischer 2008: 100)

        i. remove all layers of the old plaster (3 to 4 mm thick) to reveal the original walls of the furnace (Henein and Gout 1974)

        ii. remove all glass, slag, and corroded portions of ceramic furnace (Fischer 2008: 100)

        iii. remove layer of plaster beneath glass layer (Henein and Gout 1974)

        iv. clean entire interior of furnace with cloth (Henein and Gout 1974)

        v. replace corroded portions with new clay (Fischer 2008: 100)

        vi. fire furnace at least once before beginning glass melting and working process (Fischer 2008: 100)

3. Furnace Firing

    a. wood fueled furnaces require 1/10 ton to 1/3 ton wood each day (Fischer 2008: 101; Henein and Gout 1974)

    b. fire up furnace and heat furnace for at least 2 hours prior to heating glass cullet for wood fueled furnace (Henein and Gout 1974) and at least 1 hour prior for oil or gas fueled furnace

4. Material Selection and Preparation

    a. select and purchase recycled glass from glass bottling companies in Egypt

    b. melt glass in a crucible or pot in furnace for at least 1 hour

    c. add colorants or opacifiers to cullet and stir in

5. Glass working

    Below lists the steps involved in producing a lamp form with a small, spherical base. Note that periodic reheating of the glass is not included below:

    a. gather glass from gathering hole onto a blow pipe while heating pontil rod in separate opening of furnace with small gather of glass on end of pontil.

    b. marver glass

    c. blow a bubble into glass while marvering the bottom of the bubble

    d. stretch bubble by holding the pipe vertical and letting bubble hang

    e. put in jack line of vessel

    f. blow out the body of the vessel

    g. elongate body by swinging rod in a circle around a horizontal axis

    h. repeat steps f and g if necessary

    i. shape body with jacks

j. shape base (use jacks to squeeze a sphere at the bottom of the vessel)

k. crack off form from pipe while form is resting on metal plate

l. turn form around on metal sheet using end of blow pipe with moil

m. marver pontil glass if necessary

n. apply pontil to base of form and return end of blow pipe to furnace to reheat for next use

o. flatten open end of bubble with marver

p. open up vessel with jacks and form rim

q. compare size and shape with standard size template

r. if vessel meets standards, knock glass off pontil and return end of pontil to furnace to reheat

6. Annealing

a. place glass vessel in an annealing chamber of the furnace to cool down slowly overnight

4.3 Ethnoarchaeological Study: Roman Glassmakers

4.3.1 Methods

Nicholson initially contacted the Roman Glassmakers and obtained their permission for us to visit them at their studio and interview them. Prior to conducting interviews, we verbally communicated the aim of the study and obtained each subject's verbal consent to participate in the study. We conducted interviews at Taylor and Hill's studio in Hampshire and most of these interviews were video-recorded. Nicholson and I spent nearly seven hours with Taylor and Hill, conducting interviews and conversing about their past research and experiments. Interview

questions included the following subject matters: building and using wood burning furnaces, the various steps involved in producing a Roman vessel, which rim and base types are most difficult to produce and why, which forms are more difficult to make, how certain rim and base types are formed, past experiments and research they have conducted to arrive at their methods for making and working glass, how bubbles are introduced into the glass, and what Roman vessel types would have been most valuable and why (See Appendix 2 for a complete list of interview questions).

In preparation for their participation in the Villa Borg Roman Glass Project the following day, Taylor and Hill had shut down the furnace at their studio in Hampshire and were not glass working at the time our visit to the workshop. Therefore, data for this study are derived from their interviews as well as video footage and files of their past experiments and research with which they provided us. In addition to interviews, each artist examined photographs of glass artifacts from Karanis and evaluated their physical attributes (e.g. color, shape of vessel, finishing techniques) to gauge the skill, techniques, technology, and relative expense involved in producing these vessels.

4.3.2 *Chaîne Opératoire*, Roman Glassmakers

Some of the steps involved in producing a free-blown glass vessel differ from those needed to produce a mold-blown vessel. The following outlines the general procedure one must carry out to produce a free-blown Roman vessel, as described by Taylor (note that reheating the glass periodically is omitted in the glass working steps):

1. Furnace Construction and Firing
    a. dig a circular or oval pit with a flat bottom and line it with roof tiles or stones
    b. construct a stoke hole
    c. build a shelf with tiles (brick, stone, or clay could also be used) and a superstructure of the furnace with daub (clay, hay, sand, grit mixture), gathering/reheating hole, pontil/blow pipe hole, and lehr.
    d. allow daub to dry (about 2 weeks)
    e. burn wood fuel in firing chamber to fire the entire furnace for over 48 hrs prior to melting glass
        i. pot furnace burns approximately 288-360 kg wood per day (24hr period) (Taylor and Hill 2008; www-romanglassmakers.co.uk)
2. Furnace Maintenance
    a. since the Roman Glassmaker's Roman Furnace Project ran for only three weeks, the stripping out of glass and vitrified material from the interior was not required. They maintained the furnace by removing charcoal and ash from the firing chamber every 24 hours.
3. Procurement of Raw Materials or Cullet/Glass Making or Melting of Cullet
    a. select and procure raw materials and/or cullet
    b. add colorizers or decolorizers to raw ingredients and/or cullet
    c. melt glass in a crucible or pot in furnace for at least 24 hrs at 1020-1050 degrees centigrade to allow glass to become homogenous and gasses to escape.

i. [optional step] pour melted glass into cool water and break up into pieces to produce cullet that can be remelted in the furnace to produce a better quality glass

4. Glass Working
    a. gather glass onto a blow pipe
    b. marver glass
    c. create a small bubble in glass through controlled blowing
    d. stretch bubble into a tube to create a neck, if producing a closed form
    e. blow out the body of the vessel
    f. shape body
    g. put in jack line (breaking off point from the pipe) and neckline (if desired) with jacks*
    h. shape base or apply padded foot or base ring
    i. apply pontil or gripping device[4]
    j. crack off form from pipe
    k. for open forms, open up vessel body and then work rim; for closed forms, work rim only
    l. add trails or other decoration
    m. add handles (if any) by applying glass and casting off
    n. glass is knocked off the pontil, leaving a pontil scar on the base
5. Annealing
    a. glass vessel placed in an annealing oven to cool down slowly overnight

[4] Gripping devices were used exclusively before the invention of the pontil around the mid-first century CE (Taylor, April 2015, personal communication).

*steps I added to Taylor's description.

The process for mold-blown vessels is similar. However, one must first produce a ceramic (often terracotta) or metal mold prior to working the glass. The glass working steps f-j are different. After an initial bubble is made in the glass, a parison is formed prior to placing the parison into the mold and blowing. This parison takes time and must be appropriate for the mold and desired form. The neck is shaped as part of the parison and a neckline also is made. While using an open mold, the angle of the shoulder of the vessel is dictated by the amount of force one pushes down while blowing into the mold. If using a closed mold, the shoulder is formed by the mold itself. After the form is removed from the mold, it is either clamped with a tool to hold the bottom to crack off the pipe, or it is placed on a pontil and cracked off. The rim can then be worked.

4.4 Concluding Remarks

As mentioned, the objective of ethnoarchaeology is not to merely reveal patterns in human behavior, environment, cultural identity, and/or social aspects and mold to the data, but to test these patterns against the archaeological data (Tringham 1978 in: Gould 1978: 185; Wendrich in: Wendrich and van der Kooij 2002). To test theories regarding technology and value derived from this ethnoarchaeological research against the archaeological glass material from Karanis, I must first reveal a typology that will enable me to explore research questions concerning value. I may then investigate the archaeological context of artifacts to better understand how various glass types were used, discarded, re-used, and valued differently.

The second main goal of this ethnoarchaeological study is to identify decisions artisans make while producing glass objects and the sequence of these decisions, which affect the outward appearance of the final product. This *chaîne opératoire* of glass manufacturing forms the basis for my typology of Roman glass from Karanis. This study compares methods of glass manufacturing at two separate modern workshops: Cairene Workshop 2 and that of the Roman Glassmakers of Hampshire.

Some methods Cairene glass workers use varies from those employed by the Roman Glassmakers. When blowing a bubble in the glass, for instance, Cairene glass blowers do not use the capping technique and marver the glass while blowing into the blow pipe to shape it. The marver is positioned vertically so that the worker can see the glass while he blows and can regulate the size of the bubble. Roman Glassmakers sometime create an initial bubble in the glass by capping so that they can see the bubble and control the extent to which it expands. Taylor also forms an initial bubble through controlled blowing, however.

Although some variation among manufacturing methods is evident between the two workshops, an underlying basic structure for glass manufacturing can be identified. Although both workshops use traditional furnaces to produce most or all of their products, since the Roman Glassmakers have reconstructed Roman glass furnaces based on archaeological evidence and experimental archaeology and also make and use a glass recipe based on textual and modern analysis of Roman glass, they provide arguably the closest modern analog to ancient Roman glass manufacturing processes. The basic steps, in the order in which they occur, are outlined in the figure below:

Figure 4-1. Basic *chaîne opératoire* of manufacturing glass vessels

1. Furnace construction

2. Furnace maintenance and preparation

3. Procurement of Raw Materials or Cullet/Glass Making and/or Melting

    a. Select and procure ingredients

    b. combine ingredients

    c. melt ingredients in furnace

    d. add colorants to melted cullet, if applicable

4. Glass Working/Shaping:

    a. gather glass

    b. blow bubble

    c. shape bubble appropriately for desired end product

        i. shape body and neck (if applicable)

        ii. shape base (sometimes base is added and then shaped)

    d. apply pontil and break partly-formed vessel off pipe

    e. shape rim and body (if open form), shape rim only (if closed form)

    f. add trails, decoration*, or handles

    g. remove pontil

a. anneal

*this step can occur at earlier stages of the process

Chapter 5

Compositional Analysis of Vessel Glass from Karanis

5.1 Introduction

The first stage in the process of producing a glass object is the selection of raw materials followed by the production of the glass material. The chaîne opératoire of making a glass object can be quite complicated, as the properties of the material allow various stages of production to occur at several different locations and/or times. Once the material is made, it can be formed into an ingot or crushed into cullet and later re-melted and worked at a secondary workshop to be fashioned into a vessel or other object. Colorants, decolorizers, opacifiers, and other additions can be added into the glass at various stages in the process as well. This flexibility in the process contributes to why there is still much debate regarding the organization of the Roman glass industry and this study is intended to contribute to this discussion by helping bridge the gaps among regional studies of the composition of Roman glass found in Egypt. Two main theories center around whether glass was made on a large scale at few locations ("regional production") or on a much smaller local scale using nearby sand sources and natron imported from areas such as the Wadi el-Natrun in Egypt ("localized production") (Foster and Jackson 2009: 190; Foy *et al.* 2000; Foy *et al.* 2003). The fairly standardized glass composition among all Roman glass (see Table 5-5 below for average composition) supports the regional model of mass production of glass at few centralized locations which would then be transported to secondary production (i.e. glass working) sites to be fashioned into vessels or other objects. Minor or trace differences in composition are accounted for by changes in the glass working process over time. Uniformity in composition can be explained by other means, however, such as strict standardized glass recipes

and methods of glass production carried out among several smaller production sites (Foster and Jackson 2009).

There is some variation in Roman glass composition, however, and several types have been identified (see Tables 5-6 through 5-8 below). Levantine I (Freestone *et al.* 2000; Foy *et al.* 2003, Group 3) and II, HIMT 1 and II (Freestone 1994; Freestone *et al.* 2000), Groups 1 and 2 (Foy *et al.* 2003), blue-green, Mn-decolorized, Sb-decolorized, Mixed Mn/Sb-decolorized glasses (Foster and Jackson 2010).

Compositional studies of Roman glass from Egyptian archaeological sites include glass from the Wadi el-Natrun (Nenna *et al.* 2003, 2005), Karanis (Brill 1999; Higashi 1990), and Bubastis (Rosenow and Rehren 2014). My compositional analysis comprises a large sample size (n=464) of glass with secure archaeological contexts.

5.2 Glass Raw Materials and Fluxing Agents during the Roman Period

Roman glass is a soda-lime-silica glass. The basic components of Roman glass include alkalis, calcium, and silica. Alkalis, such as sodium carbonate are fluxing agents, meaning they interact with the silica and reduce the melting temperature of soda-lime-silica glass to around 1100 to 1200 degrees (Henderson 2013). The source of alkali can be either the ashes of halophytic plants of the *Chenopodiaceae* family. These plants can survive in soil with high alkali levels. Through transpiration, they convert the alkali to alkaline salts, such as sodium carbonate, which they hold in their tissues. They yield significant amounts of sodium carbonate when burned to ash. Sodium-rich plants suitable for glass making could have grown what is now modern Syria, France, Spain, Sicily, and North Africa (Amouric and Foy 1991). Elevated levels

of magnesium and potassium oxide of soda glass can signify plant ashes were used as fluxing agents (Sayre and Smith 1961; Henderson 1988; Freestone 1991; Rosenow and Rehren 2014).

Plant ash from halophytic plants of the *Chenopodiaceae* family was the earliest fluxing agent for glass, used commonly until around 800 BCE, when natron replaces plant ash as the main fluxing agent (Henderson 2013; Sayre and Smith 1961; Freestone *et al.* 2000). Plant ash was only intermittently used in Roman and Sassanian glass, but became commonly used again around 800 CE until the 17th century CE in the Middle East (Henderson 2013).

Natron is a mineral ($Na_2CO_3.10H_2O$) that typically has higher alkali concentrations than those of plant ash. Natron is plentiful in the Wadi el-Natrun in Egypt. Trona is another mineral ($Na_2CO_3.NaHCO_3.2H_2O$) source for sodium that would have been used for glass production (Henderson 2013). There may have been other sources for sodium rich minerals for glass making during the Roman period, such as an evaporitic lake near the ancient city of Chalestra in Macedonia, Greece (Henderson 2013; Dotsika *et al.* 2009).

Since plant ash glasses are rare during the Roman period, only a few published examples of plant ash glasses from Egypt during the Roman period have been identified (Arveiller-Dulong and Nenna 2005; Nenna *et al.* 2005; Picon *et al.* 2008; Rosenow and Rehren 2014). A few additional examples of plant ash glasses from other areas of the Empire have been identified as well (Gallo *et al.* 2013; Jackson *et al.* 2009; Schibille 2011).

Calcium oxide, or lime, is a necessary component of soda-lime-silica glasses because it is a network stabilizer. Without calcium, glass would dissolve easily in water (Nicholson and Henderson 2000). Shell fragments are thought to be the main source of calcium in most natron glasses. For plant ash glasses, the source of calcium is presumed to be the plant ash added. Other possible sources of calcium are bone and limestone (Henderson 2013).

Silica is called the glass-former because it is the fundamental ingredient of the glass. It makes up 65-70% of most soda-lime-silica glasses. The source for silica is usually sand or quartz pebbles. Sand often has impurities in it, including heavy minerals such as iron oxide (e.g. magnetite) and iron titanites (e.g. ilmenite) (Henderson 2013; Nicholson and Henderson 2000).

5.3 Roman Colorless Glass and Evidence of Recycling

Few known ancient sand sources were pure enough to yield a water-clear glass; therefore, glassmakers needed to add precise proportions of decolorizers to sufficiently oxidize the iron that would otherwise cause blue-green color in the glass (Foster and Jackson 2010: 3068). Sayre (1963) postulates that the concentrations of decolorizers added correlate to the quantity of iron present as an impurity. To produce colorless glass, ancient glassmakers also would have selected raw materials low in impurities and properly controlled the furnace atmosphere during production (Jackson 2005).

Colorless glass was developed as early as the reign of Hatshepsut (1479-1458) (Reeves 1986). During the Roman period (30 BCE - 643 CE), the two primary decolorizers employed were manganese oxide and antimony trioxide (Foster and Jackson 2010: 3068; Henderson 2001: 476). Manganese (Mn) can be present in glass as an impurity and can also be used as a colorant to produce purple glass. Antimony, on the other hand, is not typically present in commonly occurring geological materials and would not have been accidentally introduced as contaminants of the raw materials (Jackson 2005; Newton 1980). Pyrolucite (MnO_2) is one of the purest minerals containing manganese and was most likely an important manganese source in antiquity (Henderson 2013; Jackson 2005). Manganese oxides are widely distributed in Egypt, and thus local sources would have supplied the glass industry (Henderson 1985; Nicholson and

Henderson 2000: 198, 217). Antimony (Sb) is more effective in producing a water-clear colorless glass because it removes dissolved gasses (Bamford 1977), whereas manganese-decolorized glasses often maintain a residual tint (Sayre and Smith 1961; Sayre 1963). Minerals containing antimony include Stibnite (Sb2S3) and Bindheimite ($Pb_2(Sb,Bi)_2O_6(O.OH)$) (Jackson 2005). Antimony was commonly added as a decolorizer between the sixth and second centuries BCE in the Mediterranean and in the Middle East (Henderson 2000: 38; Sayre and Smith 1961). Yet subsequent to its initial use as a decolorizer during the second century BC, manganese oxide gradually replaced antimony trioxide (Henderson 2000: 38; Sayre 1963). The termination of the use of antimony as a decolorizer coincided roughly with the fall of the Western Roman Empire (Sayre 1963).

Foster and Jackson (2010: 3070) distinguish three main compositional groups among their corpus of late Roman colorless vessel glass from Britain (see Table 5-6 below, "Colourless 1, 2, and 3"). All samples investigated contain antimony and/or manganese decolorizers above trace levels, which suggests deliberate addition. Foster and Jackson (2010: 3072-3073) identify a mixed manganese/antimony glass they refer to as "Colourless 3" glass (Foster and Jackson 2010, see Table 5-6 below). Other researchers have identified similar mixed groups of colorless glasses (Huisman *et al.* 2009; Jackson 2005; Paynter 2006; Silvestri 2008).

Researchers have proposed various explanations for the significant presence of both decolorizers in colorless glasses. Foster and Jackson (2010) conjecture that during the Roman Period, either one decolorizer or the other was added to a particular batch to achieve a colorless glass. Sayre (1963) asserts that Roman glasses originating from the eastern provinces are rarely of mixed composition, while those from the western provinces more commonly contain both decolorizers. Glass recycling is a dominant hypothesis explaining the presence of both

decolorizers in some Roman colorless glasses (Foster and Jackson 2010; Huisman *et al.* 2009: 434).[5] Mixing colorless broken glass with HIMT glass, a type of glass identified by Freestone (1994; Freestone *et al.* 2005: 153) containing high levels of manganese, iron, and titanium, could result in this mixed composition (Foster and Jackson 2010: 3072; Huisman *et al.* 2009: 434; Jackson 2005). Furthermore, Foster and Jackson (2010: 3073) observe copper levels above trace amounts in nearly 50% of Late Roman colorless glass samples of mixed composition from Britain. Similar copper concentrations were identified in Roman colorless glass of mixed composition from the Netherlands (Huisman *et al.* 2009: 430) as well as from Roman Britain (Paynter 2006). Thus, Foster and Jackson hypothesize that these mixed manganese/antimony-decolorized glasses with significant copper content are the result of re-melting colorless glass and mixing it with new and/or recycled blue or green glass containing copper (Foster and Jackson 2010: 3073).

5.4 "Naturally Colored Glasses" and Evidence of Recycling

The term, "naturally colored" is used to describe glasses that have not been intentionally colored by adding colorants, but are various shades of blue, green or yellowish-green due to impurities, such as iron oxide, in the glass (Foster and Jackson 2009). They are the most common glass colors found in Roman glass assemblages dating from the 1st century BCE onward (Foster and Jackson 2009). From the late 1st-3rd centuries CE, Roman blue-green glasses are common. Foster and Jackson (2009) identify eight samples of blue-green glass dating to the 4th century CE, but typically, the naturally colored glass of the 4th century CE onward tends to be

[5] Degryse and colleagues (2006: 500) also conjecture local recycling and secondary glass production is a likely explanation for the heterogeneous elemental and isotopic composition (namely the lead and strontium isotopic composition) of early Byzantine green and HIMT vessel glass at Sagalossos in SW Turkey.

yellowish-green in color and different in composition than the earlier blue-green glasses. Two compositional groups dominant during the Late Roman period (4th-7th century CE): high manganese, iron, and titanium (HIMT) glasses (Freestone 1994) and Levantine 1 glasses (Freestone *et al.* 2000). Levantine 1 glasses are thought to have been manufactured in the Syro-Palestinian region (Foy *et al.* 2003). HIMT glass was first identified by Freestone (1994) and is characterized not only by high levels of Mn, Fe, and Ti, but also higher soda, magnesia, and lower lime than the earlier Roman glasses (Foster and Jackson 2009). Isotopic evidence supports that it was manufactured in the Near East, most likely in Egypt (Freestone *et al.* 2005). HIMT glass tends to dominate late Roman assemblages in Egypt. The high soda content typical of HIMT glass found in Egypt suggests that it was manufactured near natron deposits, such as those in the Wadi el-natrun (Freestone *et al.* 2005).

Several variants of HIMT glass have been identified (see Table 5-7 below). Foster and Jackson (2009) identify a strong type of HIMT (HIMT 1) and weak type (HIMT 2). Dilution of the HIMT composition to these weaker types can be explained through glass recycling; contaminants such as lead, copper and antimony in some HIMT glasses supports this theory (Foy *et al.* 2003; Foster and Jackson 2009; Jackson and Price 2012).

HIMT may be more common than Levantine I glass because it was most likely cheaper due to its lower quality (Nenna 2014). Levantine 1 shows trends of being used for higher quality glass wares and shows no evidence of recycling (Foster and Jackson 2009).

5.5 PXRF Background

Archaeometrists are often skeptical about using portable x-ray fluorescence (pXRF) spectrometry to quantitatively analyze the chemical composition of ancient glass (Nicholson, April 2014, personal communication), since other methods of chemically analyzing vitreous materials such as Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS), electron probe micro-analysis (EPMA), and scanning electron microscopy (SEM) often yield more consistent and accurate results (Nicholson and Henderson 2000: 206-220). Several studies, however, demonstrate that pXRF quantitative analysis yields sufficiently accurate absolute concentrations of elements as oxides[6] when done cautiously and with proper calibrations (Kato *et al.* 2009; Lui *et al.* 2012; Tantrakarn *et al.* 2009, 2012).

Tantrakarn and colleagues (2012: 517-518) compare pXRF results with LA-ICP-MS of glass samples from southern Thailand. Concentrations of all major elements vary less than 20% between these two methods[7] (Tantrakarn *et al.* 2012: 517-518). Furthermore, the results from pXRF of obsidian demonstrate that the margin of error in the detection and calibration of certain elements can be low enough to identify discrete groupings within a sample population (Milhauser *et al.* 2011). Despite an insufficient least-squares correlation between pXRF and laboratory XRF results, these researchers are still able to identify the correct obsidian sources for 97% of their samples (Milhauser *et al.* 2011: 3147).

My research further supports the efficacy of pXRF quantitative analysis and is the first chemical analysis conducted with pXRF on Roman glass found in the Fayum region of Egypt.

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[6] Oxides are chemical compounds that contain at least one oxygen atom and one other element.

[7] This excludes a 45% difference in concentration of Na oxide between the two methods due to limitations of pXRF detectors. Typically, pXRF silicon drift detectors do not accurately detect elements of lower energies than Si (Kaiser and Shugar 2012).

Egyptian law prohibits researchers from removing artifacts from the country, necessitating on-site analysis. Therefore, pXRF is the only means to interrogate the chemical composition of these artifacts. Tests I conducted on the detection, precision, and accuracy of the pXRF instrument employed in this study, a Bruker Tracer III-V, indicate that glass calibrations yield inaccurate *absolute* concentrations of elements as oxides. I demonstrate, however, that within a closed population, pXRF analysis is an effective means of conducting quantitative analysis of ancient glass to identify distinct compositional groups. I analyzed 464 Late Roman (395 CE - 643 CE) colorless glass samples from secure archaeological contexts in Karanis, Egypt (2005 - 2010 URU excavations). I distinguish five main glasses: 1) Antimony-decolorized, 2) Low manganese/low antimony, 3) High manganese/low antimony, 4) Aqua, and 5) Mixed manganese antimony glass. These results provide the first evidence for mixed manganese antimony glass at Karanis. I also identify groups that may represent high manganese, iron, and titanium glass (HIMT) glass (Freestone 1994; Foy *et al.* 2003; Foster and Jackson 2009) based on relative levels of Sb, Mn, Fe, and Ti. The large quantity of Aqua glass observed in this study is remarkable. The recently excavated glass from Karanis primarily dates to the Late Roman Period (4th-6th centuries CE), and if this group represents Roman blue-green glass, this type more commonly dates to the 1st-3rd centuries CE.

5.6 Methods: pXRF

5.6.1 Sampling Strategy

Although I make an effort to conduct random sampling of the Karanis glass assemblage, due to limitations of Bruker Tracer III-V, I select samples at least 3 mm thick with surfaces that are flat and minimally weathered. I analyze thin, curved, or weathered samples when there are

no suitable samples of a specific color and/or presumed fabric in the Karanis corpus. I primarily select diagnostic glass sherds (rims, bases, or decorated sherds), although I analyze a few body sherds of these rare, presumed fabric or color types. I also include at least one sample from each stratigraphic unit excavated at trenches KA04 and KA14 (to allow for a detailed analysis of material from this trench), and several stratigraphic layers from the remainder of the excavated trenches. Since the volume of glass material recovered from KA04 and KA14 is significantly higher than that of any other context, a larger percentage of the total glass sample population was from these two trenches.

I recorded several characteristics of each sample: maximum thickness, length, width, weathering, color, decoration, fabric (using Harden's parameters[8], see Table 6-7 for Harden's fabric criteria), and provenience (see Appendix 3 for a complete list of measurements and other variables).[9]

5.6.2 Sample Population

During 2009-2010, I analyzed 464 samples of primarily Late Roman period vessel glass using a *Bruker Tracer III-V* portable XRF. The data set comprises approximately 258 colorless glass samples, 148 of which are water-clear colorless. Both water-clear colorless and some tinted glasses are considered "colorless" because they contain decolorizers that were intentionally added to the batch to produce a colorless glass, as opposed to "naturally-colored glasses," which lack concentrations of decolorizers above trace levels (Foster and Jackson 2010). I initially

[8] Harden 1936. Donald P. Harden analyzed Karanis glass and determined fabric types by evaluating the outward appearance of the glass. He did not conduct chemical analysis to confirm these fabric types.

[9] I did not record the curvature of each sample due to the difficulty in measuring this characteristic accurately and quickly while working under the time constraints of a fieldwork season in Egypt.

separated the total sample population into two groups based on these qualitative grounds: colorless versus naturally colored glasses. Foster and Jackson (2009, 2010) assert that the production technology, provenance, and consumption patterns of these two groups differ and that they should therefore be analyzed separately (2010: 3068). After analyzing these two groups independently, however, it became apparent that I would need to include naturally colored glasses in order to determine at what levels Mn and Sb can be considered trace, since absolute concentrations of elements cannot be obtained. Furthermore, it is quite difficult to determine by the outward appearance of the glass whether or not decolorizers have been intentionally added. The thickness of the glass greatly affects one's perception of the color. A very thin piece of naturally colored glass, for instance, may appear virtually colorless and consequently be mistaken for a tinted colorless glass. Therefore, I processed all data in the same manner and statistically analyzed all samples together to ensure that all samples can be directly compared to one another, that my glass types are based solely on chemical composition, and that relationships between the outward appearance of the glass and chemical composition can be explored since the criteria for compositional groups do not include these qualitative distinctions.[10]

Several glass samples were omitted from this study due to high lead Pb content, heavily weathered surfaces, opacifiers, and/or colored trails.[11] A few samples with these characteristics were not identified until later, so were included with the sample population but were analyzed

[10] Some glass in Group 3 of this study was excluded based on qualitative distinctions (e.g. opaque glass and purple glass) due to the additives used to create these properties, which result in abnormally high levels of certain elements and obscure the patterning in the remaining data necessary to identify compositional groups.

[11] Outliers with high Pb content either represented glass post-dating the Late Roman Period, or samples opacified with lead antimonate. Opaque-colored trails also contain lead antimonate, and since the minimum diameter detected by this instrument is 3 mm, trails would be analyzed in addition to the colorless portions of the sample, rendering the results invalid. Samples with a highly weathered exterior also cannot yield accurate pXRF results, since hand-sanding the samples does not remove all of the weathered exterior. The instrument is not, therefore, analyzing the bulk (interior) material, which is the aim of this research. The weathered portions of the glass will have a slightly different chemical composition than the bulk material.

separately with other outliers (glass with unusual chemical composition or invalid spectra). Samples that were partially or fully analyzed in 2009 were also omitted from this study because they were analyzed with a different instrument. Although the same manufacturer and model, the direct comparison of data from both instruments may not yield the most accurate results due to instrument differences in measurements. My analysis of the 2009 material was an instrumental pilot study aimed at confirming that the pXRF measurements would yield valid and useful results for identifying glass groups. I only include samples analyzed during the 2010 field season in Egypt with a single instrument so as to ensure measurement consistency.

5.6.3 Sample Preparation

I conducted a series of sanding tests to verify the most effective and practical means of removing weathered material to eliminate weathering as a source of variability in the pXRF analysis of bulk material (see Kaiser and Shugar 2012). These tests led to the following sample preparation protocol: (1) sand each piece by hand using fine-grained sand paper, (2) flush the sanded piece with water, (3) thoroughly air-dry each piece, and (4) clean each piece with ethanol immediately prior to pXRF analysis. The sanding removed surface weathered material to a depth of approximately 0.5 mm, exposing the bulk material underneath for analysis. Since potassium (K) is highly soluble, and there are fairly high concentrations of K in the alkaline soil in Egypt, over time K can leach into and out of the surface of the glass (Ian Freestone, personal communication, 2010). My sanding test showed that not all K on the surface can be removed by hand sanding, which may significantly affect the K counts detected by the instrument. Consequently, I do not rely on K raw counts to distinguish glass types within the assemblage.

I analyzed the same area of each sample using two settings under the pXRF: low-Kv (kilo voltage) and high-Kv. I tested the instrument's minimum time required for data acquisition, and concluded that a 300-second trial did not yield significantly different results from a 180-second trial. Therefore, I analyzed each sample for 180 seconds at both settings. I employed different filters and settings to position the x-ray energy impacting the sample slightly higher than the absorption edges of the elements of interest. Doing so minimized the Bremsstrahlung[12] and optimized the identification of spectral peaks in the energy region of interest (Kaiser, personal communication).

The accelerating voltage for the low-Kv setting was 15 Kv, and I used the highest anode current available (37 μA). The low-Kv setting required the use of a vacuum pump (operating at between 0 and 4 Torr[13]) for the detection of lower-energy elements. The pump did not encapsulate the environment surrounding the sample, but reduced the absorption of x-rays by air. I used a titanium (Ti) filter (1 mil) at the low-Kv setting to enable the x-rays from 3 keV to 12 keV to reach the sample. Consequently, the following elements were excited sufficiently: Al, Si, P, Cl, S, K, Ca, V, Cr, and Fe (as well as any L and M energy states for elements that fall between 1.2 and 6.5 keV) (Kaiser, personal communication, 2010).

The high Kv setting did not require the use of the vacuum pump to obtain accurate results. The accelerating voltage was 40Kv for the high Kv setting, and I used the highest anode current available for this voltage (22μA). I utilized the Cu (6 mil), Ti (1 mil), Al (12 mil) filter,

[12] Bremsstrahlung is electromagnetic radiation caused by the rapid deceleration of electrons hitting the instrument's rhodium anode (metal target) (Cullity and Stock 2001). If the Bremsstrahlung occurs at energies coinciding with those of the elements of interest in the study, it obscures results.

[13] Torr is a unit of pressure. One psi is approx. 51.7 Torr.

allowing the x-rays from 17 keV to 40 keV to reach the sample. This enabled the excitation of elements from Fe to Mo (Kaiser, personal communication, 2010).

The element with the lowest atomic number that can be measured using this pXRF instrument is aluminum. It must be noted that the Bruker pXRF instrument cannot adequately detect sodium (Na), a major component in flux[14], nor can it detect magnesium (Mg). During the Roman Period (30 BCE-634 CE), glass makers primarily used natron as a flux, resulting in high Na levels and low K concentrations (Henderson 2013). Since all Karanis glass samples in this study date to the Roman Period, Na and K levels are not crucial in identifying distinct glass groups and the absence of Na and Mg data does not discount the possibility of dividing the sample population into distinct groups based on variation in amounts of other elements detectable with pXRF.

5.6.4 Converting Raw Data to Counts using *Artax* Software

The *Bruker Tracer III-V* outputs results in the form of spectra. In order to carry out quantitative analysis, these spectra need to be converted to numerical values of counts or calibrated to generate weight percentages of elements in the sample. In order to calculate counts for each element--how many times an electron of a particular energy level hit the detector during the sample duration—spectra files (pdz files) first need to be converted to text files, which can be deciphered by the *Artax* program. This conversion was done using Bruker's *S1PXRF* software (version 3.8.30), which was also used to process the spectral data generated by the machine at the time of initial data acquisition with the instrument. I completed a group conversion in

[14] A flux is added to a glass batch to lower the melting temperature of the glass. Researchers often use the ratio of Na to K to distinguish between a natron flux (containing an inorganic sodium carbonate mineral) and a potash flux (derived from soda-rich plant ash) (Henderson 2013).

S1PXRF, which converts all files in a particular folder simultaneously. I chose to replace duration with live time, which adjusted the spectra accordingly. Because I analyzed the recently excavated material in 2010 from Karanis using an older Tracer model (the *III-V* instead of the *III-V+*), for these spectra I chose to expand 1024 channel spectra to 2048 channels. The newer versions of *Artax* software are designed to analyze 2048 channel spectra. I designated the FWHM (short for Full Width Height Maximum) as 220 and used the default setting for ELin. For the Kelsey Museum samples (results discussed later), I did not expand to 2048 channels since the data were taken with a newer model (*III-V+),* which outputs 2048 channel spectra. I used all default settings for converting these museum spectra and replaced duration with live time.

The converted text files could then be uploaded into *Artax* software (version 7.4.0.0). The raw counts detected by the instrument for each element were calculated using the *Artax* net area analysis, which involves normalizing the spectra to the backscatter, curve-fitting (accounting for the Bramsstrahlung), and measuring the area inside the K, L, and M (if applicable) line peaks.

I formulated a separate method for the net area analysis of the low Kv spectra, since each setting targets a different energy range, resulting in different, visible peaks. It is crucial that all peaks present across the spectra (either low or high Kv in this case) are properly identified in the *Artax* method in order to optimize the accuracy of the net area analysis (Kaiser and Drake, personal communication). I included the following elements in the method for low Kv spectra to calculate raw counts using net area analysis: Al, Si, S, Cl, Ar, K, Ca, Ti, Mn, Fe, Co, Ni, Cu, Zn, Rh, Ba, and Pb. Corrections included “escape” and “background at 10 cycles,” starting at 1.0 KeV and ending at 15 keV.

For the high Kv spectra, I included the following elements: K, Ca, Ti, Mn, Fe, Co, Ni, Cu, Zn, Rb, Sr, Y, Zr, Rh, Sn, Sb, Ba, W, and Pb. Corrections included "escape" and "background" at 10 cycles, starting from 1 keV and ending at 40 keV. I exported the results to Excel and combined the low and high Kv counts as follows: I used counts from low Kv setting for elements lower in atomic weight than Co (Al, Si, S, Cl, Ar, K, Ca, Ti, Mn, Fe) wheres counts for elements higher in atomic weight than Fe were derived from the high Kv spectra (Co, Ni, Cu, Zn, Rb, Sr, Y ,Zr, Rh, Sn, Sb, Ba, W, Pb).

Counts for elements were then "normalized" by dividing each value by the duration of time of data acquisition (180 seconds for each sample).

5.6.5 Caveats for Using *Artax* Net Area Analysis

The main caveat for using *Artax* to calculate the raw counts is that it relies on the researcher analyzing the data to determine and design the method used, and this may introduce human error. As mentioned, it is imperative that all peaks present in all spectra are properly identified in the *Artax* method in order to optimize the accuracy of the net area analysis. Including all peaks visible in the spectra presents challenges, as Raleigh and Compton scatter create visible peaks in the spectra, which must be accounted for in some way. Furthermore, spectral interferences can make it difficult to determine which elements need to be included in the method. L-lines of Ba peaks, for instance, interfere with the K-lines of Ti peaks. There are also spectral interferences of Rh, Cl, and S. Since the Rh L-state electrons from the anode tube are not able to reach the sample, the x-rays interfere with the chlorine (Cl) and sulpher (S) K-line readings. Therefore, one must interpret the elements involved in these spectral interferences

cautiously. Spectral interferences also account for the high %RSD values for some elements in the precision test of raw counts (discussed below).

5.6.6 Precision/Accuracy Test

I conducted accuracy and precision tests using Corning Museum of Glass (CMOG) Reference B glass standard[15]. I analyzed the same area of CMOG Reference B standard twenty consecutive times under each of the two settings (low and high Kv settings described above) to test the precision of data as raw counts/second and as calibrated weight percentages of elements as oxides and to test the accuracy of calibrated results (See Table 5-1). I employed the CMOG glass calibration files to calibrate results using *S1PXRF*. Precision refers to the extent to which a given set of measurements of the same sample agree with their mean, or in other words, the reproducibility of results (Rice 1987). In the table, precision is expressed as the coefficient of variation (%RDS), which gives a standardized measurement of dispersion. The coefficient of variation is equal to one standard deviation divided by the mean, multiplied by 100 to give a percentage (Shennan 1988: 44). Good precision includes %RSD values close to 1. Accuracy refers to how close the calibrated pXRF results are to the true values of the standard (using the published composition of CMOG Reference B glass standard in Brill 1999). Accuracy is given as the difference in weight percentages between the mean pXRF calibrated results for each element and the actual values. Depending on the concentration of the elements, a small percentage difference can lead to drastic inaccuracy in the results. Z-scores for the actual value of the standard, on the other hand, represent the deviation from the mean (pXRF measured) in

[15] Corning Museum of Glass created several standards, one of which is Reference B (Brill 1999). These are not standards registered with US Standards, but are generally agreed upon. A standard has a known composition and can be used to calibrate instruments used to interrogate the chemical composition of materials.

standard deviation units (Shennan 1988: 75), and offer a helpful gauge of accuracy. Z-scores were calculated by subtracting the mean of pXRF calibrated values from the actual, then dividing that result by the standard deviation. A negative Z-score indicates a value less than the mean, while a positive value is greater than the mean. The larger the number (either negative or positive), the larger the deviation from the mean value measured by pXRF.

Table 5-1. Calibrated pXRF Results: Precision and Accuracy Test. Cells highlighted below indicate unsatisfactory Z-scores, indicating a large discrepancy between the calibrated XRF results and the actual concentrations for each oxide.

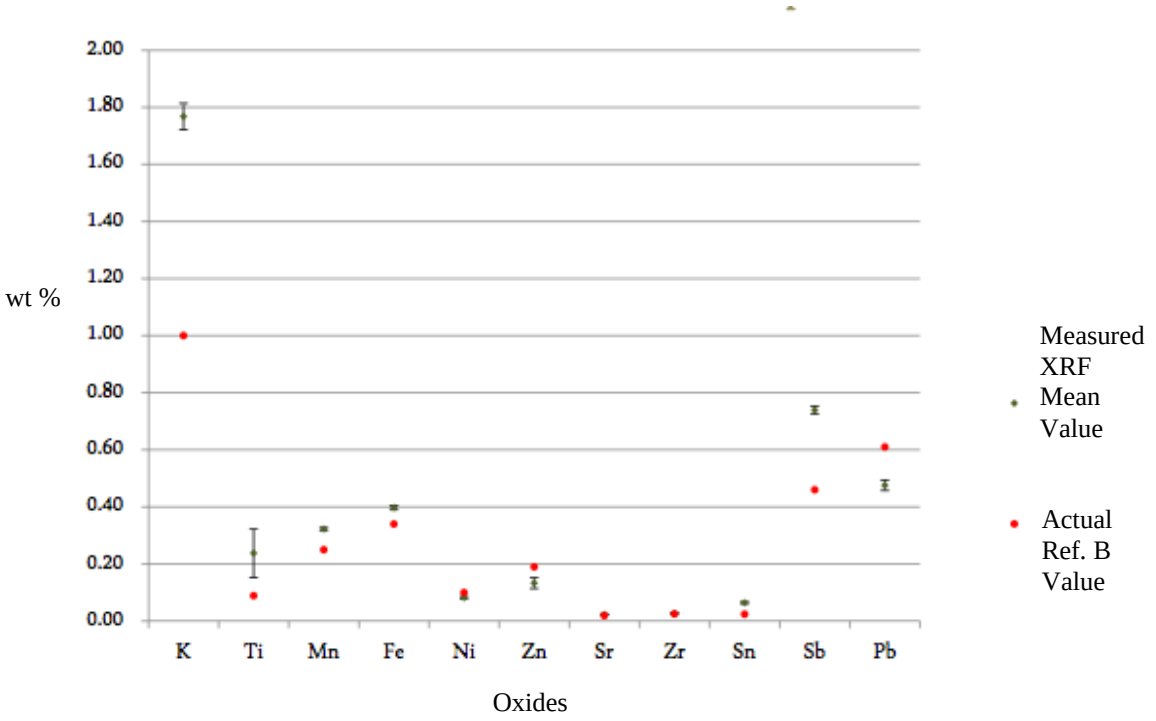
	Al_2O_3	SiO_2	K_2O	CaO	TiO_2	MnO	Fe_2O_3	ZnO	SrO	ZrO_2	Sb_2O_5	PbO	Total %**
Mean	**2.609**	**61.886**	**1.768**	**11.067**	**0.238**	**0.322**	**0.398**	**0.133**	**0.023**	**0.027**	**0.739**	**0.476**	**82.339**
Conf. interv. 0.05%	0.220	0.658	0.022	0.064	0.040	0.003	0.003	0.009	0.001	0.000	0.006	0.008	
1 STD	0.471	1.405	0.046	0.137	0.086	0.005	0.007	0.019	0.001	0.001	0.014	0.018	
2 STD	0.942	2.810	0.093	0.274	0.171	0.011	0.015	0.038	0.002	0.002	0.027	0.036	
% RSD	**18.049**	**2.270**	**2.617**	**1.240**	**35.940**	**1.669**	**1.856**	**14.175**	**5.207**	**3.622**	**1.837**	**3.762**	
Actual B Standard*	4.360	61.550	1.000	8.560	0.089	0.250	0.340	0.190	0.019	0.025	0.460	0.610	80.300
Accuracy (% difference)	**1.751**	**0.336**	**0.768**	**2.507**	**0.149**	**0.072**	**0.058**	**0.057**	**0.004**	**0.002**	**0.279**	**0.134**	**2.039**
Z score of Actual	3.719	-0.239	-16.597	-18.272	-1.742	-13.468	-7.800	3.018	-3.432	-2.054	-20.561	7.512	

* Actual composition of CMOG Reference B is derived from a revised composition proposed by Wagner *et al.* (2012) and Brill (1999).

**Not all elements as oxides included in the total are listed in this table.

Accuracy of the calibrated results is shown visually in Figure 5-21 below, where the pXRF mean values along with error bars representing one standard deviation are compared with the actual CMOG values. Especially in the cases of K and Sb, the actual value of the standard is well outside of the range of pXRF measured values.

Figure 5-1. Results from accuracy test. One standard deviation from the mean indicated for measured XRF mean values



These results helped determine the elements upon which I may rely for determining glass types and also helped clarify the optimal means of converting the pXRF raw data to a quantitative measurement for statistical analysis. It is clear from the calibrated results that the calibrations do not yield sufficiently accurate results for Mn and Sb, two main elements necessary for distinguishing compositional groups, especially colorless glass types (Foster and Jackson 2009, 2010). The precision is adequate for Sb (%RSD = 1.837), but the accuracy was extremely poor (Z-score when compared to actual Ref. B concentration = -20.561).

Instead of using calibrated results, data in the form of counts/second demonstrate a high level of precision for most elements (See Table 5-2 below). The exceptions are Cl (explanation previously stated), Ti, Co, and Ba (reading taken with high Kv settings). The elements primarily used to determine groups (highlighted in the table) all have acceptable levels of precision, except

for Ti. This is partially due to spectral interference--the L-lines of the Ba peaks overlap with the K-lines of the Ti peaks. Furthermore, the method I chose in *Artax* to conduct the net area analysis for low Kv spectra included both Ba and Ti. Including Ba in the method decreases the precision of Ti for unknown reasons. Most low Kv spectra do not contain Ba peaks. However, Ba was included in the method for three main reasons: 1) the known spectral interference, 2) Roman glass contains Ba, so if Ba levels are high enough to be detected at the low Kv settings, a peak should be present even if obscured by Ti peaks, and 3) the standard contains higher levels of Ba than the Karanis samples. The Ba peaks are clearly visible in low Kv spectra for the standard; since all elements are present, the spectra must be included in the *Artax* method, and since it was desired to use the same method for analyzing all spectra, Ba needed to be included in the method.

The precision of Ti can be increased, however, by adding Ti counts/second to Ba counts/second acquired with the low Kv setting since *Artax* calculates the value of the Ti/Ba peak and distributes the total counts between the two elements. Ba and Ti are present in Roman glass, and both elements can be used to help distinguish colorless and naturally colored glass types (Foster and Jackson 2009; 2010). Since I divide some of my glass groups based on Ti levels, I confirm these divisions of glass groups based on Ti levels through scatterplots and histograms of Ti and Ba sum counts/second rather than merely Ti counts/second (see Section 5.9).

Table 5-2. Precision test results: raw counts/second. Cells highlighted below are the coefficient of variation values for main elements used to determine compositional groups

COUNTS/SEC	Al	Ca	Cl	Fe	K	Mn	Si	Ti	Ba LowKv	Ba HighKv	Ti + Ba LKv
MEAN	**2.5989**	**122.6450**	**0.0242**	**37.3672**	**8.5097**	**18.1106**	**18.6875**	**0.6347**	**6.3906**	**9.1625**	**7.0253**
1 STD	**0.2169**	**0.7234**	**0.0393**	**0.4733**	**0.3376**	**0.3297**	**0.4379**	**0.4191**	**0.3463**	**1.1377**	**0.3925**
2 STD	0.4339	1.4468	0.0785	0.9466	0.6752	0.6595	0.8759	0.8382	0.6926	2.2753	0.7850
%RSD	**8.3473**	**0.5898**	**162.4292**	**1.2666**	**3.9671**	**1.8207**	**2.3434**	**66.0310**	**5.4187**	**12.4166**	**5.5866**

COUNTS/SEC	Co	Cu	Ni	Pb	Sb	Sn	Sr	Zn	Zr
MEAN	**0.5892**	**160.9847**	**4.5844**	**56.5094**	**205.1197**	**21.4231**	**9.6175**	**14.0683**	**15.4111**
1 STD	**0.2199**	**1.1514**	**0.2634**	**0.6507**	**1.9492**	**0.9899**	**0.3726**	**0.4447**	**0.4430**
2 STD	0.4397	2.3028	0.5268	1.3013	3.8984	1.9798	0.7451	0.8894	0.8859
%RSD	**37.3183**	**0.7152**	**5.7451**	**1.1514**	**0.9503**	**4.6207**	**3.8738**	**3.1612**	**2.8744**

The main limitation of using raw counts instead of calibrated results is that results cannot be directly compared to other published studies without absolute values for elements. However, since the precision is acceptable for key elements in determining compositional groups and raw counts result in the least amount of error introduced during the transformation of raw data to quantitative measurements (Kaiser and Shugar 2012; Kaiser, personal communication 2010), I choose to use raw counts rather than calibrated results for quantitative analysis. I also cross-checked quantitative data by looking at the actual spectra to verify that the peaks in the spectra actually correspond to the elements measured in the net area analysis.

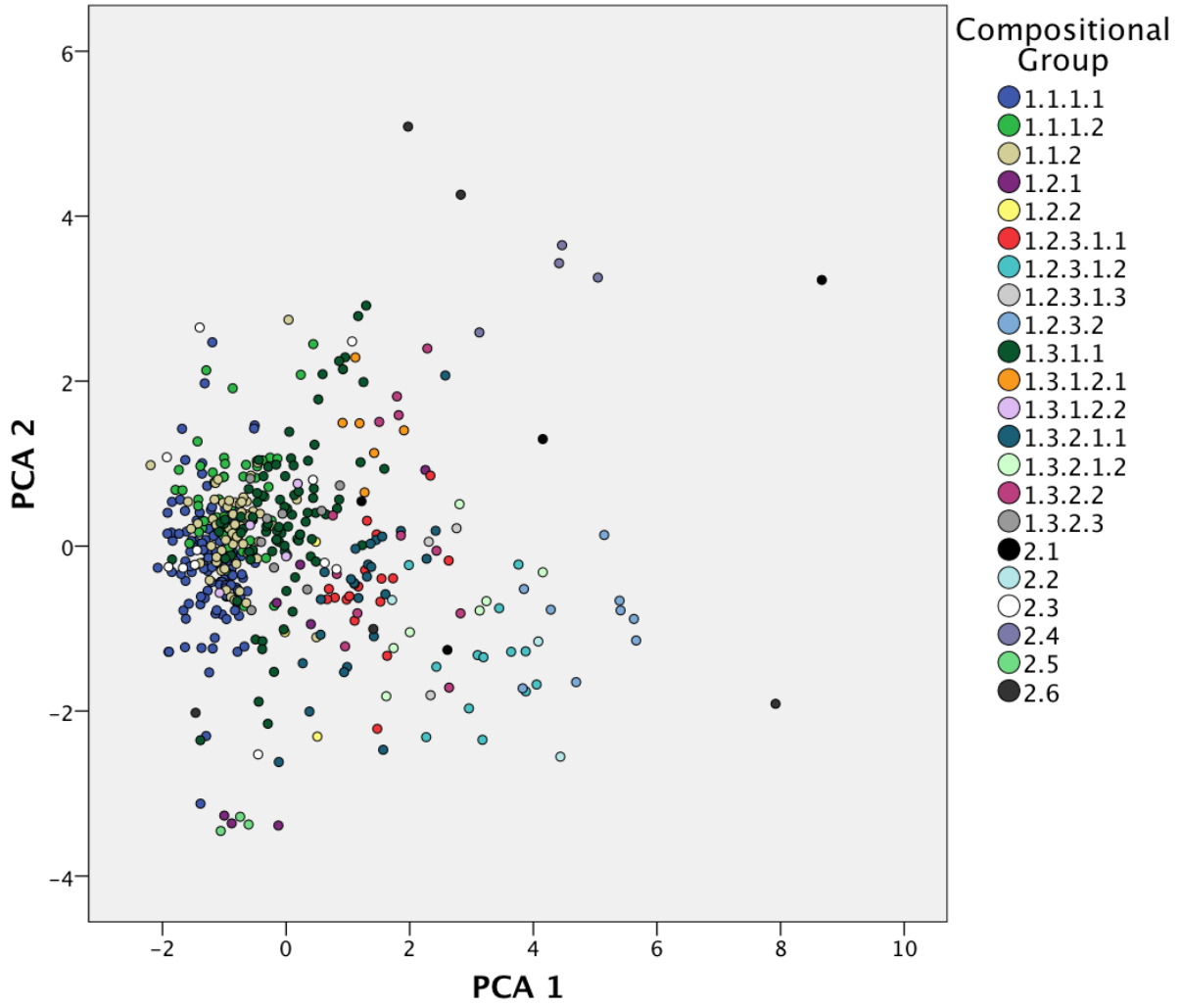
5.7 Methods: Statistical Analysis

I analyzed the quantitative data in raw counts/second primarily using simple statistical methods rather than multivariate statistics. This is because the presence of irrelevant variables when carrying out multivariate statistics can hide the structure present in other variables if they are analyzed together, resulting in the incorrect groupings. Furthermore, there are no statistical means to evaluate the veracity of results from multivariate statistical methods such as cluster analysis (Read 2007). Since there are many elements comprising the composition of glass, however, I carried out Principle Components Analysis (PCA) of seven of those variables known to be key elements for determining glass types (Al, K, Ca, Ti, Mn, Fe, and Sb) to see if I could reduce the number of dimensions to two or three new variables (principle components) to help find patterning in the data. PCA has been used to analyze glass compositional data such as these data, often using the protocol outlined by Baxter for archaeological glasses (*SPSS* v.12) (Baxter 1994; Foster 2004; Foster and Jackson 2009, 2010). This multivariate technique did not prove to be very useful for this study, since distinct groups or strong patterns were not visible in the scatterplots of the new dimensions created (Principle Components, PCA 1 and 2 in Figure 5-2). Since my main goal in carrying out PCA was to reduce the heterogeneity of the data set and this technique was not successful in doing so, I pursued other methods.

The chemical composition groups in the Figure 5-2 below are groups determined through simple statistics rather than through PCA. This shows how different groups determined through other means may not show visible patterns in this scatterplot of PCA dimensions (Read, March 2015, personal communication). This does not discount the validity of the group divisions, but rather shows how patterning in the data can be hidden when a heterogeneous sample population is analyzed all together with PCA. No distinct groupings are visible in the PCA scatterplot

below (Figure 5-2). One can only see that there is a larger group of samples that cluster together on the left, and that other points are dispersed around this large cluster.

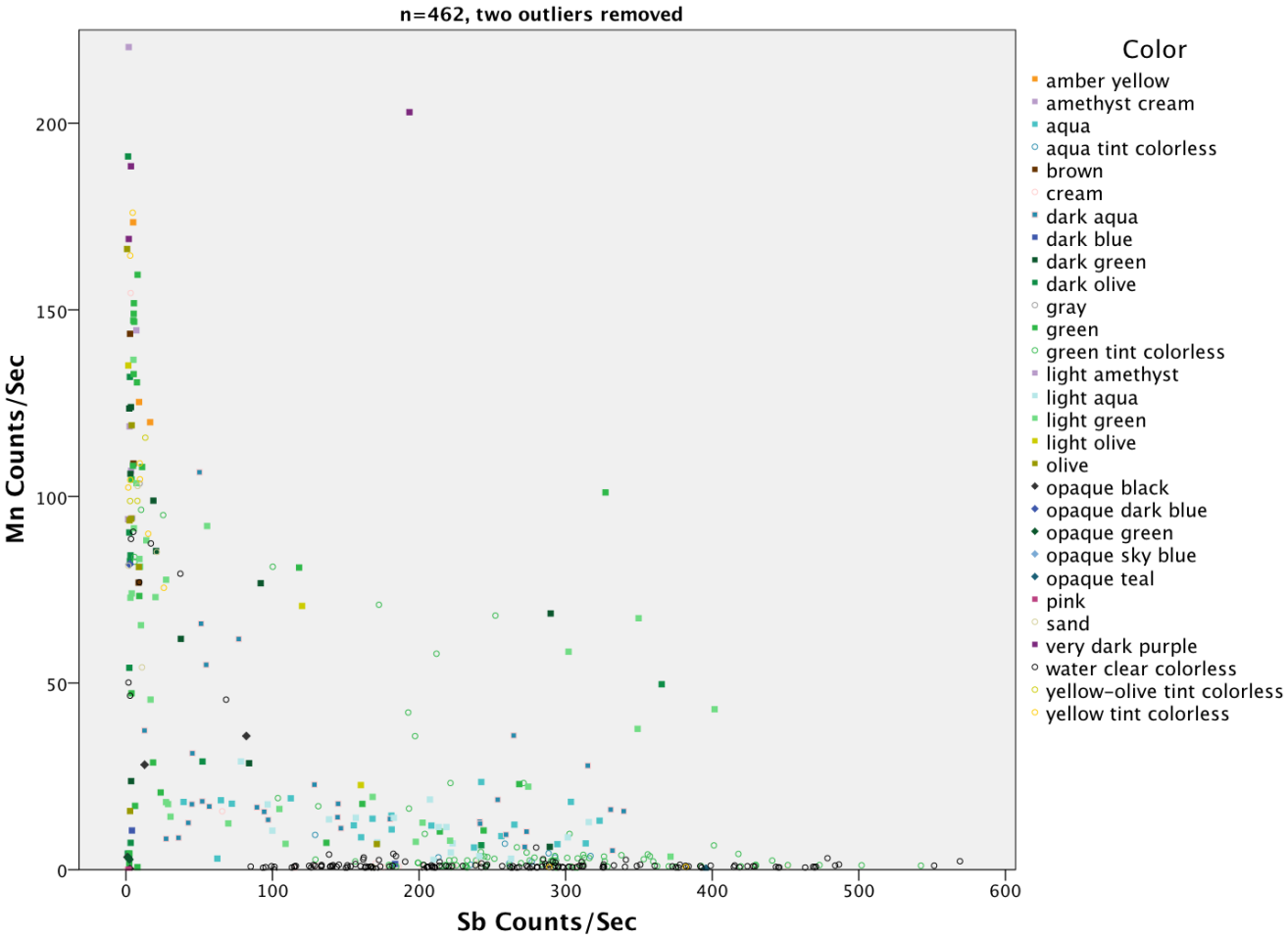
Figure 5-2. PCA Analysis, 7 variables condensed to 2 PCAs, n=464. Compositional groups in legend correspond to final compositional groups determined through Read's (2007, 2015) iterative process (see below)



PCA did not succeed in reducing the dimensionality of the data in a manner revealing easily seen patterning, so I carried out the following methods to arrive at distinct compositional groups. Knowing from preliminary results that a scatterplot of Sb and Mn shows distinct groupings, I generated the scatterplot below (Figure 5-3) and included all samples except for two extreme outliers (n=462). I excluded one sample because it contained double the amount of Mn

as was in most of the samples and its presence reduced the scale and visibility of the remaining data. I used this graph to help identify obvious patterning visible through adding a third dimension, color, as shown in the legend.

Figure 5-3. Antimony and manganese biplot of total population, n=462 (two outliers removed)



A few general patterns can be observed. The majority of the water clear colorless glass have levels of Sb ranging from about 85 counts/sec to around 500 counts/sec and virtually no Mn. There is a loose cluster of various shades of aqua and green glass that has a wide range of Sb levels (approx. 25-350 counts/sec) and a low range of Mn (approx. 5-35 counts/sec). The majority of the dark colored green and olive glasses do not contain Sb and have varying levels of

Mn. It is also apparent that the majority of the water clear colorless and tinted glasses either have Mn or Sb, but rarely have both elements present.

This scatterplot also shows that water clear colorless glasses consist of at least three different groups: Sb-decolorized, Mn-decolorized, and two samples that may contain both decolorizers. This graph also shows that tinted glass falls into these three categories as well, and so by removing a certain color of glass, one would remove more than one compositional type of glass and perhaps diminish the ability to identify patterns that characterize of each of these compositional groups. Furthermore, previous studies have shown that differences in color do not always signify significant differences in elemental composition. Since I desire to identify groups based solely on compositional groups, I chose not to divide these groups on qualitative grounds, color, since this may introduce additional error. The only exceptions are excluding the three dark purple samples mentioned above, and removing outliers.

5.7.1 Removing Outliers

Part of the reason (but only part of the reason) why PCA was not successful with this data set is that you must start out with a homogeneous data sample (Read 2015). As mentioned, I omitted the three dark purple samples from the data set. In addition, other significant outliers needed to be removed from the main sample population (n=464) because they can have a disproportionate impact on results. These outliers were assigned to Group 2 (See Table 5-3 for a list and description of these outliers and Figure 5-4 for a scatterplot showing abnormal levels of Mn and/or Sb for these outliers). Outliers included samples with certain agents added to the glass to give it certain properties: opacifiers (lead antimonate or calcium antimonate) or coloring agents (cobalt, copper, and manganese). Note that Mn is also a decolorizer, but when added at

higher levels, imparts a purple color to the glass. The high levels of Mn added to the glass may confuse which glass group this glass originally belonged to before the color was added. HIMT glass, for instance, has high levels of Mn, and these purple glasses may appear to belong to this group based on Mn levels, but have a quite different composition otherwise. Similarly, an opacified sample will contain higher levels of Sb (due to the calcium antimonate or lead antimonate), but may or may not have belonged to a Sb-decolorized glass group prior to the addition of the opacifier. I also excluded certain samples I had already flagged in my database as possible non-glass samples, including faience or perhaps modern materials. All samples flagged showed up as outliers due to their abnormal compositions. Therefore, these were removed as well. Other samples that were removed as outliers included those that may have been Roman glass samples, but had clearly invalid pXRF data (abnormally low peak levels and, consequently, invalid quantitative data for all elements). Outliers are assigned to subgroups based on qualitative differences. Group 2.1 comprises opaque glass; Group 2.2 is purple glass; Group 2.3 comprises samples high in Pb; Faience or slag samples are Group 2.4; Group 2.5 includes samples that are not glass; Group 2.6 are outliers with unusual levels of various elements or heavily weathered samples.

Figure 5-4. Sb and Mn biplot of outliers, n=30

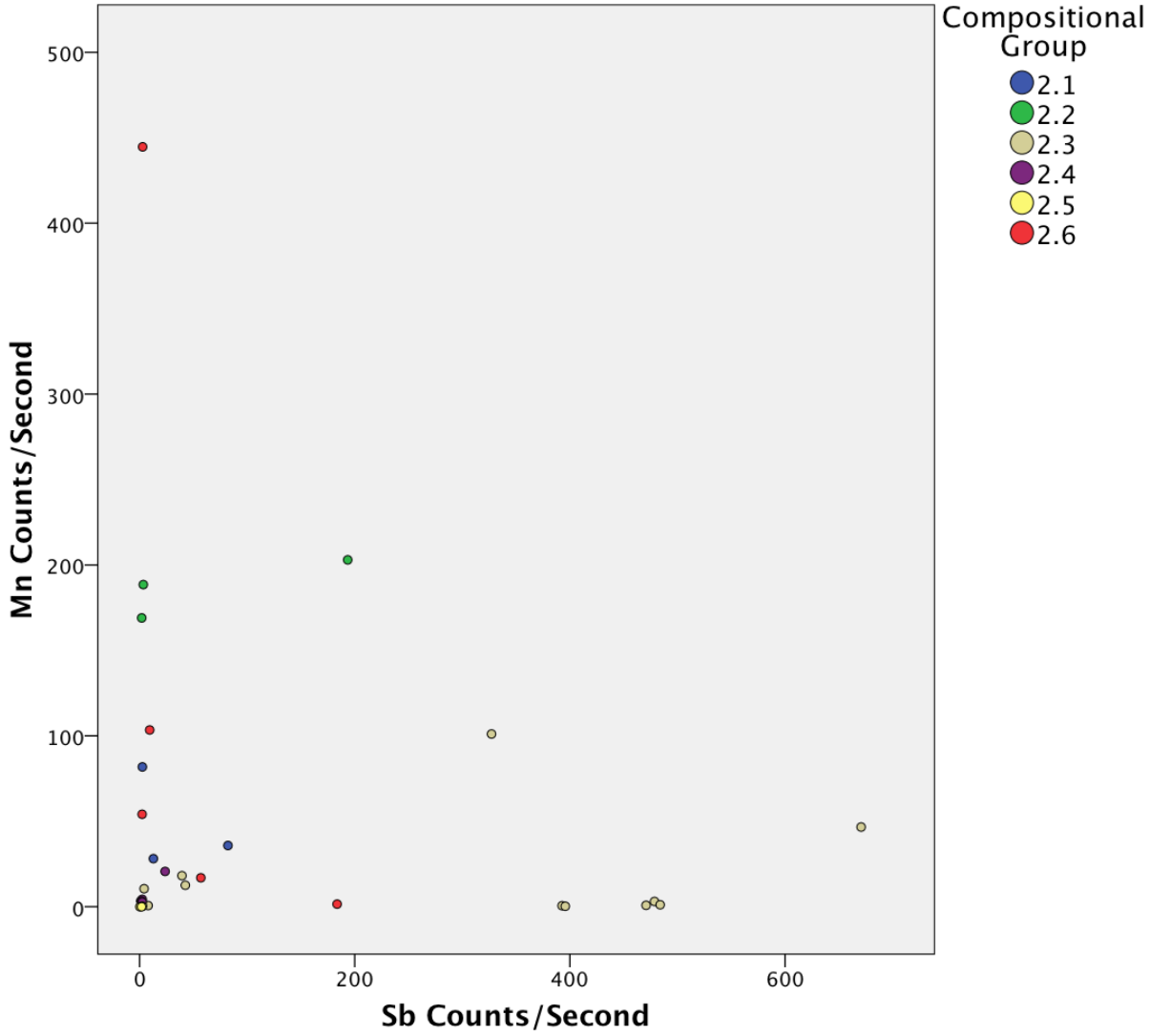


Table 5-3. Description of outliers, n=30. See Table 6-7 below for description of Harden fabric numbers (0=unknown) and see Appendix 8 for Harden form number descriptions

SPEC ID	Compositional Group	Color	Harden Fabric	Harden Form	Notes
371	2.1	opaque black	0	0	opacifier added
381	2.1	opaque black	0	0	opacifier added
417	2.1	opaque dark blue	0	14	opacifier added, colorant added
729	2.1	opaque black	0	14	opacifier added
278	2.4	green	0	14	slag or faience
280	2.4	green	0	0	slag or faience
643	2.4	opaque green	0	0	slag or faience
646	2.4	opaque green	0	0	slag or faience
295	2.5	cream	0	0	non-glass specimen
481	2.5	opaque black	0	0	non-glass specimen
548	2.5	pink	0	0	non-glass specimen
115	2.6	dark aqua	3	13	abnormally high K
236	2.6	gray	3	0	heavily weathered
238	2.6	dark olive	4	0	abnormally high Mn
312	2.6	dark blue	0	0	colorant added
721	2.6	dark olive	3	0	abnormally high Ca, heavily weathered
212	2.3	green	3	14	high lead
219	2.3	water clear colorless	1	7	high lead
377	2.3	dark blue	7	1	high lead, colorant added
456	2.3	opaque sky blue	0	9	high lead
516	2.3	water clear colorless	1	2	high lead
522	2.3	aqua	3	2	high lead
604	2.3	water clear colorless	1	7	high lead

612	2.3	dark aqua	3	9	high lead
637	2.3	water clear colorless	1	7	high lead
688	2.3	green	4	9	high lead
699	2.3	opaque teal	0	14	high lead, colorant added
439	2.2	very dark purple	6	1	Mn colorant added
535	2.2	very dark purple	6	1	Mn colorant added
666	2.2	very dark purple	6	9	Mn colorant added

5.7.2 Iterative Process of Determining Compositional Groups

I employ the method outlined in Read (2007, 2015) to convert a heterogeneous data set into a homogeneous data set. This iterative procedure involves dividing a data set according to bimodalities identified in frequency histograms of single variables or clear clusters visible in biplots (comparing two variables at a time). Bimodalities in a frequency histogram may signify a heterogeneous data set that can be divided into two separate groups, based on the boundary between the two modes (Read 2007, 2015). The total population is divided into two or more subgroups, and each subgroup is divided using the same process with other variables.

Read's (2007, 2015) iterative procedure for quantitative analysis is as follows:

1) investigate each variable individually for multiple modes
2) subdivide the data set based on these mode(s), if any
3) repeat Steps 1 and 2 with each data subset until further subdivisions based on single variables cannot be made
4) explore pairs of variables among each of the data subsets to identify any multi-modal distributions

5) subdivide the data subsets according to the modes identified in Step 5
6) repeat Steps 1-5 on each subset until further subdivisions are not possible
7) repeat Step 4 with other pairs of variables, followed by Steps 1-6 (Read 2015: 119)

All other outliers (n=28) were excluded from the main sample population and assigned to Group 2, while the remaining 436 samples belong to Group 1. To subdivide Group 1, I produced frequency histograms of key elements to identify any bimodalities. Figures 5-5 and 5-6 below illustrate the iterative process by which I divide Group 1 in order to identify compositional types. The letters under each group correspond to histograms and biplots in the text below that support the division of each group into two or more subgroups. The colored text boxes represent final compositional groups. Each color signifies general glass types. Gray text boxes indicate groups that are further subdivided. The parameters underneath the group number in each text box indicate the parameters that define that particular group. Note the hierarchical nature of the diagram, meaning that parameters for parent groups also apply their children groups. Suggestions for which known glass types from previous studies may represent a particular group are indicated at the bottom of text boxes for some groups.

Figure 5-5. Summary of the iterative process used to determine compositional groups. Group 1.1 and 1.2 are outlined in this diagram.

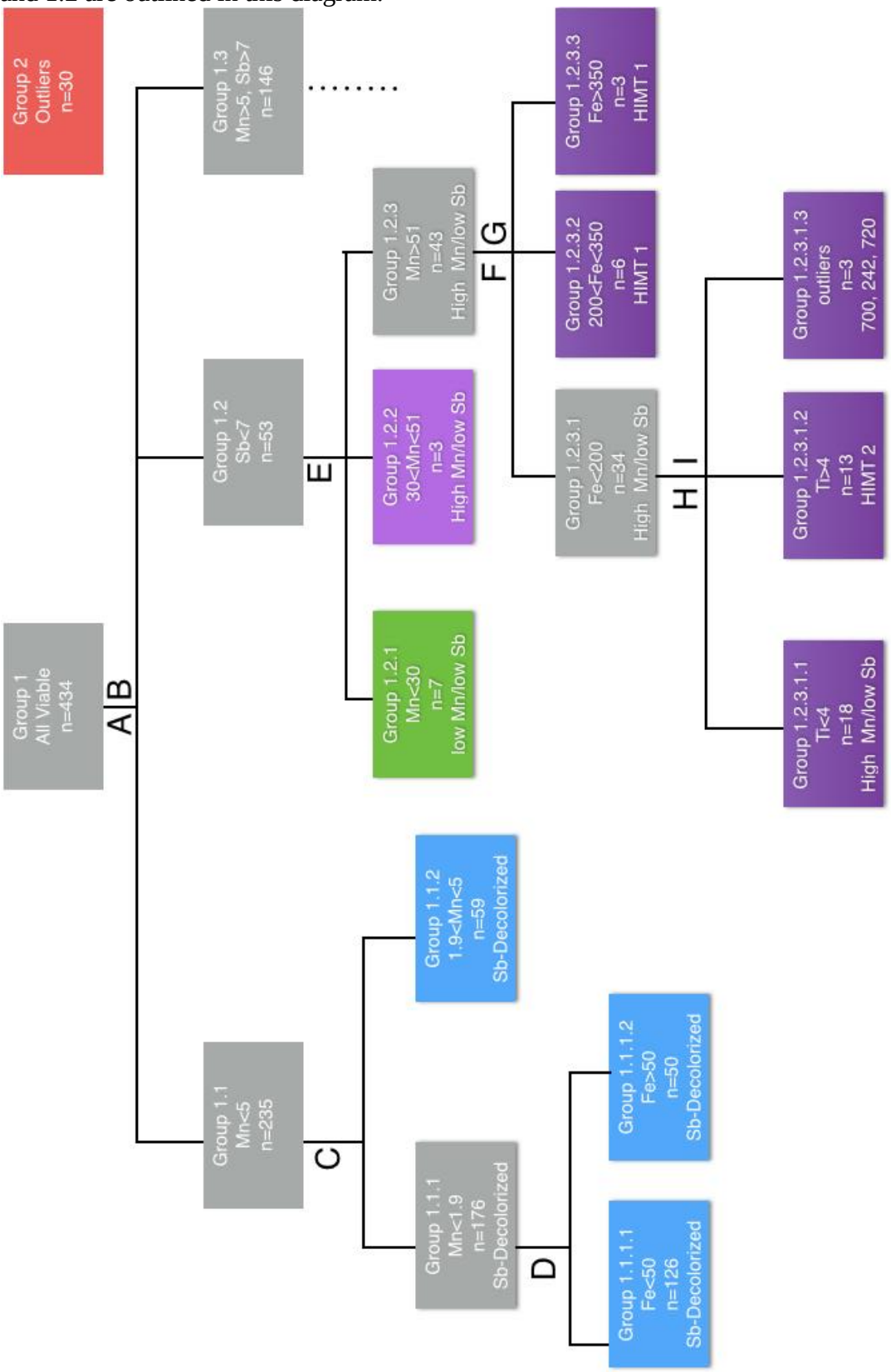
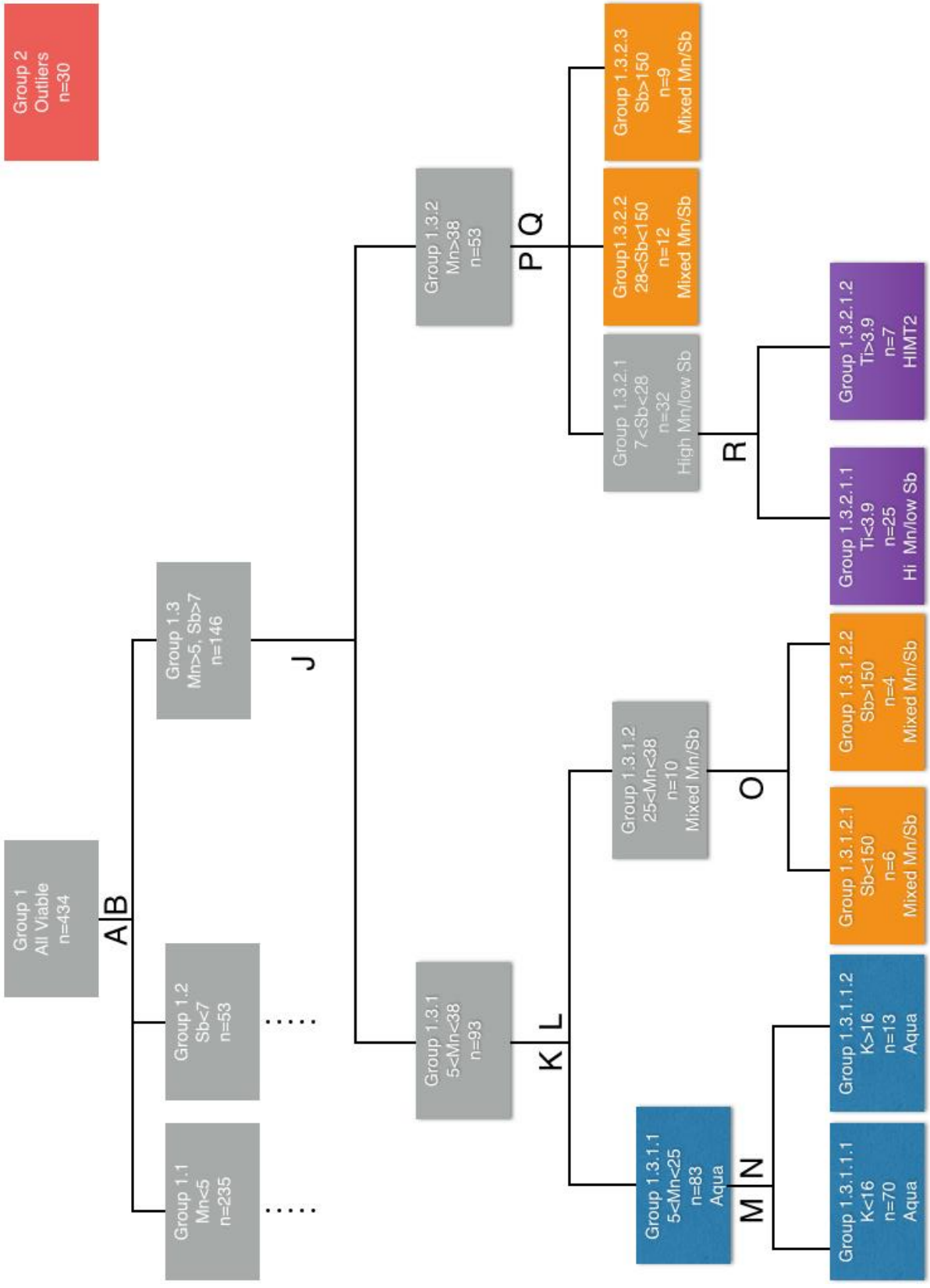


Figure 5-6. Summary of the iterative process used to determine compositional groups. Group 1.3 is outlined in this diagram.

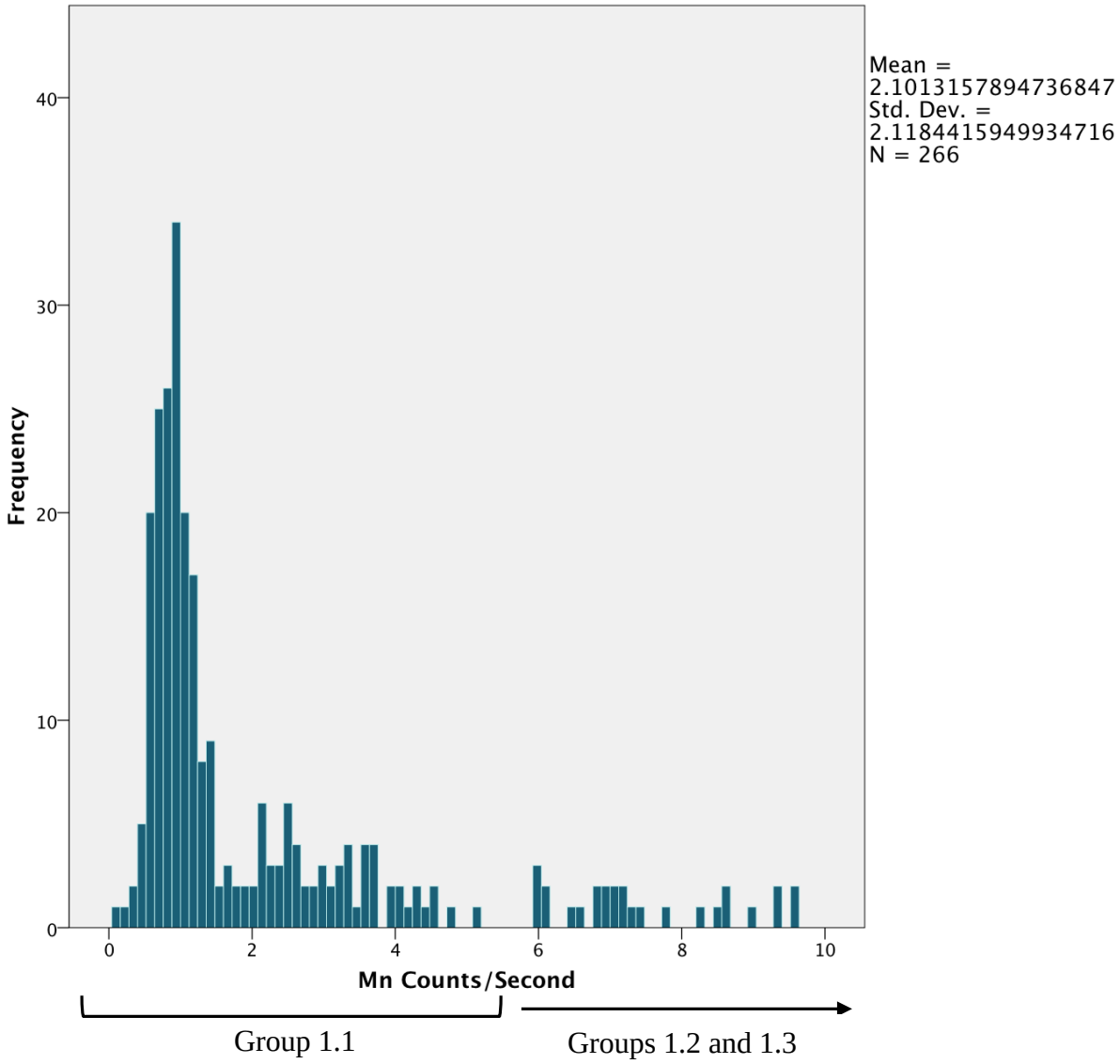


The Sb and Mn biplot above (Figure 5-3) shows two clear groups: 1) samples containing virtually no Mn and varying levels of Sb, and 2) those containing virtually no Sb and varying levels of Mn. The remaining samples comprise a much more heterogeneous data subset of samples with varying levels of both Mn and Sb. I divide Group 1 into these three qualitative groups to reduce the heterogeneity of the data set: Group 1.1 (Mn<=0, Sb>0), Group 1.2 (Mn>0, Sb<=0), and Group 1.3 (Mn>0, Sb>0). The boundaries by which I divide Group 1, however, I determine through the following quantitative analysis. I must first determine the largest value (counts/second) representing a zero value for either of the two elements. If Mn, for instance, is not present in the sample, the instrument may still output a low number of counts for Mn. Since Mn levels are below the minimum detection limit, however, these counts are inaccurate. Frequency histograms are a means to determine the minimum detection limit, as the range of values representing zero values for each variable will comprise one mode and values above the minimum detection limit will comprise another mode.

Determining the boundary between Group 1.1 and Groups 1.2 and 1.3

Although I evaluated a Mn frequency histogram of the entire population (n=464) to identify multiple modes, the histogram below (Figure 5-7) includes only Mn values less than 10. Restricting the range of the histogram allows the shortening of bin widths so that potential boundaries between modes can be determined. The histogram shows a clear bimodality, with a boundary between modes at Mn = 5 counts/second.

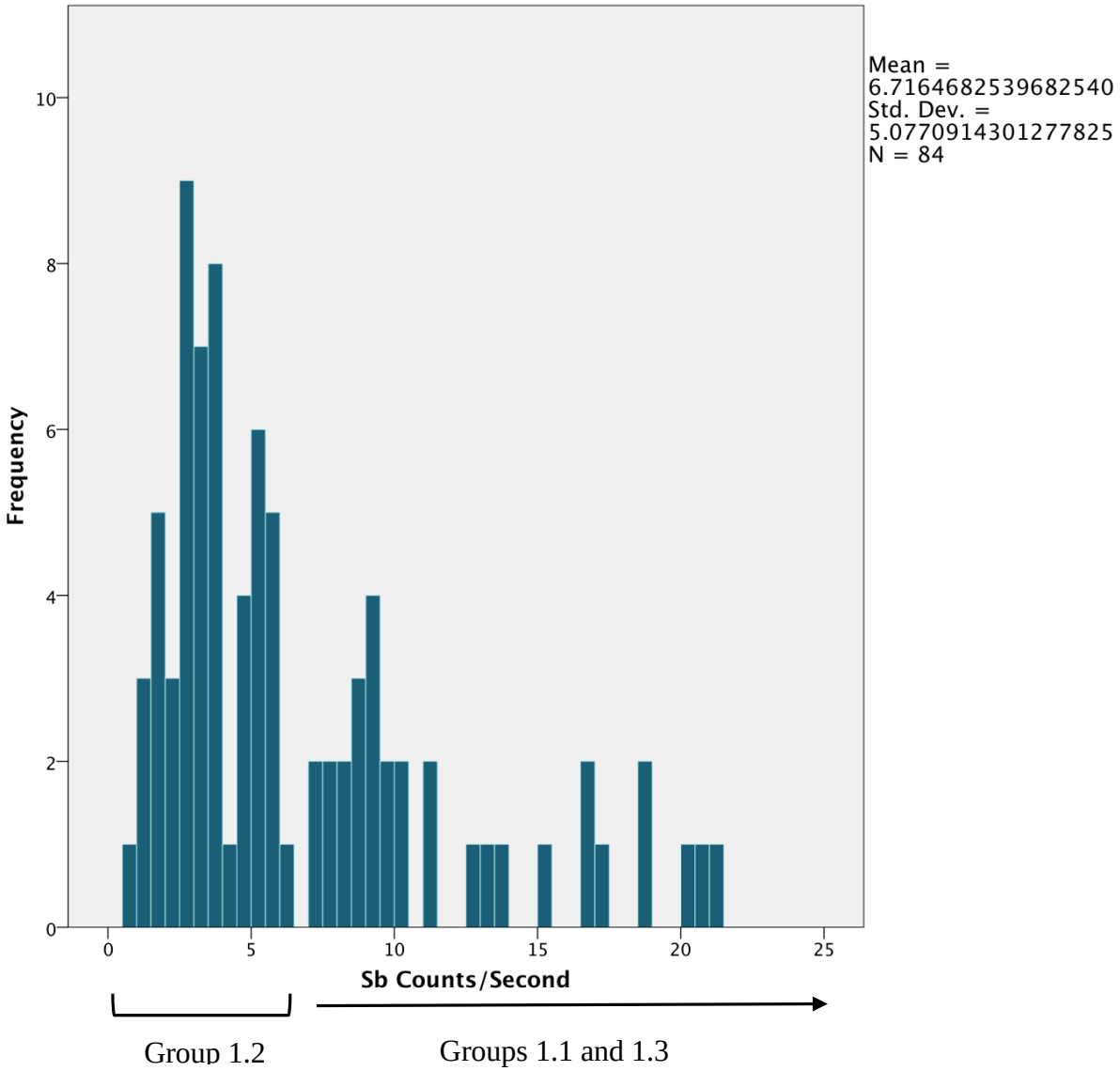
Figure 5-7. Histogram A in Fig. 5.5. Frequency histogram of Mn counts/second for Mn values less than 10 (n=266)



Determining the boundary between Group 1.2 and Group 1.3

After distinguishing the boundary between Group 1.1 and the rest of the population based on Mn levels, I determine the boundary between Group 1.2 and Group 1.3 through the evaluation of Sb levels. The histogram below (Figure 5-8) restricts the range of the total population to 25 Sb counts/second in order to shorten the bin widths and to allow for better visibility of boundaries between modes. There is a clear boundary between modes at 7 counts/second; therefore, this boundary divides Group 1.2 and 1.3.

Figure 5-8. Histogram B in Figure 5.5. Frequency histogram of Mn counts/second for Sb values less than 25 (n=84)

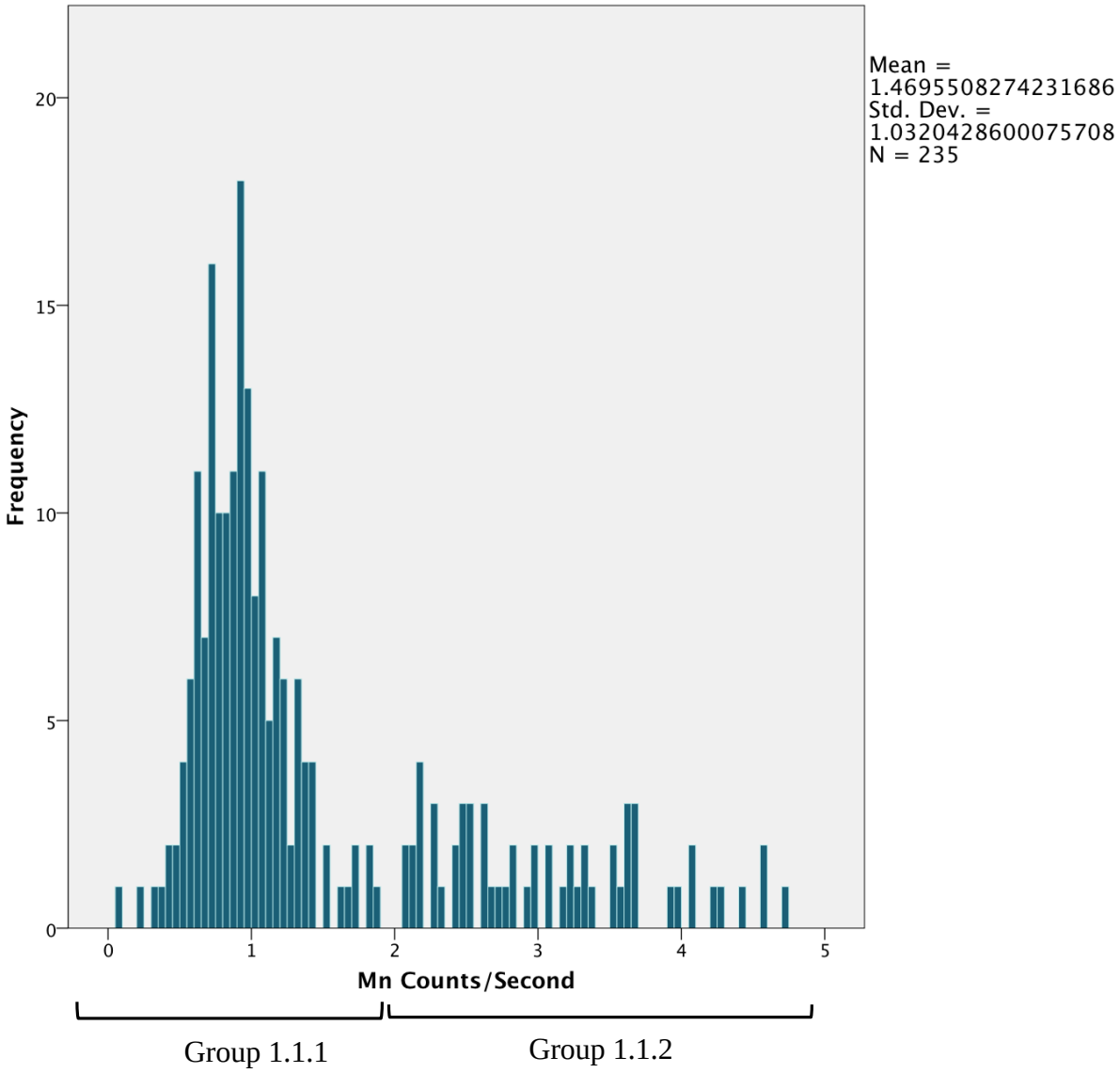


Dividing Group 1.1 into Groups 1.1.1 and 1.1.2

Group 1.1 include samples with virtually no Mn and various levels of Sb. The Sb and Mn biplot with colors of samples indicated in the legend (Figure 5-3) reveals a pattern that almost all water

clear colorless samples have Mn values under 2. The Mn histogram of Group 1.1 below (Figure 5-9) indicates a boundary between two modes at 1.9.

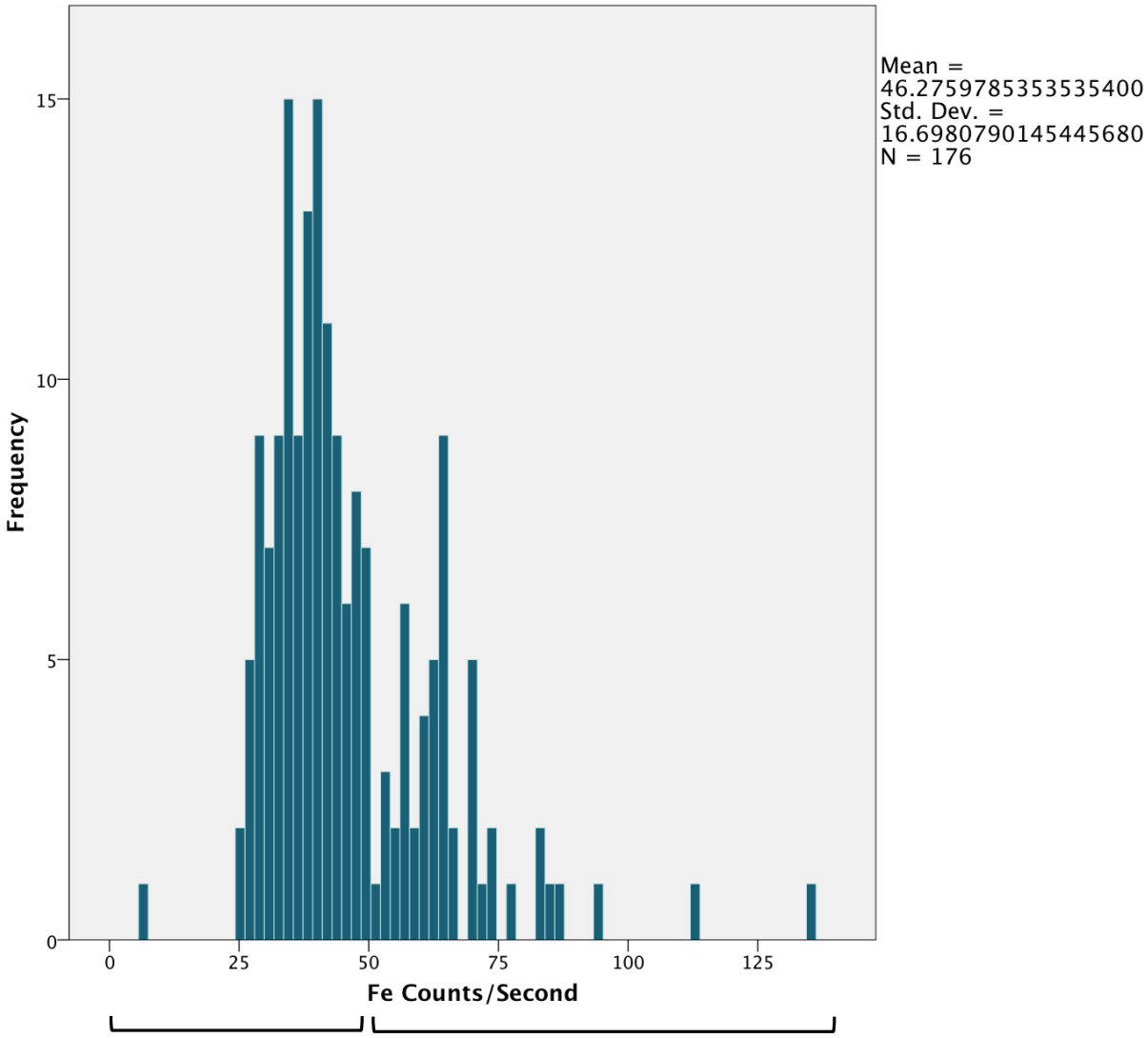
Figure 5-9. Histogram C in Fig. 5.5. Frequency histogram of Mn for Group 1.1 (n=235)



Dividing Group 1.1.1 into Groups 1.1.1.1 and 1.1.1.2

A frequency histogram of Fe counts/second indicates that Group 1.1.1 can be further subdivided. Figure 5-10 below shows a boundary between two modes at 50 counts/second.

Figure 5-10. Histogram D in Fig. 5.5. Frequency Histogram of Fe counts/second for Group 1.1.1 (n=176)



Dividing Group 1.2 into 1.2.1 and 1.2.2 and 1.2.3

The frequency histogram below (Figure 5-11) of Group 1.2 Mn counts/second shows three modes. The boundaries between modes are at 30 counts/sec and at 51 counts/second. The mode from 30 counts/second to 51 counts/second is distinct from the other two modes. A biplot of Mn and Sb (Figure 5.12 below) clarifies that these three points cluster closely together and are separate from the other two clusters.

Figure 5-11. Histogram E in Fig. 5.5. Frequency histogram of Mn counts/second for Group 1.2

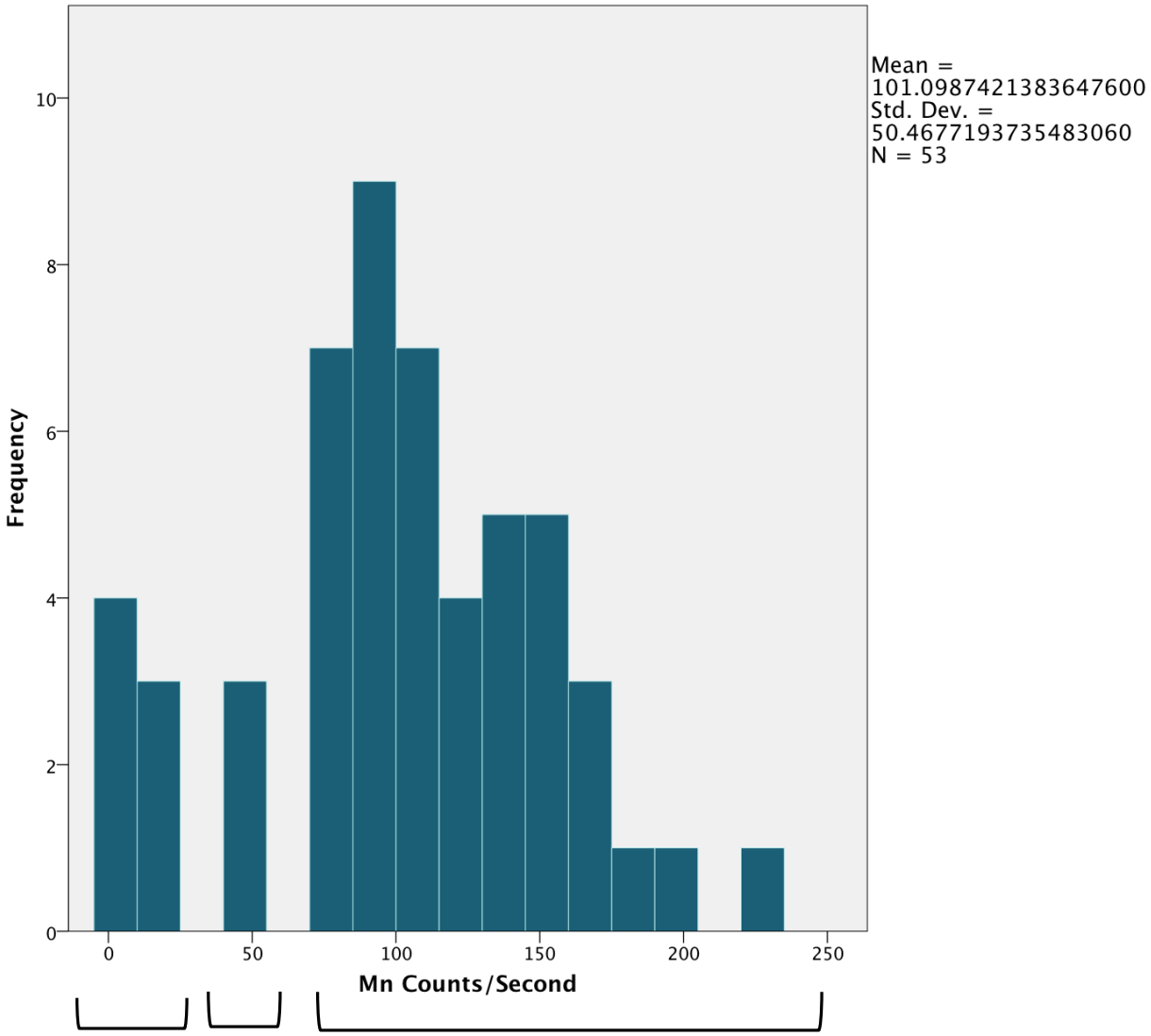
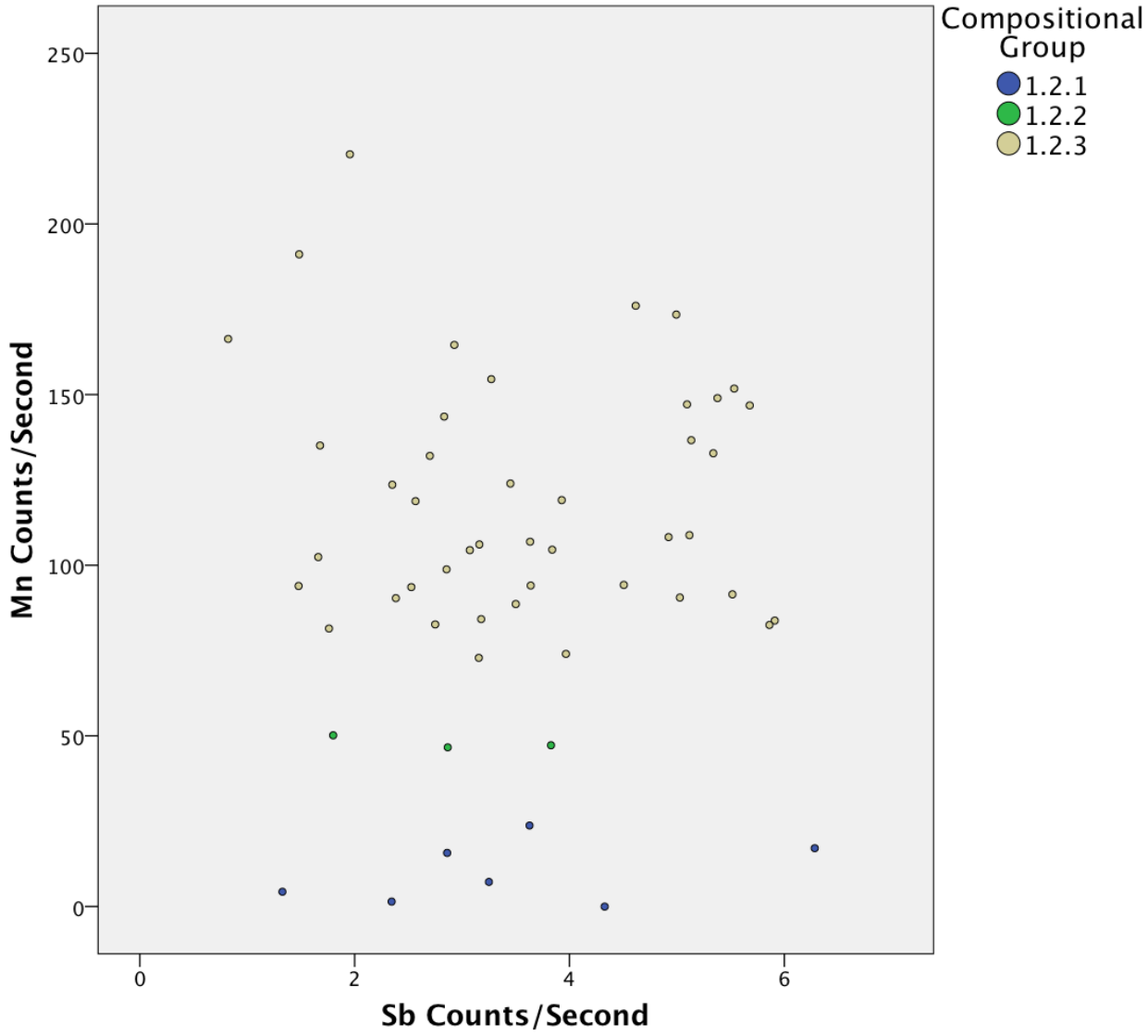


Figure 5-12. Ti and Fe biplot for Group 1.2 (n=53) showing three subgroups: 1.2.1, 1.2.2, and 1.2.3.



Dividing Group 1.2.3 into 1.2.3.1, 1.2.3.2, and 1.2.3.3

Groups 1.2.1 and 1.2.2 comprise 7 and 3 samples respectively. They are homogenous groups that do not need to be further subdivided. Group 1.2.3, however, comprises 43 samples and can be subdivided according to Fe levels. The frequency histogram below (Figure 5-13) shows a boundary between two modes at 200 counts/second and another boundary between modes at 350 counts/second. A biplot of Ti and Fe (Figure 5-14) also shows a distinct cluster of

points above 200 counts/second and another distinct cluster of three points above 350 counts/second. The red lines indicate that the boundary separating these three groups are not horizontal; rather, both Fe and Ti levels distinguish these groups.

Figure 5-13. Histogram F in Figure 5.5. Frequency histogram of Fe count/second for Group 1.2.3 (n=43)

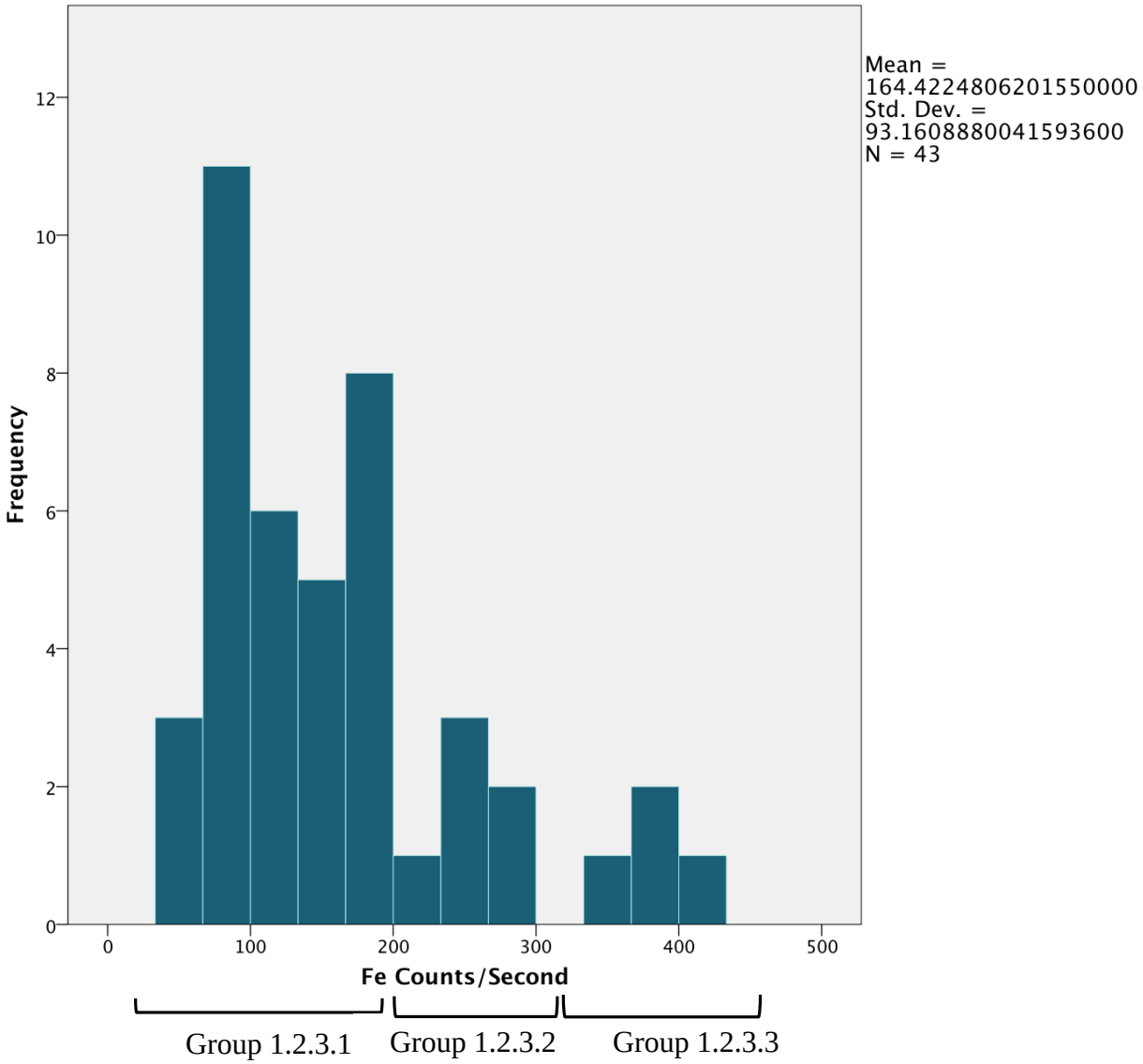
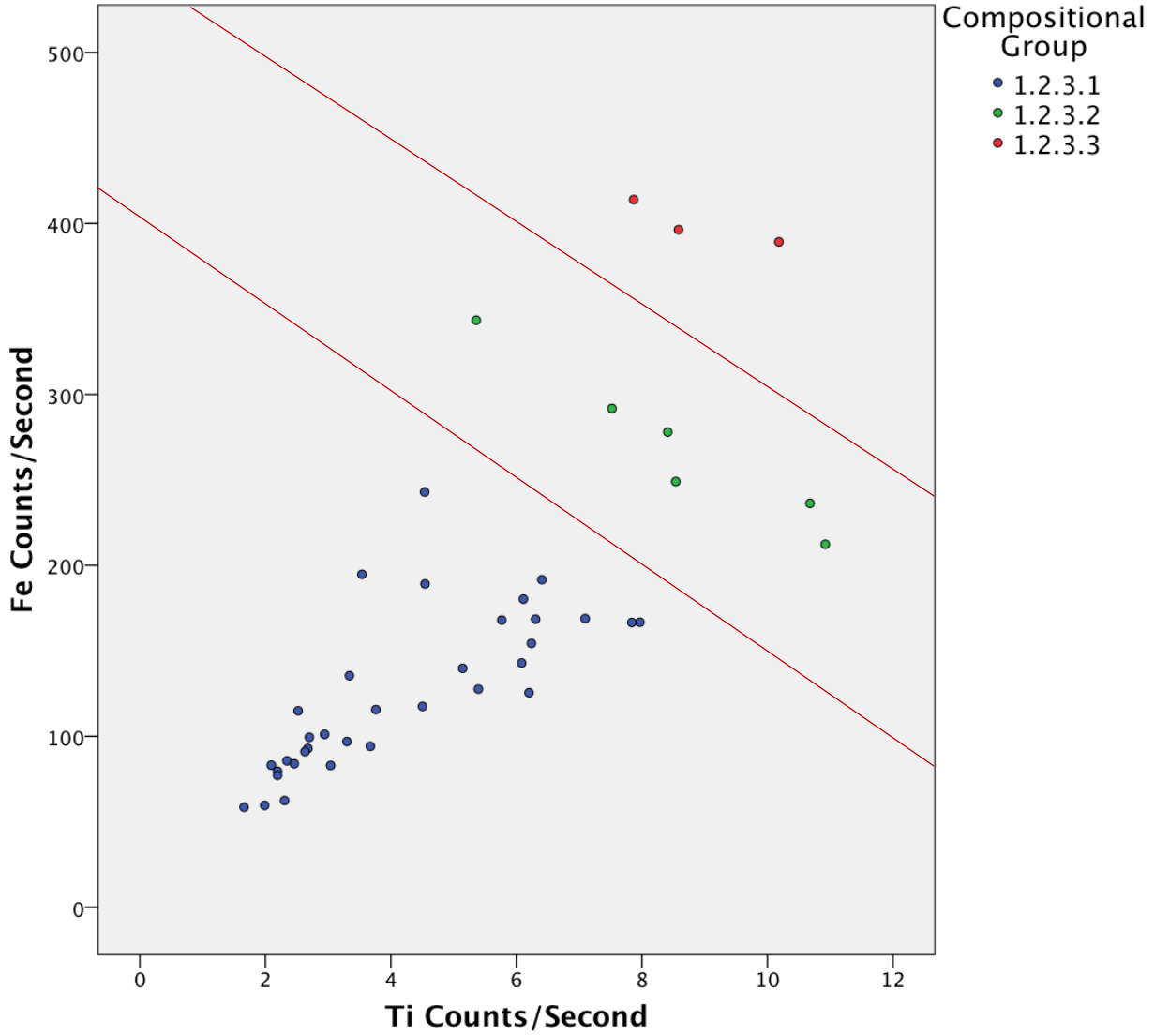


Figure 5-14. Biplot G in Fig. 5.5. Ti and Fe biplot for Group 1.2.3 (n=43)



Dividing Group 1.2.3.1 into Groups 1.2.3.1.1, 1.2.3.1.2, and 1.2.3.1.3

Group 1.2.3.1 can be divided further, since three distinct clusters can be distinguished in the biplot below (Figure 5-15). The three outliers (Group 1.2.3.1.3) form a distinct cluster in the biplot. A frequency histogram of Ti counts/second also supports the division of 1.2.3.1 into two groups (see Figure 5-17 below). Group 1.2.3.1.3 is not visible as a separate mode in the histogram because both Ti and Fe levels distinguish this group from the other two. The biplot below (Figure 5-16) of all samples belonging to Group 1.2.3.1 shows a weak positive correlation of Ti and Fe (R^2=5.47). When Group 1.2.3.1.3 outliers are removed, this correlation is significantly strengthened (R^2=8.29, see Figure 5-17 below).

Figure 5-15. Biplot H in Fig. 5.5. Biplot of Ti and Fe for Group 1.2.3.1 (n=34) showing subgroups. Linear regression shown for total points in Group 1.2.3.1.

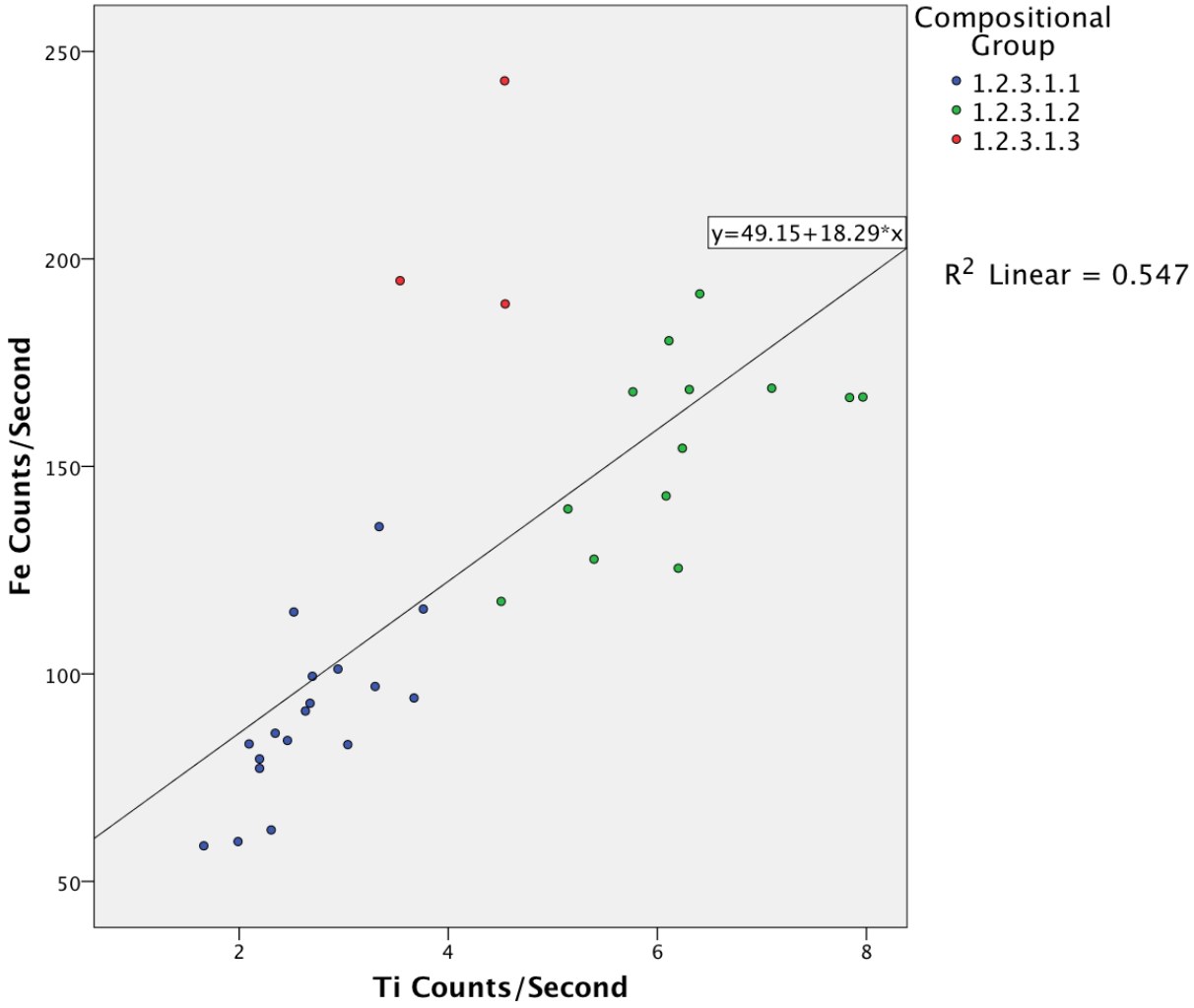


Figure 5-16. Groups 1.2.3.1.1 (n=18) and 1.2.3.1.2 (n=13) showing strong positive correlation of Ti and Fe when Group 1.2.3.1.3 outliers are removed.

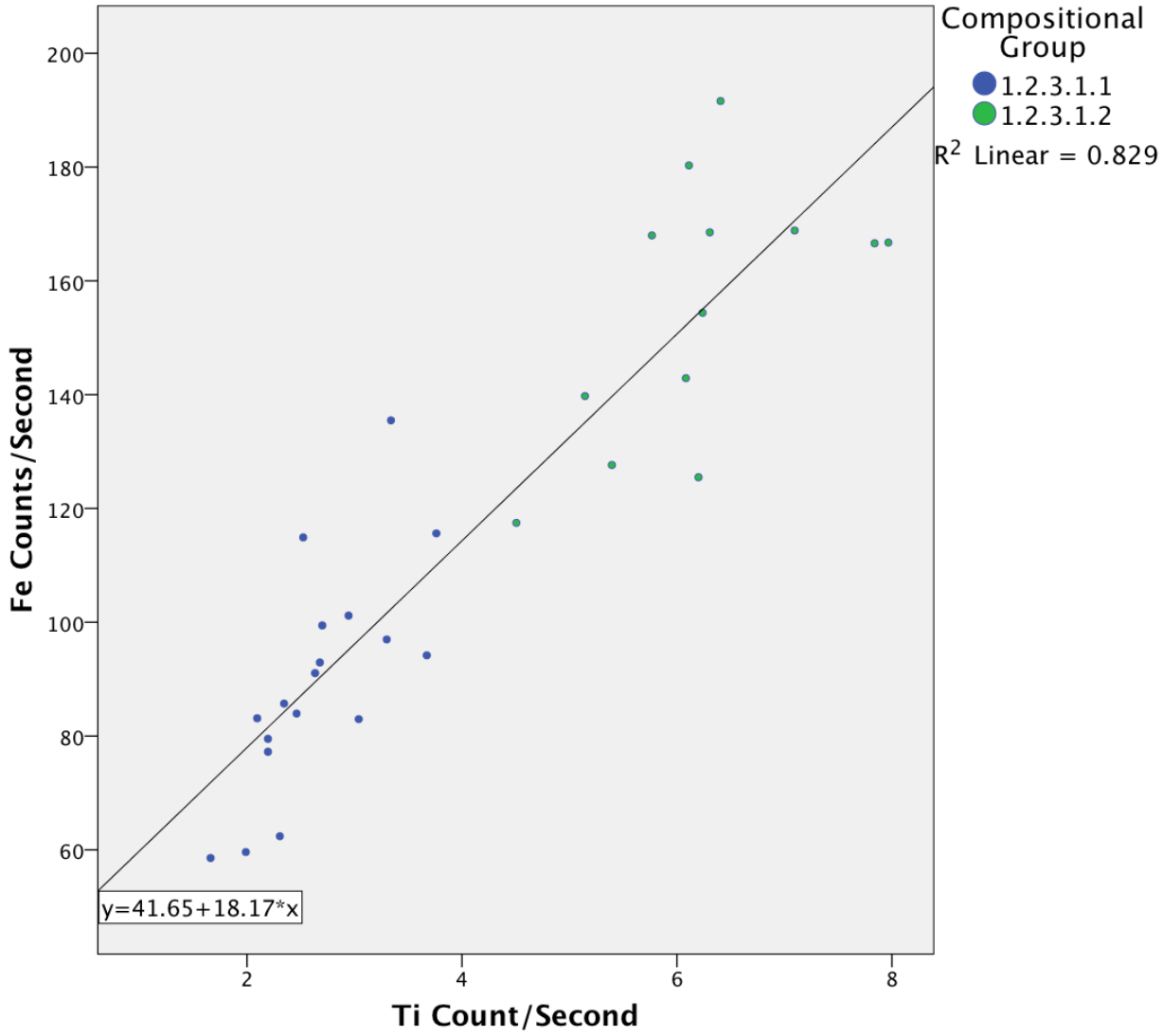
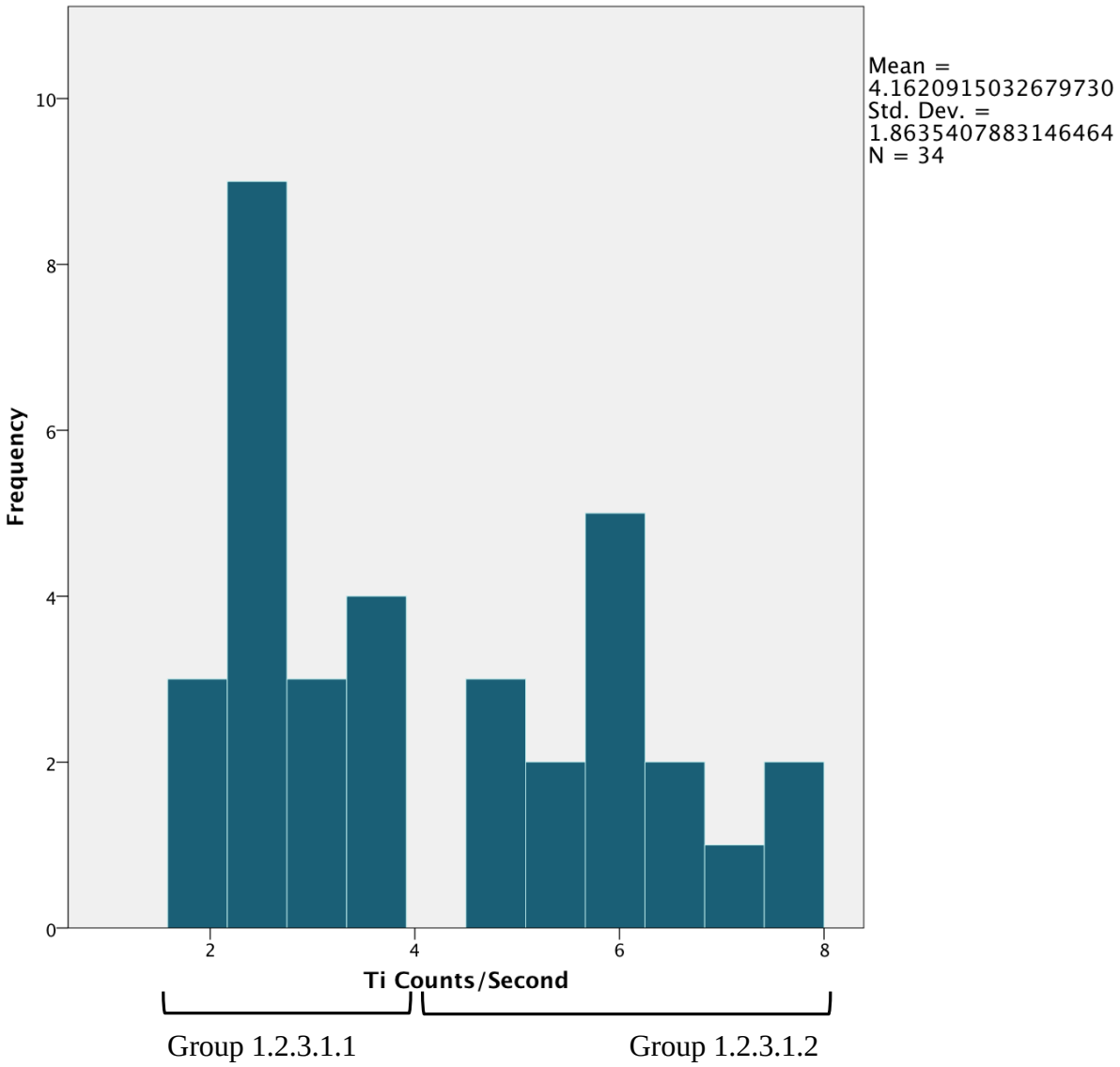


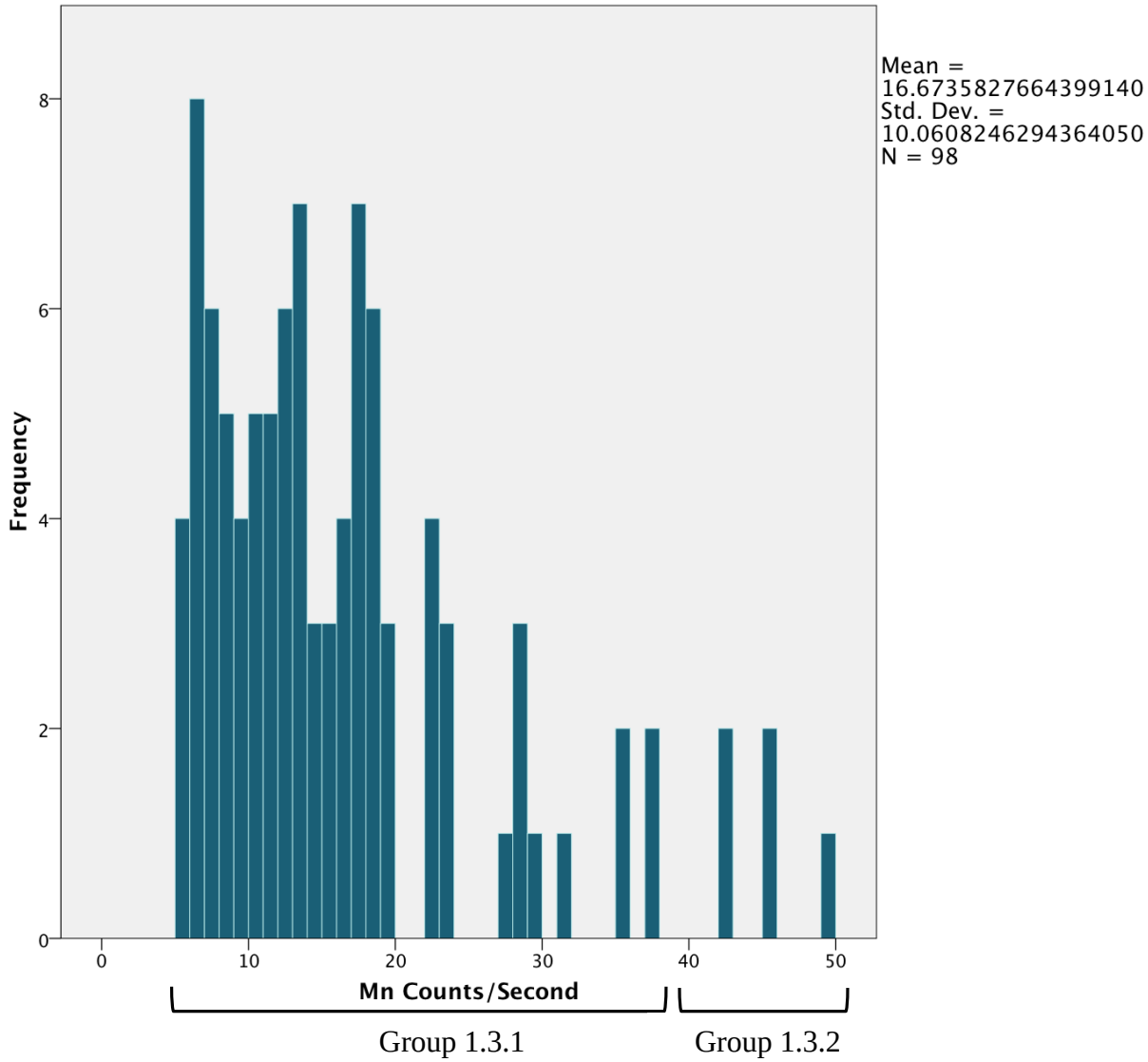
Figure 5.17. Histogram I in Fig. 5.5. Frequency histogram of Ti for Group 1.2.3.1 (n=34). Note that group 1.2.3.1.3 is hidden in the right mode, but can be seen in the biplot (Figure 5-15) above.



Dividing Group 1.3 into Groups 1.3.1 and 1.3.2

Group 1.3 is a heterogeneous group of cases containing moderate to high levels of both Mn and Sb. A histogram of Mn counts/second for Group 1.3 shows a bimodality (see Figure 5-18 below). Only samples for which Mn counts/second are less than 50 (n=98) are included so that the bins widths can be shortened and the boundary between modes can be seen. The boundary between the two modes is at 38 counts/second.

Figure 5-18. Histogram J in Fig. 5.6. Frequency histogram of Mn counts/second for samples with Mn less than 50 in Group 1.3 (n=98)



Dividing Group 1.3.1 into Groups 1.3.1.1 and 1.3.1.2

I subdivide Group 1.3.1 according to a bimodality I identify in a frequency histogram of Mn counts/second (see Figure 5-19 below). There is a boundary between two modes at 25 counts/second. This boundary can also be seen in the biplot below (Figure 5-20) of Sb and Mn.

Figure 5-19. Histogram K in Fig. 5.6. Frequency histogram of Mn counts/second for Group 1.3.1

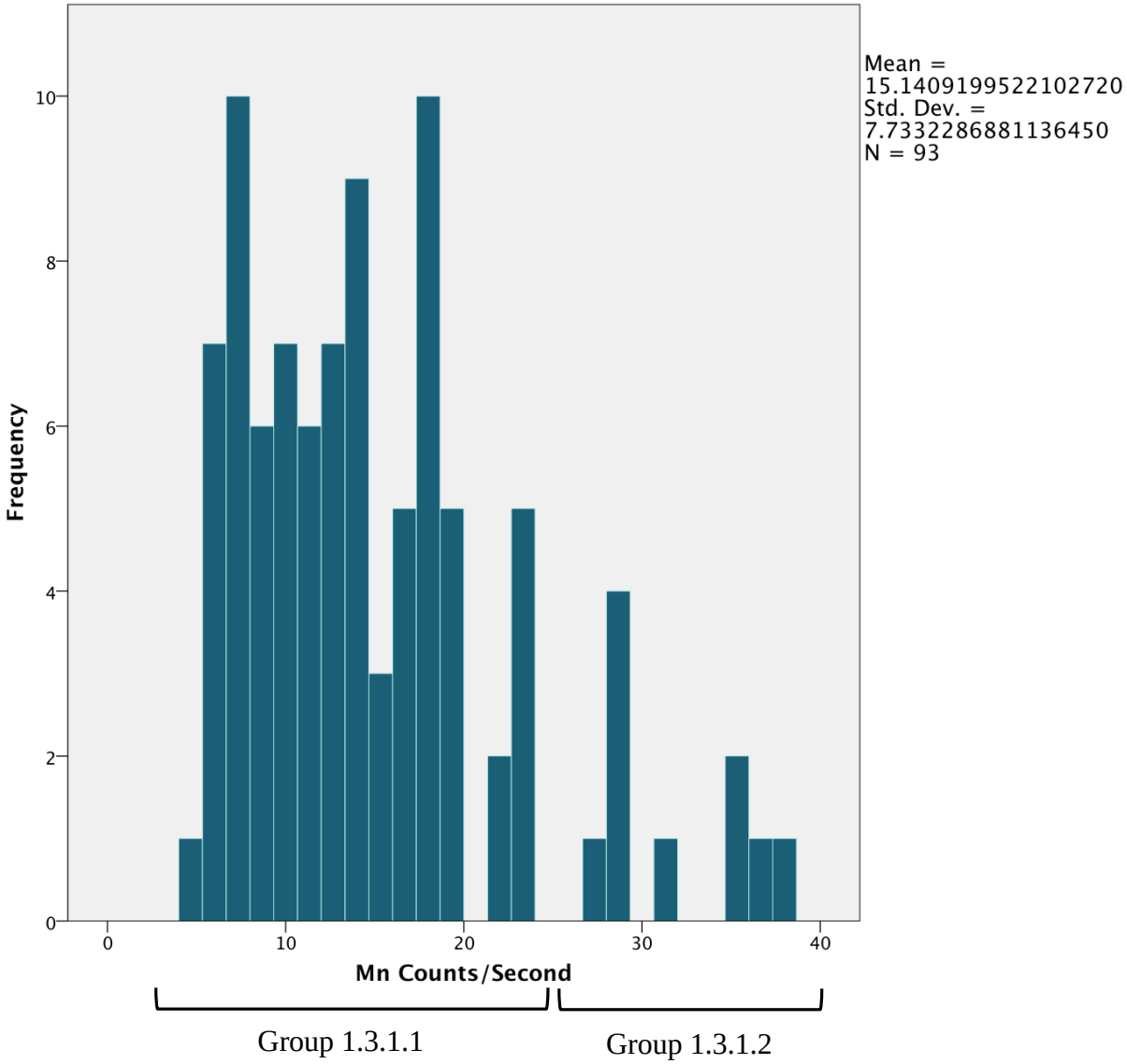
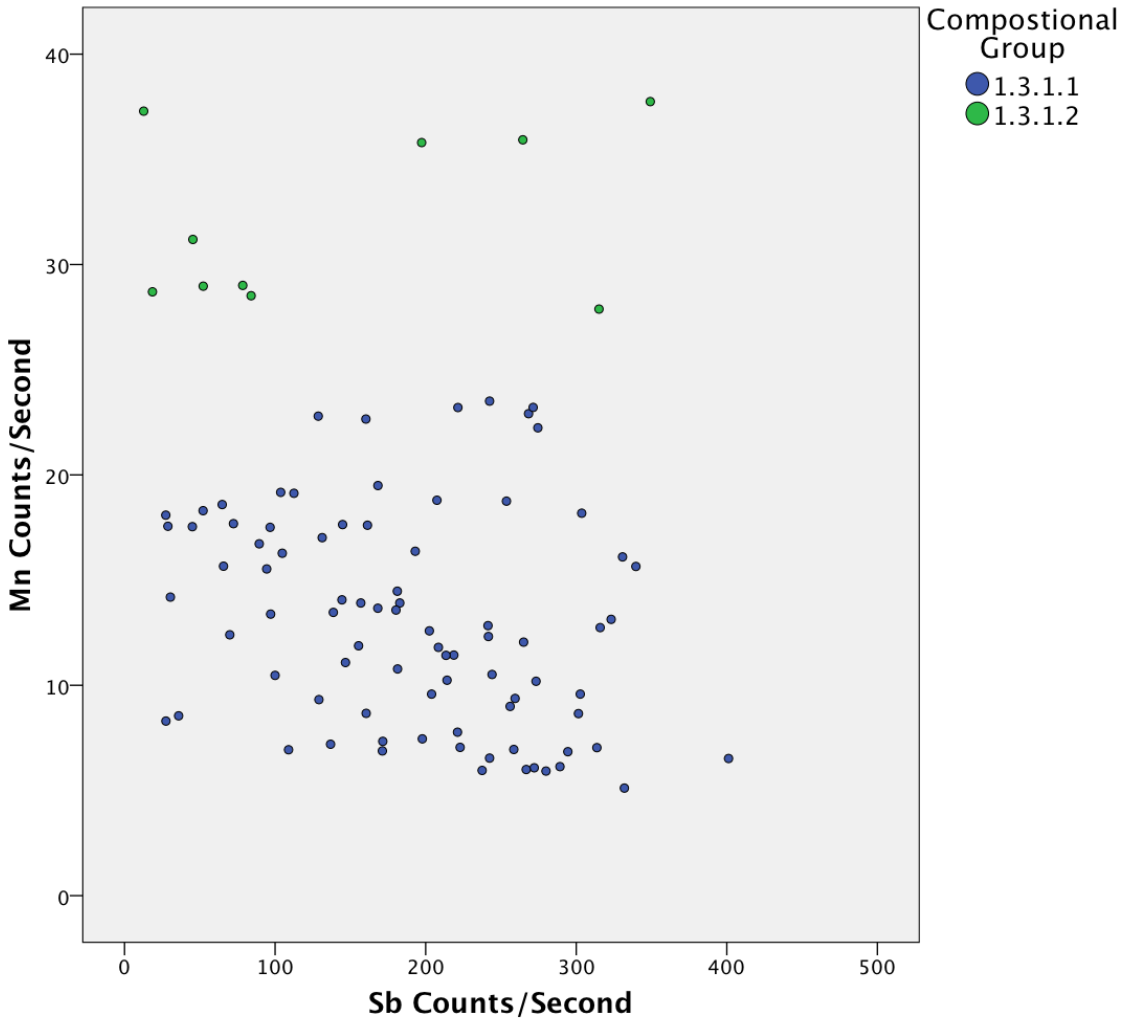


Figure 5-20. Biplot L in Figure 5.6. Biplot of Sb and Mn for Group 1.3.1 (n=93)



Group 3.1.1 can be further subdivided based on K levels. The histogram of K below (Figure 5-21) shows a boundary between two modes around 16 counts/second and this same division can be seen in the K and Fe biplot below (Figure 5-22).

Figure 5-21. Histogram M in Fig. 5.5. Frequency histogram of K counts/second for Group 1.3.1.1

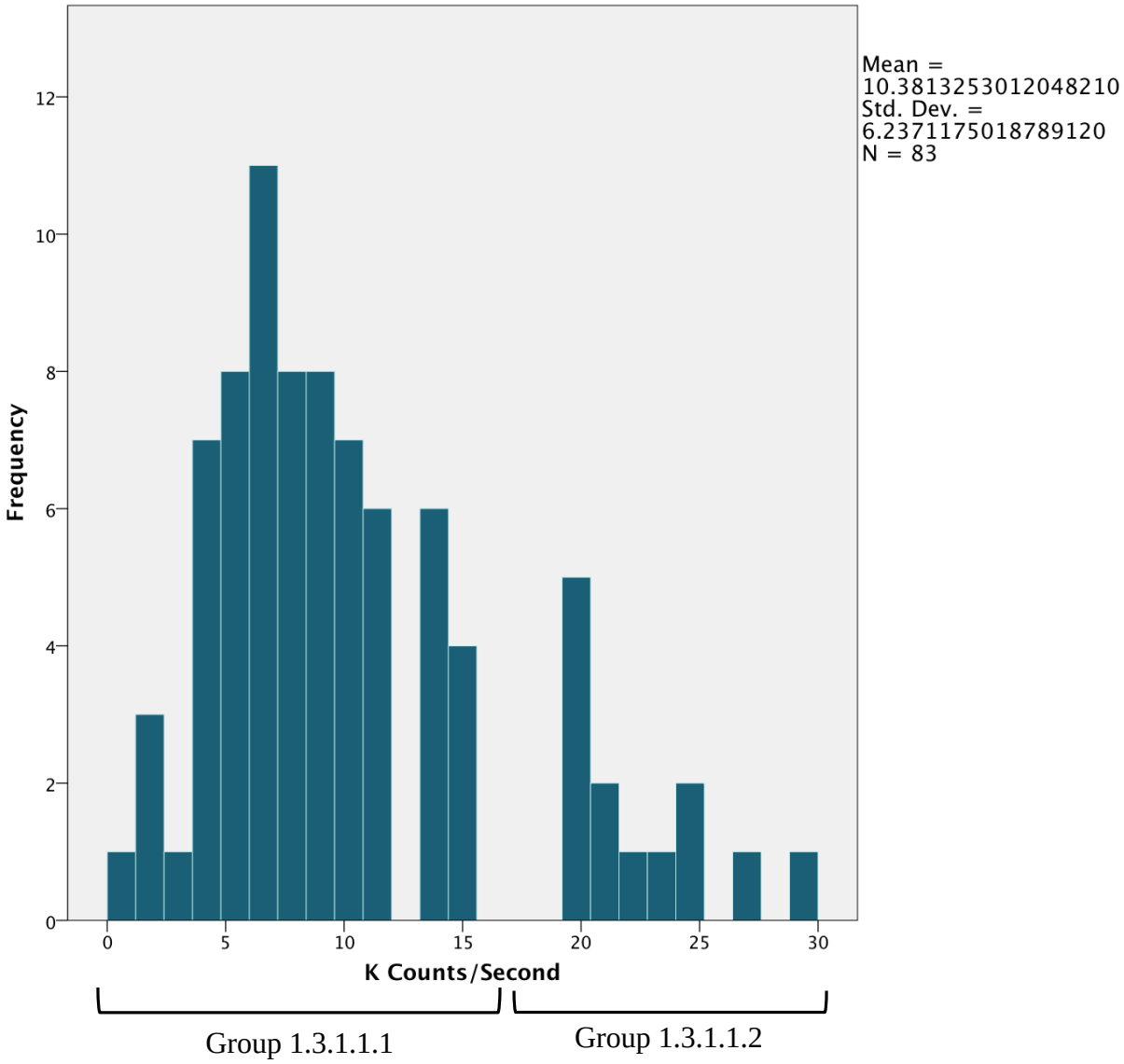
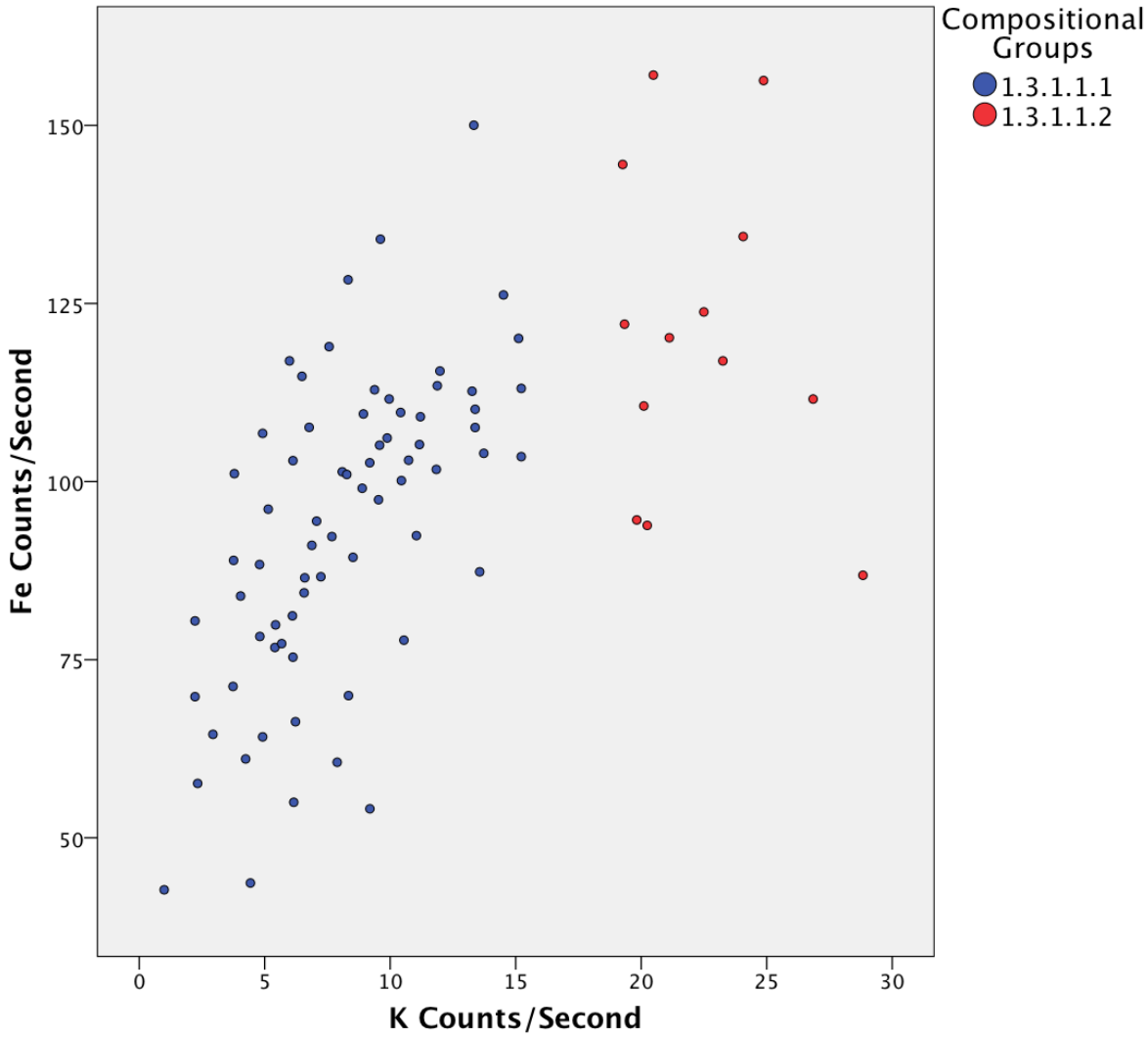


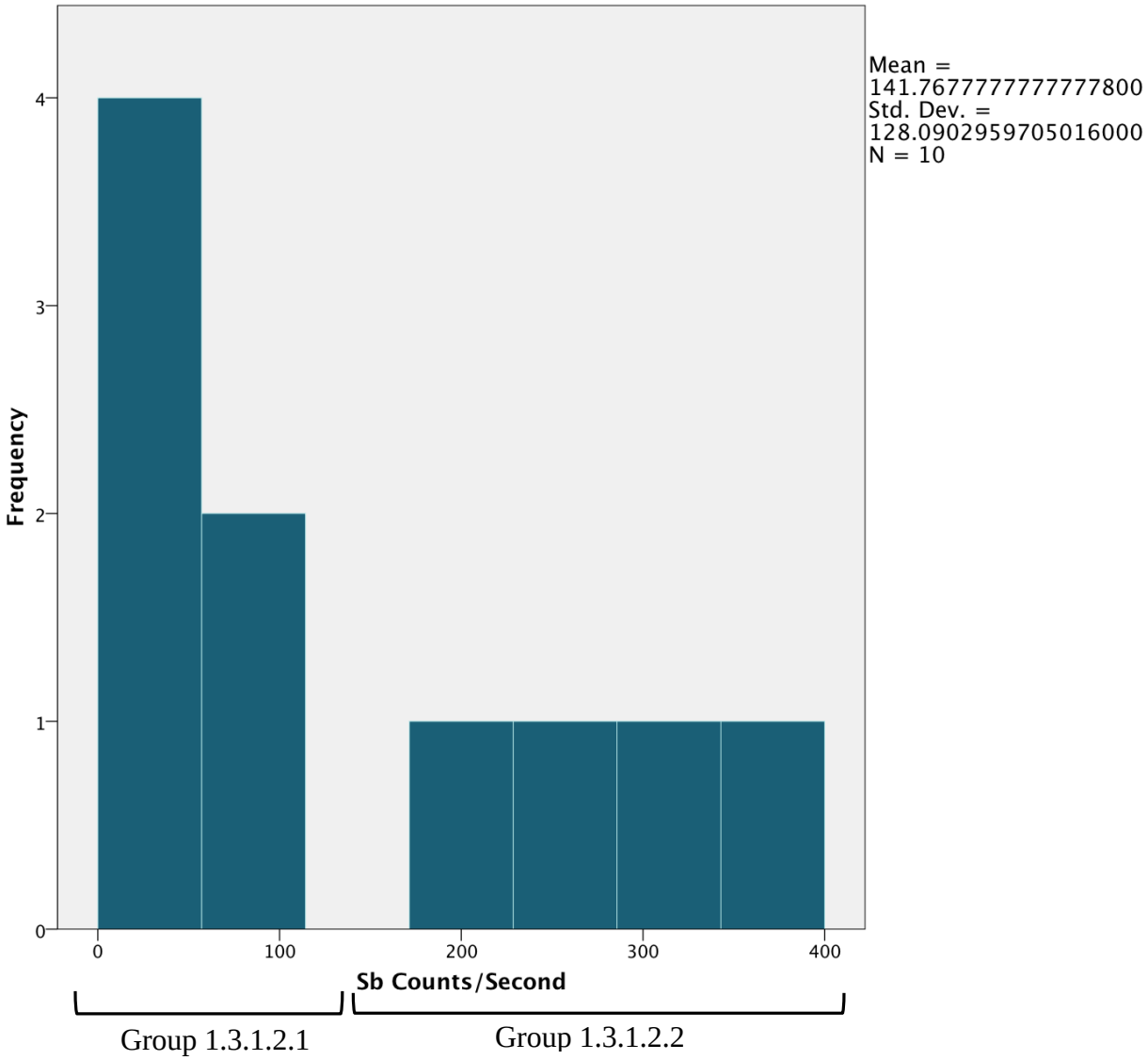
Figure 5-22. Biplot N in Fig. 5.5. K and Fe biplot for Group 1.3.1.1, n=83



Dividing Group 1.3.1.2 into Groups 1.3.1.2.1 and 1.3.1.2.2

The above biplot of Group 1.3.1 shows that Group 1.3.1.2 comprises two distinct clusters. A histogram of Sb counts/second also verifies a division at 150 counts/second (see Figure 5-23 below).

Figure 5-23. Histogram O in Fig. 5.5. Frequency histogram of Sb counts/second for Group 1.3.1.2 (n=10)



Dividing Group 1.3.2 into Groups 1.3.2.1, 1.3.2.2 and 1.3.2.3

A histogram of Sb counts/second for Group 1.3.2 yields three modes. Figure 5-24 below shows only Sb values below 75 so that the bin width can be decreased enough to clarify the boundary between modes. There is a boundary between modes at 28 counts/second. A second boundary between modes can be seen at 150 counts/second (see Figure 5-25 below).

Figure 5-24. Histogram P in Figure 5.5. Frequency histogram of Mn values under 75 counts/second for Group 1.3.2 (n=39).

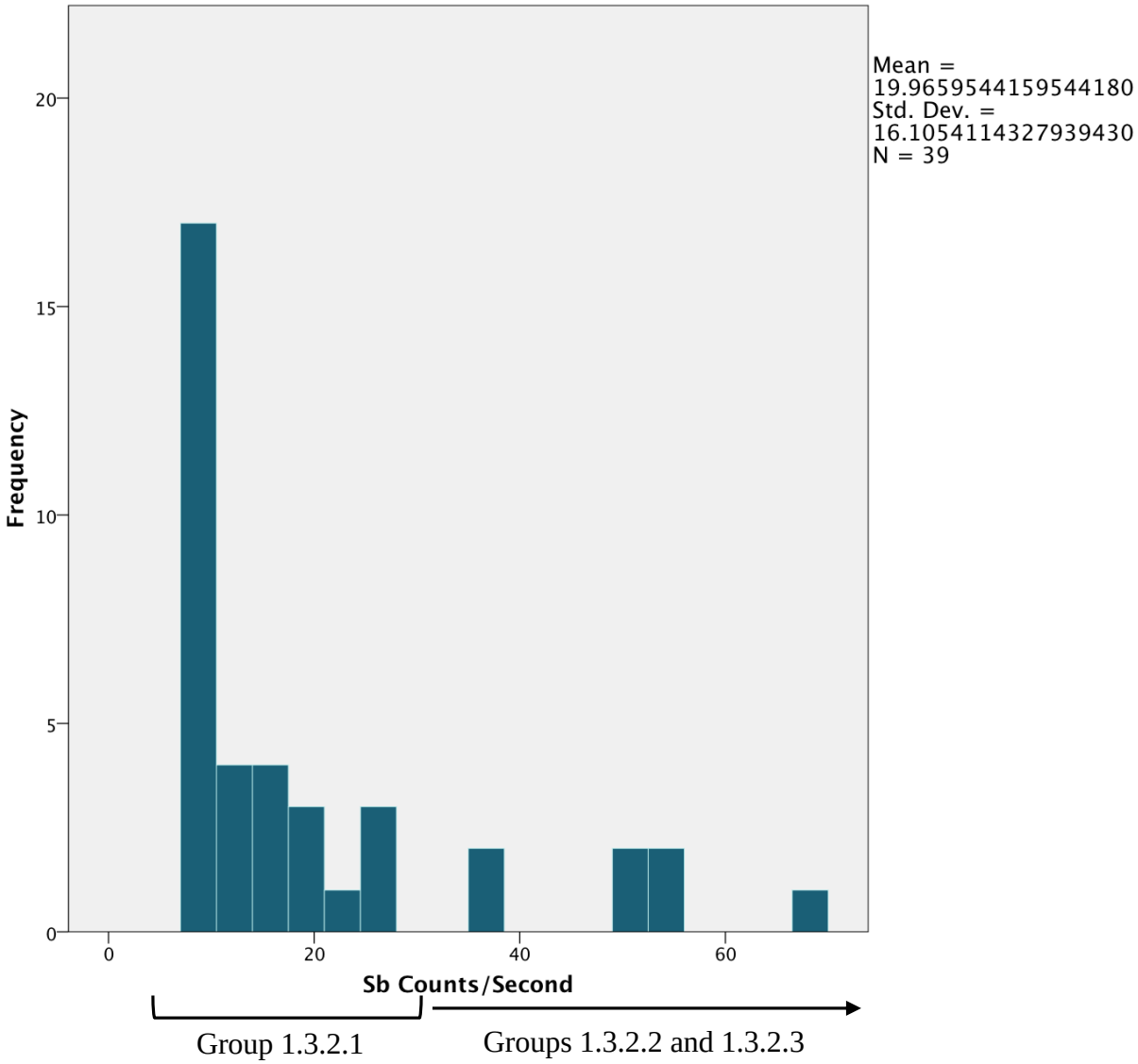
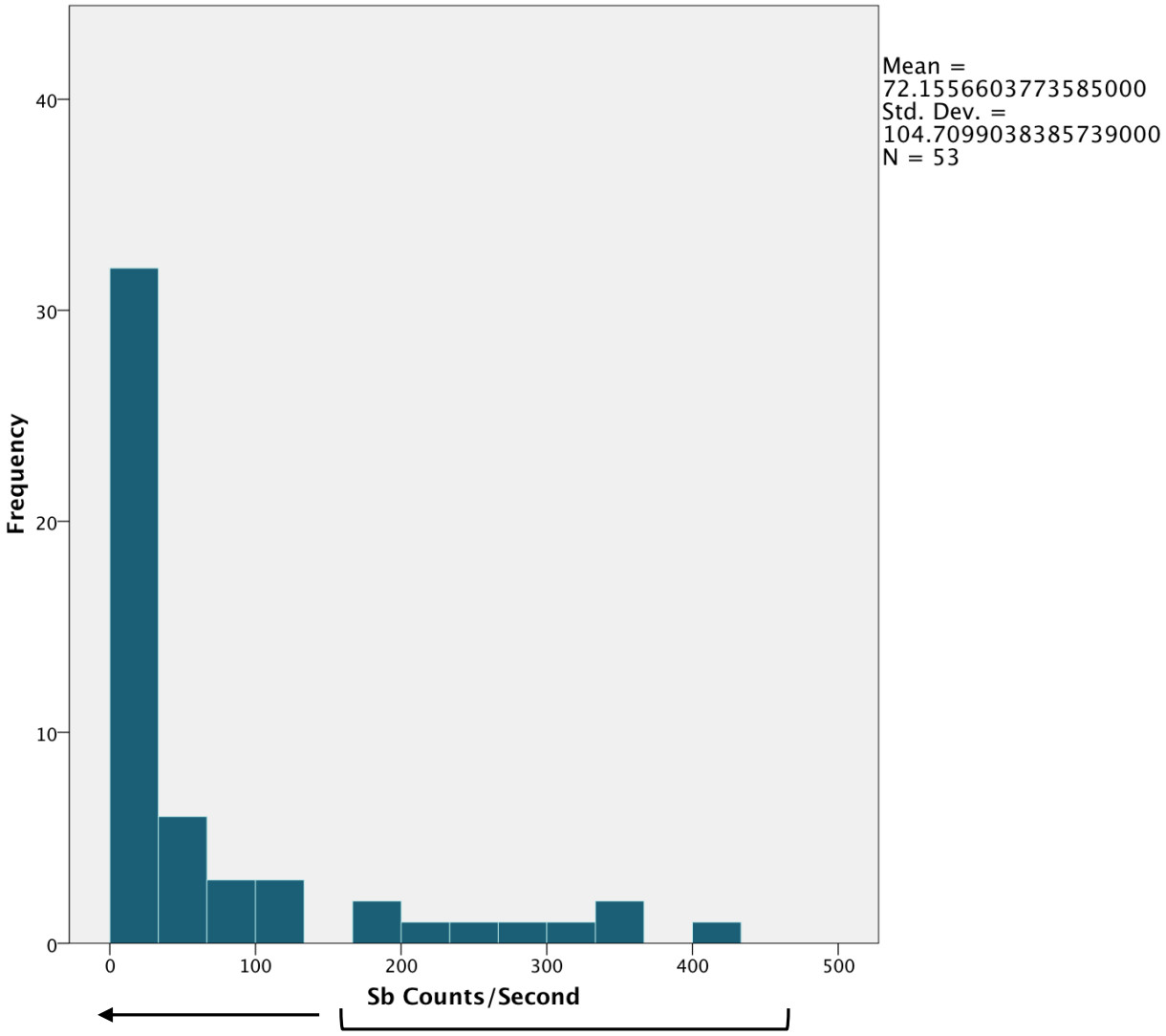


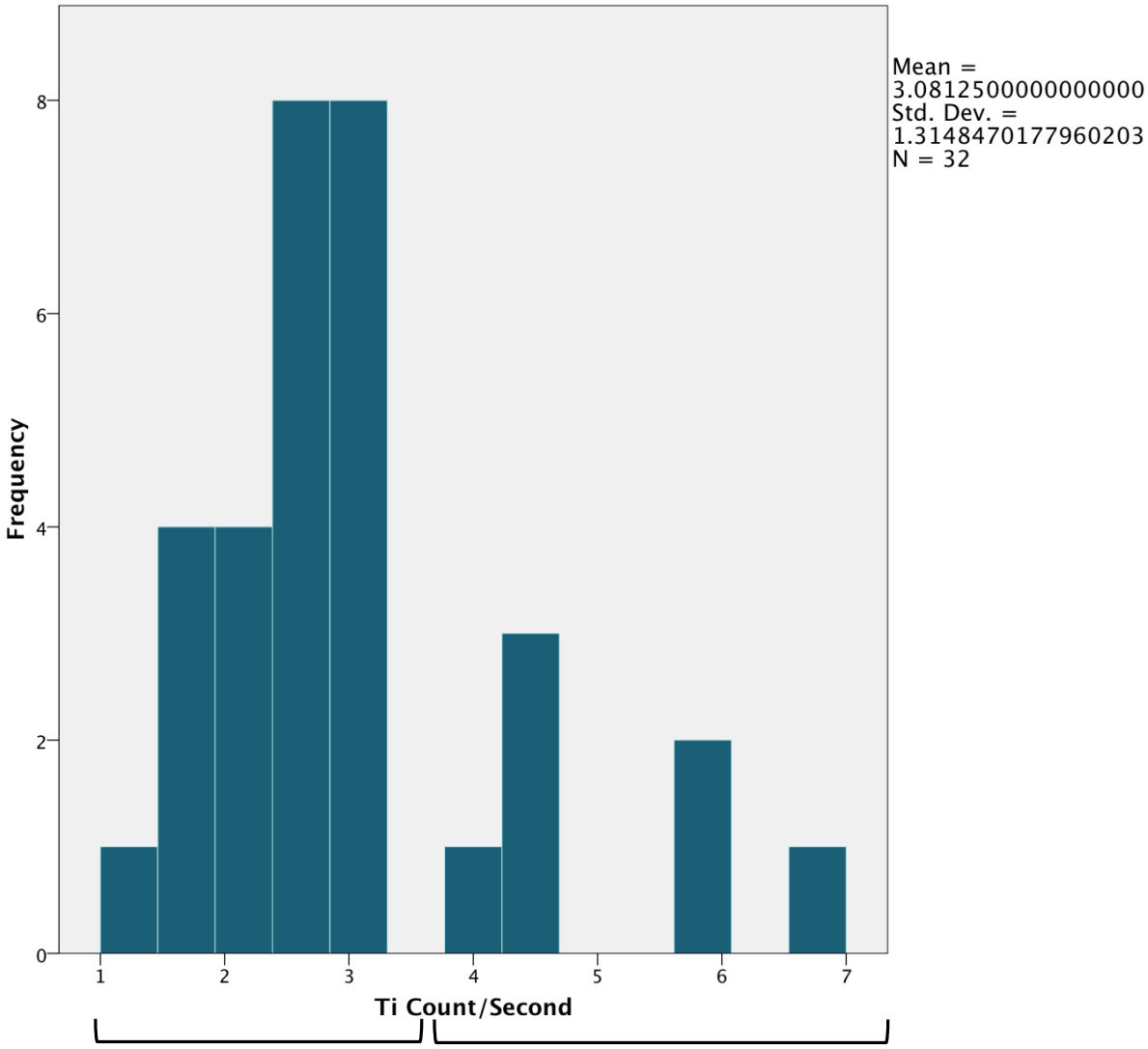
Figure 5-25. Histogram Q in Fig. 5.5. Frequency histogram of Sb counts/second for Group 1.3.2 (n=53)



Dividing Group 1.3.2.1 into Groups 1.3.2.1.1 and 1.3.2.1.2

A frequency histogram of Ti counts/second for Group 1.3.2.1 shows a clear bimodality with a boundary at 3.9 counts/second. I divide this group into two subgroups, 1.3.2.1.1 and 1.3.2.1.2 (see Figure 5-26).

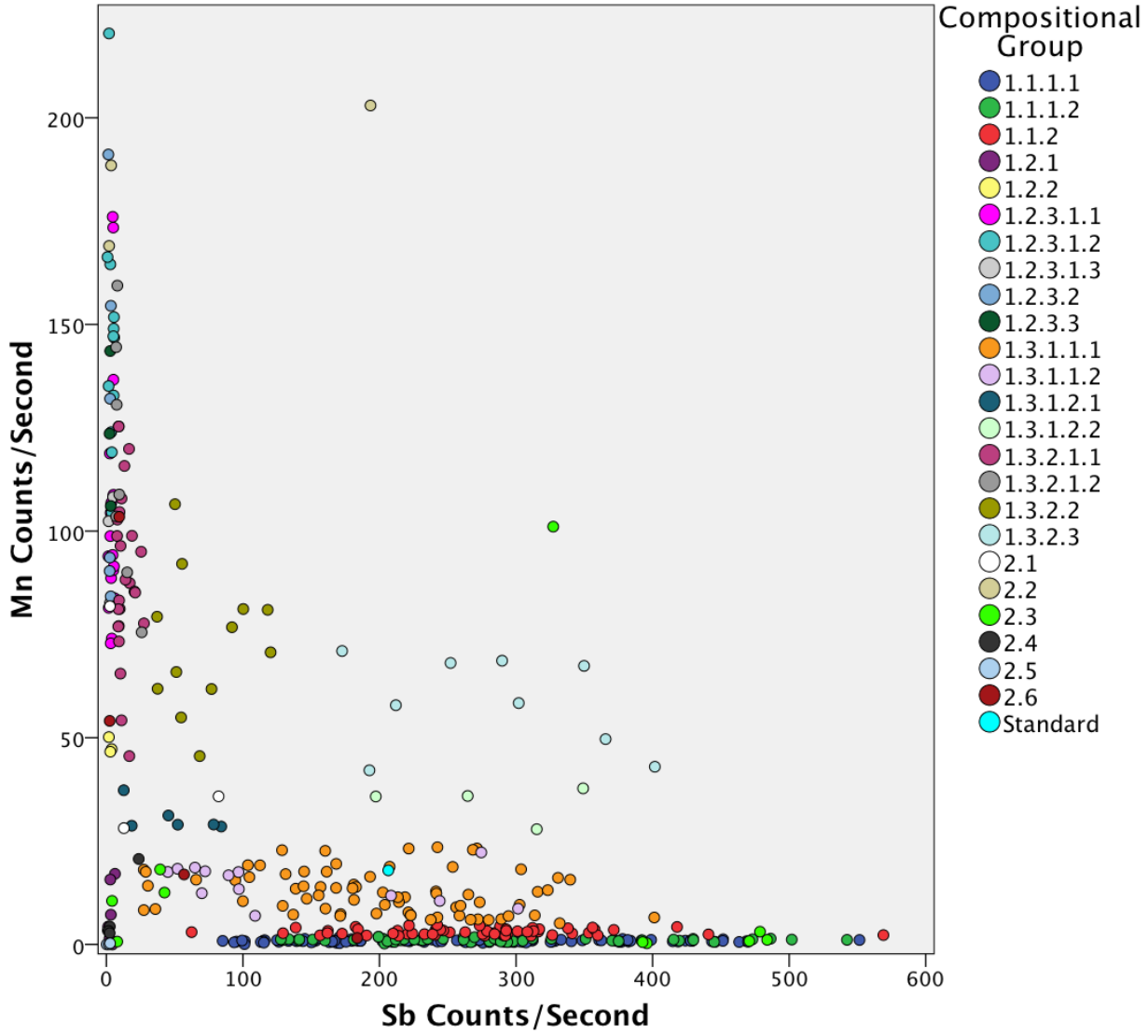
Figure 5-26. Histogram R in Fig. 5.5. Frequency histogram of Ti counts/second for Group 1.3.2.1 (n=32)



5.8 Results

I identify eighteen compositional groups through Read's iterative process (2007, 2015) which fall under one of the main compositional categories: 1) Antimony-decolorized, 2) Low manganese/low antimony, 3) High manganese/low antimony, 4) Aqua, and 5) Mixed manganese/antimony glasses. Six additional groups include outliers based on qualitative differences (Groups 2.1-2.6, see section 5.7.1). Appendix 4 gives descriptive statistics for all groups identified in this study. The biplots of compositional groups below show the overall composition of these groups and allow for a comparison of relative amounts of elements present among groups.

Figure 5-27. Sb and Mn biplot of compositional groups, n=462 (two outliers not shown).



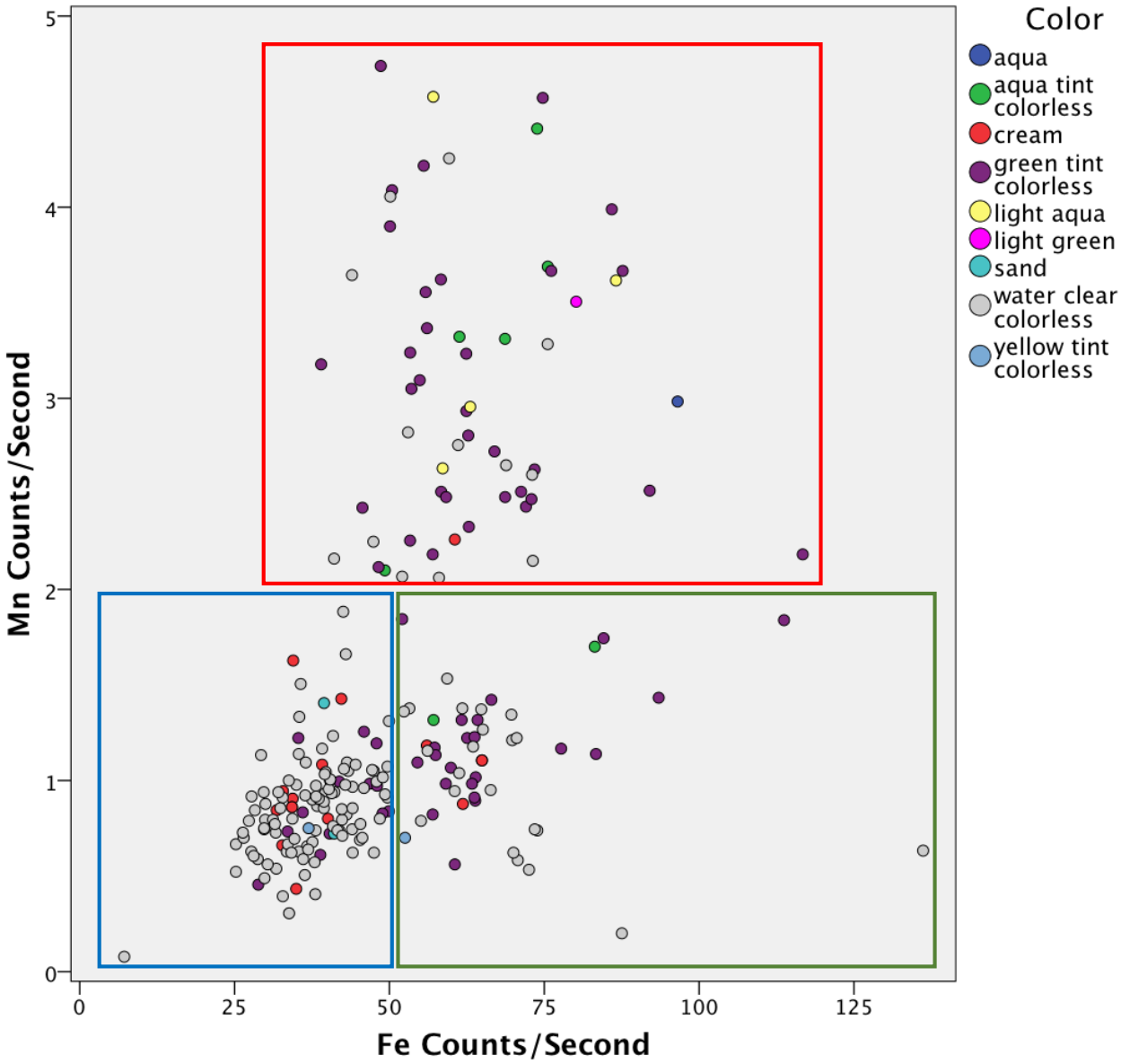
5.8.1 Antimony-Decolorized Glasses (n=235)

Group 1.1 Derivatives

Groups 1.1.2 (n=59), 1.1.1.1 (n=126), and 1.1.1.2 (n=50) can be confidently identified as antimony-decolorized glasses, even without absolute concentrations of elements as oxides to compare with other compositional studies of Roman glass. Groups 1.1.1.1 and 1.1.1.2 contain virtually no manganese (Mn), while Group 1.1.2 contains low levels of Mn. Compared to derivatives of Groups 1.2 and 1.3, Sb-decolorized glasses contain lower levels of manganese, iron, and titanium (see Figure 5-27 above and Figure 5-32 below), especially those suspected to be HIMT (high manganese, iron, and titanium)glasses, Groups 1.2.3.1.2, 1.2.3.2, and 1.3.2.1.2 (see Figure 5-33 below).

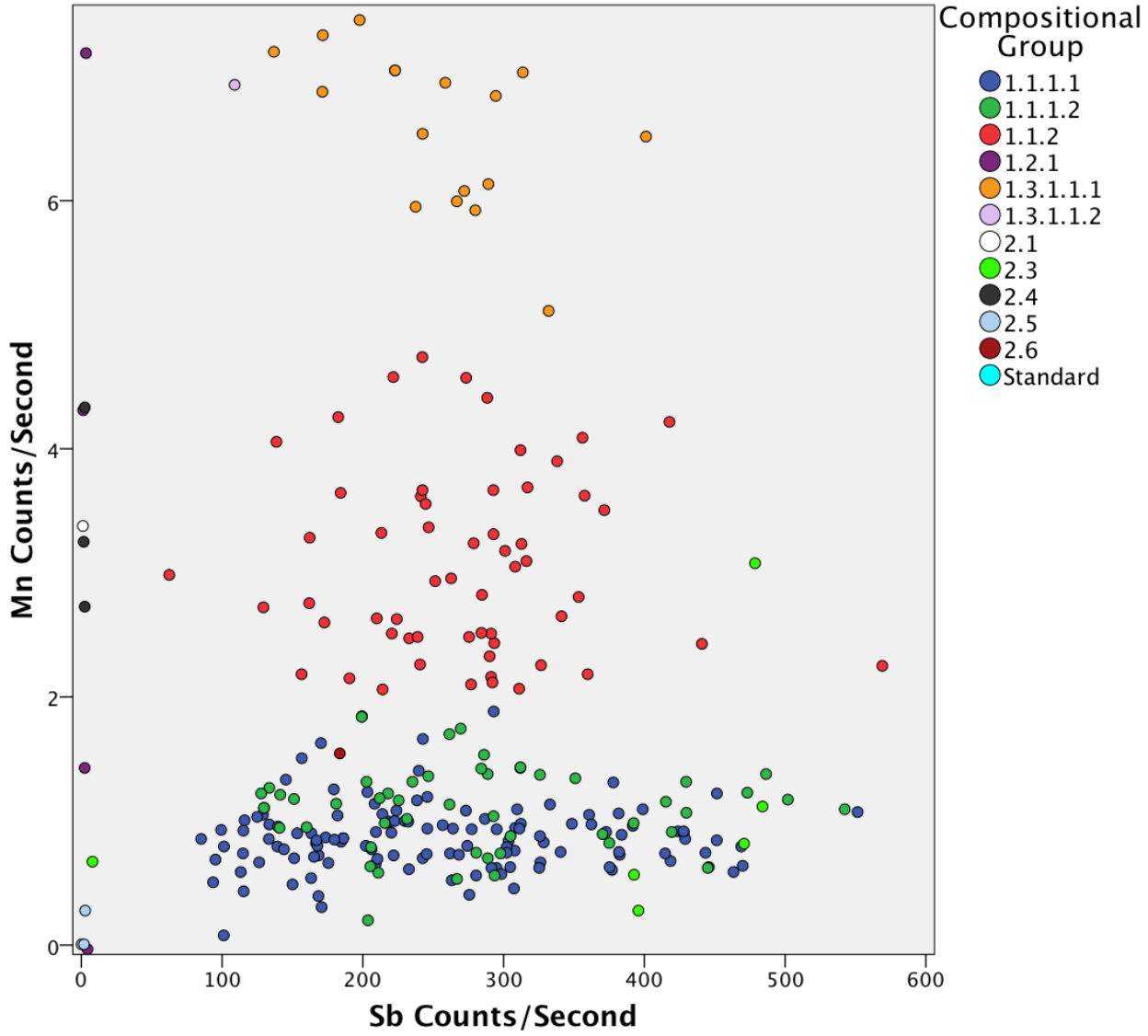
Foster and Paynter (2015) note that Sb-decolorized glass is generally less sensitive to iron oxide content than Mn-decolorized glass and tends to remain colorless regardless of elevated Fe levels. The Sb-decolorized glasses in this study, however, exhibit a different trend. The biplot of Sb-decolorized glasses below (Figure 5-28) shows that the majority of water clear colorless glass comprises Group 1.1.1.1, which has lower levels of Fe and Mn than Groups 1.1.1.2 and 1.1.2. Groups 1.1.1.2 and 1.1.2 comprise mostly tinted or lightly colored glass, with a smaller percentage of water clear colorless samples. In this case, elevated Mn and Fe content corresponds to hues of various colors in the glass.

Figure 5-28. Antimony-decolorized glass: Groups 1.1.2 (red box), 1.1.1.1 (blue box), and 1.1.1.2 (green box), n=235



The Sb and Mn biplot below (Figure 5-29) shows the distinct cluster comprising Group 1.1.2 compared to Groups 1.1.1.1 and 1.1.1.2. It also shows the separation of Group 1.1 derivatives and Groups 1.3.1.1.1 and 1.3.1.1.2, Aqua glasses.

Figure 5-29. Antimony and manganese biplot of samples with Mn counts/second less than 7.

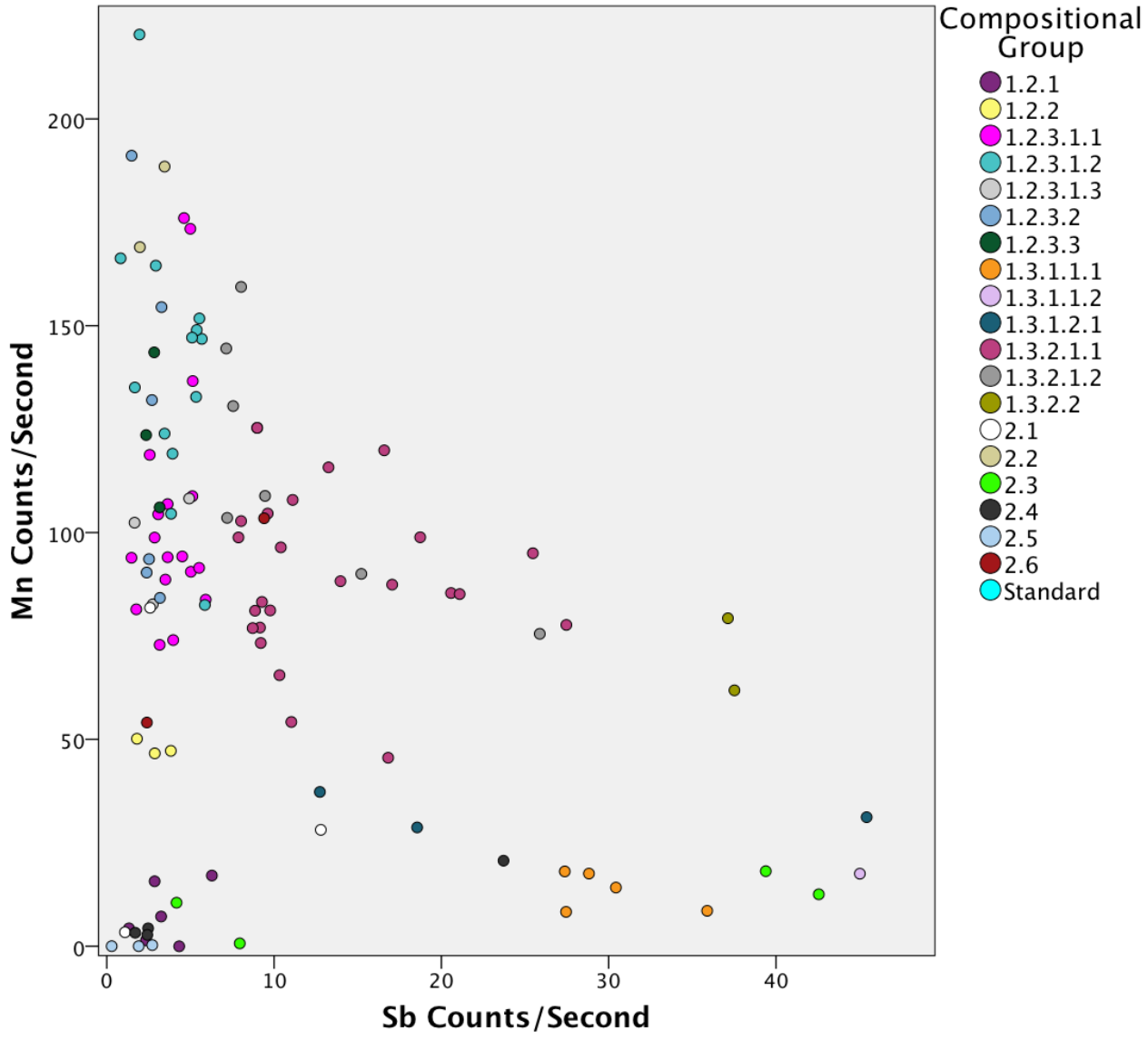


5.8.2 Low Manganese/Low Antimony Glasses (n=7)

Group 1.2 glasses contain virtually no antimony and varying levels of Mn. Group 1.2.1 (n=7) contains very low levels of manganese and no antimony. For this reason, I refer to this group as "Low manganese/low antimony." Group 1.2.1 has comparatively low levels of all elements, including Fe and Ti. All but one sample are green or olive in color, but they lack high

Fe levels. This group may correspond to Levantine 1b (Foster and Jackson 2009, see Table 5-7 below for average composition for this group). At least three samples may represent invalid spectra (SPEC ID 442, 566, and 703) since they have exceptionally low levels of Ca, K, and Fe. They share these low levels with samples that are not glass included in the outliers (Group 2.5) (see Figure 5-30 below).

Figure 5-30. Antimony and manganese biplot of samples with Sb counts/second less than 49.



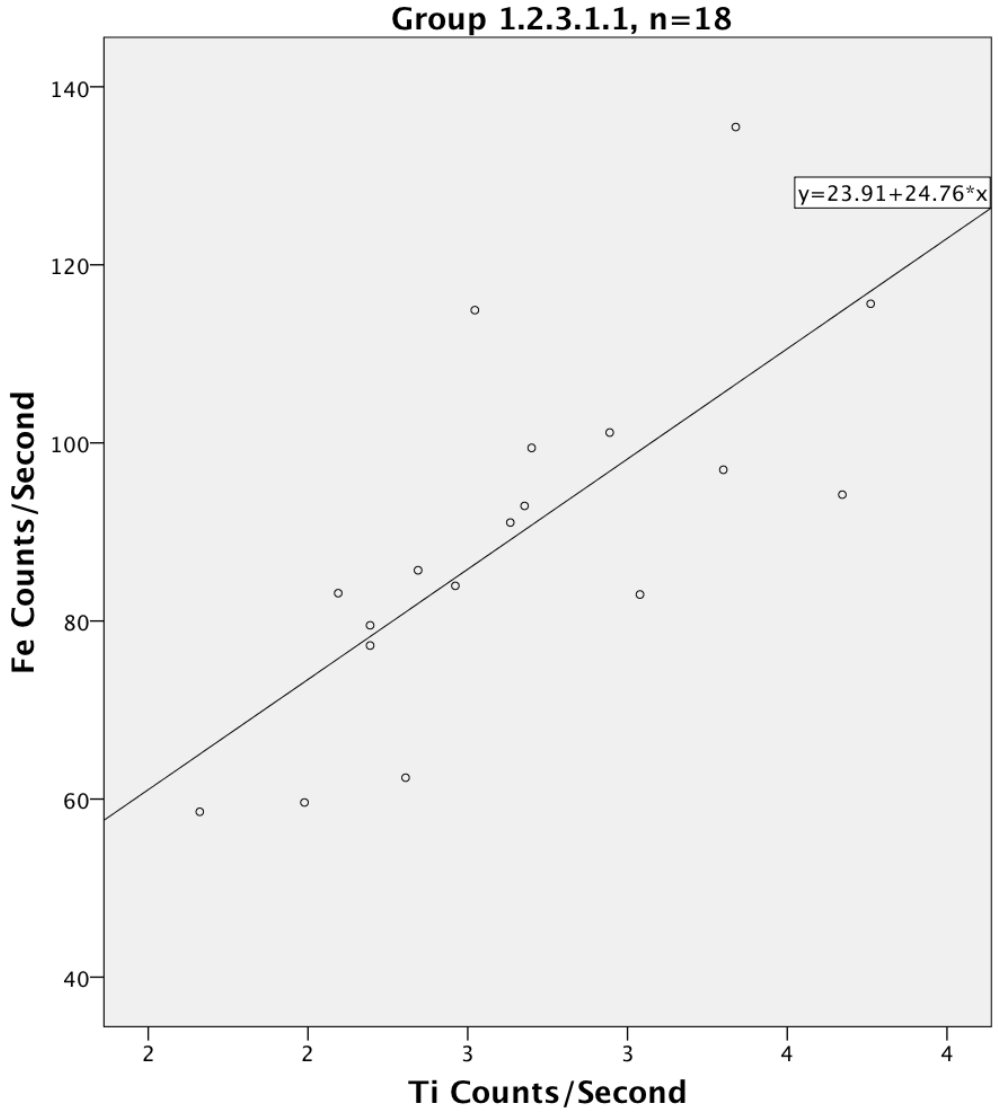
5.8.3 High Manganese/Low Antimony Glasses (n=78)

Group 1.2.2 (n=3) includes three closely clustered points in the Sb and Mn biplot above (Figure 5-30). They contain no Sb and low levels of Mn, Fe, and Ti. Two of the samples are water clear colorless glasses, and one sample is a heavily weathered green glass. It is possible that the sanding and flushing preparation of the sample was not sufficient in removing this thick, weathered surface; therefore, the results may not be reliable for this sample (SPEC ID 408).

Group 1.2.3.1.1 (n=18) are High manganese/low antimony glasses with moderate levels of titanium (Ti) and iron (Fe). Fifteen of the 18 samples comprising this group are water clear colorless or slightly tinted samples. This glass may correspond to Foster and Paynter's "High-Mn" glasses, which are high manganese, soda, lime, and alumina glasses, ranging from colorless to blue-green. Further chemical analysis is needed to identify this group, however, since soda levels cannot be detected by pXRF and alumina levels may be unreliable (see precision test and Table 4-2 above). Group 1.2.3.1.1 may correspond to Foster and Jackson's "Colourless 2b" glasses, but samples do not show a correlation of iron and aluminum (Al) typical of Colourless 2b glasses (2010: 3071-3; Jackson and Paynter 2015). There is a weak correlation of Ti and Fe (R^2=0.53) among Group 1.2.3.1.1 samples (see Figure 5-31 below).

Although Group 1.3.2.1.1 (n=25) is a derivative of 1.3, it may not be distinct from Group 1.2.3.1.1. There was a clear boundary between modes in the antimony histogram used to separate these two groups (see Figure 5-8 above and the gap between 1.2 subgroups and 1.3 subgroups at 7 counts/second in Figure 5-30 above).

Figure 5-31. Group 1.2.3.1.1, n=18. Linear regression line shown (R^2=0.530)



5.8.3.1 Possible HIMT Glasses (n=22) and Outliers (n=3)

Groups 1.2.3.1.2 (n=13), 1.2.3.2 (n=6), and 1.2.3.3 (n=3) are most likely HIMT glasses that fall under the broader, High manganese/low antimony group. They contain high levels of Mn, Ti, and Fe compared to other groups (see Figure 5-27 above and Figure 5-32 and 5-33 below). Note that the strong Al and Fe correlation characteristic of HIMT glass (Foster and Jackson 2009) is not visible for Groups 1.2.3.1.2, 1.2.3.2, and 1.2.3.3, but this may largely be due to pXRF limitations in detecting Al. There is a weak correlation between Fe and Ti (see Figure 5-

32 below, regression line not shown). The Sb and Ti biplot below (Figure 5-33) shows the elevated Ti levels characteristic of HIMT glass.

Although Group 1.3.2.1.2 (n=7) is a derivative of 1.3, it may not be distinct from Group 1.2.3.1.2 (see explanation for Group 1.3.2.1.1 in section 5.8.3 above). Groups 1.3.2.1.1 and 1.3.2.1.2 share similar overall compositions to their 1.2 subgroup counterparts (1.2.3.1.1 and 1.2.3.1.2), except for higher levels of Sb in Groups 1.3.2.1.1 and 1.3.2.1.2. Antimony, lead, and copper of varying amounts are found in some HIMT glasses (Foster and Jackson 2009; Foy *et al.* 2003). Foster and Jackson (2009) conjecture that levels of Cu, Pb, and Sb above trace levels as impurities in the raw materials may indicate recycled HIMT glass. Therefore, Group 1.3.2.1.2 may represent recycled HIMT glass, and for similar reasons, 1.3.2.1.1 may also represent recycled High manganese/low antimony glass. Since all other 1.3 derivatives represent recycled glass, this could explain why Groups 1.3.2.1.1 and 1.3.2.1.2 are 1.3 derivatives rather than 1.2 derivatives.

Groups 1.2.3.2 and 1.2.3.3 contain the highest relative concentration of Ti and Fe; therefore, they may represent HIMT 1 ("strong" and Group 1 and 2 in Foy *et al.* 2003) and Group 1.2.3.1.2 may correspond to HIMT 2 ("weak") previously identified in other studies of Late Roman glass (Foster and Jackson 2009; Foy *et al.* 2003; Freestone *et al.* 2005; Jackson and Paynter 2015; Jackson and Price 2012; Rosenow and Rehren 2014). There are three outliers (Group 1.2.3.1.3) that do not fit well with either Group 1.2.3.1.1 or 1.2.3.1.2 (see Figure 5-15 in section 5.7.2). These may represent a subgroup of 1.2.3.1.2, with slightly lower Ti and higher Fe.

Figure 5-32. Ti and Fe biplot of compositional groups, n=462 (two outliers not shown).

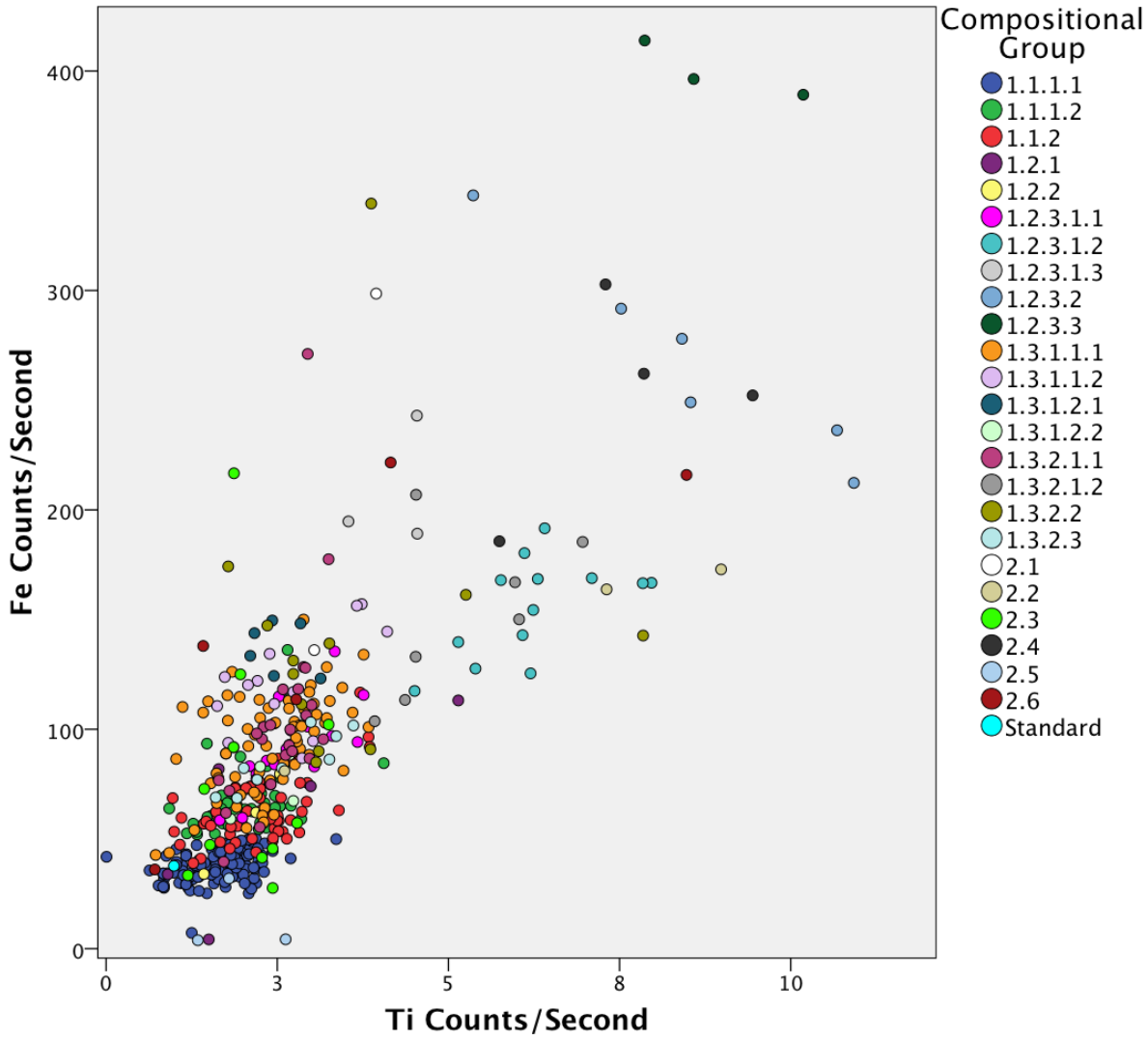
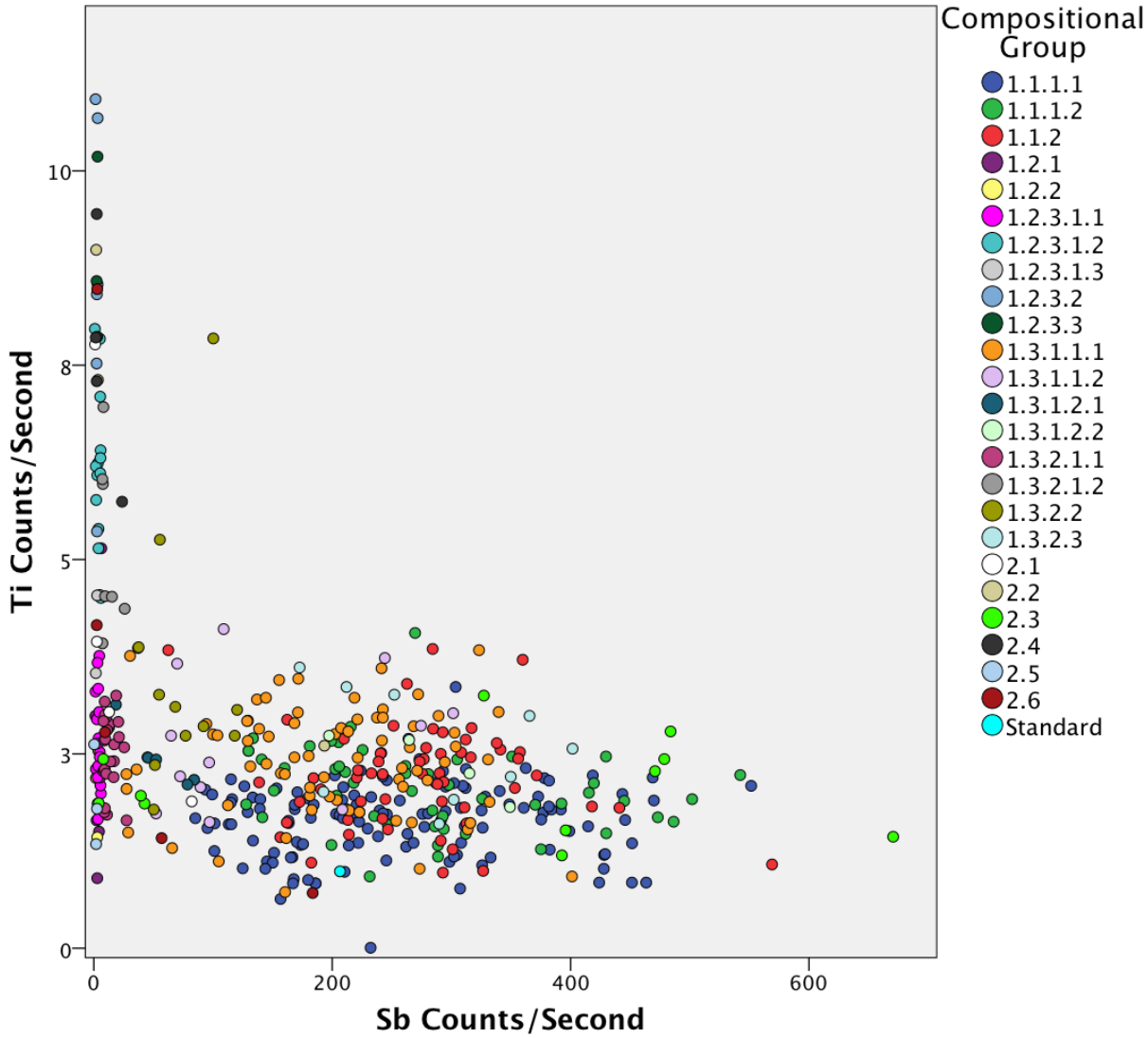


Figure 5-33. Antimony and titanium biplot with compositional groups of total population, n=464.



5.8.4 Mixed Manganese/Antimony Glasses (n=31)

These glasses are categorized by moderate to high levels of both manganese and antimony. This group most likely corresponds to Jackson and Paynter's (2015) "mixed antimony and manganese" group. Titanium and iron levels of Groups 1.3.2.2 (n=12), 1.3.2.3 (n=9), 1.3.1.2.1 (n=6), and 1.3.1.2.2 (n=4) are similar to those of High manganese/low antimony glasses and Aqua glasses, but Mn levels are generally lower than the High manganese/low antimony glasses and higher than those of Aqua glasses (see Figures 5-27 and 5-32 above). These higher levels of both Mn and Sb are likely due to the mixing of High manganese/low antimony, HIMT 1 and/or 2 glass with Antimony-decolorized glass through recycling. Further chemical analysis is necessary to confidently make this assessment, but previous studies have conjectured glass recycling causes mixed compositions such as these (Foster and Jackson 2010; Jackson and Paynter 2015).

5.8.5 Aqua Glasses (n=83)

I refer to Group 1.3.1.1 derivatives as "aqua" to distinguish it from Roman blue-green glass of the 1st-3rd centuries CE as well as the 3rd-4th century CE blue-green samples identified in Foster and Jackson (2009). Group 1.3.1.1 derivatives are primarily aqua (blue-green) colored glass, but also include glass of various shades of green (one weathered cream sample and one water clear colorless sample are also included in this group). Group 1.3.1.1 glass shares similar levels of Fe and Ti with High manganese/low antimony glasses, Groups 1.2.3.1.1 and 1.3.2.1.1 (see Figure 5-32 above). Groups 1.3.1.1.1 (n=70) and 1.3.1.1.2 (n=13) share similar ranges of Mn and Sb. Glass from Group 1.3.1.1.2, in addition to having higher K levels, also has slightly higher Fe and Ti levels on average (see descriptive statistics, Appendix 4).

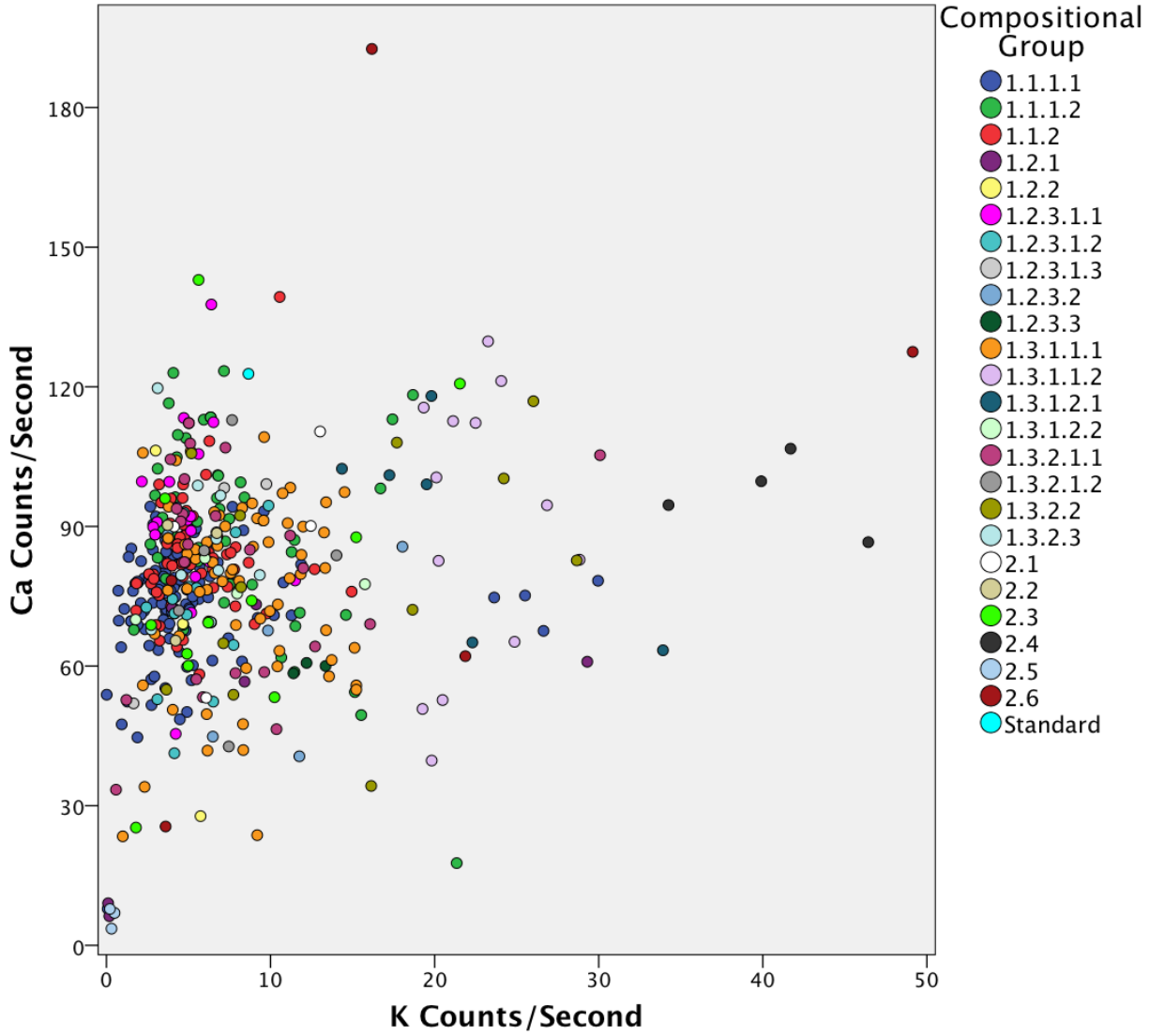
The two subgroups of 1.3.1.1 may represent previously unidentified Roman glass types. Since these samples date to the Late Roman (4th-6th centuries CE), they are later samples than the typical Roman blue-green glass, which date to the 1st-3rd centuries CE. Foster and Jackson (2009) identify a 3rd-4th century CE blue-green glass group (n=8), but the overall composition of this group does not align well with group 1.3.1.1. Group 1.3.1.1 glasses have considerably lower relative levels of Fe than the 3rd-4th centuries CE blue-green glasses (Foster and Jackson 2009). Since Group 1.3.1.1 derivatives contains significant levels of both Mn and Sb, they would best fit under the main group of Mixed manganese/antimony glasses. The fairly low and restricted range of Mn of this group (See Sb and Mn biplot, Figure 5-27 above) signifies that it is a unique group within this general category, however.

The range of Sb is quite variable among Group 1.3.1.1, as they are among Sb-decolorized glasses (see section on Groups 1.1.1.2, 1.1.1.1, and 1.1.1.2 above). The presence of varying levels of Sb in this group strongly suggest that this group represents recycled glass. I postulate that Group 1.3.1.1 derivatives represent the recycling of antimony-decolorized glass and another "naturally colored" glass group, such as High manganese/low antimony, HIMT, or blue-green glass from earlier periods. Further chemical analysis is necessary, however, to confirm this hypothesis. The sodium (Na), aluminum (Al), phosphorus (P), and magnesium (Mg) levels, in particular, need to be clarified. Based on electron probe microanalysis (EPMA) I conducted on a similar aqua fragment from Karanis housed at the Kelsey Museum of Archaeology, this group may represent a plant-ash based glass. This would have serious implications regarding the organization of the Roman glass industry and glass found in Egypt (see Chapter 8). Regardless of whether or not these are natron or plant-ash based glasses, it is possible that Group 1.3.1.1

glasses represent local glass production (Egyptian, and perhaps even Fayum origin). This will be further discussed in the EPMA results section below as well as in Chapter 8.

The biplot below (Figure 5-34) shows how types are not well defined by their potassium (K) and calcium (Ca) counts/sec. There is not great variation in Ca levels among all Roman glass types (Freestone, personal communication, 2010), so these data seem to align with typical Roman compositional types. Although the precision for K counts is acceptable with pXRF (RSD%=3.97), the reason that K levels do not distinguish groups well is more likely due to aforementioned reasons: these levels can be highly influenced by weathering and post-depositional conditions. Although I avoided testing heavily weathered material and sanded samples to remove any weathering on the surface, the weathering could not be fully removed on some samples.

Figure 5-34. Potassium and calcium biplot of compositional groups, n=464.



5.9 Titanium Precision Issue

The precision for titanium counts was unsatisfactory (see Table 5-2). Precision can be improved, however, by using the sum of titanium (Ti) and barium (Ba) counts (obtained using the low Kev settings on the instrument). The method for calculating counts from raw instrument data in *Artax* (referenced above) included both Ba and Ti, and somehow this decreased the precision of Ti counts compared to using only Ti in the *Artax* method for net area analysis of

spectra. Below, I compare Ti + Ba (Low Kv) counts/sec and Sb with Ti and Sb. The relationship among the established groups seem to hold using Ti +Ba (Low Kv) counts/sec (compare two graphs below, Figures 5-35 and 5-36). However, note how Standard Ref. B levels increase disproportionately compared to other specimen when Ti+Ba (Low Kv) counts/second are compared instead of just Ti counts.

Figure 5-35. Biplot of antimony counts/second and sum of titanium and barium counts/second, n=464

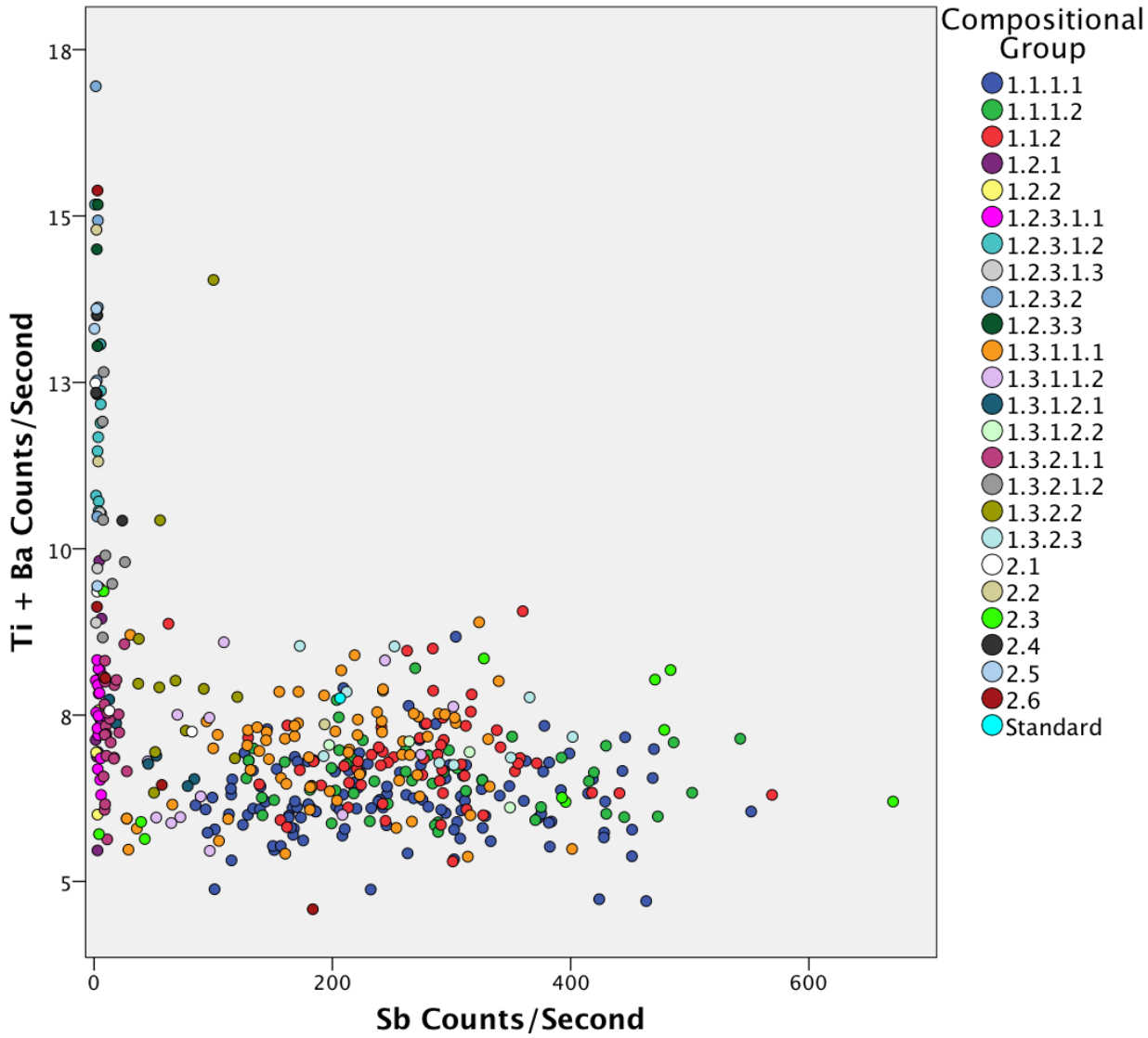
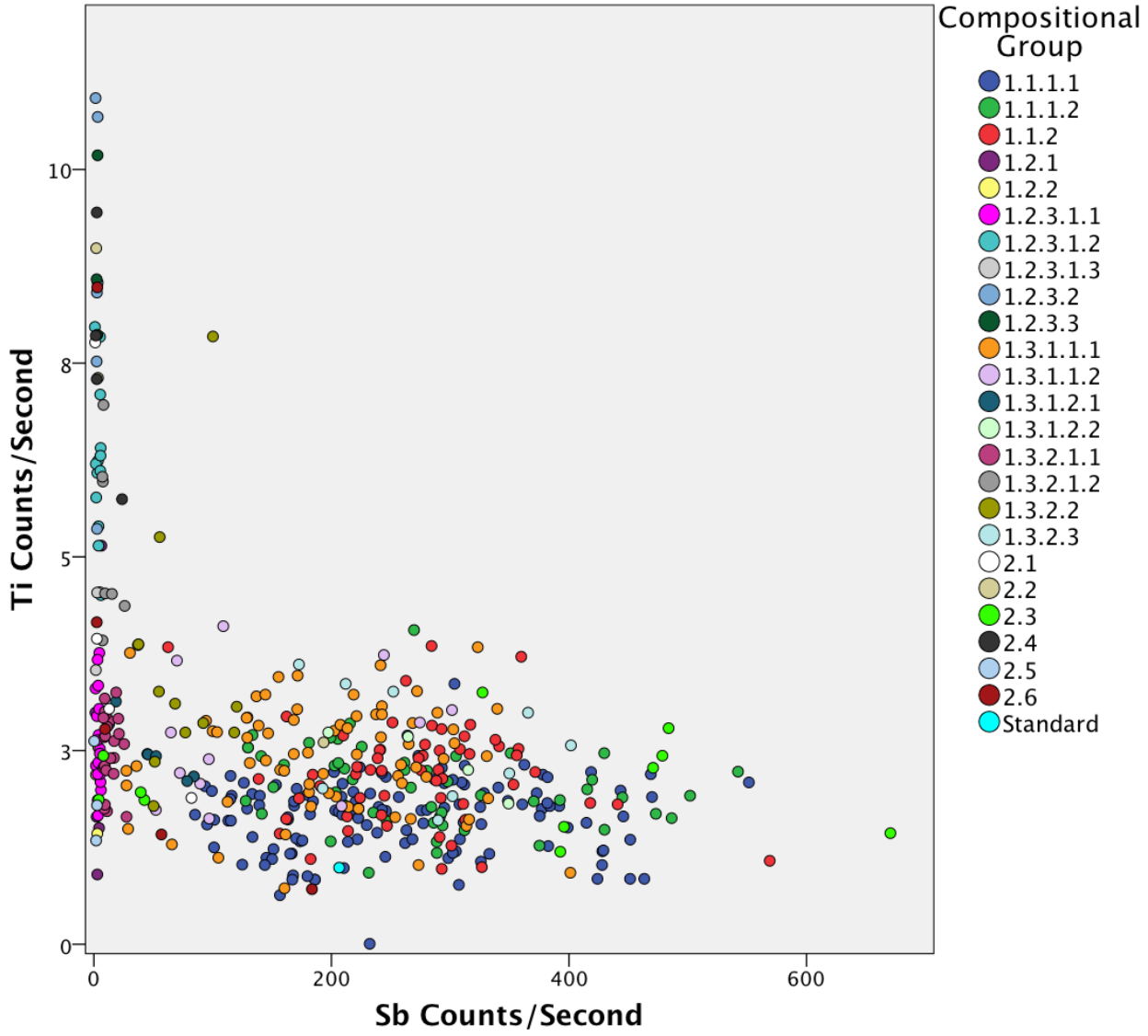


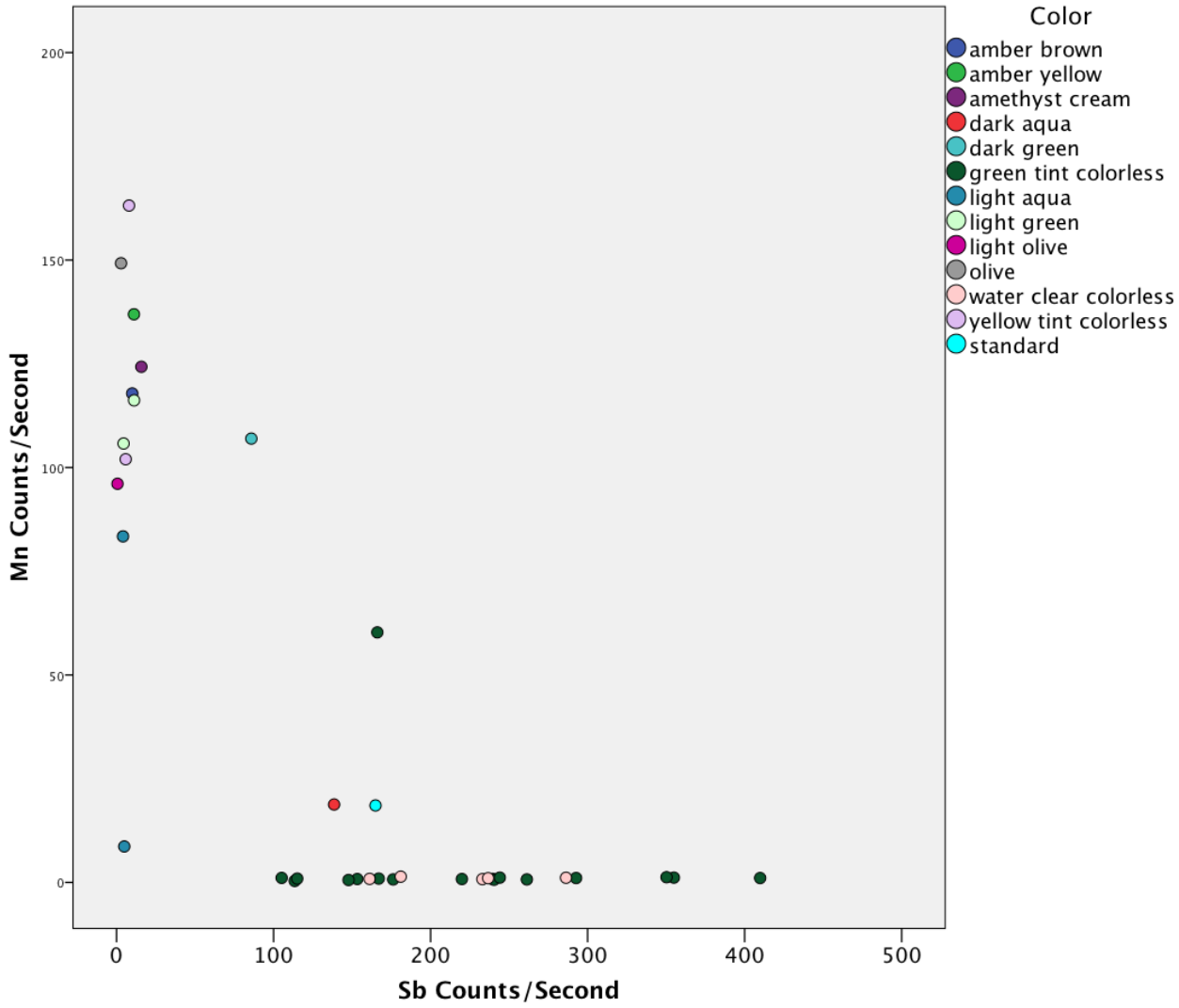
Figure 5-36. Biplot of antimony counts/second and titanium counts/second, n=464.



5.10 Kelsey Museum Karanis Samples

Similar methods were followed for the analysis of museum specimen from the Kelsey Museum. Since the pXRF instrument model used for this analysis was different than that used for the samples done in the field in Fayum, raw counts from each of these sample populations were not analyzed and compared together. Similar groupings could be distinguished, although not all groups found in the recently excavated Karanis material were present in the museum sample population. Thirty-five museum samples were analyzed and electron probe micro-analysis (EPMA) was also conducted on three of these same samples so that a general composition for each of the colorless glasses could be identified and compared to other studies (see Figures 5-37 through 5-41 below).

Figure 5-37. Biplot of antimony counts/second and manganese counts/second for Kelsey Museum samples, n=35.



The samples also analyzed with electron probe micro-analysis (EPMA) are labelled with their specialist identification number (SPEC ID: 829, 832, and 853) in the graphs below. Samples were chosen for EPMA because they represent four of the five main glass types identified in this study: Antimony-decolorized, High Mn/low Sb, Aqua, and Mixed Mn/Sb glass.

Figure 5-38. Biplot of antimony counts/second and manganese counts/second for Kelsey Museum samples, n=35. EPMA samples are labeled.

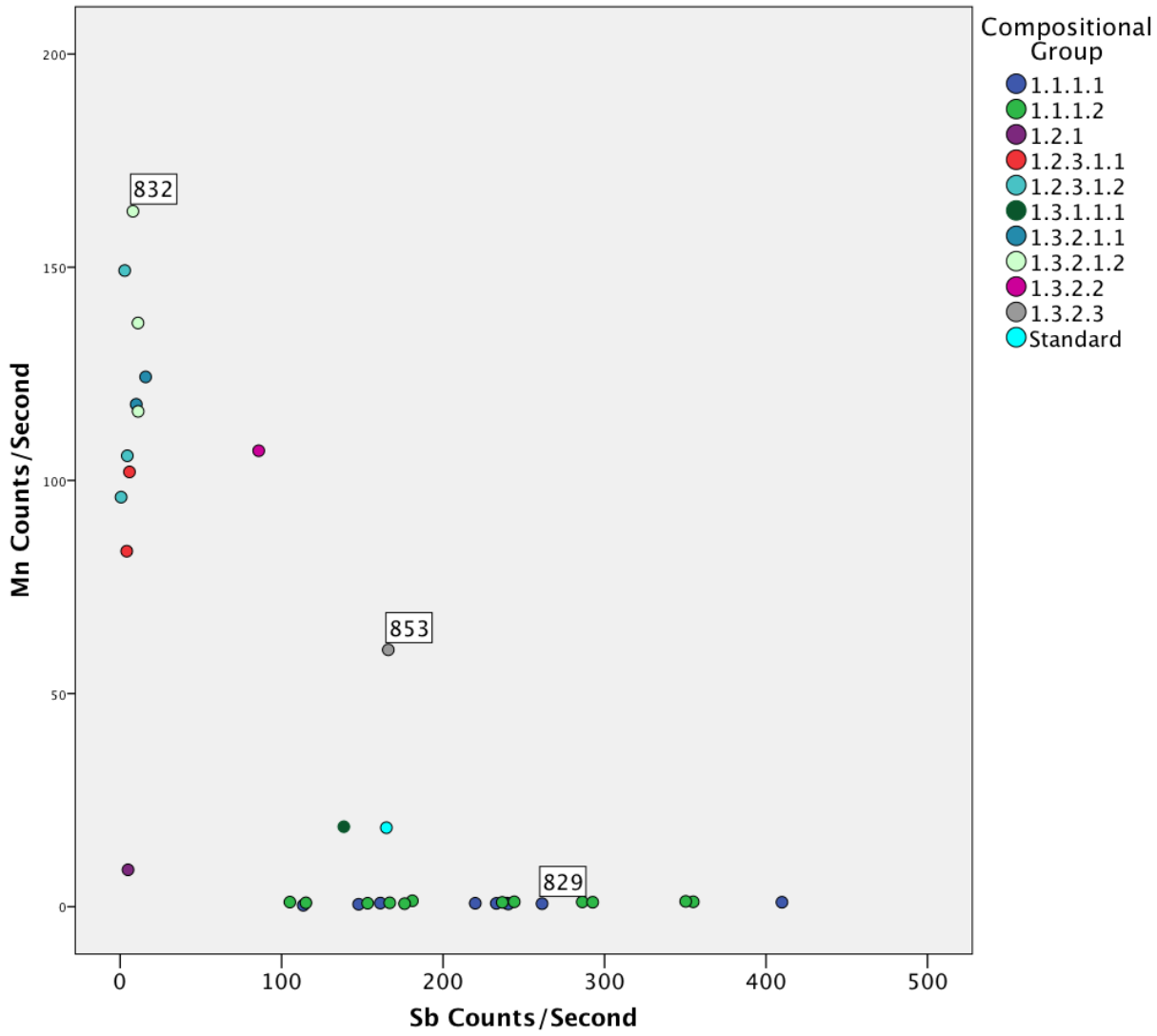


Figure 5-39. Biplot of antimony counts/second and titanium counts/second for Kelsey Museum samples, n=35. EPMA samples are labeled

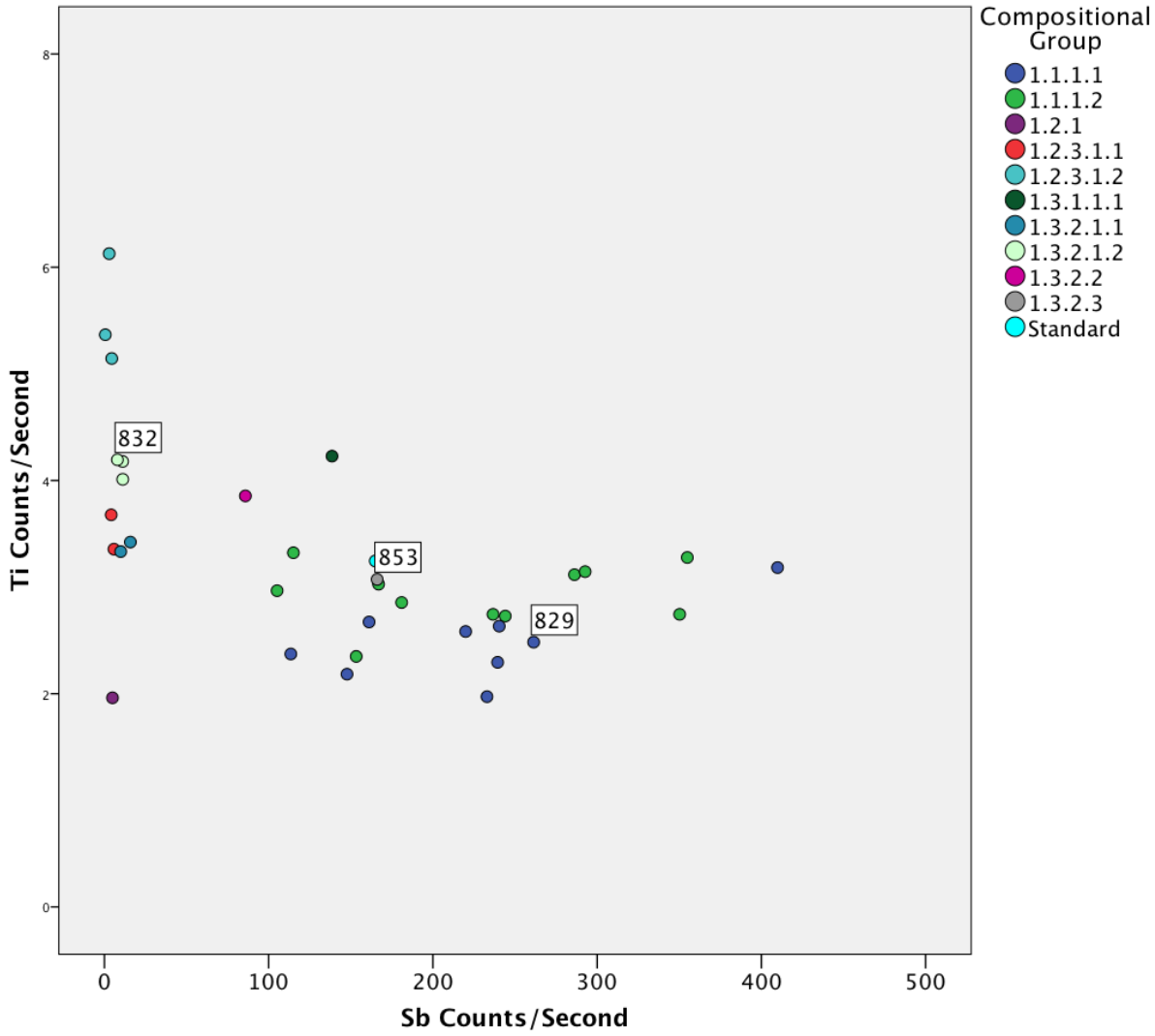


Figure 5-40. Biplot of titanium counts/second and iron counts/second for Kelsey Museum samples, n=35. EPMA samples are labeled

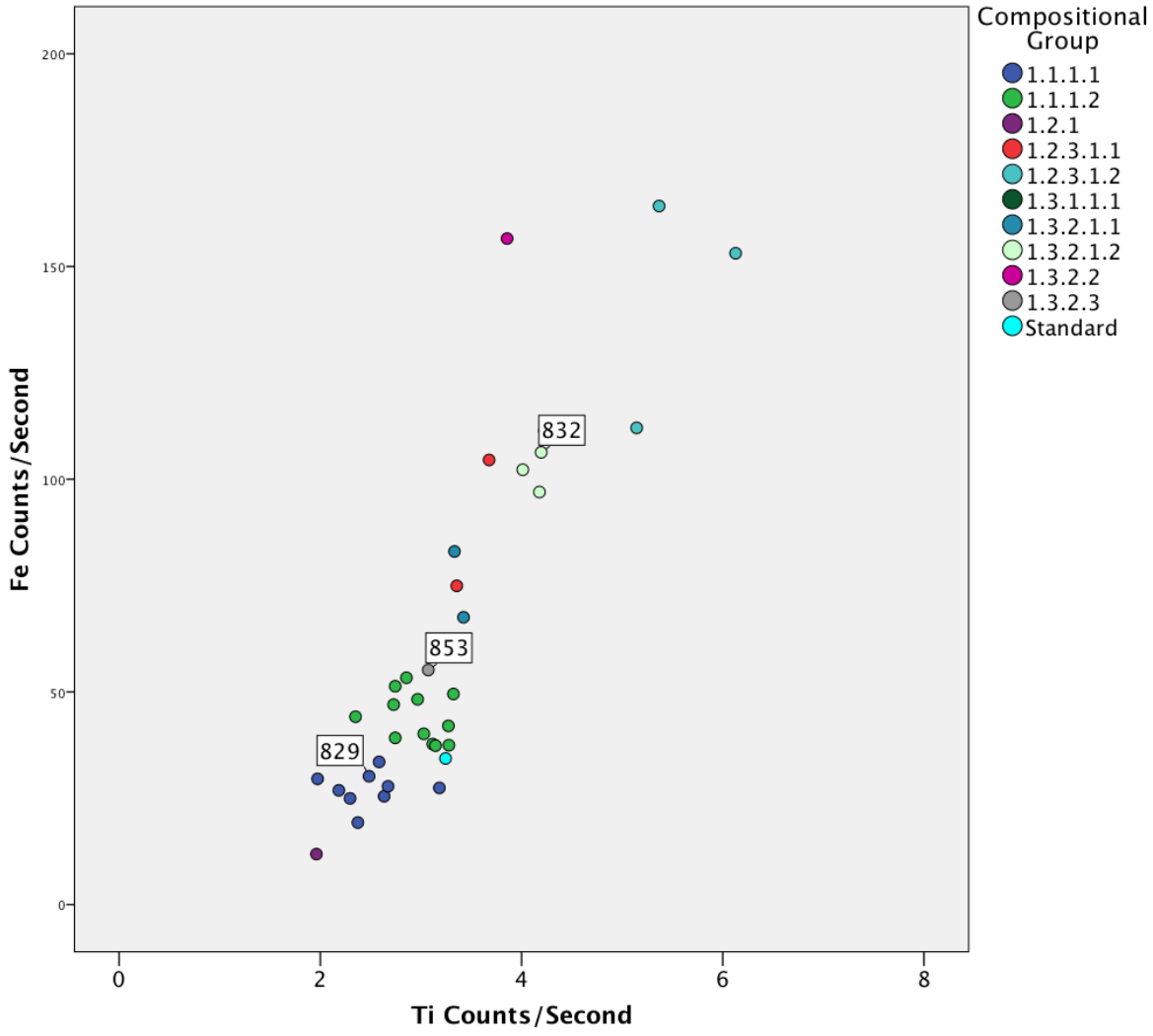
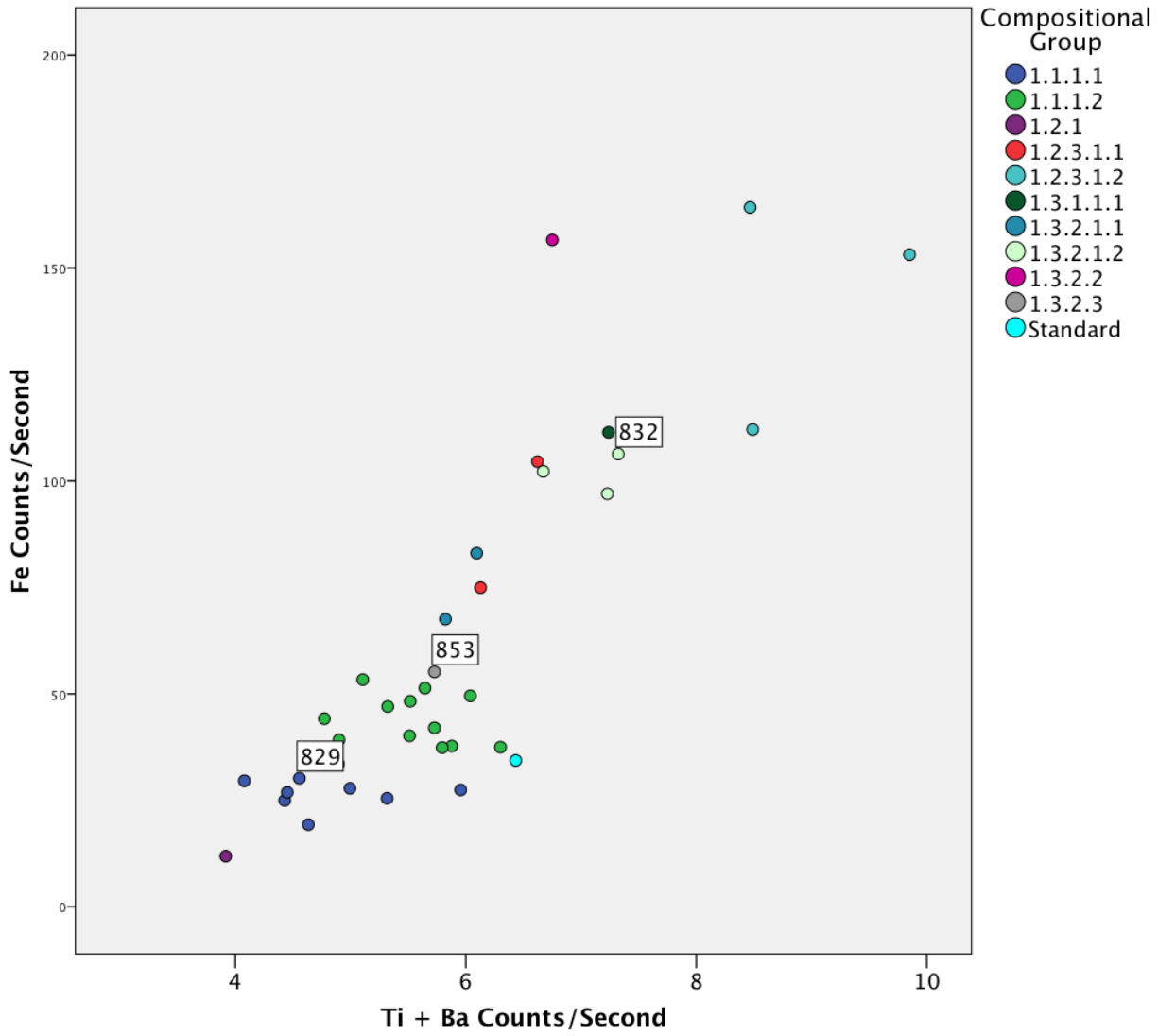


Figure 5-41. Biplot of the sum of titanium and barium counts/second and iron counts/second for Kelsey Museum samples, n=35. EPMA samples are labeled



Ti and Ba (Low KV) counts were added together to increase the precision of results.

This does not seem to result in drastic changes between the two graphs above.

5.11 EPMA of Karanis Museum Specimen: Sample preparation and methods

Four museum specimen were selected for Electron Probe Micro Analysis (EPMA) based on preliminary pXRF results indicating that they each belonged to one of four groups: Antimony-decolorized (Group 1.1 derivatives, High manganese/low antimony (Group 1.2.3 or 1.3.2.1 derivatives), Aqua (Group 1.3.1.1 derivatives), and Mixed Manganese Antimony (Group 1.3.1.2 derivatives, Group 1.3.2.2, or Group 1.3.2.3). Samples were done by museum conservators at the Kelsey Museum. Since EPMA requires a mounted and polished sample, specimen selected for sampling were not whole vessels. I conducted sample preparation at the Getty Conservation Program facilities at the Getty Villa under the instruction and supervision of Dr. David Scott. Museum samples along with a fragment of CMOG Standard Ref. B were mounted in a resin and polished to a mirror finish exposing a cross-section of the sample using a diamond saw. They were then coated with Carbon.

EPMA was conducted at UCLA Geology Department facilities using a JEOL 8200 Electron microprobe with 5 WDS spectrometers and natural mineral standards with ZAF corrections. Operating conditions were a standard setup, and each sample was analyzed several times under two settings. The lower energy operating conditions included an accelerating voltage of 15 KeV, a beam current of 15 nA and a 10 micro beam to reduce volatile loss. Each sample was measured in three different locations under this setting and 20-second measurements were taken for each peak, except for Na and K peaks, which were measured for only 10 seconds to reduce burn off. High energy settings aimed at improving the accuracy of Ba, Ti, Mg, Mn, and Sb. Two locations in close proximity to two out of the three locations previously analyzed were analyzed under the high energy settings. These were conducted at an accelerating voltage of 15 KeV, a beam of 40 nA and a micro beam spot of 20. Measurements were acquired for 120

seconds for each of the Ti and Ba peaks, and 240 seconds for each of the Mg, Mn, and Sb peaks. Oxygen for elemental oxides was calculated by stoichiometry and Fe was measured as Fe2O3. Measurement results under each setting were combined according to which setting yielded the most accurate results for each elemental oxide for Corning Standard Reference B. See Table 5-4 for precision/accuracy results for EPMA.

For EPMA, each sample was analyzed under two conditions, low and high settings. Three different readings of different areas of the sample were taken under the low settings and two readings were taken under the high settings. The mean value was then calculated for each element under each setting. Standard Ref. B was also analyzed with EM and the results from high and low settings were combined according to which setting yielded the most accurate results for the standard for a particular element. Total measurements for one point on sample SPEC ID 853 were discarded due to unreliable results.

5.12 EPMA Results

EPMA results are summarized in the table below. In addition to the three samples labeled above, electron microprobe was conducted on an additional museum sample, SPEC ID 823 (presumably belonging to Group 1.3.1.1).

Table 5-4. Results for electron probe micro-analysis of Karanis glass from the Kelsey Museum of Archaeology. Elements are given as weight percentages of oxides.

ACC. #	5583	5852	5956	6421	STANDARD REF. B	STANDARD REF. B ACTUAL (BRILL 1999)
SPEC ID	**823**	**829**	**832**	**853**		
CaO	6.197	5.2385	8.7	5.9835	8.575	8.56
SiO_2	64.829	73.11367	63.98167	67.83167	60.73267	61.55
Na_2O	19.844	15.8325	18.9045	17.5865	15.8235	17
MnO	0.645667	0.017	1.846667	0.701333	0.246	0.25
K_2O	1.172667	0.478667	0.706667	0.715333	1.091333	1
TiO_2	0.201	0.083	0.157	0.1215	0.1125	0.089
Al_2O_3	2.501333	2.020333	2.624667	2.291	4.364333	4.36
MgO	1.812	0.431333	1.314333	0.899333	1.030667	1.03
Fe_2O_3	1.326	0.3575	1.0205	0.7435	0.3665	0.34
Sb_2O_5	0.341667	0.804	0.071	0.777667	0.557333	0.46
BaO	0.045	0.0275	0.044	0.0245	0.118	0.12
P_2O_5	0.494333	0.014	0.155333	0.184333	0.831	0.82
Cl	1.249667	1.077667	0.878333	1.243333	0.179667	0
SrO	0	0	0	0	0	0.019
Total	100.6593	99.49567	100.4047	99.1035	94.0285	95.598

SPEC ID 829: Antimony-Decolorized

As presumed, SPEC ID 829 above corresponds fairly well to the composition of Romano-British Sb-decolorized glass, but has almost three times the amount of Sb_2O_5 (Group Colourless 1 in Table 5-6 below). Table 5-6 below summarizes some of Foster and Jackson's (2010) results from their study of Romano-British colorless glass. SPEC ID 829 matches even more closely to the mean value for Sb-decolorized glass from Bubastis (Rosenow and Rehren 2014, see Table 5-6 below).

SPEC ID 832: High Manganese/Low Antimony

The High manganese/low antimony EPMA sample (SPEC ID 832) does not closely match either of Foster and Jackson's (2009) Colourless 2 glasses (Table 5-6 below). It aligns more closely with Colourless 2b since it has elevated Ca and K levels. However, it has about twice as much MnO in it than the 2b glass and about 60% more Fe. SPEC ID 832 also has almost twice as much MnO as the Mn-decolorized glass analyzed by Rosenow and Rehren (2004) and more Fe2O3, Ti2O, and K2O as well (see Table 5-6 below).

Table 5-5. Average composition of Roman glass (after Foster and Jackson 2009: 190 from Nenna *et al.* 1997: 83, Table 2). Average composition of 227 Roman glass samples dating from 1st-4th cent. CE from Eastern and Western Empire.

	Wt% →									
	SiO_2	**Al_2O_3**	**Fe_2O_3**	**MgO**	**CaO**	**Na_2O**	**K_2O**	**TiO_2**	**P_2O_5**	**MnO**
Mean	69.54	2.59	0.62	0.59	7.48	16.63	0.75	0.13	0.12	0.73
SDev	2.53	0.38	0.48	0.29	1.18	1.50	0.24	0.14	0.05	0.74

Table 5-6. Average composition of oxides and elements for Romano-British (Foster and Jackson 2010) and Egyptian (Rosenow and Rehren 2014) colorless glasses (after Foster and Jackson 2010: 3070).

			WT% →										PPM	PPM
Glass Type	**n**		**Al_2O_3**	**Fe_2O_3**	**MgO**	**CaO**	**Na_2O**	**K_2O**	**TiO_2**	**P_2O_5**	**MnO**	**Pb**	**Sb**	**Ba**	**Sr**
Colourless 1	46	Mean	1.90	0.40	0.49	5.47	18.99	0.39	0.06	0.02	0.04	0.01	0.29	148	416
(Foster & Jackson 2010: 3070)		SDev	0.22	0.10	0.12	0.74	1.11	0.06	0.02	0.01	0.04	0.02	0.11	15	81
Colourless 2a	5	Mean	1.81	0.48	0.67	5.77	18.46	0.29	0.09	0.03	1.14	bd	0.06	199	442
(Foster & Jackson 2010: 3070)		SDev	0.26	0.05	0.11	0.41	0.54	0.04	0.01	0.01	0.16		0.03	27	33
Colourless 2b	8	Mean	2.37	0.40	0.41	8.02	18.29	0.61	0.06	0.06	0.92	bd	0.02	408	501
(Foster & Jackson 2010: 3070)		SDev	0.30	0.07	0.07	0.52	0.81	0.04	0.01	0.02	0.10		0.01	97	15
Colourless 3	69	Mean	2.08	0.55	0.59	6.12	19.48	0.53	0.09	0.05	0.35	0.07	0.30	219	432
(Foster & Jackson 2010: 3070)		SDev	0.23	0.11	0.15	0.44	0.93	0.09	0.02	0.02	0.15	0.12	0.09	39	39
Mn-Decolorized	6	Mean	2.25	0.31	0.62	8.05	16.0	0.60	0.05	0.08	1.00	np	<0.03	np	np
(Rosenow and Rehren 2014:177)		SDev	0.18	0.35	0.18	0.76	1.2	0.15	0.00		0.30	np		np	np
Sb-Decolorized	19	Mean	2.0	0.48	0.59	6.84	17.2	0.53	0.08	0.04	0.02	np	0.7	np	np
(Rosenow and Rehren 2014:177)		SDev	0.20	0.22	0.15	1.07	1.0	0.09	0.02	0.02	0.02	np	0.2	np	np

Table 5-7. Mean composition for of oxides for "naturally colored glasses", HIMT and Levantine types (after Foster and Jackson 2009: 190). Horizontal line separates HIMT and Levantine glasses

		WT% →							
Glass Type	**n**	**Al_2O_3**	**Fe_2O_3**	**MgO**	**CaO**	**Na_2O**	**K_2O**	**TiO_2**	**MnO**
Group E	9	2.56	1.402	0.959	5.88	17.26	1.02	0.514	1.955
(Mirti et al. 1993:232)									
HIMT	6	2.8	1.89	1.1	6.9	17.9	0.5	0.4	1.7
(Freestone 1994:290)									
Group 1	43	2.88	2.28	1.3	6.22	19.12	0.41	0.49	2.023
(Foy et al. 2003: 83-84)									
Group 2	61	2.53	1.32	1.2	7.73	18.37	0.79	0.16	1.503
(Foy et al. 2003: 83-84)									
HIMT 1	123	2.49	1.36	0.98	6.08	19.11	0.50	0.33	1.71
(Foster and Jackson 2009: 192)									
HIMT 2	221	2.25	0.72	0.76	6.00	19.65	0.58	0.12	0.98
(Foster and Jackson 2009: 192)									
Strong HIMT	28	2.70	1.84	1.03	5.70	18.1	0.42	0.50	2.01
(Rosenow and Rehren 2014: 178)									
Weak HIMT	29	2.32	0.83	0.93	7.12	17.9	0.54	0.15	1.05
(Rosenow and Rehren 2014: 178)									
Group 3	123	2.53	0.51	0.62	7.81	16.77	0.55	0.07	0.732
(Foy et al. 2003: 85)									
Levantine 1	23	2.99	0.42	0.63	9.06	15.98	0.83	<0.1	<0.1
(Freestone et al. 2000: 77-78)									
Levantine 1a	16	2.81	0.42	0.59	8.45	15.55	0.60	0.07	1.23
(Foster and Jackson 2009: 192)									
Levantine 1b	8	2.93	0.33	0.45	8.55	14.56	0.72	0.06	0.10
(Foster and Jackson 2009: 192)									

Table 5-8. Roman blue-green glass composition from Coppergate, York, dating 1st-2nd century CE (Bingham and Jackson 2008: 304), 3rd-4th century CE blue-green glass from Britain (Foster and Jackson 2009), and plant ash glass from Bubastis, Egypt (Rosenow and Rehren 2014: 177).

			Wt% →										
Glass Type	**n**		**Al_2O_3**	**Fe_2O_3**	**MgO**	**CaO**	**Na_2O**	**K_2O**	**TiO_2**	**P_2O_5**	**MnO**	**Pb**	**Sb**
Blue-Green 1st-2nd cent. CE from Coppergate, York	5	Mean	2.38	0.6	0.52	6.9	17.54	0.56	0.08	0.10	0.52	np	0.29
(Bingham and Jackson 2008: 304)													
Blue-Green 3rd-4th cent. CE Romano-British	8	Mean	2.59	0.76	0.61	7.16	17.20	0.80	0.08	0.09	0.55	0.28	0.21
(Foster and Jackson 2009: 192)													
Plant Ash 1st-2nd cent. CE (3) 1st-5th cent. CE (1)	4	Mean	1.92	1.03	2.41	7.12	17.0	1.43	0.14	0.70	0.82	np	0.5
from Bubastis, Egypt		Min	1.76	0.81	1.44	6.05	14.3	1.15	0.11	0.37	0.22	np	<0.3
(Rosenow and Rehren 2014: 177)		Max	2.09	1.17	3.39	8.85	18.5	1.75	0.16	1.10	1.55	np	0.6

SPEC ID 823: Aqua (Blue-Green or Plant Ash-Based)

SPEC ID 823 is similar in Mn and Sb levels as the 1-2nd cent. A.D blue-green glass from Coppergate, York (Bingham and Jackson 2008, see Table 5-8 above), but has much higher levels of TiO_2, K_2O, Fe_2O_3, P_2O_5, and MgO than these published samples. SPEC ID 823 does not resemble the later blue-green glasses reported by Foster and Jackson (2009, Table 5-8 above). It has a much higher concentration of MgO, P_2O_5, and K_2O than the average composition of Roman glass (see Table 5-5 above).

The high TiO_2, K_2O, and MgO levels of these glasses were explained recently by Rosenow and Rehren (2014) to be due to plant ash based fluxing agents employed rather than natron, which is typically used during the Roman period. SPEC ID EPMA results align more closely with Rosenow and Rehren's plant ash-based glasses (see Table 5-8 above). They describe these samples as three "dark green-turquois" *unguentaria* and one ridged handle (2014). Since SPEC ID 823 is from a "dark aqua" rectangular bottle it may also represent a plant ash-based glass. Even though plant ash-based glasses are quite rare in the eastern Mediterranean during the Roman period, as natron replaced plant ash as the fluxing agent in glasses around 800 BCE in Egypt and the eastern Mediterranean (Henderson 2013; Schlick-Nolte and Werthmann 2003). This type has been found at two sites within Egypt, quite disparate in location, Bubastis (Rosenow and Rehren 2014) and Wadi el-Natrun (Picon *et al.* 2008). Picon *et al.* (2008) attribute this type to local Egyptian production. Similar glass types have also been reported from Britain and France (Jackson *et al.* 2009), Italy (Gallo et al 2013) and Albania (Schibille 2011).

Brill may have analyzed at least one of these types and even noted that it did not seem typical of Karanis glass finds. It was a green bottle with high MgO, TiO_2, Fe_2O_3, K_2O, and lower levels of Sb than Group 1.3.1.1 (sample 3299, Brill 1999, Karanis V.E.). One other

sample has high MgO, TiO_2, and Fe_2O_3, but lower K_2O and no Sb_2O_5 (sample 312, Brill 1999, Karanis V.E.). This sample was an amber colored conical vessel, so it does not seem likely to be the same type.

SPEC ID 823 presumably belongs to Group 3 from pXRF analysis. Although the outward appearance of this specimen is distinctive and a similar specimen was analyzed with pXRF (SPEC ID 828), no pXRF results are available for SPEC ID 823 for comparison.

So it is unclear if all samples from Group 1.3.1.1 and its derivatives are of the same types as SPEC ID 823, since there is clearly a high-potassium subgroup of Group 1.3.1.1. (Group 1.3.1.1.2). Further investigation with EPMA is necessary to confirm the identification of this Aqua glass group.

SPEC ID 853: Mixed Manganese Antimony

SPEC ID 853 belongs to the mixed manganese antimony glass group, since it has manganese and antimony concentrations above trace levels. As mentioned, the presence of both decolorizers above trace levels can be explained through recycling of glass (Foster and Jackson 2010). Group 1.3.1.2 derivatives, Group 1.3.2.2, and Group 1.3.2.3 are the Mixed manganese/antimony glasses discovered through this pXRF analysis, some of which are colorless. Mixed manganese antimony glasses have been observed and identified in several other studies (Foster and Jackson 2010; Jackson 2005; Jackson part published in Baxter *et al.* 2005; Paynter 2006; Silvestri *et al.* 2008).

SPEC ID 853 is somewhat similar to the composition of Colourless 3 (Foster and Jackson 2009 in Table 5-6 above). However, SPEC ID 853 has much higher MnO, Sb_2O_5, and MgO concentrations, as well as slightly higher Fe_2O_3, P_2O_5, and K_2O levels and a lower Na_2O

concentration. The main characteristic of SPEC ID 853 that identifies it as a Mixed Mn/Sb glass, is the presence of both Mn and Sb decolorizers above trace levels, but below usual concentrations for Mn-decolorized or Sb-decolorized glasses.

5.13 Concluding Remarks

This study demonstrates that pXRF analysis can be effectively employed to conduct quantitative analysis of ancient glasses in order to identify distinct compositional groups within a closed population. Several cautionary measures must be taken, however, to ensure not only that the instrument is capable of detecting the elements of interest with good precision, but also that the transformation of raw data to quantitative measurements introduces the least amount of error to the data. One must use only elements that can be reliably measured by the instrument to distinguish distinct groupings within a sample population. Furthermore, when on-site analysis is necessary, the *Bruker Tracer III-V* pXRF provides an effective and non-invasive means to investigate the chemical composition of ancient materials.

I distinguish five main glass types: Antimony-decolorized (Group 1.1 derivatives), High manganese/low antimony (Group 1.2.3 derivatives), Low manganese/low antimony (Group 1.2.1), Aqua (Group 1.3.1.1 derivatives), and Mixed manganese antimony glass (Group 1.3 derivatives). As shown above, four of the five main glass types are subdivided through the careful analysis of other elemental concentrations.

These results provide the first evidence for Mixed manganese antimony glass at Karanis. Harden (1936) only identified two colorless glass types from the site of Karanis based on outward appearance. I have identified three Antimony-decolorized subgroups as well as colorless glass from the High manganese/low antimony group. Therefore, pXRF chemical

analysis of this corpus yields significant results that aid in refining the fabric classification outlined by Harden.

Chapter 6

Classification of Karanis Glass

6.1 Introduction

A classification system should not be an imposed order, but rather, it should reflect the decisions artisans made during the manufacture and production of the artifacts "using shared conceptualizations" (Read 2007:11). The decisions and series of physical actions carried out during the production of an artifact are embedded in communities of practice (Bourdieu 1977; Read 2007). By considering an object not as an end product, but as the result of a *chaîne opératoire*, I intimate the social agency underwriting the entire production process.

6.2 Chapter Overview

In Chapter 4, I outline the *chaîne opératoire* of glass working according to Cairene glass blowers and the Roman Glassmakers. The previous chapter investigates the first phase of glass manufacturing: glass making. This chapter details methods I use to establish associations among variables, including the compositional types established in Chapter 5. I describe how *chaîne opératoire* can be used to inform a morphological typology that will aid in the identification of patterning in the data. These analytical techniques also allow me to discern possible functional types. Following, is a case study of Karanis bowls that tests and validates these methods. I then formulate a new typology of Karanis bowls. Last, I apply these same analytical techniques to identify relationships between compositional groups and morphology of recently excavated glass from Karanis.

6.3 Overview of Methods

Identifying the *chaîne opératoire* of glass manufacturing is crucial in identifying which decisions in the production process were important in distinguishing one vessel from the next for the society in which the artifacts were embedded. Furthermore, the sequence of events in the process are also important in determining the final product; therefore, the morphological typology I propose takes this sequence into account.

Harden created a morphological classification for Karanis glass (see Appendix 5) and a fabric typology (see Table 6-7 below) (1936). Since the fabric typology was not informed by chemical analysis, however, many of these groups may not represent distinct compositions. The guidelines he used to delineate these groups, is useful, however, when evaluating the quality of the fabric. This relates not only to the raw ingredients used, but the temperature of the furnace used to heat the glass, the skill of the artisan, and technology employed. Consequently, I use all of this information to make morphological and fabric distinctions that help reveal patterns among several variables. Dividing the morphological types into too many or two few groups, however, may hide patterning in the data. Therefore, it is crucial to select culturally salient dimensions and to try more than one typology to reveal patterning. The database I designed to house variables allows for the combining or separation of groups based on specific parameters, enabling me to explore several typologies.

It is not necessary to modify every class type in Harden's morphological typology. Instead, I reform parts of his classification based on the *chaîne opératoire* of glass manufacturing in order to better address my research questions. After conducting a case study of bowls from Karanis analyzed by Harden (1936), I conclude that some of his designations are valid even though he does not explicitly state the parameters used to make these distinctions. For bowls, he

separates deep and shallow bowls presumably based on quantitative measurements. He does not outline which measurements, if any, he used to determine groups and what range of these measurements apply to deep bowls versus shallow ones. Therefore, I investigate his subdivision of bowls into shallow and deep groups through statistical analysis of measurements I took of bowls housed in the Kelsey Museum. I change the way in which he subdivides this group so that subgroups are separated according to the sequence of decisions necessary for the artisan to create these forms.

The ethnoarchaeological study I carried out helped me determine this sequence of steps necessary to form a glass bowl. It is this glass working phase (phase 4 in Figure 4-1 above) that informs my morphological typology of bowls. As in the case of the formulation of the fabric typology, it is ideal to make the dataset as homogenous as possible. This requires the separation of objects first by qualitative distinctions, then by quantitative dimensions (Read 2007, 2015). The iterative procedure for quantitative analysis is not necessary in the case of bowls because only two variables are considered to assess bowl depth. Furthermore, as this case study shows, types can be distinguished through qualitative rather than quantitative analysis.

To identify use types among bowls, I employ Read's method (1974) of examining frequency counts as a way to determine what type, or combination of types, accounts for deviation in the frequency counts from the expected values in a 2-dimensional contingency table with independent variables (Read 2007: 255).

6.4 Case Study: Karanis Bowls

6.4.1 Testing Harden's Categories of "Shallow" and "Deep" Bowls

Although Harden's classification of Karanis glass is based primarily on morphology, he separates bowls into two classes (Class II and III) based on a "shallow" vs. "deep" bowl distinction. His morphological typology is almost entirely based on qualitative dimensions, but with bowls, he divides types based on a quantitative measurement (bowl depth) without carrying out any quantitative analysis. Harden even admits:

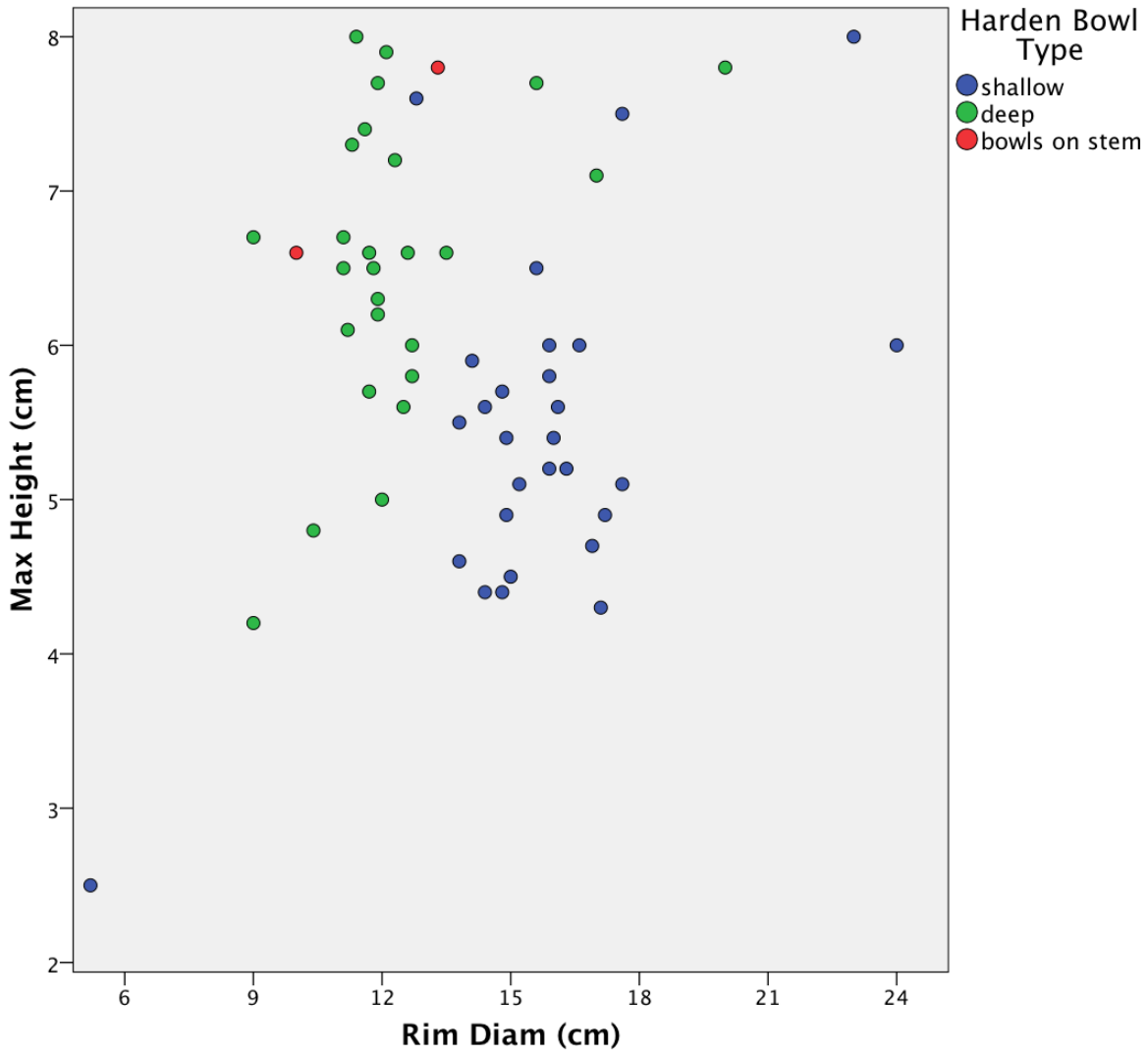
> Naturally, no hard-and-fast rule of proportion can be laid down for deciding to which of the two classes a particular specimen belongs, but in practice it will be found that, except in the case of bowls with rounded bases, the types themselves are distinctive (1936: 63).

His criteria of assigning bowls is as follows. For shallow bowls, he includes those for which the side is short in comparison with the diameter of the bowl, whereas the side is "longer" for bowls belonging to the deep bowl category (1936: 63). What he means by "longer" is slightly ambiguous. Perhaps the side profile is longer than the length of the diameter of the bowl? Or does he mean the side is still shorter than the diameter of the bowl, but greater in height than the Class II bowls? By tabulating the maximum length and maximum diameter of bowls it was obvious that he meant the latter, since no bowl has sides taller than the width of the diameter.

I analyzed 56 bowls housed at the Kelsey Museum in Michigan, forty-three of which were previously analyzed and published by Harden (1936). These bowls were primarily whole vessels; only 3 were fragmented specimen and two were virtually whole with small fragment(s) missing. The three fragmented vessels were complete enough to discern measurements. In his publication, Harden gives only the maximum height of vessels, which is presumably the vertical distance from the top of the rim to the bottom of the base. Maximum height is not an appropriate measurement to determine depth, however, since maximum height is highly affected by the

height of the base. Figure 6-1 below demonstrates that maximum height is also not culturally salient dimension by which these bowls can be divided, since both shallow and deep bowls share a similar range in maximum height values.

Figure 6-1. Maximum height and rim diameter biplot based on Harden's published measurements for these two dimensions (1936).

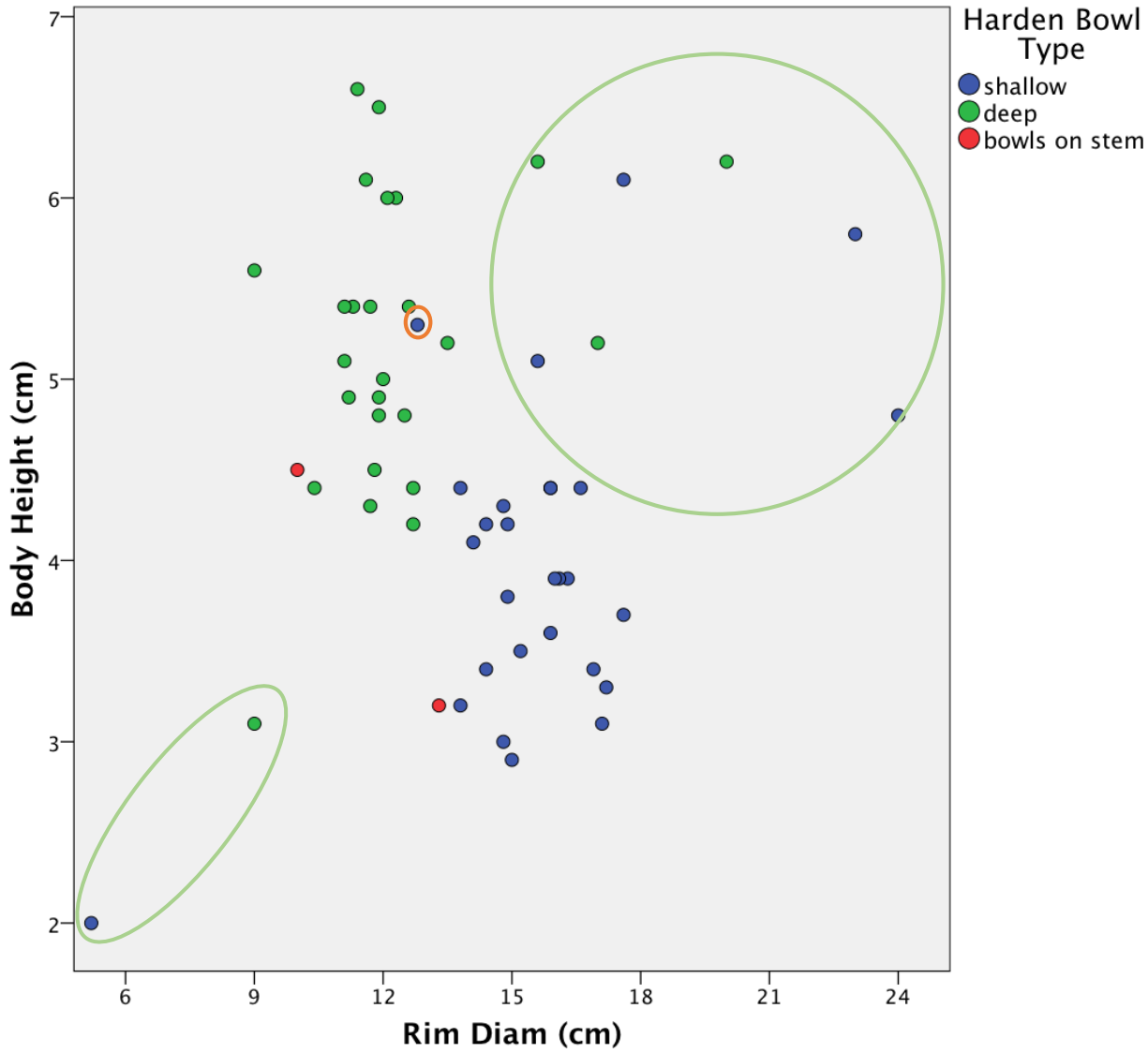


To investigate whether or not Harden's separation of bowls into shallow and deep categories is a valid distinction to make, I evaluate quantitative measurements of the body height, rather than maximum height of vessels. I use the term body height to refer to the vertical distance from the top of the rim to the junction of the body and base. In other words, body height is the maximum height minus the height of the base. I then determine what range of measurements define deep bowls versus shallow ones. To ensure consistency, I re-measured the maximum rim diameter and maximum height for each vessel (previously measured by Harden), and I measured the base height and body height as well.

The body height measurement alone cannot differentiate bowls from one another because they vary in size. A bowl twice as large as another with the same body height will appear shallower in shape. To account for this, I compared ratios of body height and maximum rim diameter using a biplot of these two measurements (see Figure 6-2). Despite 9 possible outliers, the biplot indicates that this ratio is a culturally salient dimension and that bowls should be separated into two categories based on these variables.

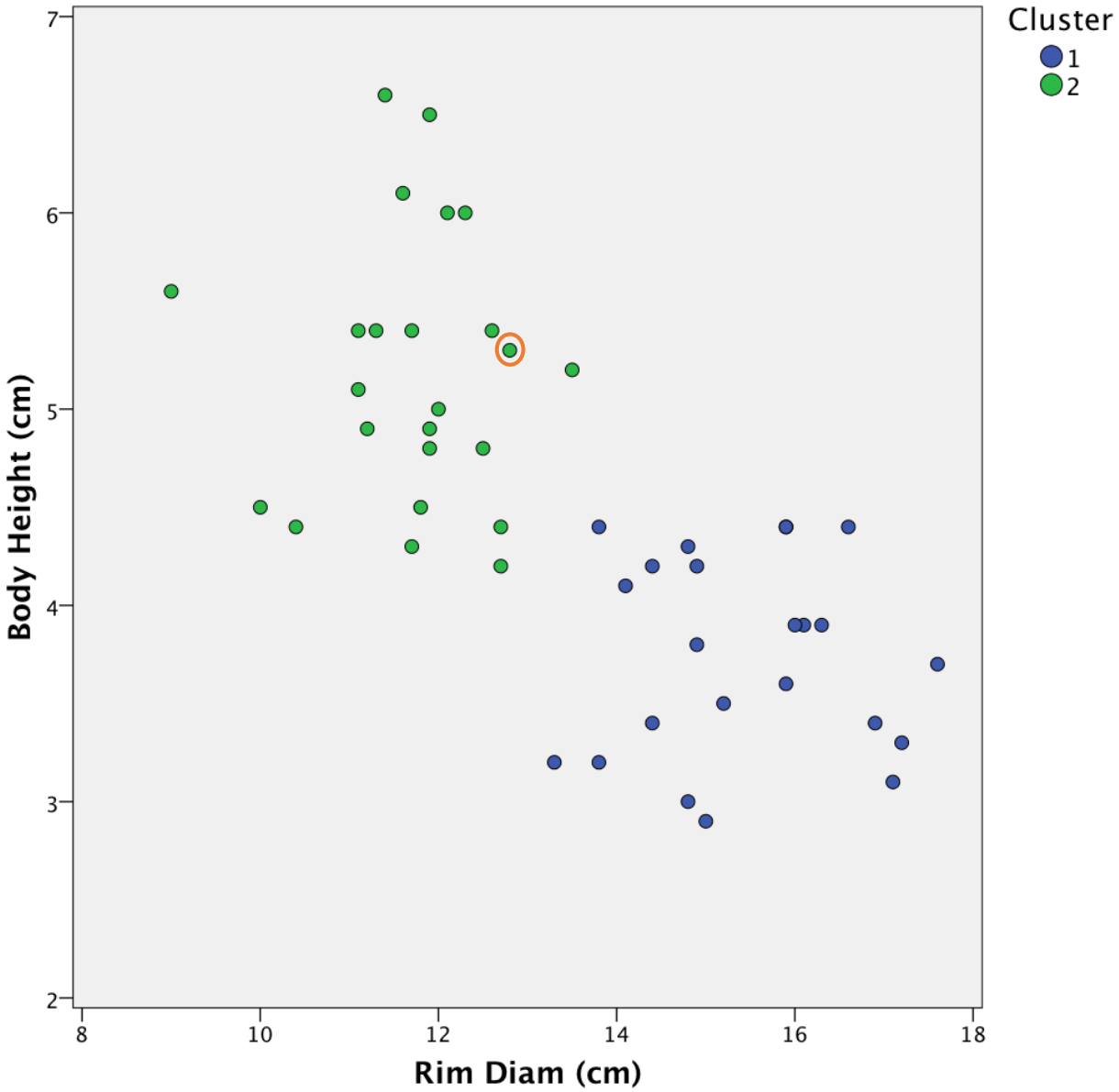
This bivariate plot shows structure that is not easily seen when body height and rim diameter are examined separately through histograms. Body height alone does not separate these bowls into two groups. Rim diameter more clearly divides these groups. But it is the combination of these two variables that clarifies the differences between these two groups. The deep bowls are constrained with rim diameter, but show large variation in body height. The shallow bowl group, on the other hand, does not show strong constraint in either rim diameter or body height.

Figure 6-2. Biplot of rim diameter and body height of Karanis bowls from the Kelsey Museum (n=57). Possible outliers are circled in green. One bowl categorized by Harden as "shallow" (circled in orange below) is grouped with the bowls Harden identifies as "deep" after k-means cluster analysis (see point circled in orange in Figure 6-3 below).



I remove these 9 outliers to determine if a k-means cluster analysis yields similar groupings if two clusters are specified and rim diameter and body height are the variables considered (see Figure 6-3 below). Note that only three samples are categorized differently compared to how Harden classified them. The two stemmed vessels are forced into one of the two cluster groups (since only two clusters are specified), and one bowl Harden classifies as "shallow" (see orange outline in Figure 6-2 above) is grouped with bowls Harden considers "deep" after k-means cluster analysis (see orange outline in Figure 6-3 below).

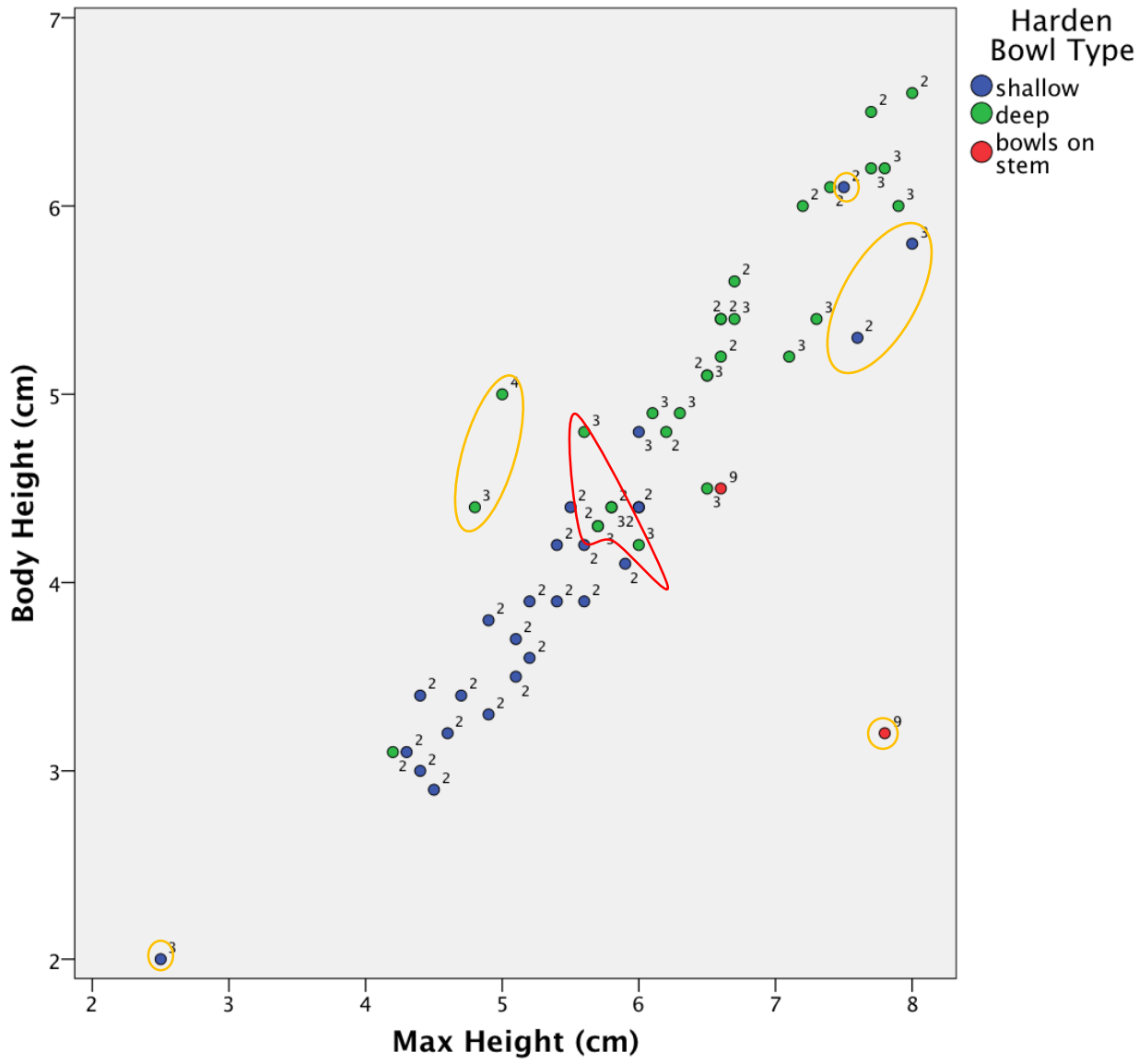
Figure 6-3. Biplot of rim diameter and body height with clusters 1 and 2 from k-means cluster analysis shown. One bowl categorized by Harden as "shallow" (circled in orange in Figure 6-2 above) is grouped with bowls Harden considers "deep" after k-means cluster analysis (circled in orange below)



This cluster analysis confirms two distinct groups. Rim diameter appears to be a more accurate variable by which to distinguish groups, since there are fewer overlapping values. There are six shallow bowls that share similar values for body height than deep bowls, so separating groups based on this one variable does not result in distinct types.

Graphing the ratio of maximum height versus body height (Figure 6-4 below) shows that bowls can again be separated by shallow and deep categories, with a few exceptions (outliers circled in orange and red). The four deep bowls that group with the shallow bowls (circled in red) have true base rings instead of the usual padded bases for shallow bowls. Since the base height is the difference between maximum height and body height, this graph shows that the base height varies regularly with the height of the vessel. This linear trend does not go through the origin, indicating that there is not a constant ratio between body height and maximum height. This means that the base height varies regularly with the maximum height of the bowl, but not in an isometric manner (Read, November 2014, personal communication).

Figure 6-4. Maximum height versus body height for all bowls (n=56). Point labels indicate base type numbers: 2=padded base, 3=true base ring, 4=rounded base, 9=stemmed base. Red outline indicates deep bowls grouped with shallow ones. Yellow outlines indicate other outliers.



6.4.2 Refining the Morphological Typology of Bowls

The above quantitative analysis shows that there are quantitative grounds for separating the bowl population into two groups. To homogenize the initial data set, however, one should separate objects first by qualitative dimensions, rather than starting with quantitative distinctions (Read 2007, 2015). There are many ways to divide this data set qualitatively: body type, base type, rim type, color, etc. Depending on the order in which you divide the data set by these variables, you will end up with different groupings. Using my Access database and query functions, I am able to explore several ways of grouping bowls.

To establish whether or not the total bowl population should be divided first according to the dating of these artifacts, I conducted several chi-squared analyses. Forty out of the 56 bowls were datable, since the dating of surface finds and some layers are unknown. Through cross-tabulation chi-squared analyses, I tested whether or not dating of the artifacts are associated with types of body shapes, rims, and/or bases. None of the analyses yielded significant Pearson chi-squared values (see Appendix 6); therefore, I do not separate bowls first according to the dating of the artifacts. Since the dating of these bowls excavated by University of Michigan are problematic (see explanation in Ch. 2), perhaps these inaccuracies in the dating are hiding patterns in types produced at different time periods. Or perhaps the types of bowls represented in this sample population truly did not change significantly during the time period represented. After I divide the total bowl population by quantitative variables based on morphology, I again explore relationships among morphological types and dating.

I now outline below my procedure for dividing the dataset using morphological traits, following the sequence of decisions that occurred during the production of these objects (refer to phase 4 in Figure 4-1 above). Note that the body of an open form, like a bowl, is partly

determined by the shape of the bubble (step c), which is then finalized during step e, after the base has been applied and/or shaped and a pontil has been attached. Since at this earlier step while shaping the bubble the artisan needs to make a decision about his/her desired end shape of the body, the body shape is the first dimension by which I separate bowls for my morphological typology.

I identify five general shape categories (see Figure 6-5). It must be noted that type 3 resembles the profile of dishes in Harden's Class 1, even in depth. The main difference is that the Class 1 dishes are ovular, not circular (see Figure 6-6). Because all vessels Harden identifies as dishes are ovular, making them fundamentally different in shape than either bowls or plates, I think that they should be categorized in a class of their own. This highlights how often distinctions between plates, bowls, dishes, and cups are arbitrarily made or the parameters by which they are distinguished are not explicitly stated. As Price and Cottam point out (1998), there is often room for interpretation when assigning artifacts to particular groups, even if efforts are made to base these distinctions on definable terms.

Figure 6-5. Body shape types of bowls as defined by this study: 1) straight-sided 2) convex-sided 3) tapering, irregular profile 4) squat rectangular or nearly rectangular 5) bell-shaped. Redrawn by Jennifer Dillon after Harden 1936, no. 221, 235, 116, 130, 228, Pl. XII and XIV.

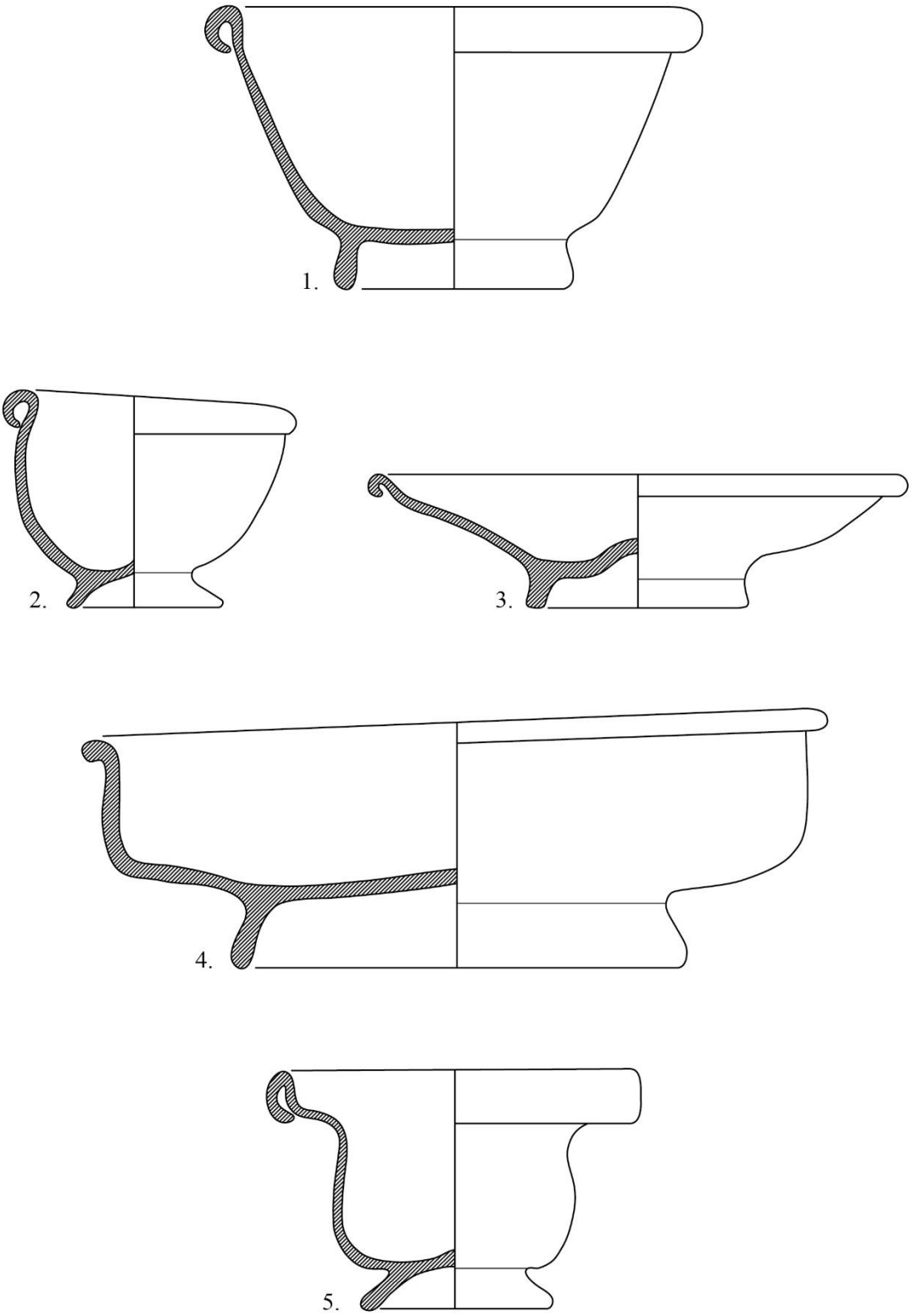


Figure 6-6. Harden Class 1 Dish. Redrawn by Jennifer Dillon, after Harden 1936, no. 17, Pl. XI

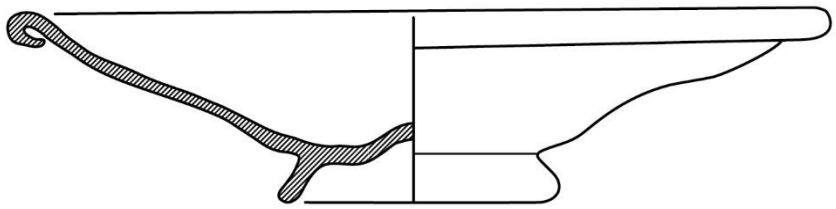


Figure 6-7. Rim diameter and body height comparison of body shapes. Legend indicates body shape type and point labels represent Harden's class number: 2=shallow bowls, 3=deep bowls, 4=bowls on stem

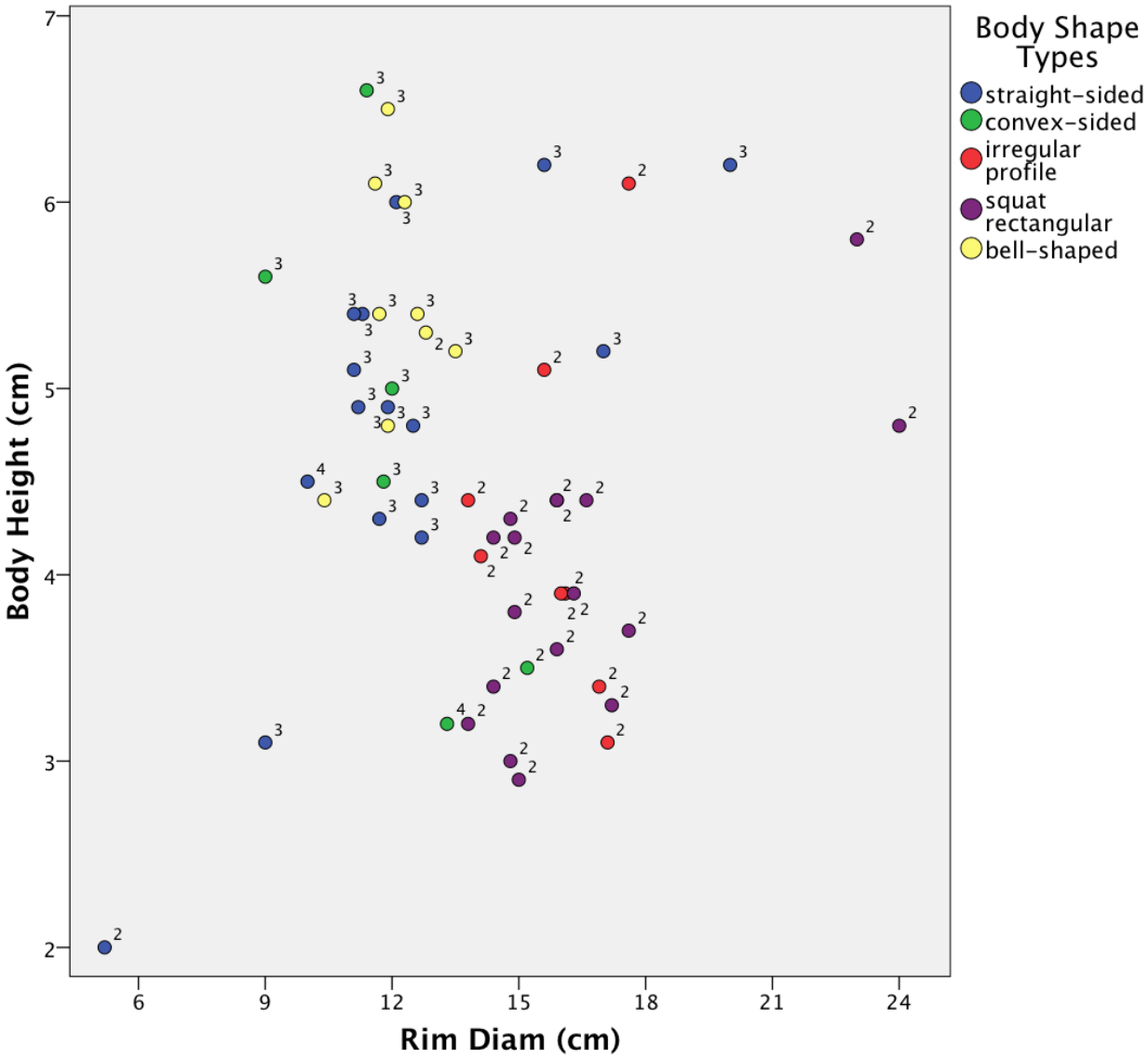


Figure 6-7 shows that the majority of the shallow bowls are squat rectangular in body shape, and that the remainder are irregularly contoured. Aside from the one convex-sided vessel in the shallow group, the body shape types represented in the shallow group are distinct from those belonging to the deep bowl category. In other words, there are no squat rectangular or irregularly contoured bowls in the deep bowl group. Similarly, there are no shallow bowls that have straight-sided or bell-shaped bodies. The bowl I categorize as convex-sided in the shallow bowl group (SPID 786) has an ambiguous shape; it is nearly rectangular in profile, see Figure 6-8). SPID 768 is also ambiguous in shape, as it has both a squat rectangular profile and convex profile (see Figure 6-9). The stemmed bowl that is straight-sided but shares the ratio of rim diameter and body height with the shallow bowls, is also close to squat rectangular in shape. So, it appears that there are distinct shapes common to each of the two categories (shallow and deep), and that the quantitative differences in depth may be a product of the variation in general shape of the objects rather than depth being a defining variable in itself.

Figure 6-8. The nearly rectangular profile of the convex-sided shallow bowl (SPID 786). Redrawn by Jennifer Dillon, after Harden 1936, no. 107, Pl. XII.

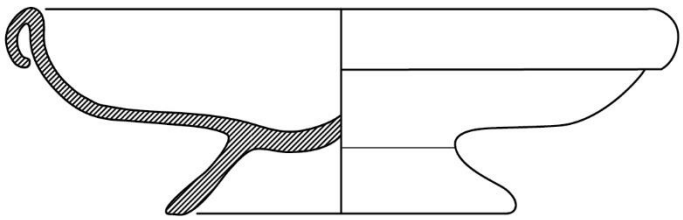
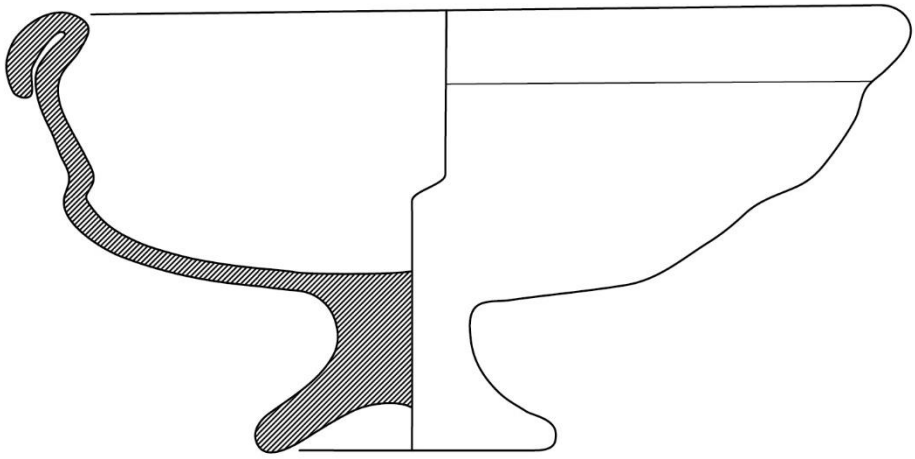


Figure 6-9. Sketch of SPID 768 showing the nearly rectangular profile of one half of the vessel and convex profile of the other half. Note that this sketch only shows the different profile contours of the vessel and does not accurately reflect the metric proportions of the vessel, such as rim diameter and vessel body height ratio. Sketch by Susak Pitzer, rendering by Jennifer Dillon, Harden no. 356, Pl. XV.



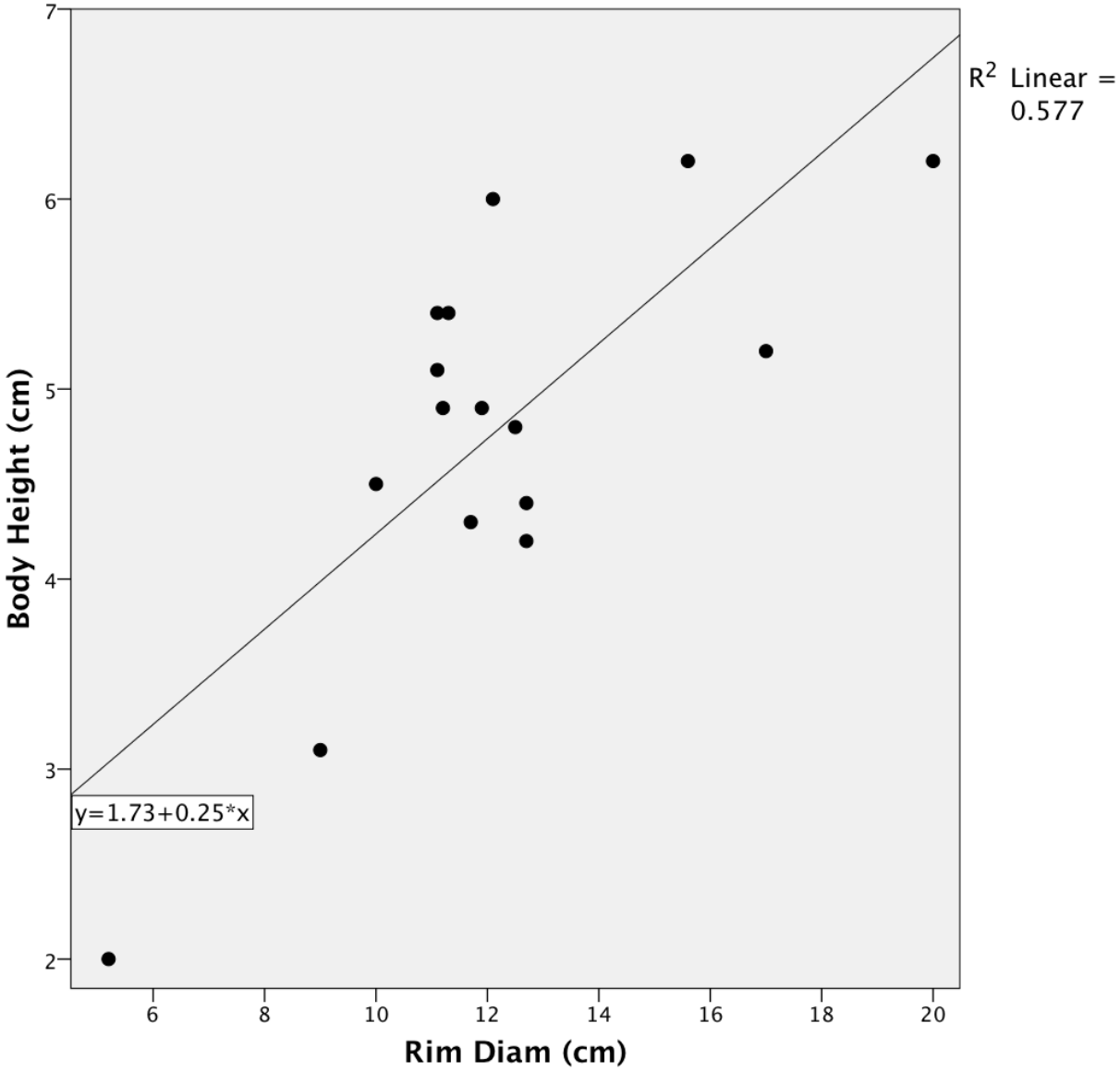
In short, subdividing based on a qualitative assessment of shape results in two vessels that have ambiguous shapes. Dividing bowls according to quantitative differences in depth, on the other hand, results in 9 possible outliers and overlap in values (ratio of rim diameter and body height) that define each group.

According to the *chaîne opératoire* of forming a bowl, one must first conceptualize what general body shape is desired and then create a suitable bubble. The next step is forming and/or attaching the base. Consequently, I separate these body shape groups further according to base types. I created a detailed base typology for the entire Karanis assemblage, but I use more general base type categories to formulate a bowl typology. These categories are: 1) pushed-in, 2) padded, 3) true base ring, 4) rounded/convex, 5) toed, 6) flat, 7) concave, 8) coiled, and 9) stemmed (see Appendix 7 for detailed description of categories).

Regression analysis further supports that the bowls are better divided by body type first, then base type. If all of these bowls with various body shapes are graphed together, they show no correlation between rim diameter and body height (R^2=1.247E-4) (see Fig. 6-7 above, no

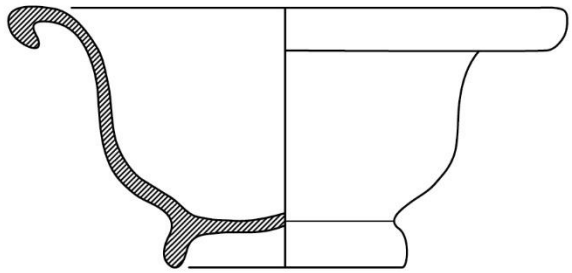
regression line shown). If the outliers identified through quantitative analysis are not removed, the straight-sided bowls show a weak positive correlation (R^2=0.577) between rim diameter and body height (see Figure 6-10 below).

Figure 6-10. Biplot of rim diameter and body height for straight-sided bowls (n=16). Regression line shows a weak positive correlation (R^2=0.577) between rim diameter and body height



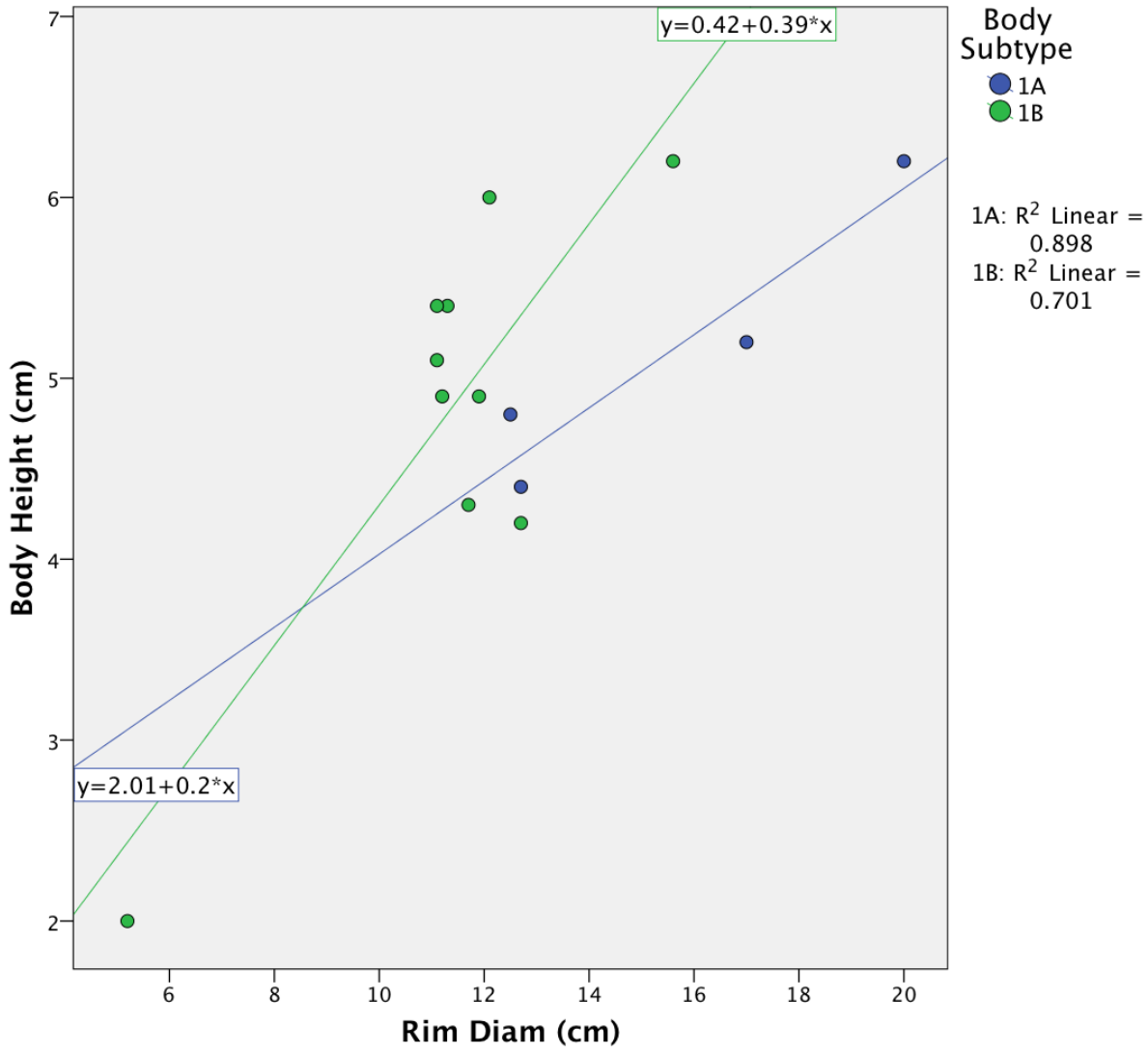
The straight-sided bowls can be further subdivided by base type according to the *chaîne opératoire* of bowl making. Fourteen out of the 16 straight-sided bowls have true base rings, so I separate them by base type. After the base has been added, a pontil can be attached so that the rim can be worked. So, the rim is one of the last phases of bowl production and consequently, determines the final split of this bowl subgroup. There are four straight-sided bowls with true base rings that have horizontally outsplayed rims. They are distinct from the bell-shaped vessels, as they do not have an s-shaped profile (see Figure 6-11 below). I designate these four vessels with horizontally flared rims and true ring bases as group 1A, while the ten other straight-sided vessels with true ring bases are group 1B.

Figure 6-11. Example of bowl 1A type, with true ring base and horizontally outsplayed rim. Compare with example of bell-shaped bowl (Figure 6-5, no. 5 above). Redrawn by Jennifer Dillon, after Harden 1936, no. 247, Pl. XVI.



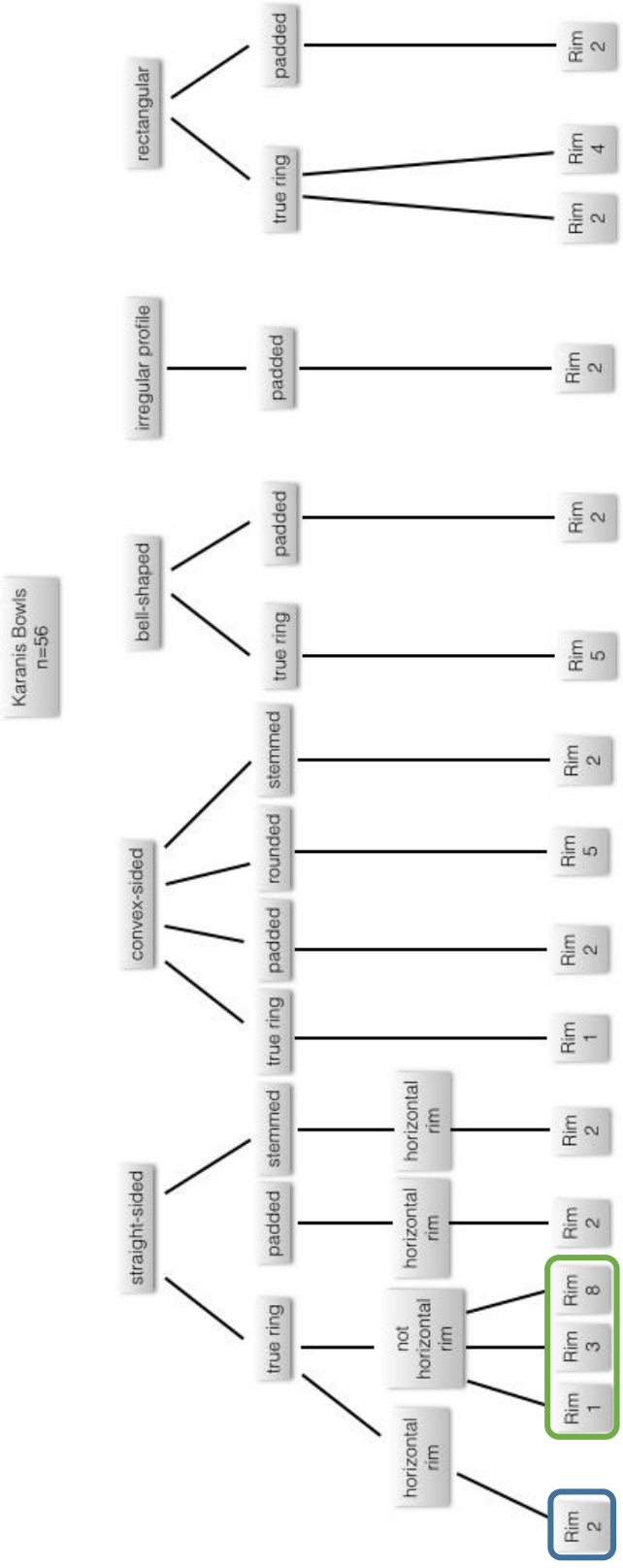
The correlation between rim diameter and body height then becomes stronger for each of these subgroups (see Figure 6-12 below), compared to the coefficient of determination value of all the straight-sided bowls together (R^2=0.577) (see Figure 6-10 above). This may indicate that artisans were aiming for specific proportions of bowl depth and rim diameter for this type of vessel, which could be linked to consumer preference and/or function of the vessel.

Figure 6-12. Rim diameter and body height biplot, straight-sided bowls with true ring bases, n=14



This relationship between rim diameter and body height is not visible in the aggregate or when bowls are separated into two groups through quantitative analysis of depth. Rather, this division is only evident after separating the bowl population by body shape, followed by base type, then rim type. If this method of separating bowls according to the *chaîne opératoire* of manufacturing is carried out for all body shape types, the typology below (see Figure 6-13) is the primary result.

Figure 6-13. Bowl typology based on *chaîne opératoire*. The type outlined in blue corresponds to type 1A and the types outlined in green represents type 1B in Figure 6-12 above



There are notable differences between the above bowl typology and the bowl typology proposed by Harden (refer to Appendix 8 for Harden's bowl typology). First, the initial bowl divisions are based on qualitative differences in body shape, rather than quantitative measurements of depth. Second, the subsequent divisions are made according to the *chaîne opératoire* of bowl manufacturing. Harden's typology does not follow this sequence of dividing the bowl population and he does not divide groups in a consistent manner, which is a key problem with his typology. He separates bowls first into shallow, deep, and stemmed categories. The stemmed bowls should not be separated out initially, since this is a designation made according to the base type, which is not the same dimension by which shallow and deep bowls are separated. He then divides the shallow and deep bowls by base type, then rim type, then by more specific designations of base type, leading to a typology that has no clear pattern to what it shows about the vessels. Harden is not consistent in the way in which he composes types, since he divides the stemmed bowls into shallow and deep categories, reversing the sequence of divisions made for the rest of the bowls without stemmed bases. The 56 bowls comprising my bowls study do not include sufficiently diverse base types to warrant more specific designations than what I indicate in Figure 6-13However, if I were to divide the base groups further, I would do so prior to dividing them by rim type, since the rim is the last feature created during the bowl manufacturing process.

6.4.3 Identifying Preferred Types through Read's Recursive Method

An exploration of relationships among shape and other nominal variables through cross-tabulation chi-squared analysis, supports that these bowls are better defined by their shape than depth. Variables I consider include: body shape, base type, rim type, date, and Harden's fabric

type. This analysis also draws into question whether or not the 9 outliers identified through quantitative analysis are in fact, outliers, since possible patterns can be seen among the data when they are included.

I employ Read's recursive method (2007, 2015) to determine preferred types. This involves identifying what type, or combination of types, accounts for the deviation in observed frequency counts from the expected values in a 2-dimensional contingency table with independent variables (Read 2007: 255). I first identify deviant and then modify them in descending order of deviance until the observed values of these cells equal that of the expected values. This in a sense neutralizes cells that account for the overall significant chi-squared value. Once the chi-squared value (p value) is no longer significant, one can conclude all types accounting for the dependency of the two variables have been identified (Read 2007). Possible functional types can also be identified through a comparison of chi-squared values for each cell (Read 2007, 2015). Cells with similar chi-squared values may share similar functions (Read 2007, 2015). This requires further investigation of the archaeological and historical record to determine if these functional types are valid.

The Pearson's chi-squared value is highly significant for the relationship between body shape and base type (see Table 6-2 below). The p value is 0.000 with 12 degrees of freedom. There is a significant probability, then, that a relationship between base type and body type exists. A Chi-squared analysis cannot, however, determine the strength of this relationship (Shennan 1988).

Some useful information can be gleaned from the 5x4 contingency table below (Table 6-1). Cell 3:2 indicates that all bowls with irregular profiles (n=8) have padded bases. Fifteen out of seventeen squat rectangular bowls also have padded bases. And overall, 62.5% of the total

bowls analyzed have padded bases. Therefore, padded bases seem to be a preferred base type for bowls.

Table 6-1. Initial chi-squared analysis results: 5x4 contingency table for two variables, body shape type and base type

Chi2 Body Type x Base Type Crosstabulation

			Base Type				
			2	3	4	9	Total
Body Type	1	Count	1	14	0	1	16
		Expected Count	10.0	5.1	.3	.6	16.0
		% of Total	1.8%	25.0%	0.0%	1.8%	28.6%
		Std. Residual	-2.8	3.9	-.5	.6	
	2	Count	3	1	1	1	6
		Expected Count	3.8	1.9	.1	.2	6.0
		% of Total	5.4%	1.8%	1.8%	1.8%	10.7%
		Std. Residual	-.4	-.7	2.7	1.7	
	3	Count	8	0	0	0	8
		Expected Count	5.0	2.6	.1	.3	8.0
		% of Total	14.3%	0.0%	0.0%	0.0%	14.3%
		Std. Residual	1.3	-1.6	-.4	-.5	
	4	Count	15	2	0	0	17
		Expected Count	10.6	5.5	.3	.6	17.0
		% of Total	26.8%	3.6%	0.0%	0.0%	30.4%
		Std. Residual	1.3	-1.5	-.6	-.8	
	5	Count	8	1	0	0	9
		Expected Count	5.6	2.9	.2	.3	9.0
		% of Total	14.3%	1.8%	0.0%	0.0%	16.1%
		Std. Residual	1.0	-1.1	-.4	-.6	
Total		Count	35	18	1	2	56
		Expected Count	35.0	18.0	1.0	2.0	56.0
		% of Total	62.5%	32.1%	1.8%	3.6%	100.0%

Table 6-2. Chi-squared results from Table 6-1 above.

	value	df	p value
Pearson Chi-Square	47.312[a]	12	.000
Likelihood Ratio	46.806	12	.000
Linear-by-Linear Association	9.610	1	.002
N of Valid Cases	56		

a.14 cells (70.0%) have expected count less than 5. The minimum expected count is .11.

Further investigation using Read's recursive method, however, reveals that padded bases do not account for the significant p value for this chi-squared analysis. The cell that is most deviant, meaning the actual count differs most from the expected count, is cell 1:3. There are 14 straight-sided bowls out of 16 that have true base rings. The expected amount of straight-sided bowls with true base rings is 5.1. In order to change the observed value to the expected, I delete 9 cases in the data set that are straight-sided bowls with true base rings. I then conduct another chi-squared analysis with the altered data set (see Table 6-3 and 6-4 below). This changes both the observed and the expected value for cell 1:3, as well as the degrees of freedom. Normally, one calculates the degrees of freedom in a table with m rows and n columns as df = (m-1)(n-1) (Read 2007, 2015; Shennan 1988). Since one cell has been altered, however, the degrees of freedom should be calculated as df = (m-1)(n-1) – 1 (Read 2007; 2015). In the 2x2 contingency table below, df = (5-1)(4-1) – 1 = 11.

Table 6-3. Second iteration of chi-squared analysis: 5x4 contingency table after cell 1:3 observed value is changed to 5 (expected value for cell 1:3 in initial contingency table)

Chi2 Body Type x Base Type Crosstabulation

			Base Class Type #				
			2	3	4	9	Total
Chi2 Body type	1	Count	1	5	0	1	7
		Expected Count	5.2	1.3	.1	.3	7.0
		% of Total	2.1%	10.6%	0.0%	2.1%	14.9%
		Std. Residual	-1.8	3.2	-.4	1.3	
	2	Count	3	1	1	1	6
		Expected Count	4.5	1.1	.1	.3	6.0
		% of Total	6.4%	2.1%	2.1%	2.1%	12.8%
		Std. Residual	-.7	-.1	2.4	1.5	
	3	Count	8	0	0	0	8
		Expected Count	6.0	1.5	.2	.3	8.0
		% of Total	17.0%	0.0%	0.0%	0.0%	17.0%
		Std. Residual	.8	-1.2	-.4	-.6	
	4	Count	15	2	0	0	17
		Expected Count	12.7	3.3	.4	.7	17.0
		% of Total	31.9%	4.3%	0.0%	0.0%	36.2%
		Std. Residual	.7	-.7	-.6	-.9	
	5	Count	8	1	0	0	9
		Expected Count	6.7	1.7	.2	.4	9.0
		% of Total	17.0%	2.1%	0.0%	0.0%	19.1%
		Std. Residual	.5	-.6	-.4	-.6	
Total		Count	35	9	1	2	47
		Expected Count	35.0	9.0	1.0	2.0	47.0
		% of Total	74.5%	19.1%	2.1%	4.3%	100.0%

Table 6-4. Chi-squared results from Table 6-3 above.

	value	**df**	**p value**
Pearson Chi-Square	29.709 [a]	11	Approx. 0.003

a. 16 cells (80.0%) have expected count less than 5. The minimum expected count is 0.13.

Since the observed and expected values for cell 1:3 are still not equal to one another after altering the observed value of this cell, I repeat the process of deleting cases and conducting chi-squared analyses until the observed value equals the expected.

Table 6-5. Third and final iteration of chi-squared Analysis: 5x4 contingency table after cell 1:3 observed value is changed to zero.

Chi2 Body ?Type x Base Type Crosstabulation

			Base Type				
			2	3	4	9	Total
Body Type	1	Count	1	1	0	1	3
		Expected Count	2.4	.3	.1	.1	3.0
		% of Total	2.3%	2.3%	0.0%	2.3%	7.0%
		Std. Residual	-.9	1.1	-.3	2.3	
	2	Count	3	1	1	1	6
		Expected Count	4.9	.7	.1	.3	6.0
		% of Total	7.0%	2.3%	2.3%	2.3%	14.0%
		Std. Residual	-.9	.4	2.3	1.4	
	3	Count	8	0	0	0	8
		Expected Count	6.5	.9	.2	.4	8.0
		% of Total	18.6%	0.0%	0.0%	0.0%	18.6%
		Std. Residual	.6	-1.0	-.4	-.6	
	4	Count	15	2	0	0	17
		Expected Count	13.8	2.0	.4	.8	17.0
		% of Total	34.9%	4.7%	0.0%	0.0%	39.5%
		Std. Residual	.3	.0	-.6	-.9	
	5	Count	8	1	0	0	9
		Expected Count	7.3	1.0	.2	.4	9.0
		% of Total	18.6%	2.3%	0.0%	0.0%	20.9%
		Std. Residual	.2	.0	-.5	-.6	
Total		Count	35	5	1	2	43
		Expected Count	35.0	5.0	1.0	2.0	43.0
		% of Total	81.4%	11.6%	2.3%	4.7%	100.0%

Table 6-6. Chi-squared results from Table 6-5 above.

	value	df	p value
Pearson Chi-Square	19.274 [a]	11	approx. 0.082

a. 17 cells (85.0%) have expected count less than 5. The minimum expected count is 0.07.

The p-value is now above 0.05, meaning the Pearson Chi-Square value is no longer significant at the 0.05 level. Cell 1:3 has essentially been neutralized by this process, and it is the only cell that is needed to account for the dependency of the two variables: body type and base type. Provided that this is a representative sample of bowls from Karanis, the makers of these bowls gave preference to true base rings for straight-sided bowls. There are no other preferred combinations of body shape and base type.

6.4.4 Karanis Bowl Study: Concluding Remarks

The patterns found within these groups demonstrates that some patterns are hidden when all morphological types are analyzed together. However, when groups are divided according to *chaîne opératoire*, patterns are visible within subgroups that do not apply to the aggregate as a whole. This demonstrates the need to separate groups based first on qualitative body form differences (bell-shaped, irregular profile, convex-sided, straight-sided, etc.), then by quantitative dimensions (rim diameter, depth of body). Although there are quantitative grounds to separate bowls into shallow and deep categories, the bifurcation of the depth variable for these objects is essentially a product of their general shape. In other words, by separating these objects out first by their body shape (qualitative grounds), the deep bowls are already separated from the shallow ones. Further, when the quantitative difference is done first (as occurs with Harden's typology) there are two or more body shapes represented in each of the two groups identified through quantitative analysis. But the artisan decides initially what body shape he/she will make and produces a bubble that will yield this final shape, hence the shape difference should be made first. If one divides the bowls initially into two groups, as Harden did, it must be assumed there are two main ways to shape a bubble—one resulting in the obtuse angle of the sides toward the base of shallow bowls and the other resulting in the steeper angle from the base of the deep bowls. Instead, the artisans were most likely aiming for a general shape when creating bowls, rather than a certain depth. Therefore, the labels of "shallow" and "deep" are misleading, especially since several of the bowls from different shape categories share the same depth.

Harden's classification of bowls into shallow, deep, and stemmed class types ignores the *chaîne opératoire* of manufacturing these vessels. He considers the body shape, base, type, and rim types of bowls, but the order in which he divides bowls into subgroups ignores the sequence

of the decisions artisans made during the process of making them (compare Figure 4-1 with Appendix 8). Consequently, bowls with a similar body shape that may signify a similar function are separated because they have different base types. This is the case for stemmed bowls. Since function often is linked to value, it is important to understand how these objects would have been used and which objects may serve similar functions. Harden's typology subdivides objects with similar functions into different categories. The most general bowl division I make is body type, since it represents one of the first decisions the artisan makes while forming the vessel. Exploring associations with body type and other variables, such as base types, allows me to identify preferred types combinations such as straight-sided bowls and true bases, which can be interpreted as possible use types; that is, a type combination that has occurred much more frequently than would be expected were the vessel shape and base shape independent variables for all of the vessels.

6.5 Applying the Recursive Method to Investigate Harden's Fabric Types

This same recursive method can be employed to identify other relationships among variables for the recently excavated Karanis material, preferred types, and possible use/functional types. I first test to see how accurate Harden's fabric types are in distinguishing glass compositional types. I do so by conducting a similar chi-squared analysis of general compositional types I identify in Chapter 5 and fabric types I assigned to pXRF samples based on fabric type descriptions outlined in Harden (1936: 20-24) (see Tables 6-7 and 6-8 below). I then carry out Read's (2007, 2015) recursive method to identify compositional group/fabric type combinations that account for the significant Chi-Square value. These cells represent combinations of compositional groups and fabric types for which there is an association between

the two variables, meaning there is a likelihood that Harden's fabric description accurately identifies a compositionally distinct type.

Table 6-7. Summary of Harden's fabric types (1936)

HARDEN'S FABRIC NUMBER	HARDEN'S FABRIC NAME	BRIEF DESCRIPTION
1	Colourless ware a	Early ware of good material, colorless to green tint; vessels usually polished and highly finished
2	Colourless ware b	Early ware of good material, colorless to green tint; vessels are not symmetrical or highly finished
3	Table ware a	Late ware in various shades of green and yellow; the best quality table ware with fewest bubbles and impurities
4	Table ware b	Late ware in various shades of green and yellow; bubbly and full of impurities; common in hoards
5	Table ware c	Late ware in various shades of green and yellow; worst quality of the table wares with many bubbles and impurities
6	Purple ware	Late ware; tinted purple to deep purple in color
7	Dark blue ware	Like Table ware c, but colored deep blue with copper or cobalt
8	Green, bubbly ware	Early ware, probably cheaper version of Colourless ware a and b; very bubbly
9	Bottle ware	Early and late ware, various shades of green; poorest quality fabric with many impurities and bubbles

Table 6-8. Chi-squared Analysis: 12x7 contingency table of compositional groups and fabric types

General Compositional Grp * Harden's Fabric Type Crosstabulation

			Fabric							
			1	2	3	4	5	8	9	Total
General Chem Grp	1.1.1	Count	114	57	0	1	1	3	0	176
		Expected Count	54.3	48.5	24.3	19.3	9.0	10.3	10.3	176.0
		% of Total	26.6 %	13.3 %	0.0%	0.2%	0.2%	0.7%	0.0%	41.1 %
		Std. Residual	8.1	1.2	-4.9	-4.2	-2.7	-2.3	-3.2	
	1.1.2	Count	12	32	3	1	1	9	1	59
		Expected Count	18.2	16.3	8.1	6.5	3.0	3.4	3.4	59.0
		% of Total	2.8%	7.5%	0.7%	0.2%	0.2%	2.1%	0.2%	13.8 %
		Std. Residual	-1.5	3.9	-1.8	-2.2	-1.2	3.0	-1.3	
	1.2.1	Count	1	0	3	1	1	0	0	6
		Expected Count	1.9	1.7	.8	.7	.3	.4	.4	6.0
		% of Total	0.2%	0.0%	0.7%	0.2%	0.2%	0.0%	0.0%	1.4%
		Std. Residual	-.6	-1.3	2.4	.4	1.2	-.6	-.6	
	1.2.2	Count	0	2	0	1	0	0	0	3
		Expected Count	.9	.8	.4	.3	.2	.2	.2	3.0
		% of Total	0.0%	0.5%	0.0%	0.2%	0.0%	0.0%	0.0%	0.7%
		Std. Residual	-1.0	1.3	-.6	1.2	-.4	-.4	-.4	
	1.2.3.1	Count	2	5	14	8	1	0	0	30
		Expected Count	9.3	8.3	4.1	3.3	1.5	1.8	1.8	30.0
		% of Total	0.5%	1.2%	3.3%	1.9%	0.2%	0.0%	0.0%	7.0%
		Std. Residual	-2.4	-1.1	4.9	2.6	-.4	-1.3	-1.3	

1.2.3.2	Count	0	0	1	3	2	0	0	6
	Expected Count	1.9	1.7	.8	.7	.3	.4	.4	6.0
	% of Total	0.0%	0.0%	0.2%	0.7%	0.5%	0.0%	0.0%	1.4%
	Std. Residual	-1.4	-1.3	.2	2.9	3.0	-.6	-.6	
1.2.3.3	Count	0	0	2	0	1	0	0	3
	Expected Count	.9	.8	.4	.3	.2	.2	.2	3.0
	% of Total	0.0%	0.0%	0.5%	0.0%	0.2%	0.0%	0.0%	0.7%
	Std. Residual	-1.0	-.9	2.5	-.6	2.2	-.4	-.4	
1.3.1.1	Count	0	11	22	17	6	10	17	83
	Expected Count	25.6	22.9	11.4	9.1	4.3	4.8	4.8	83.0
	% of Total	0.0%	2.6%	5.1%	4.0%	1.4%	2.3%	4.0%	19.4%
	Std. Residual	-5.1	-2.5	3.1	2.6	.8	2.3	5.5	
1.3.1.2	Count	0	0	4	2	1	1	2	10
	Expected Count	3.1	2.8	1.4	1.1	.5	.6	.6	10.0
	% of Total	0.0%	0.0%	0.9%	0.5%	0.2%	0.2%	0.5%	2.3%
	Std. Residual	-1.8	-1.7	2.2	.9	.7	.5	1.9	
1.3.2.1	Count	1	6	7	10	5	0	2	31
	Expected Count	9.6	8.5	4.3	3.4	1.6	1.8	1.8	31.0
	% of Total	0.2%	1.4%	1.6%	2.3%	1.2%	0.0%	0.5%	7.2%
	Std. Residual	-2.8	-.9	1.3	3.6	2.7	-1.3	.1	
1.3.2.2	Count	1	4	3	1	1	0	2	12
	Expected Count	3.7	3.3	1.7	1.3	.6	.7	.7	12.0
	% of Total	0.2%	0.9%	0.7%	0.2%	0.2%	0.0%	0.5%	2.8%
	Std. Residual	-1.4	.4	1.0	-.3	.5	-.8	1.6	

	1.3.2.3	Count	1	1	0	2	2	2	1	9
		Expected Count	2.8	2.5	1.2	1.0	.5	.5	.5	9.0
		% of Total	0.2%	0.2%	0.0%	0.5%	0.5%	0.5%	0.2%	2.1%
		Std. Residual	-1.1	-.9	-1.1	1.0	2.3	2.0	.7	
Total		Count	132	118	59	47	22	25	25	428
		Expected Count	132.0	118.0	59.0	47.0	22.0	25.0	25.0	428.0
		% of Total	30.8%	27.6%	13.8%	11.0%	5.1%	5.8%	5.8%	100.0%

Table 6-9. Chi-squared results from Table 6-8 above.

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	413.029[a]	66	.000
Likelihood Ratio	448.133	66	.000
N of Valid Cases	428		

a. 65 cells (77.4%) have expected count less than 5. The minimum expected count is .15.

This is a highly significant chi-squared value (413.029) at the 0.001 level, meaning the associations between compositional groups and fabric types are so great that the probability of them being the result of chance variation is exceptionally low (Shennan 1988: 106). The two variables are not independent of one another. I identify the most deviant cell in which the difference between the observed and expected value is greatest. This is cell 1.1.1:1. Group 1.1.1 is Sb-decolorized glass, which is typically water clear colorless. It is easily recognizable by its lack of color; therefore, it is no surprise that fabric 1, which is supposed to be truly colorless glass of high quality, shows association with Group 1.1.1. I "neutralize" this cell by changing

the number of observed cases to equal that of the expected. Therefore, I delete 60 cases where 1.1.1 glass is identified as Fabric 1 and then conduct another chi-squared analysis with the altered data set. I repeat this process until the observed and expected value for this cell are equal. Five iterations were required to get the expected and observed value for cell 1.1.1:1 to equal 5 (see Table 6-10 below).

Table 6-10. Chi-squared analysis: 12x7 contingency table of compositional groups and fabric types after 5 iterations of altering observed values for cell 1.1.1:1

General Compositional Grp * Harden's Fabric Type Crosstabulation

			Fabric							
			1	2	3	4	5	8	9	Total
General Chem Grp	1.1.1	Count	5	57	0	1	1	3	0	67
		Expected Count	4.8	24.8	12.4	9.9	4.6	5.3	5.3	67.0
		% of Total	1.6%	17.9 %	0.0%	0.3%	0.3%	0.9%	0.0%	21.0 %
		Std. Residual	.1	6.5	-3.5	-2.8	-1.7	-1.0	-2.3	
	1.1.2	Count	12	32	3	1	1	9	1	59
		Expected Count	4.3	21.8	10.9	8.7	4.1	4.6	4.6	59.0
		% of Total	3.8%	10.0 %	0.9%	0.3%	0.3%	2.8%	0.3%	18.5 %
		Std. Residual	3.8	2.2	-2.4	-2.6	-1.5	2.0	-1.7	
	1.2.1	Count	1	0	3	1	1	0	0	6
		Expected Count	.4	2.2	1.1	.9	.4	.5	.5	6.0
		% of Total	0.3%	0.0%	0.9%	0.3%	0.3%	0.0%	0.0%	1.9%
		Std. Residual	.9	-1.5	1.8	.1	.9	-.7	-.7	
	1.2.2	Count	0	2	0	1	0	0	0	3

	Expected Count	.2	1.1	.6	.4	.2	.2	.2	3.0
	% of Total	0.0%	0.6%	0.0%	0.3%	0.0%	0.0%	0.0%	0.9%
	Std. Residual	-.5	.8	-.7	.8	-.5	-.5	-.5	
1.2.3.1	Count	2	5	14	8	1	0	0	30
	Expected Count	2.2	11.1	5.5	4.4	2.1	2.4	2.4	30.0
	% of Total	0.6%	1.6%	4.4%	2.5%	0.3%	0.0%	0.0%	9.4%
	Std. Residual	-.1	-1.8	3.6	1.7	-.7	-1.5	-1.5	
1.2.3.2	Count	0	0	1	3	2	0	0	6
	Expected Count	.4	2.2	1.1	.9	.4	.5	.5	6.0
	% of Total	0.0%	0.0%	0.3%	0.9%	0.6%	0.0%	0.0%	1.9%
	Std. Residual	-.7	-1.5	-.1	2.3	2.5	-.7	-.7	
1.2.3.3	Count	0	0	2	0	1	0	0	3
	Expected Count	.2	1.1	.6	.4	.2	.2	.2	3.0
	% of Total	0.0%	0.0%	0.6%	0.0%	0.3%	0.0%	0.0%	0.9%
	Std. Residual	-.5	-1.1	1.9	-.7	1.7	-.5	-.5	
1.3.1.1	Count	0	11	22	17	6	10	17	83
	Expected Count	6.0	30.7	15.4	12.2	5.7	6.5	6.5	83.0
	% of Total	0.0%	3.4%	6.9%	5.3%	1.9%	3.1%	5.3%	26.0%
	Std. Residual	-2.4	-3.6	1.7	1.4	.1	1.4	4.1	
1.3.1.2	Count	0	0	4	2	1	1	2	10
	Expected Count	.7	3.7	1.8	1.5	.7	.8	.8	10.0
	% of Total	0.0%	0.0%	1.3%	0.6%	0.3%	0.3%	0.6%	3.1%
	Std. Residual	-.8	-1.9	1.6	.4	.4	.2	1.4	
	Count	1	6	7	10	5	0	2	31

	1.3.2.1	Expected Count	2.2	11.5	5.7	4.6	2.1	2.4	2.4	31.0
		% of Total	0.3%	1.9%	2.2%	3.1%	1.6%	0.0%	0.6%	9.7%
		Std. Residual	-.8	-1.6	.5	2.5	2.0	-1.6	-.3	
	1.3.2.2	Count	1	4	3	1	1	0	2	12
		Expected Count	.9	4.4	2.2	1.8	.8	.9	.9	12.0
		% of Total	0.3%	1.3%	0.9%	0.3%	0.3%	0.0%	0.6%	3.8%
		Std. Residual	.1	-.2	.5	-.6	.2	-1.0	1.1	
	1.3.2.3	Count	1	1	0	2	2	2	1	9
		Expected Count	.6	3.3	1.7	1.3	.6	.7	.7	9.0
		% of Total	0.3%	0.3%	0.0%	0.6%	0.6%	0.6%	0.3%	2.8%
		Std. Residual	.4	-1.3	-1.3	.6	1.8	1.5	.4	
Total		Count	23	118	59	47	22	25	25	319
		Expected Count	23.0	118.0	59.0	47.0	22.0	25.0	25.0	319.0
		% of Total	7.2%	37.0%	18.5%	14.7%	6.9%	7.8%	7.8%	100.0%

Table 6-11. Chi-squared results from Table 6-10 above.

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	251.000[a]	65	.000
Likelihood Ratio	277.366	65	.000
N of Valid Cases	319		

a. 65 cells (77.4%) have expected count less than 5. The minimum expected count is .21.

The Ch2 value (251.00) is still highly significant at the 0.001 level after neutralizing this cell. Note, the df is one less than that of Table 6-9 because one cell has been altered. I identify

the next deviant cell as cell 1.1.1:2. This also is not a surprising association, since Harden notes that there may not be a compositional difference between his Fabric 1 and Fabric 2. He separates them based on differences in quality and outward appearance. Both types are colorless to greenish colorless glass, but he notes four main differences between them: 1) Fabric 1 vessels are thicker than Fabric 2 ones; 2) Fabric 1 is duller than Fabric 2; 3) Fabric 1 vessels are higher quality, more symmetrical, and often polished, while Fabric 2 vessels are not as symmetrical, highly finished, and usually unpolished, and 4) Fabric 1 weathers differently than Fabric 2, or it is not weathered at all (Harden 1936). Note that although Harden intends fabric types to represent chemical compositional groups, most of his parameters for distinguishing these two fabric groups relate to the products produced with these types, rather than to qualitative differences in the outward appearance of the glass material itself that may signify compositionally distinct groups.

I alter 1.1.1:2 so that the observed equals the expected value. I delete 32 cases in my first iteration, and continue with several iterations until the observed and expected values for this cell equal 3. This changes the expected value for cell 1.1.1:1, so I need to alter the observed from 5 counts to 1. After doing this, the expected value for 1.1.1:2 changes to 2, so I delete three more cases so that both cells have equal values for observed and expected (see Table 6-12 below).

Table 6-12. 12x7 contingency table of compositional groups and fabric types

General Chem Grp * Fabric Crosstabulation

			Fabric							Total
			1	2	3	4	5	8	9	
General Chem Grp	1.1.1	Count	1	2	0	1	1	3	0	8
		Expected Count	.6	1.9	1.8	1.4	.7	.8	.8	8.0
		% of Total	0.4%	0.8%	0.0%	0.4%	0.4%	1.2%	0.0%	3.1%
		Std. Residual	.5	.0	-1.3	-.4	.4	2.5	-.9	
	1.1.2	Count	12	32	3	1	1	9	1	59
		Expected Count	4.3	14.3	13.4	10.7	5.0	5.7	5.7	59.0
		% of Total	4.6%	12.3%	1.2%	0.4%	0.4%	3.5%	0.4%	22.7%
		Std. Residual	3.7	4.7	-2.8	-3.0	-1.8	1.4	-2.0	
	1.2.1	Count	1	0	3	1	1	0	0	6
		Expected Count	.4	1.5	1.4	1.1	.5	.6	.6	6.0
		% of Total	0.4%	0.0%	1.2%	0.4%	0.4%	0.0%	0.0%	2.3%
		Std. Residual	.8	-1.2	1.4	-.1	.7	-.8	-.8	
	1.2.2	Count	0	2	0	1	0	0	0	3
		Expected Count	.2	.7	.7	.5	.3	.3	.3	3.0
		% of Total	0.0%	0.8%	0.0%	0.4%	0.0%	0.0%	0.0%	1.2%
		Std. Residual	-.5	1.5	-.8	.6	-.5	-.5	-.5	
	1.2.3.1	Count	2	5	14	8	1	0	0	30
		Expected Count	2.2	7.3	6.8	5.4	2.5	2.9	2.9	30.0
		% of Total	0.8%	1.9%	5.4%	3.1%	0.4%	0.0%	0.0%	11.5%
		Std. Residual	-.1	-.8	2.8	1.1	-1.0	-1.7	-1.7	

1.2.3.2	Count	0	0	1	3	2	0	0	6
	Expected Count	.4	1.5	1.4	1.1	.5	.6	.6	6.0
	% of Total	0.0%	0.0%	0.4%	1.2%	0.8%	0.0%	0.0%	2.3%
	Std. Residual	-.7	-1.2	-.3	1.8	2.1	-.8	-.8	
1.2.3.3	Count	0	0	2	0	1	0	0	3
	Expected Count	.2	.7	.7	.5	.3	.3	.3	3.0
	% of Total	0.0%	0.0%	0.8%	0.0%	0.4%	0.0%	0.0%	1.2%
	Std. Residual	-.5	-.9	1.6	-.7	1.5	-.5	-.5	
1.3.1.1	Count	0	11	22	17	6	10	17	83
	Expected Count	6.1	20.1	18.8	15.0	7.0	8.0	8.0	83.0
	% of Total	0.0%	4.2%	8.5%	6.5%	2.3%	3.8%	6.5%	31.9%
	Std. Residual	-2.5	-2.0	.7	.5	-.4	.7	3.2	
1.3.1.2	Count	0	0	4	2	1	1	2	10
	Expected Count	.7	2.4	2.3	1.8	.8	1.0	1.0	10.0
	% of Total	0.0%	0.0%	1.5%	0.8%	0.4%	0.4%	0.8%	3.8%
	Std. Residual	-.9	-1.6	1.1	.1	.2	.0	1.1	
1.3.2.1	Count	1	6	7	10	5	0	2	31
	Expected Count	2.3	7.5	7.0	5.6	2.6	3.0	3.0	31.0
	% of Total	0.4%	2.3%	2.7%	3.8%	1.9%	0.0%	0.8%	11.9%
	Std. Residual	-.8	-.6	.0	1.9	1.5	-1.7	-.6	
1.3.2.2	Count	1	4	3	1	1	0	2	12
	Expected Count	.9	2.9	2.7	2.2	1.0	1.2	1.2	12.0
	% of Total	0.4%	1.5%	1.2%	0.4%	0.4%	0.0%	0.8%	4.6%

		Std. Residual	.1	.6	.2	-.8	.0	-1.1	.8	
	1.3.2.3	Count	1	1	0	2	2	2	1	9
		Expected Count	.7	2.2	2.0	1.6	.8	.9	.9	9.0
		% of Total	0.4%	0.4%	0.0%	0.8%	0.8%	0.8%	0.4%	3.5%
		Std. Residual	.4	-.8	-1.4	.3	1.4	1.2	.1	
Total		Count	19	63	59	47	22	25	25	260
		Expected Count	19.0	63.0	59.0	47.0	22.0	25.0	25.0	260.0
		% of Total	7.3%	24.2%	22.7%	18.1%	8.5%	9.6%	9.6%	100.0%

Table 6-13. Chi-squared results from Table 6-12 above.

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	161.930[a]	64	.000
Likelihood Ratio	182.847	64	.000
N of Valid Cases	260		

a. 66 cells (78.6%) have expected count less than 5. The minimum expected count is .22.

The chi-squared value (161.930) is still significant at the 0.001 level, so I continue by identifying the next deviant cell, which is 1.1.2:2. I alter this cell until both the observed and the expected equal 5 and then alter any of the two previously altered cells if their expected values change.

Table 6-14. 12x7 contingency table of compositional groups and fabric types

General Chem Grp * Fabric Crosstabulation

			Fabric							
			1	2	3	4	5	8	9	Total
General Chem Grp	1.1.1	Count	1	1	0	1	1	3	0	7
		Expected Count	.6	1.1	1.8	1.4	.7	.8	.8	7.0
		% of Total	0.4%	0.4%	0.0%	0.4%	0.4%	1.3%	0.0%	3.0%
		Std. Residual	.6	-.1	-1.3	-.4	.4	2.6	-.9	
	1.1.2	Count	12	5	3	1	1	9	1	32
		Expected Count	2.6	4.8	8.1	6.5	3.0	3.4	3.4	32.0
		% of Total	5.2%	2.2%	1.3%	0.4%	0.4%	3.9%	0.4%	13.8 %
		Std. Residual	5.8	.1	-1.8	-2.2	-1.2	3.0	-1.3	
	1.2.1	Count	1	0	3	1	1	0	0	6
		Expected Count	.5	.9	1.5	1.2	.6	.6	.6	6.0
		% of Total	0.4%	0.0%	1.3%	0.4%	0.4%	0.0%	0.0%	2.6%
		Std. Residual	.7	-1.0	1.2	-.2	.6	-.8	-.8	
	1.2.2	Count	0	2	0	1	0	0	0	3
		Expected Count	.2	.5	.8	.6	.3	.3	.3	3.0
		% of Total	0.0%	0.9%	0.0%	0.4%	0.0%	0.0%	0.0%	1.3%
		Std. Residual	-.5	2.3	-.9	.5	-.5	-.6	-.6	
	1.2.3.1	Count	2	5	14	8	1	0	0	30
		Expected Count	2.5	4.5	7.6	6.1	2.8	3.2	3.2	30.0
		% of Total	0.9%	2.2%	6.0%	3.4%	0.4%	0.0%	0.0%	12.9 %
		Std. Residual	-.3	.2	2.3	.8	-1.1	-1.8	-1.8	

1.2.3.2	Count	0	0	1	3	2	0	0	6
	Expected Count	.5	.9	1.5	1.2	.6	.6	.6	6.0
	% of Total	0.0%	0.0%	0.4%	1.3%	0.9%	0.0%	0.0%	2.6%
	Std. Residual	-.7	-1.0	-.4	1.6	1.9	-.8	-.8	
1.2.3.3	Count	0	0	2	0	1	0	0	3
	Expected Count	.2	.5	.8	.6	.3	.3	.3	3.0
	% of Total	0.0%	0.0%	0.9%	0.0%	0.4%	0.0%	0.0%	1.3%
	Std. Residual	-.5	-.7	1.4	-.8	1.3	-.6	-.6	
1.3.1.1	Count	0	11	22	17	6	10	17	83
	Expected Count	6.8	12.5	21.1	16.8	7.9	8.9	8.9	83.0
	% of Total	0.0%	4.7%	9.5%	7.3%	2.6%	4.3%	7.3%	35.8%
	Std. Residual	-2.6	-.4	.2	.0	-.7	.4	2.7	
1.3.1.2	Count	0	0	4	2	1	1	2	10
	Expected Count	.8	1.5	2.5	2.0	.9	1.1	1.1	10.0
	% of Total	0.0%	0.0%	1.7%	0.9%	0.4%	0.4%	0.9%	4.3%
	Std. Residual	-.9	-1.2	.9	.0	.1	-.1	.9	
1.3.2.1	Count	1	6	7	10	5	0	2	31
	Expected Count	2.5	4.7	7.9	6.3	2.9	3.3	3.3	31.0
	% of Total	0.4%	2.6%	3.0%	4.3%	2.2%	0.0%	0.9%	13.4%
	Std. Residual	-1.0	.6	-.3	1.5	1.2	-1.8	-.7	
1.3.2.2	Count	1	4	3	1	1	0	2	12
	Expected Count	1.0	1.8	3.1	2.4	1.1	1.3	1.3	12.0
	% of Total	0.4%	1.7%	1.3%	0.4%	0.4%	0.0%	0.9%	5.2%

		Std. Residual	.0	1.6	.0	-.9	-.1	-1.1	.6	
	1.3.2.3	Count	1	1	0	2	2	2	1	9
		Expected Count	.7	1.4	2.3	1.8	.9	1.0	1.0	9.0
		% of Total	0.4%	0.4%	0.0%	0.9%	0.9%	0.9%	0.4%	3.9%
		Std. Residual	.3	-.3	-1.5	.1	1.2	1.0	.0	
Total		Count	19	35	59	47	22	25	25	232
		Expected Count	19.0	35.0	59.0	47.0	22.0	25.0	25.0	232.0
		% of Total	8.2%	15.1%	25.4%	20.3%	9.5%	10.8%	10.8%	100.0%

Table 6-15. Chi-squared results from Table 6-14 above.

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	141.957[a]	63	.000
Likelihood Ratio	148.624	633	.000
N of Valid Cases	232		

a. 71 cells (84.5%) have expected count less than 5. The minimum expected count is .25.

The next deviant cell is 1.1.2:1. I alter this cell and any previously modified cells whose expected values change. I eventually change the observed value to 1 (see Table 6-16 below).

Table 6-16. 12x7 contingency table of compositional groups and fabric types.

General Chem Grp * Fabric Crosstabulation

			Fabric							
			1	2	3	4	5	8	9	Total
General Chem Grp	1.1.1	Count	1	1	0	1	1	3	0	7
		Expected Count	.3	1.1	1.9	1.5	.7	.8	.8	7.0
		% of Total	0.5%	0.5%	0.0%	0.5%	0.5%	1.4%	0.0%	3.2%
		Std. Residual	1.5	-.1	-1.4	-.4	.4	2.5	-.9	
	1.1.2	Count	1	3	3	1	1	9	1	19
		Expected Count	.7	2.9	5.1	4.1	1.9	2.2	2.2	19.0
		% of Total	0.5%	1.4%	1.4%	0.5%	0.5%	4.1%	0.5%	8.7%
		Std. Residual	.4	.1	-.9	-1.5	-.7	4.6	-.8	
	1.2.1	Count	1	0	3	1	1	0	0	6
		Expected Count	.2	.9	1.6	1.3	.6	.7	.7	6.0
		% of Total	0.5%	0.0%	1.4%	0.5%	0.5%	0.0%	0.0%	2.7%
		Std. Residual	1.7	-1.0	1.1	-.3	.5	-.8	-.8	
	1.2.2	Count	0	2	0	1	0	0	0	3
		Expected Count	.1	.5	.8	.6	.3	.3	.3	3.0
		% of Total	0.0%	0.9%	0.0%	0.5%	0.0%	0.0%	0.0%	1.4%
		Std. Residual	-.3	2.3	-.9	.4	-.5	-.6	-.6	
	1.2.3.1	Count	2	5	14	8	1	0	0	30
		Expected Count	1.1	4.5	8.1	6.4	3.0	3.4	3.4	30.0
		% of Total	0.9%	2.3%	6.4%	3.7%	0.5%	0.0%	0.0%	13.7%

	Std. Residual	.9	.2	2.1	.6	-1.2	-1.9	-1.9	
1.2.3.2	Count	0	0	1	3	2	0	0	6
	Expected Count	.2	.9	1.6	1.3	.6	.7	.7	6.0
	% of Total	0.0%	0.0%	0.5%	1.4%	0.9%	0.0%	0.0%	2.7%
	Std. Residual	-.5	-1.0	-.5	1.5	1.8	-.8	-.8	
1.2.3.3	Count	0	0	2	0	1	0	0	3
	Expected Count	.1	.5	.8	.6	.3	.3	.3	3.0
	% of Total	0.0%	0.0%	0.9%	0.0%	0.5%	0.0%	0.0%	1.4%
	Std. Residual	-.3	-.7	1.3	-.8	1.3	-.6	-.6	
1.3.1.1	Count	0	11	22	17	6	10	17	83
	Expected Count	3.0	12.5	22.4	17.8	8.3	9.5	9.5	83.0
	% of Total	0.0%	5.0%	10.0%	7.8%	2.7%	4.6%	7.8%	37.9%
	Std. Residual	-1.7	-.4	-.1	-.2	-.8	.2	2.4	
1.3.1.2	Count	0	0	4	2	1	1	2	10
	Expected Count	.4	1.5	2.7	2.1	1.0	1.1	1.1	10.0
	% of Total	0.0%	0.0%	1.8%	0.9%	0.5%	0.5%	0.9%	4.6%
	Std. Residual	-.6	-1.2	.8	-.1	.0	-.1	.8	
1.3.2.1	Count	1	6	7	10	5	0	2	31
	Expected Count	1.1	4.7	8.4	6.7	3.1	3.5	3.5	31.0
	% of Total	0.5%	2.7%	3.2%	4.6%	2.3%	0.0%	0.9%	14.2%
	Std. Residual	-.1	.6	-.5	1.3	1.1	-1.9	-.8	

	1.3.2.2	Count	1	4	3	1	1	0	2	12
		Expected Count	.4	1.8	3.2	2.6	1.2	1.4	1.4	12.0
		% of Total	0.5%	1.8%	1.4%	0.5%	0.5%	0.0%	0.9%	5.5%
		Std. Residual	.8	1.6	-.1	-1.0	-.2	-1.2	.5	
	1.3.2.3	Count	1	1	0	2	2	2	1	9
		Expected Count	.3	1.4	2.4	1.9	.9	1.0	1.0	9.0
		% of Total	0.5%	0.5%	0.0%	0.9%	0.9%	0.9%	0.5%	4.1%
		Std. Residual	1.2	-.3	-1.6	.0	1.2	1.0	.0	
Total		Count	8	33	59	47	22	25	25	219
		Expected Count	8.0	33.0	59.0	47.0	22.0	25.0	25.0	219.0
		% of Total	3.7%	15.1%	26.9%	21.5%	10.0%	11.4%	11.4%	100.0%

Table 6-17. Chi-squared results from Table 6-16 above.

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	111.244[a]	62	.000
Likelihood Ratio	119.252	62	.000
N of Valid Cases	219		

a. 73 cells (86.9%) have expected count less than 5. The minimum expected count is .11.

The next deviant cell is 1.1.2:8. I alter this cell.

Table 6-18. 12x7 contingency table of compositional groups and fabric types.

General Chem Grp * Fabric Crosstabulation

			Fabric							
			1	2	3	4	5	8	9	Total
General Chem Grp	1.1.1	Count	1	1	0	1	1	3	0	7
		Expected Count	.3	1.1	2.0	1.6	.7	.6	.8	7.0
		% of Total	0.5%	0.5%	0.0%	0.5%	0.5%	1.4%	0.0%	3.3%
		Std. Residual	1.4	-.1	-1.4	-.5	.3	3.2	-.9	
	1.1.2	Count	1	2	3	1	1	1	1	10
		Expected Count	.4	1.5	2.8	2.2	1.0	.8	1.2	10.0
		% of Total	0.5%	1.0%	1.4%	0.5%	0.5%	0.5%	0.5%	4.8%
		Std. Residual	1.0	.4	.1	-.8	.0	.2	-.2	
	1.2.1	Count	1	0	3	1	1	0	0	6
		Expected Count	.2	.9	1.7	1.3	.6	.5	.7	6.0
		% of Total	0.5%	0.0%	1.4%	0.5%	0.5%	0.0%	0.0%	2.9%
		Std. Residual	1.6	-1.0	1.0	-.3	.5	-.7	-.8	
	1.2.2	Count	0	2	0	1	0	0	0	3

	Expected Count	.1	.5	.8	.7	.3	.2	.4	3.0
	% of Total	0.0%	1.0%	0.0%	0.5%	0.0%	0.0%	0.0%	1.4%
	Std. Residual	-.3	2.3	-.9	.4	-.6	-.5	-.6	
1.2.3.1	Count	2	5	14	8	1	0	0	30
	Expected Count	1.1	4.6	8.4	6.7	3.1	2.4	3.6	30.0
	% of Total	1.0%	2.4%	6.7%	3.8%	0.5%	0.0%	0.0%	14.3%
	Std. Residual	.8	.2	1.9	.5	-1.2	-1.6	-1.9	
1.2.3.2	Count	0	0	1	3	2	0	0	6
	Expected Count	.2	.9	1.7	1.3	.6	.5	.7	6.0
	% of Total	0.0%	0.0%	0.5%	1.4%	1.0%	0.0%	0.0%	2.9%
	Std. Residual	-.5	-1.0	-.5	1.4	1.7	-.7	-.8	
1.2.3.3	Count	0	0	2	0	1	0	0	3
	Expected Count	.1	.5	.8	.7	.3	.2	.4	3.0
	% of Total	0.0%	0.0%	1.0%	0.0%	0.5%	0.0%	0.0%	1.4%
	Std. Residual	-.3	-.7	1.3	-.8	1.2	-.5	-.6	
1.3.1.1	Count	0	11	22	17	6	10	17	83
	Expected Count	3.2	12.6	23.3	18.6	8.7	6.7	9.9	83.0
	% of Total	0.0%	5.2%	10.5%	8.1%	2.9%	4.8%	8.1%	39.5%
	Std. Residual	-1.8	-.5	-.3	-.4	-.9	1.3	2.3	
1.3.1.2	Count	0	0	4	2	1	1	2	10
	Expected Count	.4	1.5	2.8	2.2	1.0	.8	1.2	10.0
	% of Total	0.0%	0.0%	1.9%	1.0%	0.5%	0.5%	1.0%	4.8%
	Std. Residual	-.6	-1.2	.7	-.2	.0	.2	.7	

	1.3.2.1	Count	1	6	7	10	5	0	2	31
		Expected Count	1.2	4.7	8.7	6.9	3.2	2.5	3.7	31.0
		% of Total	0.5%	2.9%	3.3%	4.8%	2.4%	0.0%	1.0%	14.8%
		Std. Residual	-.2	.6	-.6	1.2	1.0	-1.6	-.9	
	1.3.2.2	Count	1	4	3	1	1	0	2	12
		Expected Count	.5	1.8	3.4	2.7	1.3	1.0	1.4	12.0
		% of Total	0.5%	1.9%	1.4%	0.5%	0.5%	0.0%	1.0%	5.7%
		Std. Residual	.8	1.6	-.2	-1.0	-.2	-1.0	.5	
	1.3.2.3	Count	1	1	0	2	2	2	1	9
		Expected Count	.3	1.4	2.5	2.0	.9	.7	1.1	9.0
		% of Total	0.5%	0.5%	0.0%	1.0%	1.0%	1.0%	0.5%	4.3%
		Std. Residual	1.1	-.3	-1.6	.0	1.1	1.5	-.1	
Total		Count	8	32	59	47	22	17	25	210
		Expected Count	8.0	32.0	59.0	47.0	22.0	17.0	25.0	210.0
		% of Total	3.8%	15.2%	28.1%	22.4%	10.5%	8.1%	11.9%	100.0%

Table 6-19. Chi-squared results from Table 6-18 above.

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	88.795[a]	61	.032
Likelihood Ratio	100.669	61	.004
N of Valid Cases	210		

a. 74 cells (88.1%) have expected count less than 5. The minimum expected count is .11.

This changes the chi-squared value to 88.795 with df= 61. This is still significant at the 0.05 level, so I continue to the next deviant cell, 1.3.1.1:9 (see Table 6-21 below).

Table 6-20. Chi-squared results after cell 1.3.1.1:9 is altered.

General Chem Grp * Fabric Crosstabulation

			Fabric							
			1	2	3	4	5	8	9	Total
General Chem Grp	1.1.1	Count	1	1	0	1	1	3	0	7
		Expected Count	.3	1.1	2.1	1.7	.8	.6	.5	7.0
		% of Total	0.5%	0.5%	0.0%	0.5%	0.5%	1.5%	0.0%	3.5%
		Std. Residual	1.3	-.1	-1.4	-.5	.3	3.1	-.7	
	1.1.2	Count	1	2	3	1	1	1	1	10
		Expected Count	.4	1.6	3.0	2.4	1.1	.9	.7	10.0
		% of Total	0.5%	1.0%	1.5%	0.5%	0.5%	0.5%	0.5%	5.1%
		Std. Residual	.9	.3	.0	-.9	-.1	.2	.4	
	1.2.1	Count	1	0	3	1	1	0	0	6
		Expected Count	.2	1.0	1.8	1.4	.7	.5	.4	6.0
		% of Total	0.5%	0.0%	1.5%	0.5%	0.5%	0.0%	0.0%	3.0%
		Std. Residual	1.5	-1.0	.9	-.4	.4	-.7	-.6	
	1.2.2	Count	0	2	0	1	0	0	0	3
		Expected Count	.1	.5	.9	.7	.3	.3	.2	3.0
		% of Total	0.0%	1.0%	0.0%	0.5%	0.0%	0.0%	0.0%	1.5%
		Std. Residual	-.3	2.2	-.9	.3	-.6	-.5	-.4	
	1.2.3.1	Count	2	5	14	8	1	0	0	30
		Expected Count	1.2	4.8	8.9	7.1	3.3	2.6	2.0	30.0

	% of Total	1.0%	2.5%	7.1%	4.0%	0.5%	0.0%	0.0%	15.2 %
	Std. Residual	.7	.1	1.7	.3	-1.3	-1.6	-1.4	
1.2.3.2	Count	0	0	1	3	2	0	0	6
	Expected Count	.2	1.0	1.8	1.4	.7	.5	.4	6.0
	% of Total	0.0%	0.0%	0.5%	1.5%	1.0%	0.0%	0.0%	3.0%
	Std. Residual	-.5	-1.0	-.6	1.3	1.6	-.7	-.6	
1.2.3.3	Count	0	0	2	0	1	0	0	3
	Expected Count	.1	.5	.9	.7	.3	.3	.2	3.0
	% of Total	0.0%	0.0%	1.0%	0.0%	0.5%	0.0%	0.0%	1.5%
	Std. Residual	-.3	-.7	1.2	-.8	1.2	-.5	-.4	
1.3.1.1	Count	0	11	22	17	6	10	5	71
	Expected Count	2.9	11.5	21.2	16.9	7.9	6.1	4.7	71.0
	% of Total	0.0%	5.6%	11.1 %	8.6%	3.0%	5.1%	2.5%	35.9 %
	Std. Residual	-1.7	-.1	.2	.0	-.7	1.6	.2	
1.3.1.2	Count	0	0	4	2	1	1	2	10
	Expected Count	.4	1.6	3.0	2.4	1.1	.9	.7	10.0
	% of Total	0.0%	0.0%	2.0%	1.0%	0.5%	0.5%	1.0%	5.1%
	Std. Residual	-.6	-1.3	.6	-.2	-.1	.2	1.7	
1.3.2.1	Count	1	6	7	10	5	0	2	31
	Expected Count	1.3	5.0	9.2	7.4	3.4	2.7	2.0	31.0
	% of Total	0.5%	3.0%	3.5%	5.1%	2.5%	0.0%	1.0%	15.7 %
	Std. Residual	-.2	.4	-.7	1.0	.8	-1.6	.0	
	Count	1	4	3	1	1	0	2	12

	1.3.2.2	Expected Count	.5	1.9	3.6	2.8	1.3	1.0	.8	12.0
		% of Total	0.5%	2.0%	1.5%	0.5%	0.5%	0.0%	1.0%	6.1%
		Std. Residual	.7	1.5	-.3	-1.1	-.3	-1.0	1.4	
	1.3.2.3	Count	1	1	0	2	2	2	1	9
		Expected Count	.4	1.5	2.7	2.1	1.0	.8	.6	9.0
		% of Total	0.5%	0.5%	0.0%	1.0%	1.0%	1.0%	0.5%	4.5%
		Std. Residual	1.1	-.4	-1.6	-.1	1.0	1.4	.5	
Total		Count	8	32	59	47	22	17	13	198
		Expected Count	8.0	32.0	59.0	47.0	22.0	17.0	13.0	198.0
		% of Total	4.0%	16.2%	29.8%	23.7%	11.1%	8.6%	6.6%	100.0%

Table 6-21. Chi-squared results from Table 6-20 above.

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	79.698[a]	60	.120
Likelihood Ratio	91.285	60	.021
N of Valid Cases	198		

a. 74 cells (88.1%) have expected count less than 5. The minimum expected count is .12.

The chi-squared value of 79.698 is just barely significant at the 0.05 level with df=60 (a significant value is above 79.0819 at this level and df). The next deviant cell is 1.1.1: 8, so I change the observed to 1.

Table 6-22. Chi-squared results after cell 1.1.1:8 is altered.

General Chem Grp * Fabric Crosstabulation

			Fabric							
			1	2	3	4	5	8	9	Total
General Chem Grp	1.1.1	Count	1	1	0	1	1	1	0	5
		Expected Count	.2	.8	1.5	1.2	.6	.4	.3	5.0
		% of Total	0.5%	0.5%	0.0%	0.5%	0.5%	0.5%	0.0%	2.6%
		Std. Residual	1.8	.2	-1.2	-.2	.6	1.0	-.6	
	1.1.2	Count	1	2	3	1	1	1	1	10
		Expected Count	.4	1.6	3.0	2.4	1.1	.8	.7	10.0
		% of Total	0.5%	1.0%	1.5%	0.5%	0.5%	0.5%	0.5%	5.1%
		Std. Residual	.9	.3	.0	-.9	-.1	.3	.4	
	1.2.1	Count	1	0	3	1	1	0	0	6
		Expected Count	.2	1.0	1.8	1.4	.7	.5	.4	6.0
		% of Total	0.5%	0.0%	1.5%	0.5%	0.5%	0.0%	0.0%	3.1%
		Std. Residual	1.5	-1.0	.9	-.4	.4	-.7	-.6	
	1.2.2	Count	0	2	0	1	0	0	0	3
		Expected Count	.1	.5	.9	.7	.3	.2	.2	3.0
		% of Total	0.0%	1.0%	0.0%	0.5%	0.0%	0.0%	0.0%	1.5%
		Std. Residual	-.3	2.2	-1.0	.3	-.6	-.5	-.4	
	1.2.3.1	Count	2	5	14	8	1	0	0	30
		Expected Count	1.2	4.9	9.0	7.2	3.4	2.3	2.0	30.0
		% of Total	1.0%	2.6%	7.1%	4.1%	0.5%	0.0%	0.0%	15.3%
		Std. Residual	.7	.0	1.7	.3	-1.3	-1.5	-1.4	
		Count	0	0	1	3	2	0	0	6

1.2.3.2	Expected Count	.2	1.0	1.8	1.4	.7	.5	.4	6.0
	% of Total	0.0%	0.0%	0.5%	1.5%	1.0%	0.0%	0.0%	3.1%
	Std. Residual	-.5	-1.0	-.6	1.3	1.6	-.7	-.6	
1.2.3.3	Count	0	0	2	0	1	0	0	3
	Expected Count	.1	.5	.9	.7	.3	.2	.2	3.0
	% of Total	0.0%	0.0%	1.0%	0.0%	0.5%	0.0%	0.0%	1.5%
	Std. Residual	-.3	-.7	1.2	-.8	1.1	-.5	-.4	
1.3.1.1	Count	0	11	22	17	6	10	5	71
	Expected Count	2.9	11.6	21.4	17.0	8.0	5.4	4.7	71.0
	% of Total	0.0%	5.6%	11.2%	8.7%	3.1%	5.1%	2.6%	36.2%
	Std. Residual	-1.7	-.2	.1	.0	-.7	2.0	.1	
1.3.1.2	Count	0	0	4	2	1	1	2	10
	Expected Count	.4	1.6	3.0	2.4	1.1	.8	.7	10.0
	% of Total	0.0%	0.0%	2.0%	1.0%	0.5%	0.5%	1.0%	5.1%
	Std. Residual	-.6	-1.3	.6	-.3	-.1	.3	1.6	
1.3.2.1	Count	1	6	7	10	5	0	2	31
	Expected Count	1.3	5.1	9.3	7.4	3.5	2.4	2.1	31.0
	% of Total	0.5%	3.1%	3.6%	5.1%	2.6%	0.0%	1.0%	15.8%
	Std. Residual	-.2	.4	-.8	.9	.8	-1.5	.0	
1.3.2.2	Count	1	4	3	1	1	0	2	12
	Expected Count	.5	2.0	3.6	2.9	1.3	.9	.8	12.0
	% of Total	0.5%	2.0%	1.5%	0.5%	0.5%	0.0%	1.0%	6.1%
	Std. Residual	.7	1.5	-.3	-1.1	-.3	-1.0	1.3	

	1.3.2.3	Count	1	1	0	2	2	2	1	9
		Expected Count	.4	1.5	2.7	2.2	1.0	.7	.6	9.0
		% of Total	0.5%	0.5%	0.0%	1.0%	1.0%	1.0%	0.5%	4.6%
		Std. Residual	1.0	-.4	-1.6	-.1	1.0	1.6	.5	
Total		Count	8	32	59	47	22	15	13	196
		Expected Count	8.0	32.0	59.0	47.0	22.0	15.0	13.0	196.0
		% of Total	4.1%	16.3%	30.1%	24.0%	11.2%	7.7%	6.6%	100.0%

Table 6-23. Chi-squared results from Table 6-22 above.

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	72.336[a]	59	.277
Likelihood Ratio	85.796	59	.051
N of Valid Cases	196		

a. 74 cells (88.1%) have expected count less than 5. The minimum expected count is .12.

The chi-squared value (72.336) is clearly insignificant for df=59 at the 0.05 level, so I have successfully identified all cells responsible for the significant overall chi-squared value. This analysis demonstrates several important points. First, that compositional groups and fabric types appear to be related for 7 combinations of these two variables. Six out of seven of these combinations include either group 1.1.1 or 1.1.1, Sb-decolorized glasses. Therefore, these glasses can be roughly identified by the outward appearance of the material and other parameters outlined by Harden. Fabric 1 and 2 are colorless fabrics. Fabric 8 is "green bubbly ware." This vague description of this fabric type says that it is easily recognizable by the large quantity of bubbles in the fabric. However, it must not be that easily identified, since using the parameters, I identify five different compositionally distinct groups as Fabric 8. The color of Fabric 8 can

range from faint green or bluish green to green or blue green (Harden 1936:24). Therefore, the defining quality Harden gives this type is the large amount of bubbles.

Another interesting association between compositional groups and Fabric types is cell 1.3.1.1:9. Fabric 9 is what Harden calls "bottle ware". This is a poor quality fabric Harden notes is used primarily for bottles and toilet bottles. The above analysis shows that this compositional type can be identified by the outward appearance of the glass based on Harden's description of Fabric 9, bottle ware. He states that it is the "coarsest and heaviest of all, and stands in a class apart, not only by reason of its poor quality, but also by reason of shape, colour, and weathering" (1936: 24). Fabric 9 includes glass of various shades of green and containing many bubbles and impurities. He says the careless craftsmanship and material is "obviously the result of mass production for commercial uses". He confirms that this fabric is ubiquitous throughout all periods of occupation of Karanis. He also notes that the typical forms made from Fabric 9 include: rectangular bottles and toilet bottles (Harden 1936).

6.6 Applying the Recursive Method to Identify Preferred Types among Recently Excavated Glass from Karanis.

This same recursive method can be employed to method to identify preferred types and possible use types through the consideration of two variables: glass composition and morphology. I only include samples for which I am fairly certain about their morphology. During on-site analysis of these artifacts, I ranked the certainty of my morphological distinction for each sample on a scale from 1-5 (1 representing the least confident assessments). For all morphological analyses in this dissertation, I include only samples I have ranked 3 or above. This significantly decreases the sample size (by more than half), but since this corpus is

extremely fragmented, it is necessary to stay within the limits of the information these objects are able to provide.

I start with basic, more generalized categories for each of the two variables to see if any patterns are visible. The "basic" morphological groups are: 1) beakers, cups, and conical lamps, 2) bottles and toilet bottles, 3) jars and flasks, 4) plates and bowls.

There is a significant p-value at the 0.001 level with df=12. Some trends can be identified. As Harden noted, the common forms for bottle ware are bottles and toilet bottles. More than half of all bottles and toilet bottles are made with Aqua glass and 58.1% of all Aqua glass are bottles and toilet bottles. Mixed Mn/Sb glass comprises 26.5% of all bottles and toilet bottles. This means that if aqua and Mixed Mn/Sb glasses represent recycled glass, close to 80% of all bottles are made from recycled material. Conversely, only 14.7% of all bottles and toilet bottles are made from Sb-decolorized glass and this is significantly lower than the expected value for this combination of compositional and morphological types.

Therefore, the more general grouping of these morphological groups actually hide patterning in the data, as there are clear associations between compositional groups and morphological types that will be revealed below, which are not visible in this analysis. Note in the table below, that there is no significant association between High manganese/low antimony glass and the beakers, cups, and conical lamps category. High manganese/low antimony plates and bowls occur much more frequently than the expected value, however, so this seems to also be a preferred type. I do not carry out Read's recursive method using this 5x4 contingency table, because more specific morphological group designations still show a significant p-value and yield more accurate results.

Table 6-24. 5x4 contingency table of basic compositional groups and general morphological groups.

basic compositional Grp * general form Crosstabulation

			General form				
			beakers, cups, conical lamps	bottles, toilet bottles	jars, flasks	plates, bowls	Total
Basic Comp Grp	Aqua	Count	1	18	4	8	31
		Expected Count	7.2	5.2	11.1	7.5	31.0
		% within Basic Chem Grp	3.2%	58.1%	12.9%	25.8%	100.0 %
		% within final form grps	2.1%	52.9%	5.5%	16.3%	15.3%
		% of Total	0.5%	8.9%	2.0%	3.9%	15.3%
		Std. Residual	-2.3	5.6	-2.1	.2	
	High Mn/low Sb	Count	8	2	4	17	31
		Expected Count	7.2	5.2	11.1	7.5	31.0
		% within Basic Chem Grp	25.8%	6.5%	12.9%	54.8%	100.0 %
		% within final form grps	17.0%	5.9%	5.5%	34.7%	15.3%
		% of Total	3.9%	1.0%	2.0%	8.4%	15.3%
		Std. Residual	.3	-1.4	-2.1	3.5	
	Low Mn/low Sb	Count	0	0	0	2	2
		Expected Count	.5	.3	.7	.5	2.0
		% within Basic Chem Grp	0.0%	0.0%	0.0%	100.0%	100.0 %

		% within final form grps	0.0%	0.0%	0.0%	4.1%	1.0%
		% of Total	0.0%	0.0%	0.0%	1.0%	1.0%
		Std. Residual	-.7	-.6	-.8	2.2	
	Mixed Mn/Sb	Count	2	9	5	0	16
		Expected Count	3.7	2.7	5.8	3.9	16.0
		% within Basic Chem Grp	12.5%	56.3%	31.3%	0.0%	100.0 %
		% within final form grps	4.3%	26.5%	6.8%	0.0%	7.9%
		% of Total	1.0%	4.4%	2.5%	0.0%	7.9%
		Std. Residual	-.9	3.9	-.3	-2.0	
	Sb Decol Glass	Count	36	5	60	22	123
		Expected Count	28.5	20.6	44.2	29.7	123.0
		% within Basic Chem Grp	29.3%	4.1%	48.8%	17.9%	100.0 %
		% within final form grps	76.6%	14.7%	82.2%	44.9%	60.6%
		% of Total	17.7%	2.5%	29.6%	10.8%	60.6%
		Std. Residual	1.4	-3.4	2.4	-1.4	
Total		Count	47	34	73	49	203
		Expected Count	47.0	34.0	73.0	49.0	203.0
		% within Basic Chem Grp	23.2%	16.7%	36.0%	24.1%	100.0 %
		% within final form grps	100.0%	100.0%	100.0%	100.0%	100.0 %

% of Total	23.2%	16.7%	36.0%	24.1%	100.0 %

Table 6-25. Chi-squared results for Table 6-24 above.

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	107.626[a]	12	.000
Likelihood Ratio	101.045	12	.000
N of Valid Cases	203		

a. 7 cells (35.0%) have expected count less than 5. The minimum expected count is .33.

Next, I use Read's (2007, 2015) recursive method using the basic compositional group categories and what I call "general" morphological groups. These morphological types are loosely based on Harden's classification (see Appendix 5) with some modifications. The "general" groups are: 1) plates, 24) bowls, 57) beakers, goblets, drinking cups, goblets on stem, and 6) conical lamps, 810) jars, flasks, bottle flasks without handles, 11) one-handled jugs and bottles (rectangular bottles), 12) two-handled flask and bottles (oil flasks), 13) toilet bottles. Since I establish the need to reform the classification of bowls earlier in this chapter, I combine all three bowl types (Harden's Class 2, 3, and 4) into one type, Group 24. I also combine certain groups that are difficult to distinguish from one another without having a nearly complete vessel. For example, Harden's Class 5 (beakers and goblets) and Class 7 (Drinking cups and goblets on

stem) combine to Group 57. Similarly, Harden's Class 8 (jars), Class 9 (flasks), and Class 10 (bottle flasks) combine to Group 810.

Table 6-26. 5x8 contingency table of basic compositional groups and general morphological groups.

Basic Compositional Grp * General Form Crosstabulation

			General Form								
			1	6	11	12	13	24	57	810	Total
Basic Comp Grp	Aqua	Count	3	0	3	0	15	5	1	4	31
		Expected Count	1.8	.9	.9	2.0	4.3	5.7	6.3	9.2	31.0
		% within Basic Chem Grp	9.7%	0.0%	9.7%	0.0%	48.4%	16.1%	3.2%	12.9%	100.0%
		% within Combined Spec Form	25.0%	0.0%	50.0%	0.0%	53.6%	13.5%	2.4%	6.7%	15.3%
		% of Total	1.5%	0.0%	1.5%	0.0%	7.4%	2.5%	0.5%	2.0%	15.3%
		Std. Residual	.9	-1.0	2.2	-1.4	5.2	-.3	-2.1	-1.7	
	High Mn/low Sb	Count	5	5	0	0	2	12	3	4	31
		Expected Count	1.8	.9	.9	2.0	4.3	5.7	6.3	9.2	31.0
		% within Basic Chem Grp	16.1%	16.1%	0.0%	0.0%	6.5%	38.7%	9.7%	12.9%	100.0%
		% within Combined Spec Form	41.7%	83.3%	0.0%	0.0%	7.1%	32.4%	7.3%	6.7%	15.3%
		% of Total	2.5%	2.5%	0.0%	0.0%	1.0%	5.9%	1.5%	2.0%	15.3%
		Std. Residual	2.3	4.3	-1.0	-1.4	-1.1	2.7	-1.3	-1.7	
	Low Mn/low Sb	Count	0	0	0	0	0	2	0	0	2
		Expected Count	.1	.1	.1	.1	.3	.4	.4	.6	2.0
		% within Basic Chem Grp	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	100.0%
		% within Combined Spec Form	0.0%	0.0%	0.0%	0.0%	0.0%	5.4%	0.0%	0.0%	1.0%
		% of Total	0.0%	0.0%	0.0%	0.0%	0.0%	1.0%	0.0%	0.0%	1.0%

		Std. Residual	-.3	-.2	-.2	-.4	-.5	2.7	-.6	-.8	
	Mixed Mn/Sb	Count	0	1	1	0	8	0	1	5	16
		Expected Count	.9	.5	.5	1.0	2.2	2.9	3.2	4.7	16.0
		% within Basic Chem Grp	0.0%	6.3%	6.3%	0.0%	50.0%	0.0%	6.3%	31.3%	100.0%
		% within Combined Spec Form	0.0%	16.7%	16.7%	0.0%	28.6%	0.0%	2.4%	8.3%	7.9%
		% of Total	0.0%	0.5%	0.5%	0.0%	3.9%	0.0%	0.5%	2.5%	7.9%
		Std. Residual	-1.0	.8	.8	-1.0	3.9	-1.7	-1.2	.1	
	Sb Decol Glass	Count	4	0	2	13	3	18	36	47	123
		Expected Count	7.3	3.6	3.6	7.9	17.0	22.4	24.8	36.4	123.0
		% within Basic Chem Grp	3.3%	0.0%	1.6%	10.6%	2.4%	14.6%	29.3%	38.2%	100.0%
		% within Combined Spec Form	33.3%	0.0%	33.3%	100.0%	10.7%	48.6%	87.8%	78.3%	60.6%
		% of Total	2.0%	0.0%	1.0%	6.4%	1.5%	8.9%	17.7%	23.2%	60.6%
		Std. Residual	-1.2	-1.9	-.9	1.8	-3.4	-.9	2.2	1.8	
Total		Count	12	6	6	13	28	37	41	60	203
		Expected Count	12.0	6.0	6.0	13.0	28.0	37.0	41.0	60.0	203.0
		% within Basic Chem Grp	5.9%	3.0%	3.0%	6.4%	13.8%	18.2%	20.2%	29.6%	100.0%
		% within Combined Spec Form	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	5.9%	3.0%	3.0%	6.4%	13.8%	18.2%	20.2%	29.6%	100.0%

Table 6-27. Chi-squared results for Table 6-26 above.

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	143.686[a]	28	.000
Likelihood Ratio	134.233	28	.000
N of Valid Cases	203		

a. 28 cells (70.0%) have expected count less than 5. The minimum expected count is .06.

The most deviant cell is Aqua:13. I change the observed value to from 15 to 1 to equal that of the expected to neutralize the effect of this cell on the overall chi-squared value (resulting table not shown). The next deviant cell is Mixed Mn/Sb: 13. I change the observed value from 8 to 0 to equal that of the expected (resulting table not shown). The next deviant cell is then High Mn/low Sb: 6. I change the observed value from 5 to zero. This changes the expected value of Mixed Mn/Sb Mn Sb: 6, which is the next deviant cell. This changes from 1 observed to 0, and this eliminates Class 6 (conical vessels) from the morphological types. The table is now a 5 rows x 7 columns and the df = (5-1)(7-1)-3 cells altered = 21. The p-value is still significant at the 0.001 level, so I continue to alter cells.

Table 6-28. 5x7 contingency table of basic compositional groups and general morphological groups

Basic Chem Grp General Form Crosstabulation

			General Form							
			1	11	12	13	24	57	810	Total
Basic Chem Grp	Aqua	Count	3	3	0	1	5	1	4	17
		Expected Count	1.2	.6	1.3	.6	3.6	4.0	5.8	17.0
		% within Basic Chem Grp	17.6%	17.6%	0.0%	5.9%	29.4%	5.9%	23.5%	100.0 %
		% within Combined Spec Form	25.0%	50.0%	0.0%	16.7%	13.5%	2.4%	6.7%	9.7%
		% of Total	1.7%	1.7%	0.0%	0.6%	2.9%	0.6%	2.3%	9.7%
		Std. Residual	1.7	3.2	-1.1	.5	.7	-1.5	-.8	
	High Mn/low Sb	Count	5	0	0	2	12	3	4	26
		Expected Count	1.8	.9	1.9	.9	5.5	6.1	8.9	26.0

	% within Basic Chem Grp	19.2%	0.0%	0.0%	7.7%	46.2%	11.5%	15.4%	100.0 %
	% within Combined Spec Form	41.7%	0.0%	0.0%	33.3%	32.4%	7.3%	6.7%	14.9%
	% of Total	2.9%	0.0%	0.0%	1.1%	6.9%	1.7%	2.3%	14.9%
	Std. Residual	2.4	-.9	-1.4	1.2	2.8	-1.3	-1.6	
Low Mn/low Sb	Count	0	0	0	0	2	0	0	2
	Expected Count	.1	.1	.1	.1	.4	.5	.7	2.0
	% within Basic Chem Grp	0.0%	0.0%	0.0%	0.0%	100.0 %	0.0%	0.0%	100.0 %
	% within Combined Spec Form	0.0%	0.0%	0.0%	0.0%	5.4%	0.0%	0.0%	1.1%
	% of Total	0.0%	0.0%	0.0%	0.0%	1.1%	0.0%	0.0%	1.1%
	Std. Residual	-.4	-.3	-.4	-.3	2.4	-.7	-.8	
Mixed Mn/Sb	Count	0	1	0	0	0	1	5	7
	Expected Count	.5	.2	.5	.2	1.5	1.6	2.4	7.0
	% within Basic Chem Grp	0.0%	14.3%	0.0%	0.0%	0.0%	14.3%	71.4%	100.0 %
	% within Combined Spec Form	0.0%	16.7%	0.0%	0.0%	0.0%	2.4%	8.3%	4.0%
	% of Total	0.0%	0.6%	0.0%	0.0%	0.0%	0.6%	2.9%	4.0%
	Std. Residual	-.7	1.6	-.7	-.5	-1.2	-.5	1.7	
Sb Decol Glass	Count	4	2	13	3	18	36	47	123
	Expected Count	8.4	4.2	9.1	4.2	26.0	28.8	42.2	123.0

	% within Basic Chem Grp	3.3%	1.6%	10.6%	2.4%	14.6%	29.3%	38.2%	100.0 %
	% within Combined Spec Form	33.3%	33.3%	100.0 %	50.0%	48.6%	87.8%	78.3%	70.3%
	% of Total	2.3%	1.1%	7.4%	1.7%	10.3%	20.6%	26.9%	70.3%
	Std. Residual	-1.5	-1.1	1.3	-.6	-1.6	1.3	.7	
Total	Count	12	6	13	6	37	41	60	175
	Expected Count	12.0	6.0	13.0	6.0	37.0	41.0	60.0	175.0
	% within Basic Chem Grp	6.9%	3.4%	7.4%	3.4%	21.1%	23.4%	34.3%	100.0 %
	% within Combined Spec Form	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %
	% of Total	6.9%	3.4%	7.4%	3.4%	21.1%	23.4%	34.3%	100.0 %

Table 6-29. Chi-squared results for Table 6-28 above.

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	65.748[a]	21	.000
Likelihood Ratio	62.287	21	.000
N of Valid Cases	175		

a. 26 cells (74.3%) have expected count less than 5. The minimum expected count is .07.

The next deviant cell is Aqua: 11. The expected value of 3 changes to 0 (resulting table not shown). The next deviant cell is High Mn/low Sb: 24, bowls. This observed value changes from 12 to 3. The p-value (54.006) is still significant at the 0.001 level and df=20 (see Table 6-30 and 6-31 below). There are not, however, any more cells in which the expected varies more

than a few cases from the observed. It appears that the chi-squared value is inflated for many of the cells where the expected value is less than 1, which inflates the overall chi-squared p value as well. The same is true for cells where the difference between the expected and observed are less than 5 (Read, May 2015, personal communication). Consequently, the chi-squared p value is still significant at the 0.001 level and df=20, but all deviant cells that account for a significant chi-squared p value in the initial 4x7 contingency table have already been eliminated. For this reason, I do not alter any more cells and critically evaluate the ones I have already changed.

Table 6-30. Final 4x7 contingency table of basic compositional groups and general morphological groups.

Basic Chem Grp * Combined Spec Form Crosstabulation

			Combined Spec Form							
			1	11	12	13	24	57	810	Total
Basic Chem Grp	Aqua	Count	3	0	0	1	5	1	4	14
		Expected Count	1.0	.3	1.1	.5	2.4	3.5	5.2	14.0
		% within Basic Chem Grp	21.4%	0.0%	0.0%	7.1%	35.7%	7.1%	28.6%	100.0 %
		% within Combined Spec Form	25.0%	0.0%	0.0%	16.7%	17.9%	2.4%	6.7%	8.6%
		% of Total	1.8%	0.0%	0.0%	0.6%	3.1%	0.6%	2.5%	8.6%
		Std. Residual	1.9	-.5	-1.1	.7	1.7	-1.3	-.5	
	High Mn/low Sb	Count	5	0	0	2	3	3	4	17
		Expected Count	1.3	.3	1.4	.6	2.9	4.3	6.3	17.0
		% within Basic Chem Grp	29.4%	0.0%	0.0%	11.8%	17.6%	17.6%	23.5%	100.0 %

	% within Combined Spec Form	41.7%	0.0%	0.0%	33.3%	10.7%	7.3%	6.7%	10.4%
	% of Total	3.1%	0.0%	0.0%	1.2%	1.8%	1.8%	2.5%	10.4%
	Std. Residual	3.4	-.6	-1.2	1.7	.0	-.6	-.9	
Low Mn/low Sb	Count	0	0	0	0	2	0	0	2
	Expected Count	.1	.0	.2	.1	.3	.5	.7	2.0
	% within Basic Chem Grp	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	100.0%
	% within Combined Spec Form	0.0%	0.0%	0.0%	0.0%	7.1%	0.0%	0.0%	1.2%
	% of Total	0.0%	0.0%	0.0%	0.0%	1.2%	0.0%	0.0%	1.2%
	Std. Residual	-.4	-.2	-.4	-.3	2.8	-.7	-.9	
Mixed Mn/Sb	Count	0	1	0	0	0	1	5	7
	Expected Count	.5	.1	.6	.3	1.2	1.8	2.6	7.0
	% within Basic Chem Grp	0.0%	14.3%	0.0%	0.0%	0.0%	14.3%	71.4%	100.0%
	% within Combined Spec Form	0.0%	33.3%	0.0%	0.0%	0.0%	2.4%	8.3%	4.3%
	% of Total	0.0%	0.6%	0.0%	0.0%	0.0%	0.6%	3.1%	4.3%
	Std. Residual	-.7	2.4	-.7	-.5	-1.1	-.6	1.5	
Sb Decol Glass	Count	4	2	13	3	18	36	47	123
	Expected Count	9.1	2.3	9.8	4.5	21.1	30.9	45.3	123.0
	% within Basic Chem Grp	3.3%	1.6%	10.6%	2.4%	14.6%	29.3%	38.2%	100.0%

	% within Combined Spec Form	33.3%	66.7%	100.0%	50.0%	64.3%	87.8%	78.3%	75.5%
	% of Total	2.5%	1.2%	8.0%	1.8%	11.0%	22.1%	28.8%	75.5%
	Std. Residual	-1.7	-.2	1.0	-.7	-.7	.9	.3	
Total	Count	12	3	13	6	28	41	60	163
	Expected Count	12.0	3.0	13.0	6.0	28.0	41.0	60.0	163.0
	% within Basic Chem Grp	7.4%	1.8%	8.0%	3.7%	17.2%	25.2%	36.8%	100.0%
	% within Combined Spec Form	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
	% of Total	7.4%	1.8%	8.0%	3.7%	17.2%	25.2%	36.8%	100.0%

Table 6-31. Chi-squared results for Table 6-30 above.

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	54.006[a]	20	.000
Likelihood Ratio	46.578	20	.004
N of Valid Cases	163		

a. 28 cells (80.0%) have expected count less than 5. The minimum expected count is .04.

6.7 Possible Functional Types Discerned through a Comparison of Altered Cell Values

A total of 6 cells were altered and "neutralized" because the observed values deviated significantly from the expected values. The expected value is the number of cases you would expect in the cell if there is no relationship between the two variables. Therefore, the altered cells represent combinations where the two variables are not independent. Table 6-32 below summarizes the changes made to the altered cells in the above analysis.

Table 6-32. Cells altered during iterative process. Cells that show significant differences between observed and expected are highlighted.

Altered Cell Row	**Altered Cell Column**	Initial Observed	Altered Observed	Percentage Altered
Aqua	**13**	15	0	100
Mixed Mn/Sb	**13**	8	0	100
High Mn/low Sb	**6**	5	0	100
Mixed Mn/Sb	**6**	1	0	100
Aqua	**11**	3	0	100
High Mn/low Sb	**24**	12	2	83

Possible functional types can be discerned by identifying cells for which the observed values were altered by a similar percentage to make the observed and expected values agree. This means they would be "equally preferred" (Read, May 2015, personal communication; 2007; 2015).

The four highlighted cells in Table 6-32 above do not share identical percentages in which observed values were altered. Therefore, each row would represent its own use type. However, since the first two cells altered are similar vessel types, toilet bottles made from either aqua or mixed manganese antimony glass, it would make sense that these two preferred types represent one functional type.

6.8 Concluding Remarks

The ethnoarchaeological study of modern Cairene glass workers and the Roman Glass Makers of Hampshire, UK provides crucial insight into the manufacturing process. This *chaîne opératoire* informs my typology of bowls and allows me to identify patterns in bowl making that are neither visible in the aggregate, nor evident if the bowl population is divided in the order and manner in which Harden divides them. Composing a typology using culturally salient dimensions is important in understanding what differentiates glass objects from the viewpoint of the makers and users of these ancient objects, and how these differences reflect shared notions of value in their society. Therefore, the compositional and morphological typologies I explore in Chapters 5 and 6 form the foundation of this study about value. I must first identify types in order to compare how certain objects are valued over others. The recursive method I employ in this chapter allows me to identify preferred types and possible functional types. The next chapter examines object biographies of individual artifacts. For object biographies, I consider the archaeological context of artifacts in order to better understand their use, possible reuse, and discard. I then compare trends among object types and place these trends in a broader, cultural context in chapter 8, where I investigate life histories of object types, namely *unguentaria*, rectangular bottles, and oil flasks.

Chapter 7

Context of Karanis Glass

7.1 Introduction

To investigate object biographies through a contextual analysis of glass artifacts at Karanis I am using the same statistical analysis techniques I employ to identify patterns among variables in other chapters exploring relationships among variables and archaeological context. To identify patterning, I discern different levels of specificity in archaeological context: general site area, trenches, and stratigraphic units. Exploring how compositional groups as well as morphological groups relate to archaeological context enables our understanding of the development of the town and the relative level of affluence of inhabitants of the various parts of the town. I also explore patterns of consumption based on the types of stratigraphic units in which objects were found. The type of stratigraphic unit helps to understand the use or discard of certain types of artifacts, which contributes to the discussion of object value. Heirlooms can present stratigraphic anomalies in the archaeological record. They date to an earlier period than the other objects found in a particular context, and if not recognized, can obscure a proper interpretation of archaeological material. Lillios defines an heirloom as "objects that are curated for multiple generations before entering the archaeological record" (1999: 239).

7.2 General Date and Compositional Types

Although the site itself is datable to a broad time span based on previous excavations and pottery dates, temporal sequence of events and more specific dates can be determined through pottery dates and/or C-14 dates of specific stratigraphic layers. Not all stratigraphic units from which glass objects in this study were found have been dated through these means. Therefore, I

include in my chi-squared analysis only those samples that were recovered from datable layers (n=166 samples from datable layers, n=153 excluding compositional outliers, and only n=65 for datable artifacts with discernable morphology).

Table 7-1. 3x5 contingency table of general date and basic compositional groups, n=153.

Date * Basic Chem Grp Crosstabulation

			Basic Chem Grp					
			Aqua	High Mn/low Sb	Low Mn/low Sb	Mixed Mn/Sb	Sb Decol Glass	Total
Date	C1-C3	Count	0	0	0	1	3	4
		Expected Count	.5	1.0	.1	.4	2.1	4.0
		% of Total	0.0%	0.0%	0.0%	0.7%	2.0%	2.6%
		Std. Residual	-.7	-1.0	-.2	1.0	.6	
	C3-C4	Count	1	0	0	1	7	9
		Expected Count	1.1	2.2	.1	.8	4.8	9.0
		% of Total	0.7%	0.0%	0.0%	0.7%	4.6%	5.9%
		Std. Residual	-.1	-1.5	-.3	.2	1.0	
	C4-C6	Count	17	37	2	12	72	140
		Expected Count	16.5	33.9	1.8	12.8	75.0	140.0
		% of Total	11.1%	24.2%	1.3%	7.8%	47.1%	91.5%
		Std. Residual	.1	.5	.1	-.2	-.4	
Total		Count	18	37	2	14	82	153
		Expected Count	18.0	37.0	2.0	14.0	82.0	153.0
		% of Total	11.8%	24.2%	1.3%	9.2%	53.6%	100.0%

Table 7-2. Chi-squared results for Table 7-1 above.

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	6.746[a]	8	.564
Likelihood Ratio	10.006	8	.265
N of Valid Cases	153		

a. 11 cells (73.3%) have expected count less than 5. The minimum expected count is .05.

This chi-squared value (6.746) is not significant with df =8 at the 0.05 level. Therefore, there does not seem to be a relationship between object date and compositional group. As specified in the beginning of this study, the majority of glass recovered and analyzed in this study dates to the Late Roman period (4th-6th century CE for Karanis). The table above confirms that 91.5% of the total glass in this study dates to the Late Roman period. Only 8.5% may pre-date the Late Roman period, based on pottery dates. All those compositional types found in the possible earlier contexts (1st-4th centuries CE) are also found in the Late Roman period (4th-6th centuries CE).

A chi-squared analysis of more specific compositional groups and the same general date categories for stratigraphic layers adds some additional information about these earlier compositional types (see Table 7-3 below). The three antimony (Sb)-decolorized samples found in 1st-3rd century CE contexts are type 1.1.1, meaning they contain the lowest levels of iron (Fe) and manganese (Mn) of the antimony (Sb)-decolorized subgroups. They are typically water clear colorless due to a lack of impurities in the glass and the effective antimony (Sb) decolorizer used. None of what could be considered lower quality colorless glass (Group 1.1.2) is found in 1st-3rd century CE context. Even the 4th-6th century CE colorless glass, however, is primarily Group 1.1.1 glass. This contrasts with Harden's observation that both colorless fabrics (Type 1: Colourless ware a, and Type 2: Colourless ware b) are earlier wares, and that there are only "some" late examples of both fabrics, which are lower quality with more bubbles and impurities (1936:22) (see Appendix 9 for Harden's observed relationships between archaeological context and fabric types). Colorless glass makes up 47.1% of the total glass in this study recovered from stratigraphic layers dating from the 4th-6th centuries CE.

Table 7-3. 3x12 contingency table of general date and general compositional groups, n=153.

Date * General Chem Grp Crosstabulation

			General Chem Grp												
			1.1.1	1.1.2	1.2.1	1.2.2	1.2.3.1	1.2.3.2	1.2.3.3	1.3.1.1	1.3.1.2	1.3.2.1	1.3.2.2	1.3.2.3	Total
Date	C1-C3	Count	3	0	0	0	0	0	0	0	0	0	1	0	4
		Expected Count	1.6	.5	.1	.1	.4	.1	.1	.5	.1	.4	.2	.1	4.0
		% of Total	2.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.7%	0.0%	2.6%
		Std. Residual	1.1	-.7	-.2	-.2	-.7	-.2	-.2	-.7	-.3	-.6	1.9	-.3	
	C3-C4	Count	4	3	0	0	0	0	0	1	0	0	1	0	9
		Expected Count	3.7	1.1	.1	.1	1.0	.1	.1	1.1	.2	.8	.4	.2	9.0
		% of Total	2.6%	2.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.7%	0.0%	0.0%	0.7%	0.0%	5.9%
		Std. Residual	.2	1.8	-.3	-.3	-1.0	-.3	-.3	-.1	-.5	-.9	.9	-.4	
	C4-C6	Count	56	16	2	2	17	2	2	17	4	14	5	3	140
		Expected Count	57.6	17.4	1.8	1.8	15.6	1.8	1.8	16.5	3.7	12.8	6.4	2.7	140.0
		% of Total	36.6%	10.5%	1.3%	1.3%	11.1%	1.3%	1.3%	11.1%	2.6%	9.2%	3.3%	2.0%	91.5%
		Std. Residual	-.2	-.3	.1	.1	.4	.1	.1	.1	.2	.3	-.6	.2	
Total		Count	63	19	2	2	17	2	2	18	4	14	7	3	153
		Expected Count	63.0	19.0	2.0	2.0	17.0	2.0	2.0	18.0	4.0	14.0	7.0	3.0	153.0
		% of Total	41.2%	12.4%	1.3%	1.3%	11.1%	1.3%	1.3%	11.8%	2.6%	9.2%	4.6%	2.0%	100.0%

Table 7-4. Chi-squared results for Table 7-3 above.

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	14.517[a]	22	.882
Likelihood Ratio	16.054	22	.813
N of Valid Cases	153		

a. 30 cells (83.3%) have expected count less than 5. The minimum expected count is .05.

7.3 General Date and Morphological Types

Using a my modified version of Harden's basic morphological groups helps determine if there are any patterns in the date and morphology of artifacts. Too specific form categories restricts the ability to identify any possible patterning since there will be too few examples of some or many types, especially given there are only 65 datable samples for which morphology can be confidently determined. As in my previous analysis of morphology and compositional groups, I only include samples I have scored 3-5 (out of 5) in confidence level of form identification

Creating sets of morphological groups of various specificity reveal more patterning in the data. For "specific Harden types", I combine all three of Harden's bowl groups (shallow, deep, bowls on stem) into one general bowl category (designated as Type 24, since they combine Harden types 2-4). Other than combining the bowl categories, these "specific Harden type" categories keep Harden's designations and numbers for morphological types (see Appendix 5). For such generalized Harden forms, I create three main groups: 1) plates, bowls, 2) beakers, cups, conical lamps, 3) jars, flasks, bottles, *unguentaria*. For "basic forms" I use two categories: open and closed forms. Closed forms include any vessel with a neck or constricted opening

(including jars). I use these same three sets of form categories to conduct my analysis exploring the relationship between chemical composition and form (Chapter 6) as well as geographic location and form (see sections 7-6 through 7-8).

Despite these efforts to generalize form categories to reveal patterning, since there are only 9 samples dating earlier than the Late Roman Period, I was unable to identify any significant patterning or relation between date and morphology. The chi-squared value of 6.221 with df=4 is not significant at the 0.05 level. Since the sample population of earlier glass objects is so small, I do not attempt to interpret results for these 9 samples. It may be notable, however, that the total frequency count for the three morphological groups dating to the 4th-6th centuries CE are fairly equal: beakers, cups, conical lamps (27.7% of total dating C4-C6); jars, flasks, bottles, *unguentaria* (35.4%); and plates and bowls (23.1%).

Table 7-5. 3x3 Contingency table of date and general form groups

Date * General Form Crosstabulation

			General Form			
			beaker, cup, conical lamp	jar, flasks, bottles, *unguentaria*	plate, bowl	Total
Date	C1-C3	Count	2	1	0	3
		Expected Count	1.0	1.3	.7	3.0
		% of Total	3.1%	1.5%	0.0%	4.6%
		Std. Residual	1.0	-.3	-.8	
	C3-C4	Count	1	5	0	6
		Expected Count	1.9	2.7	1.4	6.0
		% of Total	1.5%	7.7%	0.0%	9.2%
		Std. Residual	-.7	1.4	-1.2	
	C4-C6	Count	18	23	15	56
		Expected Count	18.1	25.0	12.9	56.0
		% of Total	27.7%	35.4%	23.1%	86.2%
		Std. Residual	.0	-.4	.6	
Total		Count	21	29	15	65
		Expected Count	21.0	29.0	15.0	65.0
		% of Total	32.3%	44.6%	23.1%	100.0%

Table 7-6. Chi-squared results for Table 7-5 above.

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	6.221[a]	4	.183
Likelihood Ratio	7.718	4	.102
N of Valid Cases	65		

a. 6 cells (66.7%) have expected count less than 5. The minimum expected count is .69.

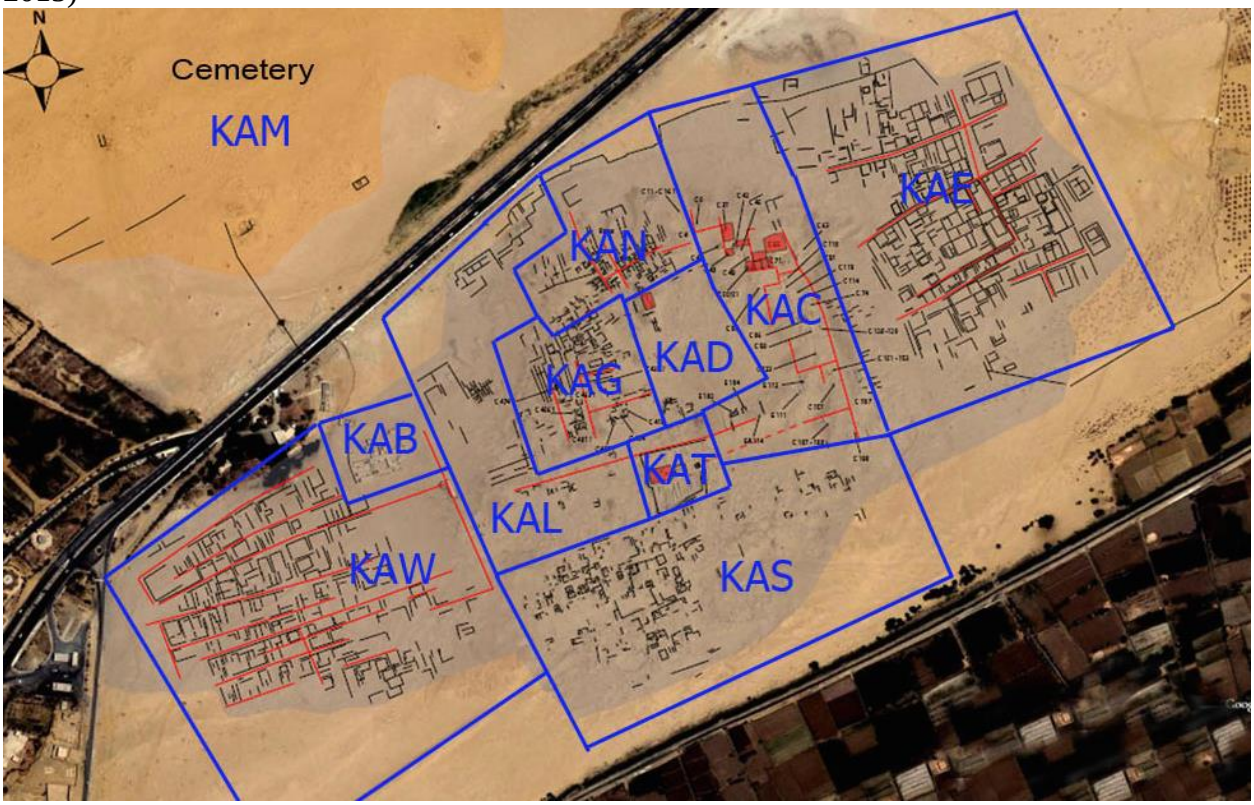
7.4 Patterns in Geographic Distribution of Compositional Groups at Karanis

In order to reveal patterning, I designate several levels of precision of provenience. From most general to specific, I use the following categories: site area, trench, and stratigraphic unit. Stratigraphic units are too specific to reveal patterning in chi-squared analyses, so I primarily explore relationships among site areas and trenches and other variables, including compositional types and morphology.

7.4.1 Site Areas and Compositional Groups

I first explore associations between site area and general chemical compositional group. Chemical compositional groups were combined to more general categories based loosely on how previous studies have grouped Roman glass (Foster and Paynter 2015): antimony (Sb)-decolorized, low magnesium (Mn), high Magnesium (Mn), aqua, mixed magnesium/antimony (Mn/Sb) composition. Outliers in the compositional study (Ch. 6) were excluded from this particular chi-squared test so that I do not risk the results being skewed by the distribution of these outliers at the site. The site of Karanis is divided by the URU Project in 11 sectors (see Figure 4-1): Karanis East (KAE), West (KAW), South (KAS), North (KAN), Beyt Sobek (KAB), Central (KAC), KAD Destroyed (KAD), "Area G" as named by the University of Michigan excavators (KAG), "Area L" as named by the University of Michigan team (KAL), South Temple (KAT) and the cemetery across the main road that leads from Cairo to Fayum City. Note that glass from this assemblage was not recovered from all areas above.

Figure 7-1. Satellite image of Karanis with area boundaries designated (courtesy of URU Project 2015)



A chi-squared analysis of site are and general compositional groups yields a highly significant Pearson chi-squared value (185.282) with df=20 at the .001 level (see Tables 7-6 and 7-7). This means that for some combinations of these two variables, site area and compositional groups are not independent variables. To identify which combinations account for this significant chi-squared p value, I employ Read's recursive method (outlined in Ch. 5).

Table 7-7. 6x5 contingency table of site area and basic compositional groups

Site Area * Basic Chem Grp Crosstabulation

			Basic Chem Grp					
			Aqua	High Mn/low Sb	Low Mn/low Sb	Mixed Mn/Sb	Sb Decol Glass	Total
Site Area	KAC	Count	2	15	1	1	1	20
		Expected Count	3.9	3.6	.3	1.4	10.8	20.0
		% within Site Area	10.0%	75.0%	5.0%	5.0%	5.0%	100.0%
		% within Basic Chem Grp	2.4%	19.2%	16.7%	3.2%	0.4%	4.6%
		% of Total	0.5%	3.5%	0.2%	0.2%	0.2%	4.6%
		Std. Residual	-1.0	6.0	1.4	-.4	-3.0	
	KAD	Count	0	3	0	0	0	3
		Expected Count	.6	.5	.0	.2	1.6	3.0
		% within Site Area	0.0%	100.0%	0.0%	0.0%	0.0%	100.0%
		% within Basic Chem Grp	0.0%	3.8%	0.0%	0.0%	0.0%	0.7%
		% of Total	0.0%	0.7%	0.0%	0.0%	0.0%	0.7%
		Std. Residual	-.8	3.4	-.2	-.5	-1.3	
	KAE	Count	50	11	2	20	145	228
		Expected Count	44.1	41.0	3.2	16.3	123.5	228.0
		% within Site Area	21.9%	4.8%	0.9%	8.8%	63.6%	100.0%
		% within Basic Chem Grp	59.5%	14.1%	33.3%	64.5%	61.7%	52.5%
		% of Total	11.5%	2.5%	0.5%	4.6%	33.4%	52.5%
		Std. Residual	.9	-4.7	-.6	.9	1.9	
	KAG	Count	29	26	2	8	79	144
		Expected Count	27.9	25.9	2.0	10.3	78.0	144.0
		% within Site Area	20.1%	18.1%	1.4%	5.6%	54.9%	100.0%
		% within Basic Chem Grp	34.5%	33.3%	33.3%	25.8%	33.6%	33.2%
		% of Total	6.7%	6.0%	0.5%	1.8%	18.2%	33.2%

		Std. Residual	.2	.0	.0	-.7	.1	
	KAS	Count	1	23	0	0	2	26
		Expected Count	5.0	4.7	.4	1.9	14.1	26.0
		% within Site Area	3.8%	88.5%	0.0%	0.0%	7.7%	100.0%
		% within Basic Chem Grp	1.2%	29.5%	0.0%	0.0%	0.9%	6.0%
		% of Total	0.2%	5.3%	0.0%	0.0%	0.5%	6.0%
		Std. Residual	-1.8	8.5	-.6	-1.4	-3.2	
	KAW	Count	2	0	1	2	8	13
		Expected Count	2.5	2.3	.2	.9	7.0	13.0
		% within Site Area	15.4%	0.0%	7.7%	15.4%	61.5%	100.0%
		% within Basic Chem Grp	2.4%	0.0%	16.7%	6.5%	3.4%	3.0%
		% of Total	0.5%	0.0%	0.2%	0.5%	1.8%	3.0%
		Std. Residual	-.3	-1.5	1.9	1.1	.4	
Total		Count	84	78	6	31	235	434
		Expected Count	84.0	78.0	6.0	31.0	235.0	434.0
		% within Site Area	19.4%	18.0%	1.4%	7.1%	54.1%	100.0%
		% within Basic Chem Grp	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	19.4%	18.0%	1.4%	7.1%	54.1%	100.0%

Table 7-8. Chi-squared results for Table 7-7 above

Chi-Square Results

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	185.282[a]	20	.000
Likelihood Ratio	154.725	20	.000
N of Valid Cases	434		

a. 18 cells (60.0%) have expected count less than 5. The minimum expected count is .04.

The most deviant cell is cell KAS: High Mn/low Sb. I neutralize this cell and the chi-squared is still significant with df = 19 (20-1) at the 0.001 level.

Table 7-9. 6x5 contingency table of site area and basic compositional groups. Cell KAS: High Mn/low Sb altered.

Site Area * Basic Compositional Group Crosstabulation

			Basic Comp Grp					
			Aqua	High Mn/low Sb	Low Mn/low Sb	Mixed Mn/Sb	Sb Decol Glass	Total
Site Area	KAC	Count	2	15	1	1	1	20
		Expected Count	4.1	2.7	.3	1.5	11.4	20.0
		% of Total	0.5%	3.6%	0.2%	0.2%	0.2%	4.9%
		Std. Residual	-1.0	7.4	1.3	-.4	-3.1	
	KAD	Count	0	3	0	0	0	3
		Expected Count	.6	.4	.0	.2	1.7	3.0
		% of Total	0.0%	0.7%	0.0%	0.0%	0.0%	0.7%
		Std. Residual	-.8	4.1	-.2	-.5	-1.3	
	KAE	Count	50	11	2	20	145	228
		Expected Count	46.5	31.0	3.3	17.2	130.0	228.0
		% of Total	12.1%	2.7%	0.5%	4.9%	35.2%	55.3%
		Std. Residual	.5	-3.6	-.7	.7	1.3	
	KAG	Count	29	26	2	8	79	144
		Expected Count	29.4	19.6	2.1	10.8	82.1	144.0
		% of Total	7.0%	6.3%	0.5%	1.9%	19.2%	35.0%
		Std. Residual	-.1	1.5	-.1	-.9	-.3	
	KAS	Count	1	1	0	0	2	4
		Expected Count	.8	.5	.1	.3	2.3	4.0
		% of Total	0.2%	0.2%	0.0%	0.0%	0.5%	1.0%
		Std. Residual	.2	.6	-.2	-.5	-.2	

	KAW	Count	2	0	1	2	8	13
		Expected Count	2.7	1.8	.2	1.0	7.4	13.0
		% of Total	0.5%	0.0%	0.2%	0.5%	1.9%	3.2%
		Std. Residual	-.4	-1.3	1.9	1.0	.2	
Total		Count	84	56	6	31	235	412
		Expected Count	84.0	56.0	6.0	31.0	235.0	412.0
		% of Total	20.4%	13.6%	1.5%	7.5%	57.0%	100.0%

Table 7-10. Chi-squared results from Table 7-9

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	113.193[a]	19	.000
Likelihood Ratio	87.551	19	.000
N of Valid Cases	412		

a. 20 cells (66.7%) have expected count less than 5. The minimum expected count is .04.

The next deviant cell is KAC: High Mn/low Sb. I alter this cell and this value changes to 1 as well. There is still a significant p value with df = 18.

Table 7-11. 6x5 contingency table of site area and basic compositional groups after cells KAS: High Mn/low Sb and KAC: High Mn/low Sb are altered.

Site Area * Basic Compositional Group Crosstabulation

			Basic Chem Grp					
			Aqua	High Mn/low Sb	Low Mn/low Sb	Mixed Mn/Sb	Sb Decol Glass	Total
Site Area	KAC	Count	2	1	1	1	1	6
		Expected Count	1.3	.6	.1	.5	3.5	6.0
		% of Total	0.5%	0.3%	0.3%	0.3%	0.3%	1.5%
		Std. Residual	.7	.5	3.0	.8	-1.4	
	KAD	Count	0	3	0	0	0	3
		Expected Count	.6	.3	.0	.2	1.8	3.0
		% of Total	0.0%	0.8%	0.0%	0.0%	0.0%	0.8%
		Std. Residual	-.8	4.8	-.2	-.5	-1.3	
	KAE	Count	50	11	2	20	145	228
		Expected Count	48.1	24.1	3.4	17.8	134.6	228.0
		% of Total	12.6%	2.8%	0.5%	5.0%	36.4%	57.3%
		Std. Residual	.3	-2.7	-.8	.5	.9	
	KAG	Count	29	26	2	8	79	144
		Expected Count	30.4	15.2	2.2	11.2	85.0	144.0
		% of Total	7.3%	6.5%	0.5%	2.0%	19.8%	36.2%
		Std. Residual	-.3	2.8	-.1	-1.0	-.7	
	KAS	Count	1	1	0	0	2	4
		Expected Count	.8	.4	.1	.3	2.4	4.0
		% of Total	0.3%	0.3%	0.0%	0.0%	0.5%	1.0%
		Std. Residual	.2	.9	-.2	-.6	-.2	
	KAW	Count	2	0	1	2	8	13
		Expected Count	2.7	1.4	.2	1.0	7.7	13.0
		% of Total	0.5%	0.0%	0.3%	0.5%	2.0%	3.3%
		Std. Residual	-.4	-1.2	1.8	1.0	.1	

Total	Count	84	42	6	31	235	398
	Expected Count	84.0	42.0	6.0	31.0	235.0	398.0
	% of Total	21.1%	10.6%	1.5%	7.8%	59.0%	100.0%

Table 7-12. Chi-squared results from Table 7-11

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	62.694[a]	18	.000
Likelihood Ratio	45.405	18	.001
N of Valid Cases	398		

a. 21 cells (70.0%) have expected count less than 5. The minimum expected count is .05.

I modify cell KAD: High Mn/low Sb next. I change the observed value of KAD: High Mn/low Sb to zero. Since Area D only yielded High Mn/low Sb glass, this area is eliminated from the table. This changes the size of the table. The df are now equal to (5-1)*(5-1)-2=14.

Table 7-13. 5x5 contingency table of site area and basic compositional groups after cells KAS: High Mn/low Sb, KAC: High Mn/low Sb, and KAD: High Mn/low Sb are altered. Row KAD is eliminated.

Site Area * Basic Compositional Group Crosstabulation

			Basic Chem Grp					
			Aqua	High Mn/low Sb	Low Mn/low Sb	Mixed Mn/Sb	Sb Decol Glass	Total
Site Area	KAC	Count	2	1	1	1	1	6
		Expected Count	1.3	.6	.1	.5	3.6	6.0
		% of Total	0.5%	0.3%	0.3%	0.3%	0.3%	1.5%
		Std. Residual	.6	.5	3.0	.8	-1.4	
	KAE	Count	50	11	2	20	145	228
		Expected Count	48.5	22.5	3.5	17.9	135.6	228.0
		% of Total	12.7%	2.8%	0.5%	5.1%	36.7%	57.7%
		Std. Residual	.2	-2.4	-.8	.5	.8	
	KAG	Count	29	26	2	8	79	144
		Expected Count	30.6	14.2	2.2	11.3	85.7	144.0
		% of Total	7.3%	6.6%	0.5%	2.0%	20.0%	36.5%
		Std. Residual	-.3	3.1	-.1	-1.0	-.7	
	KAS	Count	1	1	0	0	2	4
		Expected Count	.9	.4	.1	.3	2.4	4.0
		% of Total	0.3%	0.3%	0.0%	0.0%	0.5%	1.0%
		Std. Residual	.2	1.0	-.2	-.6	-.2	
	KAW	Count	2	0	1	2	8	13
		Expected Count	2.8	1.3	.2	1.0	7.7	13.0
		% of Total	0.5%	0.0%	0.3%	0.5%	2.0%	3.3%
		Std. Residual	-.5	-1.1	1.8	1.0	.1	
Total		Count	84	39	6	31	235	395
		Expected Count	84.0	39.0	6.0	31.0	235.0	395.0
		% of Total	21.3%	9.9%	1.5%	7.8%	59.5%	100.0%

Table 7-14. Chi-squared results from Table 7-13.

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	38.089[a]	14	.001
Likelihood Ratio	31.716	14	.011
N of Valid Cases	395		

a. 16 cells (64.0%) have expected count less than 5. The minimum expected count is .06.

This is still a significant p-value at the 0.05 significance level, so I continue to alter cell KAG: High Mn/low Sb. The observed changes to 6 to equal the expected, and two other previously modified cells needed to be altered. The final 5x5 contingency table is below (Table 7-15). Four cells total were modified, but only three still remain in the table, so the df=13.

Table 7-15. Final 5x5 contingency table of site area and basic compositional groups after cells KAS: High Mn/low Sb, KAC: High Mn/low Sb, KAD: High Mn/low Sb, and KAG: High Mn/low Sb are altered. Row KAD is eliminated.

Site Area * Basic Compositional Group Crosstabulation

			Basic Chem Grp					
			Aqua	High Mn/low Sb	Low Mn/low Sb	Mixed Mn/Sb	Sb Decol Glass	Total
Site Area	KAC	Count	2	0	1	1	1	5
		Expected Count	1.1	.2	.1	.4	3.2	5.0
		% of Total	0.5%	0.0%	0.3%	0.3%	0.3%	1.3%
		Std. Residual	.8	-.5	3.2	.9	-1.2	
	KAE	Count	50	11	2	20	145	228
		Expected Count	51.3	10.4	3.7	18.9	143.6	228.0
		% of Total	13.4%	2.9%	0.5%	5.4%	38.9%	61.1%
		Std. Residual	-.2	.2	-.9	.2	.1	
	KAG	Count	29	6	2	8	79	124
		Expected Count	27.9	5.7	2.0	10.3	78.1	124.0
		% of Total	7.8%	1.6%	0.5%	2.1%	21.2%	33.2%
		Std. Residual	.2	.1	.0	-.7	.1	
	KAS	Count	1	0	0	0	2	3
		Expected Count	.7	.1	.0	.2	1.9	3.0
		% of Total	0.3%	0.0%	0.0%	0.0%	0.5%	0.8%
		Std. Residual	.4	-.4	-.2	-.5	.1	
	KAW	Count	2	0	1	2	8	13
		Expected Count	2.9	.6	.2	1.1	8.2	13.0
		% of Total	0.5%	0.0%	0.3%	0.5%	2.1%	3.5%
		Std. Residual	-.5	-.8	1.7	.9	-.1	
Total		Count	84	17	6	31	235	373
		Expected Count	84.0	17.0	6.0	31.0	235.0	373.0
		% of Total	22.5%	4.6%	1.6%	8.3%	63.0%	100.0%

Table 7-16. Chi-squared results from Table 7-15

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	20.459[a]	13	.200
Likelihood Ratio	13.184	13	.659
N of Valid Cases	373		

a. 16 cells (64.0%) have expected count less than 5. The minimum expected count is .05.

These results show that the distribution of High Mn/low Sb samples is not uniform throughout the site. Instead, four areas have disproportionately higher levels of High Mn/low Sb glass compared to other types of glass found in these areas. Karanis East shows a disproportionately low output of High Mn/low Sb glass initially, but when the appropriate cells are altered, the difference between observed and expected values of High Mn/low Sb for KAE are insignificant. Glass derived from KAE shows a notable distribution of compositional types. As mentioned, it lacks High Mn/low Sb glass: It makes up only 4.8% of total glass recovered from KAE. Instead, there is a very high percentage of high quality Sb-decolorized glass (63.3% of total recovered from KAE). Also, 33.4% of Sb-decolorized site recovered from the entire site is from KAE.

If the High Mn/low Sb glasses are used to produce certain types of shapes, this may be significant to report in terms of value and social demographics of the site.

Other types of glass are fairly evenly distributed among the site, when the total output from each area is considered, as is demonstrated through chi-squared analysis.

7.4.2 Trenches and Basic Compositional Types

Trenches from which glass in this study was recovered include Trenches 1 and 3-27. The table below (Table 7-17) includes a full list of URU trenches from each area. Figure 7-2 shows the geographic location of these trenches within the site and Figure 7-3 shows the location of trenches in area KAE.

Table 7-17. List of Karanis areas and corresponding trenches. Note, the assemblage analyzed does not include glass from all trenches.

Area	Trench(es)
KAC	7, 9
KAD	2, 3
KAE	11, 12, 13, 15, 17, 18, 19, 20, 21, 22, 23, 25, 26, 27, 28
KAG	1, 4, 10, 13, 24, 34
KAN	29
KAS	8, 16, 30, 31, 32
KAW	5, 6, 33

Figure 7-2. General locations of trenches at Karanis including multiple trenches in Karanis East (KAE), called "Granary" here (courtesy of URU Project 2015)

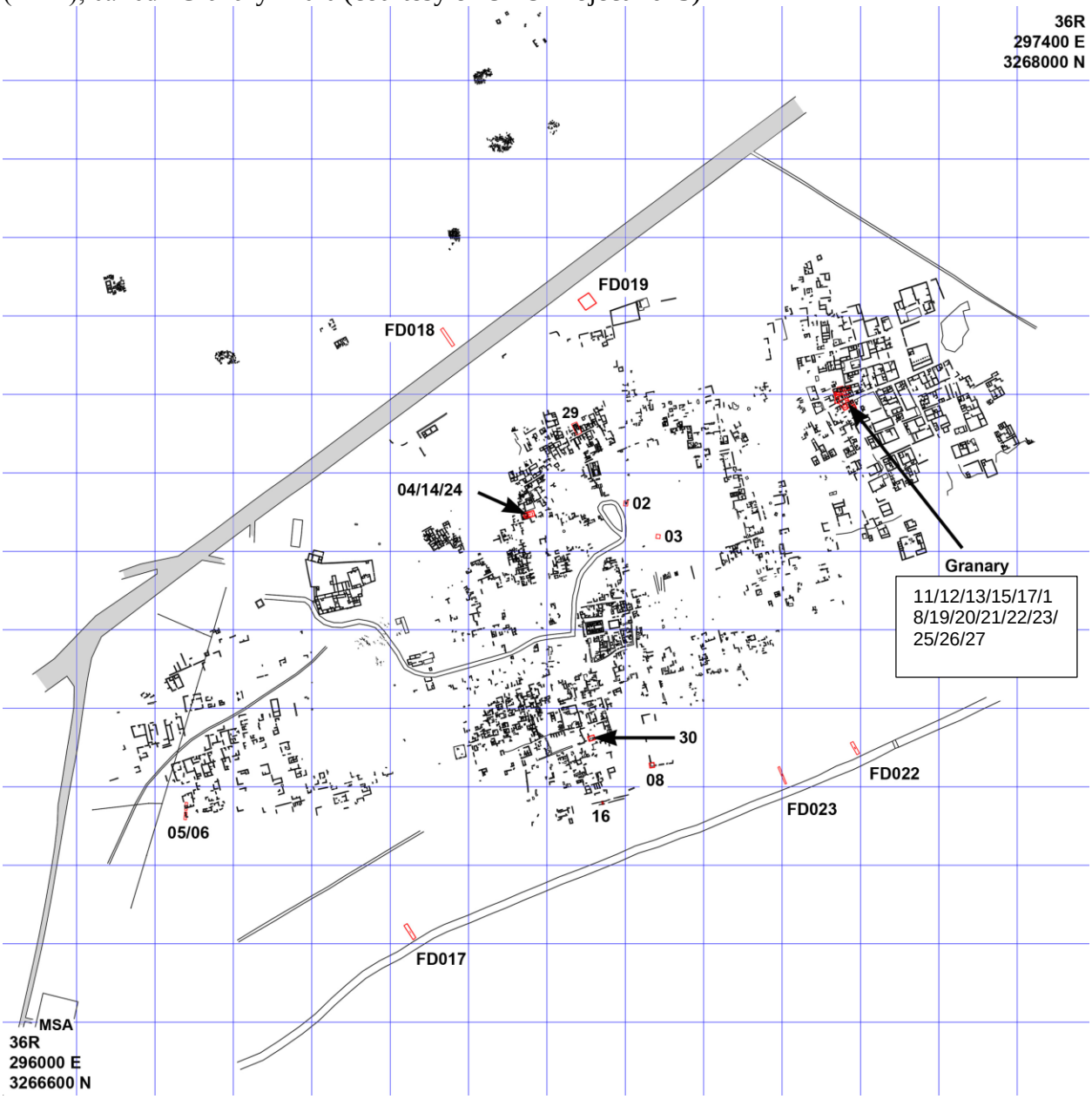


Figure 7-3. Trench locations at KAE, "Granary" in plan above (courtesy of URU Project 2015)



A chi-squared of trenches and compositional types yields similar results as the site area and compositional types. The chi-squared p-value (284.469) is significant with df=100 at the 0.001 significance level (see Table 7- 18 below).

Table 7-18. Initial 26x5 contingency table of trenches and basic compositional groups.

Trenches * Basic Chem Grp Crosstabulation

			Basic Chem Grp					
			Aqua	High Mn/low Sb	Low Mn/low Sb	Mixed Mn/Sb	Sb Decol Glass	Total
Trenches	KA01	Count	1	0	0	3	1	5
		Expected Count	1.0	.9	.1	.4	2.7	5.0
		% of Total	0.2%	0.0%	0.0%	0.7%	0.2%	1.2%
		Std. Residual	.0	-.9	-.3	4.4	-1.0	
	KA03	Count	0	3	0	0	0	3
		Expected Count	.6	.5	.0	.2	1.6	3.0
		% of Total	0.0%	0.7%	0.0%	0.0%	0.0%	0.7%
		Std. Residual	-.8	3.4	-.2	-.5	-1.3	
	KA04	Count	26	18	1	4	68	117
		Expected Count	22.6	21.0	1.6	8.4	63.4	117.0
		% of Total	6.0%	4.1%	0.2%	0.9%	15.7%	27.0%
		Std. Residual	.7	-.7	-.5	-1.5	.6	
	KA05	Count	1	0	1	1	4	7
		Expected Count	1.4	1.3	.1	.5	3.8	7.0
		% of Total	0.2%	0.0%	0.2%	0.2%	0.9%	1.6%
		Std. Residual	-.3	-1.1	2.9	.7	.1	
	KA06	Count	1	0	0	1	4	6
		Expected Count	1.2	1.1	.1	.4	3.2	6.0
		% of Total	0.2%	0.0%	0.0%	0.2%	0.9%	1.4%
		Std. Residual	-.1	-1.0	-.3	.9	.4	
	KA07	Count	0	1	0	1	0	2
		Expected Count	.4	.4	.0	.1	1.1	2.0
		% of Total	0.0%	0.2%	0.0%	0.2%	0.0%	0.5%

	Std. Residual	-.6	1.1	-.2	2.3	-1.0	
KA08	Count	0	22	0	0	2	24
	Expected Count	4.6	4.3	.3	1.7	13.0	24.0
	% of Total	0.0%	5.1%	0.0%	0.0%	0.5%	5.5%
	Std. Residual	-2.2	8.5	-.6	-1.3	-3.1	
KA09	Count	2	14	1	0	1	18
	Expected Count	3.5	3.2	.2	1.3	9.7	18.0
	% of Total	0.5%	3.2%	0.2%	0.0%	0.2%	4.1%
	Std. Residual	-.8	6.0	1.5	-1.1	-2.8	
KA10	Count	0	1	0	0	0	1
	Expected Count	.2	.2	.0	.1	.5	1.0
	% of Total	0.0%	0.2%	0.0%	0.0%	0.0%	0.2%
	Std. Residual	-.4	1.9	-.1	-.3	-.7	
KA11	Count	1	0	0	0	6	7
	Expected Count	1.4	1.3	.1	.5	3.8	7.0
	% of Total	0.2%	0.0%	0.0%	0.0%	1.4%	1.6%
	Std. Residual	-.3	-1.1	-.3	-.7	1.1	
KA12	Count	3	1	0	0	4	8
	Expected Count	1.5	1.4	.1	.6	4.3	8.0
	% of Total	0.7%	0.2%	0.0%	0.0%	0.9%	1.8%
	Std. Residual	1.2	-.4	-.3	-.8	-.2	
KA13	Count	7	0	0	5	26	38
	Expected Count	7.4	6.8	.5	2.7	20.6	38.0
	% of Total	1.6%	0.0%	0.0%	1.2%	6.0%	8.8%
	Std. Residual	-.1	-2.6	-.7	1.4	1.2	
KA14	Count	2	4	0	1	5	12
	Expected Count	2.3	2.2	.2	.9	6.5	12.0
	% of Total	0.5%	0.9%	0.0%	0.2%	1.2%	2.8%
	Std. Residual	-.2	1.3	-.4	.2	-.6	

	KA15	Count	5	0	0	2	17	24
		Expected Count	4.6	4.3	.3	1.7	13.0	24.0
		% of Total	1.2%	0.0%	0.0%	0.5%	3.9%	5.5%
		Std. Residual	.2	-2.1	-.6	.2	1.1	
	KA16	Count	1	1	0	0	0	2
		Expected Count	.4	.4	.0	.1	1.1	2.0
		% of Total	0.2%	0.2%	0.0%	0.0%	0.0%	0.5%
		Std. Residual	1.0	1.1	-.2	-.4	-1.0	
	KA17	Count	4	1	0	0	6	11
		Expected Count	2.1	2.0	.2	.8	6.0	11.0
		% of Total	0.9%	0.2%	0.0%	0.0%	1.4%	2.5%
		Std. Residual	1.3	-.7	-.4	-.9	.0	
	KA18	Count	3	2	0	1	10	16
		Expected Count	3.1	2.9	.2	1.1	8.7	16.0
		% of Total	0.7%	0.5%	0.0%	0.2%	2.3%	3.7%
		Std. Residual	-.1	-.5	-.5	-.1	.5	
	KA19	Count	0	0	0	0	4	4
		Expected Count	.8	.7	.1	.3	2.2	4.0
		% of Total	0.0%	0.0%	0.0%	0.0%	0.9%	0.9%
		Std. Residual	-.9	-.8	-.2	-.5	1.2	
	KA20	Count	2	1	0	0	1	4
		Expected Count	.8	.7	.1	.3	2.2	4.0
		% of Total	0.5%	0.2%	0.0%	0.0%	0.2%	0.9%
		Std. Residual	1.4	.3	-.2	-.5	-.8	
	KA21	Count	12	3	0	3	22	40
		Expected Count	7.7	7.2	.6	2.9	21.7	40.0
		% of Total	2.8%	0.7%	0.0%	0.7%	5.1%	9.2%
		Std. Residual	1.5	-1.6	-.7	.1	.1	
	KA22	Count	1	0	0	2	4	7

		Expected Count	1.4	1.3	.1	.5	3.8	7.0
		% of Total	0.2%	0.0%	0.0%	0.5%	0.9%	1.6%
		Std. Residual	-.3	-1.1	-.3	2.1	.1	
	KA23	Count	3	0	0	1	16	20
		Expected Count	3.9	3.6	.3	1.4	10.8	20.0
		% of Total	0.7%	0.0%	0.0%	0.2%	3.7%	4.6%
		Std. Residual	-.4	-1.9	-.5	-.4	1.6	
	KA24	Count	0	3	1	0	5	9
		Expected Count	1.7	1.6	.1	.6	4.9	9.0
		% of Total	0.0%	0.7%	0.2%	0.0%	1.2%	2.1%
		Std. Residual	-1.3	1.1	2.5	-.8	.1	
	KA25	Count	6	1	2	4	19	32
		Expected Count	6.2	5.8	.4	2.3	17.3	32.0
		% of Total	1.4%	0.2%	0.5%	0.9%	4.4%	7.4%
		Std. Residual	-.1	-2.0	2.3	1.1	.4	
	KA26	Count	3	1	0	0	6	10
		Expected Count	1.9	1.8	.1	.7	5.4	10.0
		% of Total	0.7%	0.2%	0.0%	0.0%	1.4%	2.3%
		Std. Residual	.8	-.6	-.4	-.8	.3	
	KA27	Count	0	1	0	2	4	7
		Expected Count	1.4	1.3	.1	.5	3.8	7.0
		% of Total	0.0%	0.2%	0.0%	0.5%	0.9%	1.6%
		Std. Residual	-1.2	-.2	-.3	2.1	.1	
Total		Count	84	78	6	31	235	434
		Expected Count	84.0	78.0	6.0	31.0	235.0	434.0
		% of Total	19.4%	18.0%	1.4%	7.1%	54.1%	100.0%

Table 7-19. Chi-squared results from Table 7-18 above.

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	284.469[a]	100	.000
Likelihood Ratio	247.486	100	.000
N of Valid Cases	434		

a. 109 cells (83.8%) have expected count less than 5. The minimum expected count is .01.

Using Read's (2007, 2015) recursive method, I modify the following cells (in order of deviance) KA08: High Mn/low Sb, KA09: High Mn/low Sb, and KA03: High Mn/low Sb, KA01: Mixed Mn/Sb, and KA10: High Mn/low Sb (see Table 7-20 below for the final table). KA03: High Mn/low Sb changes to zero, so the entire row is cancelled out. I also alter KA10: High Mn/low Sb to zero and this cancels out the whole row. The compositional type that deviates most in its expected distribution within the site is High Mn/low Sb glass. Trenches KA03, 08, 09, and 10 all were modified because of higher High Mn/low Sb glass present than expected. High Mn/low Sb glass comprises the majority of the total glass sampled from each of these trenches. For Trench KA08, initially 22 out of 24 samples are High Mn/low Sb; For Trench KA 09, 14 out of 18 total samples are High Mn/low Sb. The only sample found in Trench KA10 is High Mn/low Sb and all three of the samples from Trench KA03 are High Mn/low Sb.

Table 7-20. Final 24x5 contingency table of trenches and basic compositional groups.

Trenches * Basic Chem Grp Crosstabulation

			Basic Chem Grp					
			Aqua	High Mn/low Sb	Low Mn/low Sb	Mixed Mn/Sb	Sb Decol Glass	Total
Trenches	KA01	Count	1	0	0	0	1	2
		Expected Count	.4	.2	.0	.1	1.2	2.0
		% within Provenance	50.0%	0.0%	0.0%	0.0%	50.0%	100.0%
		% within Basic Chem Grp	1.2%	0.0%	0.0%	0.0%	0.4%	0.5%
		% of Total	0.3%	0.0%	0.0%	0.0%	0.3%	0.5%
		Std. Residual	.9	-.5	-.2	-.4	-.2	
	KA04	Count	26	18	1	4	68	117
		Expected Count	25.1	11.9	1.5	8.4	70.1	117.0
		% within Provenance	22.2%	15.4%	0.9%	3.4%	58.1%	100.0%
		% within Basic Chem Grp	31.0%	45.0%	20.0%	14.3%	28.9%	29.8%
		% of Total	6.6%	4.6%	0.3%	1.0%	17.3%	29.8%
		Std. Residual	.2	1.8	-.4	-1.5	-.3	
	KA05	Count	1	0	1	1	4	7
		Expected Count	1.5	.7	.1	.5	4.2	7.0
		% within Provenance	14.3%	0.0%	14.3%	14.3%	57.1%	100.0%
		% within Basic Chem Grp	1.2%	0.0%	20.0%	3.6%	1.7%	1.8%
		% of Total	0.3%	0.0%	0.3%	0.3%	1.0%	1.8%
		Std. Residual	-.4	-.8	3.0	.7	-.1	
	KA06	Count	1	0	0	1	4	6
		Expected Count	1.3	.6	.1	.4	3.6	6.0
		% within Provenance	16.7%	0.0%	0.0%	16.7%	66.7%	100.0%
		% within Basic Chem Grp	1.2%	0.0%	0.0%	3.6%	1.7%	1.5%

	% of Total	0.3%	0.0%	0.0%	0.3%	1.0%	1.5%
	Std. Residual	-.3	-.8	-.3	.9	.2	
KA07	Count	0	1	0	1	0	2
	Expected Count	.4	.2	.0	.1	1.2	2.0
	% within Provenance	0.0%	50.0%	0.0%	50.0%	0.0%	100.0%
	% within Basic Chem Grp	0.0%	2.5%	0.0%	3.6%	0.0%	0.5%
	% of Total	0.0%	0.3%	0.0%	0.3%	0.0%	0.5%
	Std. Residual	-.7	1.8	-.2	2.3	-1.1	
KA08	Count	0	1	0	0	2	3
	Expected Count	.6	.3	.0	.2	1.8	3.0
	% within Provenance	0.0%	33.3%	0.0%	0.0%	66.7%	100.0%
	% within Basic Chem Grp	0.0%	2.5%	0.0%	0.0%	0.9%	0.8%
	% of Total	0.0%	0.3%	0.0%	0.0%	0.5%	0.8%
	Std. Residual	-.8	1.3	-.2	-.5	.2	
KA09	Count	2	1	0	0	1	4
	Expected Count	.9	.4	.1	.3	2.4	4.0
	% within Provenance	50.0%	25.0%	0.0%	0.0%	25.0%	100.0%
	% within Basic Chem Grp	2.4%	2.5%	0.0%	0.0%	0.4%	1.0%
	% of Total	0.5%	0.3%	0.0%	0.0%	0.3%	1.0%
	Std. Residual	1.2	.9	-.2	-.5	-.9	
KA11	Count	1	0	0	0	6	7
	Expected Count	1.5	.7	.1	.5	4.2	7.0
	% within Provenance	14.3%	0.0%	0.0%	0.0%	85.7%	100.0%
	% within Basic Chem Grp	1.2%	0.0%	0.0%	0.0%	2.6%	1.8%
	% of Total	0.3%	0.0%	0.0%	0.0%	1.5%	1.8%
	Std. Residual	-.4	-.8	-.3	-.7	.9	
KA12	Count	3	1	0	0	4	8
	Expected Count	1.7	.8	.1	.6	4.8	8.0

	% within Provenance	37.5%	12.5%	0.0%	0.0%	50.0%	100.0%
	% within Basic Chem Grp	3.6%	2.5%	0.0%	0.0%	1.7%	2.0%
	% of Total	0.8%	0.3%	0.0%	0.0%	1.0%	2.0%
	Std. Residual	1.0	.2	-.3	-.8	-.4	
KA13	Count	7	0	0	5	26	38
	Expected Count	8.1	3.9	.5	2.7	22.8	38.0
	% within Provenance	18.4%	0.0%	0.0%	13.2%	68.4%	100.0%
	% within Basic Chem Grp	8.3%	0.0%	0.0%	17.9%	11.1%	9.7%
	% of Total	1.8%	0.0%	0.0%	1.3%	6.6%	9.7%
	Std. Residual	-.4	-2.0	-.7	1.4	.7	
KA14	Count	2	4	0	1	5	12
	Expected Count	2.6	1.2	.2	.9	7.2	12.0
	% within Provenance	16.7%	33.3%	0.0%	8.3%	41.7%	100.0%
	% within Basic Chem Grp	2.4%	10.0%	0.0%	3.6%	2.1%	3.1%
	% of Total	0.5%	1.0%	0.0%	0.3%	1.3%	3.1%
	Std. Residual	-.4	2.5	-.4	.2	-.8	
KA15	Count	5	0	0	2	17	24
	Expected Count	5.1	2.4	.3	1.7	14.4	24.0
	% within Provenance	20.8%	0.0%	0.0%	8.3%	70.8%	100.0%
	% within Basic Chem Grp	6.0%	0.0%	0.0%	7.1%	7.2%	6.1%
	% of Total	1.3%	0.0%	0.0%	0.5%	4.3%	6.1%
	Std. Residual	-.1	-1.6	-.6	.2	.7	
KA16	Count	1	1	0	0	0	2
	Expected Count	.4	.2	.0	.1	1.2	2.0
	% within Provenance	50.0%	50.0%	0.0%	0.0%	0.0%	100.0%
	% within Basic Chem Grp	1.2%	2.5%	0.0%	0.0%	0.0%	0.5%
	% of Total	0.3%	0.3%	0.0%	0.0%	0.0%	0.5%

	Std. Residual	.9	1.8	-.2	-.4	-1.1	
KA17	Count	4	1	0	0	6	11
	Expected Count	2.4	1.1	.1	.8	6.6	11.0
	% within Provenance	36.4%	9.1%	0.0%	0.0%	54.5%	100.0%
	% within Basic Chem Grp	4.8%	2.5%	0.0%	0.0%	2.6%	2.8%
	% of Total	1.0%	0.3%	0.0%	0.0%	1.5%	2.8%
	Std. Residual	1.1	-.1	-.4	-.9	-.2	
KA18	Count	3	2	0	1	10	16
	Expected Count	3.4	1.6	.2	1.1	9.6	16.0
	% within Provenance	18.8%	12.5%	0.0%	6.3%	62.5%	100.0%
	% within Basic Chem Grp	3.6%	5.0%	0.0%	3.6%	4.3%	4.1%
	% of Total	0.8%	0.5%	0.0%	0.3%	2.6%	4.1%
	Std. Residual	-.2	.3	-.5	-.1	.1	
KA19	Count	0	0	0	0	4	4
	Expected Count	.9	.4	.1	.3	2.4	4.0
	% within Provenance	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%
	% within Basic Chem Grp	0.0%	0.0%	0.0%	0.0%	1.7%	1.0%
	% of Total	0.0%	0.0%	0.0%	0.0%	1.0%	1.0%
	Std. Residual	-.9	-.6	-.2	-.5	1.0	
KA20	Count	2	1	0	0	1	4
	Expected Count	.9	.4	.1	.3	2.4	4.0
	% within Provenance	50.0%	25.0%	0.0%	0.0%	25.0%	100.0%
	% within Basic Chem Grp	2.4%	2.5%	0.0%	0.0%	0.4%	1.0%
	% of Total	0.5%	0.3%	0.0%	0.0%	0.3%	1.0%
	Std. Residual	1.2	.9	-.2	-.5	-.9	
KA21	Count	12	3	0	3	22	40
	Expected Count	8.6	4.1	.5	2.9	24.0	40.0

	% within Provenance	30.0%	7.5%	0.0%	7.5%	55.0%	100.0%
	% within Basic Chem Grp	14.3%	7.5%	0.0%	10.7%	9.4%	10.2%
	% of Total	3.1%	0.8%	0.0%	0.8%	5.6%	10.2%
	Std. Residual	1.2	-.5	-.7	.1	-.4	
KA22	Count	1	0	0	2	4	7
	Expected Count	1.5	.7	.1	.5	4.2	7.0
	% within Provenance	14.3%	0.0%	0.0%	28.6%	57.1%	100.0%
	% within Basic Chem Grp	1.2%	0.0%	0.0%	7.1%	1.7%	1.8%
	% of Total	0.3%	0.0%	0.0%	0.5%	1.0%	1.8%
	Std. Residual	-.4	-.8	-.3	2.1	-.1	
KA23	Count	3	0	0	1	16	20
	Expected Count	4.3	2.0	.3	1.4	12.0	20.0
	% within Provenance	15.0%	0.0%	0.0%	5.0%	80.0%	100.0%
	% within Basic Chem Grp	3.6%	0.0%	0.0%	3.6%	6.8%	5.1%
	% of Total	0.8%	0.0%	0.0%	0.3%	4.1%	5.1%
	Std. Residual	-.6	-1.4	-.5	-.4	1.2	
KA24	Count	0	3	1	0	5	9
	Expected Count	1.9	.9	.1	.6	5.4	9.0
	% within Provenance	0.0%	33.3%	11.1%	0.0%	55.6%	100.0%
	% within Basic Chem Grp	0.0%	7.5%	20.0%	0.0%	2.1%	2.3%
	% of Total	0.0%	0.8%	0.3%	0.0%	1.3%	2.3%
	Std. Residual	-1.4	2.2	2.6	-.8	-.2	
KA25	Count	6	1	2	4	19	32
	Expected Count	6.9	3.3	.4	2.3	19.2	32.0
	% within Provenance	18.8%	3.1%	6.3%	12.5%	59.4%	100.0%
	% within Basic Chem Grp	7.1%	2.5%	40.0%	14.3%	8.1%	8.2%
	% of Total	1.5%	0.3%	0.5%	1.0%	4.8%	8.2%

		Std. Residual	-.3	-1.3	2.5	1.1	.0	
	KA26	Count	3	1	0	0	6	10
		Expected Count	2.1	1.0	.1	.7	6.0	10.0
		% within Provenance	30.0%	10.0%	0.0%	0.0%	60.0%	100.0%
		% within Basic Chem Grp	3.6%	2.5%	0.0%	0.0%	2.6%	2.6%
		% of Total	0.8%	0.3%	0.0%	0.0%	1.5%	2.6%
		Std. Residual	.6	.0	-.4	-.8	.0	
	KA27	Count	0	1	0	2	4	7
		Expected Count	1.5	.7	.1	.5	4.2	7.0
		% within Provenance	0.0%	14.3%	0.0%	28.6%	57.1%	100.0%
		% within Basic Chem Grp	0.0%	2.5%	0.0%	7.1%	1.7%	1.8%
		% of Total	0.0%	0.3%	0.0%	0.5%	1.0%	1.8%
		Std. Residual	-1.2	.3	-.3	2.1	-.1	
Total		Count	84	40	5	28	235	392
		Expected Count	84.0	40.0	5.0	28.0	235.0	392.0
		% within Provenance	21.4%	10.2%	1.3%	7.1%	59.9%	100.0%
		% within Basic Chem Grp	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	21.4%	10.2%	1.3%	7.1%	59.9%	100.0%

Table 7-21. Chi-squared results from Table 7-20 above.

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	113.085[a]	92	.067
Likelihood Ratio	109.548	92	.102
N of Valid Cases	392		

a. 102 cells (85.0%) have expected count less than 5. The minimum expected count is .03.

It is notable that Trench KA08 was one of only two trenches excavated in area KAS from which glass in this study was recovered. So it is exceptional that it yielded almost exclusively High Mn/low Sb glass (22 out of 24 samples included in this study). However, a closer look at the types of units excavated in Trench KA08 (and KA16 from KAS), reveals that all but one glass artifact recovered in this area was from disturbed (fill) units or windblown sand deposits. Therefore, although it unlikely that these artifacts were transported post-depositionally from other areas of the site, these High Mn/low Sb samples from area KAS were found in disturbed contexts. Trench KA08 is in an industrial portion of the town with several pottery kilns nearby. It is unclear how High Mn/low Sb glass may relate to these industrial activities, such as pottery manufacture.

7.5 Unit Types and Basic Compositional Types

As the above example shows, the type of stratigraphic unit in which an object is found provides crucial information for the interpretation of the archaeological context. It is important to distinguish between disturbed and undisturbed stratigraphic units that represent natural, occupational, trash and other layers related to human activity. Especially since the entire central area of the site was destroyed by *sebbakhin* activity in the early 1900's (see Chapter 2), artifacts from disturbed contexts must be interpreted cautiously. To find patterning in the data, I reduce the unit types to five categories: unknown (data missing from Fayum database), abandonment (windblown sand deposits), mixed (tumble, some fill units), occupational (floors, street levels, structural elements, fill layers), and trash (including tumble deposits, if deliberately dumped as trash deposits).

The aim of this analysis is to see if trash and occupational deposits exhibit unusual frequency patterns of compositional types. I am particularly interested in learning if the frequency of certain types discarded in trash deposits that deviate from the expected frequency, since this may indicate types that are either disproportionately absent or frequent in trash deposits. A chi-squared analysis of these unit types (excluding the unknown group) and basic compositional types yields a significant p-value. The most deviant cell is Trash: High Mn/low Sb, in which there are much fewer High Mn/low Sb glasses recovered in trash deposits than would be expected. This may indicate that this type was being recycled and collected separately. Considering 34.2% of all glass artifacts are derived from trash deposits, this is quite exceptional that these High Mn/low Sb compositional groups are not commonly found in deposits. There is half as much High Mn/low Sb glass in trash deposits as would be expected.

Table 7-22. 4x5 contingency table of unit types and basic compositional groups

General Arch Context * Basic Chem Grp Crosstabulation

			Basic Chem Grp					
			Aqua	High Mn/low Sb	Low Mn/low Sb	Mixed Mn/Sb	Sb Decol Glass	Total
General Arch Context	Abandonment	Count	32	37	4	11	68	152
		Expected Count	29.6	28.2	2.2	10.8	81.2	152.0
		% of Total	7.6%	8.8%	1.0%	2.6%	16.2%	36.1%
		Std. Residual	.4	1.7	1.2	.1	-1.5	
	Mixed	Count	9	26	0	7	50	92
		Expected Count	17.9	17.0	1.3	6.6	49.2	92.0
		% of Total	2.1%	6.2%	0.0%	1.7%	11.9%	21.9%
		Std. Residual	-2.1	2.2	-1.1	.2	.1	
	Occupational	Count	7	2	1	5	18	33
		Expected Count	6.4	6.1	.5	2.4	17.6	33.0
		% of Total	1.7%	0.5%	0.2%	1.2%	4.3%	7.8%
		Std. Residual	.2	-1.7	.8	1.7	.1	
	Trash	Count	34	13	1	7	89	144
		Expected Count	28.0	26.7	2.1	10.3	77.0	144.0
		% of Total	8.1%	3.1%	0.2%	1.7%	21.1%	34.2%
		Std. Residual	1.1	-2.6	-.7	-1.0	1.4	
Total		Count	82	78	6	30	225	421
		Expected Count	82.0	78.0	6.0	30.0	225.0	421.0
		% of Total	19.5%	18.5%	1.4%	7.1%	53.4%	100.0%

Table 7-23. Chi-squared results for Table 7-22 above.

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	35.321[a]	12	.000
Likelihood Ratio	38.378	12	.000
N of Valid Cases	421		

a. 5 cells (25.0%) have expected count less than 5. The minimum expected count is .47.

I add 27 cases to make the observed and expected values of cell Trash: High Mn/low Sb equal (see Table 7-24 below).

Table 7-24. 4x5 contingency table of unit types and basic compositional groups after cell Trash: High Mn/low Sb is altered.

General Arch Context * Basic Chem Grp Crosstabulation

			Basic Chem Grp					
			Aqua	High Mn/low Sb	Low Mn/low Sb	Mixed Mn/Sb	Sb Decol Glass	Total
General Arch Context	Abandonment	Count	32	37	4	11	68	152
		Expected Count	27.8	35.6	2.0	10.2	76.3	152.0
		% of Total	7.1%	8.3%	0.9%	2.5%	15.2%	33.9%
		Std. Residual	.8	.2	1.4	.3	-1.0	
	Mixed	Count	9	26	0	7	50	92
		Expected Count	16.8	21.6	1.2	6.2	46.2	92.0
		% of Total	2.0%	5.8%	0.0%	1.6%	11.2%	20.5%
		Std. Residual	-1.9	1.0	-1.1	.3	.6	
	Occupational	Count	7	2	1	5	18	33
		Expected Count	6.0	7.7	.4	2.2	16.6	33.0
		% of Total	1.6%	0.4%	0.2%	1.1%	4.0%	7.4%
		Std. Residual	.4	-2.1	.8	1.9	.4	
	Trash	Count	34	40	1	7	89	171
		Expected Count	31.3	40.1	2.3	11.5	85.9	171.0
		% of Total	7.6%	8.9%	0.2%	1.6%	19.9%	38.2%
		Std. Residual	.5	.0	-.9	-1.3	.3	
Total		Count	82	105	6	30	225	448
		Expected Count	82.0	105.0	6.0	30.0	225.0	448.0
		% of Total	18.3%	23.4%	1.3%	6.7%	50.2%	100.0 %

Table 7-25. Chi-squared results from Table 7-24 above.

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	21.332[a]	11	.046
Likelihood Ratio	23.970	11	.021
N of Valid Cases	448		

a. 5 cells (25.0%) have expected count less than 5. The minimum expected count is .44.

The chi-squared results after this cell is altered are barely significant (21.332) with df = 11 at the 0.05 level. I alter the next deviant cell (Occupational: High Mn/low Sb) to make the results insignificant. The final 2x2 contingency table is below (Table 7-26), after this cell and the previously altered cell have been adjusted.

Table 7-26. Final 4x5 contingency table after 2 cells altered.

General Arch Context * Basic Chem Grp Crosstabulation

			Basic Chem Grp					
			Aqua	High Mn/low Sb	Low Mn/low Sb	Mixed Mn/Sb	Sb Decol Glass	Total
General Arch Context	Abandonment	Count	32	37	4	11	68	152
		Expected Count	27.1	38.7	2.0	9.9	74.3	152.0
		% of Total	7.0%	8.0%	0.9%	2.4%	14.8%	33.0%
		Std. Residual	.9	-.3	1.4	.3	-.7	
	Mixed	Count	9	26	0	7	50	92
		Expected Count	16.4	23.4	1.2	6.0	45.0	92.0
		% of Total	2.0%	5.7%	0.0%	1.5%	10.9%	20.0%
		Std. Residual	-1.8	.5	-1.1	.4	.7	
	Occupational	Count	7	10	1	5	18	41
		Expected Count	7.3	10.4	.5	2.7	20.1	41.0
		% of Total	1.5%	2.2%	0.2%	1.1%	3.9%	8.9%
		Std. Residual	-.1	-.1	.6	1.4	-.5	
	Trash	Count	34	44	1	7	89	175
		Expected Count	31.2	44.5	2.3	11.4	85.6	175.0
		% of Total	7.4%	9.6%	0.2%	1.5%	19.3%	38.0%
		Std. Residual	.5	-.1	-.8	-1.3	.4	
Total		Count	82	117	6	30	225	460
		Expected Count	82.0	117.0	6.0	30.0	225.0	460.0
		% of Total	17.8%	25.4%	1.3%	6.5%	48.9%	100.0%

Table 7-27. Chi-squared results from Table 7-26 above

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	14.713[a]	10	.258
Likelihood Ratio	15.994	10	.191
N of Valid Cases	460		

a. 5 cells (25.0%) have expected count less than 5. The minimum expected count is .53.

This analysis confirms that High Mn/low Sb glass more frequently occurs in disturbed contexts. This may indicate that these represent later glass types, which would have been in units closest to the surface, and therefore, more susceptible to post-depositional disturbances, such as wind, erosion, and human activity.

What is also notable is that the Aqua glass group, which is potentially recycled glass, is not absent from trash deposits. If this type was systematically collected and recycled at Karanis, one would expect this type of glass to be infrequently discarded in trash deposits and to occur more frequently in occupational layers than in trash deposits (see Chapter 8 for further discussion)

7.6 Site Areas and Morphological Groups

Creating sets of morphological categories of varying specificity reveals further/different patterning in the data. My main aim in interrogating the geographic distribution of glass artifacts at Karanis is to discern whether or not certain areas contain more high status objects than others. For instance, the jars, flasks, bottles, and *unguentaria* group are generally lower status items for daily use. Beakers, cups, goblets, plates and bowls are considered "tableware", and their high frequency in hoards suggest they were highly valued items. Conical lamps are included with beakers, cups, and goblets because they are open forms. Bowls and plates are grouped together also because they are open forms distinguishable in form and dimensions from beakers, cups, goblets, and conical lamps.

Table 7-28. 5x3 contingency table of site area and basic morphological types

Site Area * basic form Crosstabulation

			basic form			
			beakers, cups, goblets conical lamps	jars, flasks, bottles, *unguentaria*	plates, bowls	Total
Site Area	KAC	Count	3	4	9	16
		Expected Count	3.6	8.5	3.9	16.0
		% of Total	1.4%	1.9%	4.3%	7.7%
		Std. Residual	-.3	-1.5	2.6	
	KAE	Count	31	75	19	125
		Expected Count	28.4	66.4	30.2	125.0
		% of Total	15.0%	36.2%	9.2%	60.4%
		Std. Residual	.5	1.1	-2.0	
	KAG	Count	8	28	16	52
		Expected Count	11.8	27.6	12.6	52.0
		% of Total	3.9%	13.5%	7.7%	25.1%
		Std. Residual	-1.1	.1	1.0	
	KAS	Count	3	0	5	8
		Expected Count	1.8	4.3	1.9	8.0
		% of Total	1.4%	0.0%	2.4%	3.9%
		Std. Residual	.9	-2.1	2.2	
	KAW	Count	2	3	1	6
		Expected Count	1.4	3.2	1.4	6.0
		% of Total	1.0%	1.4%	0.5%	2.9%
		Std. Residual	.5	-.1	-.4	
Total		Count	47	110	50	207
		Expected Count	47.0	110.0	50.0	207.0
		% of Total	22.7%	53.1%	24.2%	100.0%

Table 7-29. Chi-squared results for Table 7-28 above

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	27.331[a]	8	.001
Likelihood Ratio	29.320	8	.000
N of Valid Cases	207		

a. 8 cells (53.3%) have expected count less than 5. The minimum expected count is 1.36.

In the analysis below (Table 7-30), I divide the jars, flasks, bottles, and *unguentaria* into two groups: 1) jars and flasks, 2) bottles and toilet bottles. Similar results are produced, but a less significant p-value is generated. These seem to be the most useful groupings, however, in determining the distribution of similar morphological types.

Table 7-30. 5x4 contingency table of site area and general morphological types

Site Area * general form grps Crosstabulation

			general form grps				
			beakers, cups, conical lamps	bottles, toilet bottles	jars, flasks	plates, bowls	Total
Site Area	KAC	Count	3	2	2	9	16
		Expected Count	3.6	2.7	5.8	3.9	16.0
		% of Total	1.4%	1.0%	1.0%	4.3%	7.7%
		Std. Residual	-.3	-.4	-1.6	2.6	
	KAE	Count	31	24	51	19	125
		Expected Count	28.4	21.1	45.3	30.2	125.0
		% of Total	15.0%	11.6%	24.6%	9.2%	60.4%
		Std. Residual	.5	.6	.8	-2.0	
	KAG	Count	8	9	19	16	52
		Expected Count	11.8	8.8	18.8	12.6	52.0
		% of Total	3.9%	4.3%	9.2%	7.7%	25.1%
		Std. Residual	-1.1	.1	.0	1.0	
	KAS	Count	3	0	0	5	8
		Expected Count	1.8	1.4	2.9	1.9	8.0
		% of Total	1.4%	0.0%	0.0%	2.4%	3.9%
		Std. Residual	.9	-1.2	-1.7	2.2	
	KAW	Count	2	0	3	1	6
		Expected Count	1.4	1.0	2.2	1.4	6.0
		% of Total	1.0%	0.0%	1.4%	0.5%	2.9%
		Std. Residual	.5	-1.0	.6	-.4	
Total		Count	47	35	75	50	207
		Expected Count	47.0	35.0	75.0	50.0	207.0
		% of Total	22.7%	16.9%	36.2%	24.2%	100.0%

Table 7-31. Chi-squared results for Table 7-30 above.

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	28.938[a]	12	.004
Likelihood Ratio	32.188	12	.001
N of Valid Cases	207		

a. 11 cells (55.0%) have expected count less than 5. The minimum expected count is 1.01.

The most deviant cell is KAC: plates, bowls, and this is the only cell that needs to be altered to make the chi-squared p-value insignificant at the 0.05 level.

Table 7-32. 5x4 contingency table of site area and general morphological types after cell KAC: plates, bowls is altered.

Site Area * final form grps Crosstabulation

			final form grps				
			beakers, cups, conical lamps	bottles, toilet bottles	jars, flasks	plates, bowls	Total
Site Area	KAC	Count	3	2	2	2	9
		Expected Count	2.1	1.6	3.4	1.9	9.0
		% of Total	1.5%	1.0%	1.0%	1.0%	4.5%
		Std. Residual	.6	.3	-.7	.0	
	KAE	Count	31	24	51	19	125
		Expected Count	29.4	21.9	46.9	26.9	125.0
		% of Total	15.5%	12.0%	25.5%	9.5%	62.5%
		Std. Residual	.3	.5	.6	-1.5	
	KAG	Count	8	9	19	16	52
		Expected Count	12.2	9.1	19.5	11.2	52.0
		% of Total	4.0%	4.5%	9.5%	8.0%	26.0%
		Std. Residual	-1.2	.0	-.1	1.4	
	KAS	Count	3	0	0	5	8
		Expected Count	1.9	1.4	3.0	1.7	8.0
		% of Total	1.5%	0.0%	0.0%	2.5%	4.0%
		Std. Residual	.8	-1.2	-1.7	2.5	
	KAW	Count	2	0	3	1	6
		Expected Count	1.4	1.1	2.3	1.3	6.0
		% of Total	1.0%	0.0%	1.5%	0.5%	3.0%
		Std. Residual	.5	-1.0	.5	-.3	
Total		Count	47	35	75	43	200
		Expected Count	47.0	35.0	75.0	43.0	200.0
		% of Total	23.5%	17.5%	37.5%	21.5%	100.0%

Table 7-33. Chi-squared results for Table 7-32 above.

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	20.498[a]	12	.058
Likelihood Ratio	23.903	12	.021
N of Valid Cases	200		

a. 12 cells (60.0%) have expected count less than 5. The minimum expected count is 1.05.

More specific designations of morphology yield slightly different results because the most deviant cell is KAS: 6, conical lamps. This makes sense because conical lamps are typically made with High Mn/low Sb glass (based on chi-squared analysis in Ch. 6). Only three cells need to be modified to make the p value insignificant at the 0.05 level (in order of deviance from expected values): KAS: 6, KAC: 1, KAC: 6. It is also notable that oil flasks (Grp 12 below) are only found in areas KAE and KAG. There are undisturbed stratigraphic units in both these areas. Toilet bottles are not found in area KAS or KAW.

Table 7-34. 5x8 contingency table of site area and more specific morphological types

Site Area * Specific Form Crosstabulation

			Specific Form								
			1	6	11	12	13	24	57	810	Total
Site Area	KAC	Count	4	2	0	0	2	5	1	2	16
		Expected Count	1.0	.5	.5	1.0	2.2	2.9	3.2	4.8	16.0
		% of Total	1.9%	1.0%	0.0%	0.0%	1.0%	2.4%	0.5%	1.0%	7.7%
		Std. Residual	3.0	2.3	-.7	-1.0	-.2	1.3	-1.2	-1.3	
	KAE	Count	3	0	5	9	19	16	31	42	125
		Expected Count	7.9	3.6	3.6	7.9	17.5	22.3	24.8	37.4	125.0
		% of Total	1.4%	0.0%	2.4%	4.3%	9.2%	7.7%	15.0%	20.3%	60.4%
		Std. Residual	-1.7	-1.9	.7	.4	.4	-1.3	1.3	.7	
	KAG	Count	5	2	1	4	8	11	6	15	52
		Expected Count	3.3	1.5	1.5	3.3	7.3	9.3	10.3	15.6	52.0
		% of Total	2.4%	1.0%	0.5%	1.9%	3.9%	5.3%	2.9%	7.2%	25.1%
		Std. Residual	1.0	.4	-.4	.4	.3	.6	-1.3	-.1	
	KAS	Count	1	2	0	0	0	4	1	0	8
		Expected Count	.5	.2	.2	.5	1.1	1.4	1.6	2.4	8.0
		% of Total	0.5%	1.0%	0.0%	0.0%	0.0%	1.9%	0.5%	0.0%	3.9%
		Std. Residual	.7	3.7	-.5	-.7	-1.1	2.1	-.5	-1.5	
	KAW	Count	0	0	0	0	0	1	2	3	6
		Expected Count	.4	.2	.2	.4	.8	1.1	1.2	1.8	6.0
		% of Total	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	1.0%	1.4%	2.9%
		Std. Residual	-.6	-.4	-.4	-.6	-.9	-.1	.7	.9	
Total		Count	13	6	6	13	29	37	41	62	207
		Expected Count	13.0	6.0	6.0	13.0	29.0	37.0	41.0	62.0	207.0

	% of Total	6.3%	2.9%	2.9%	6.3%	14.0%	17.9%	19.8%	30.0%	100.0 %

Table 7-35. Chi-squared results for Table 7-34 above.

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	61.576[a]	28	.000
Likelihood Ratio	58.248	28	.001
N of Valid Cases	207		

a. 30 cells (75.0%) have expected count less than 5. The minimum expected count is .17.

Table 7-36. Final 5x8 contingency table of site area and more specific morphological types after three cells are modified.

Site Area * Specific Form Crosstabulation

			Specific Form								Total
			1	6	11	12	13	24	57	810	
Site Area	KAC	Count	1	0	0	0	2	5	1	2	11
		Expected Count	.6	.1	.3	.7	1.6	2.0	2.3	3.4	11.0
		% of Total	0.5%	0.0%	0.0%	0.0%	1.0%	2.5%	0.5%	1.0%	5.5%
		Std. Residual	.6	-.3	-.6	-.8	.3	2.1	-.8	-.8	
	KAE	Count	3	0	5	9	19	16	31	42	125
		Expected Count	6.3	1.3	3.8	8.1	18.1	23.1	25.6	38.8	125.0
		% of Total	1.5%	0.0%	2.5%	4.5%	9.5%	8.0%	15.5%	21.0%	62.5%
		Std. Residual	-1.3	-1.1	.6	.3	.2	-1.5	1.1	.5	
	KAG	Count	5	2	1	4	8	11	6	15	52
		Expected Count	2.6	.5	1.6	3.4	7.5	9.6	10.7	16.1	52.0

		% of Total	2.5%	1.0%	0.5%	2.0%	4.0%	5.5%	3.0%	7.5%	26.0%
		Std. Residual	1.5	2.1	-.4	.3	.2	.4	-1.4	-.3	
	KAS	Count	1	0	0	0	0	4	1	0	6
		Expected Count	.3	.1	.2	.4	.9	1.1	1.2	1.9	6.0
		% of Total	0.5%	0.0%	0.0%	0.0%	0.0%	2.0%	0.5%	0.0%	3.0%
		Std. Residual	1.3	-.2	-.4	-.6	-.9	2.7	-.2	-1.4	
	KAW	Count	0	0	0	0	0	1	2	3	6
		Expected Count	.3	.1	.2	.4	.9	1.1	1.2	1.9	6.0
		% of Total	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	1.0%	1.5%	3.0%
		Std. Residual	-.5	-.2	-.4	-.6	-.9	-.1	.7	.8	
Total		Count	10	2	6	13	29	37	41	62	200
		Expected Count	10.0	2.0	6.0	13.0	29.0	37.0	41.0	62.0	200.0
		% of Total	5.0%	1.0%	3.0%	6.5%	14.5%	18.5%	20.5%	31.0%	100.0 %

Table 7-37. Chi-squared results for Table 7-36 above.

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	38.952[a]	28	.082
Likelihood Ratio	40.298	28	.062
N of Valid Cases	200		

a. 30 cells (75.0%) have expected count less than 5. The minimum expected count is .06.

7.7 Trenches and Morphological Types

There is a relationship between form types and trenches in which they are found. The p value (94.617) for the chi-squared analysis below is significant at the 0.05 level with df=66.

Table 7-38. 23x4 contingency table of trenches and general morphological types

Provenance * general form Crosstabulation

			general form				
			beakers, cups, conical lamps	bottles, toilet bottles	jars, flasks	plates, bowls	Total
Provenance	KA01	Count	1	0	0	0	1
		Expected Count	.2	.2	.4	.2	1.0
		% of Total	0.5%	0.0%	0.0%	0.0%	0.5%
		Std. Residual	1.6	-.4	-.6	-.5	
	KA04	Count	6	9	14	14	43
		Expected Count	9.8	7.3	15.6	10.4	43.0
		% of Total	2.9%	4.3%	6.8%	6.8%	20.8%
		Std. Residual	-1.2	.6	-.4	1.1	
	KA05	Count	0	0	2	1	3
		Expected Count	.7	.5	1.1	.7	3.0
		% of Total	0.0%	0.0%	1.0%	0.5%	1.4%
		Std. Residual	-.8	-.7	.9	.3	
	KA06	Count	2	0	1	0	3
		Expected Count	.7	.5	1.1	.7	3.0
		% of Total	1.0%	0.0%	0.5%	0.0%	1.4%
		Std. Residual	1.6	-.7	-.1	-.9	
	KA07	Count	0	1	0	0	1
		Expected Count	.2	.2	.4	.2	1.0
		% of Total	0.0%	0.5%	0.0%	0.0%	0.5%
		Std. Residual	-.5	2.0	-.6	-.5	

	KA08	Count	3	0	0	5	8
		Expected Count	1.8	1.4	2.9	1.9	8.0
		% of Total	1.4%	0.0%	0.0%	2.4%	3.9%
		Std. Residual	.9	-1.2	-1.7	2.2	
	KA09	Count	3	1	2	9	15
		Expected Count	3.4	2.5	5.4	3.6	15.0
		% of Total	1.4%	0.5%	1.0%	4.3%	7.2%
		Std. Residual	-.2	-1.0	-1.5	2.8	
	KA11	Count	2	0	3	0	5
		Expected Count	1.1	.8	1.8	1.2	5.0
		% of Total	1.0%	0.0%	1.4%	0.0%	2.4%
		Std. Residual	.8	-.9	.9	-1.1	
	KA12	Count	2	2	3	0	7
		Expected Count	1.6	1.2	2.5	1.7	7.0
		% of Total	1.0%	1.0%	1.4%	0.0%	3.4%
		Std. Residual	.3	.8	.3	-1.3	
	KA13	Count	2	3	12	4	21
		Expected Count	4.8	3.6	7.6	5.1	21.0
		% of Total	1.0%	1.4%	5.8%	1.9%	10.1%
		Std. Residual	-1.3	-.3	1.6	-.5	
	KA14	Count	0	0	3	2	5
		Expected Count	1.1	.8	1.8	1.2	5.0
		% of Total	0.0%	0.0%	1.4%	1.0%	2.4%
		Std. Residual	-1.1	-.9	.9	.7	
	KA15	Count	9	2	5	0	16
		Expected Count	3.6	2.7	5.8	3.9	16.0
		% of Total	4.3%	1.0%	2.4%	0.0%	7.7%
		Std. Residual	2.8	-.4	-.3	-2.0	
	KA17	Count	0	1	2	2	5

	Expected Count	1.1	.8	1.8	1.2	5.0
	% of Total	0.0%	0.5%	1.0%	1.0%	2.4%
	Std. Residual	-1.1	.2	.1	.7	
KA18	Count	3	3	2	1	9
	Expected Count	2.0	1.5	3.3	2.2	9.0
	% of Total	1.4%	1.4%	1.0%	0.5%	4.3%
	Std. Residual	.7	1.2	-.7	-.8	
KA19	Count	1	0	1	0	2
	Expected Count	.5	.3	.7	.5	2.0
	% of Total	0.5%	0.0%	0.5%	0.0%	1.0%
	Std. Residual	.8	-.6	.3	-.7	
KA20	Count	0	0	1	0	1
	Expected Count	.2	.2	.4	.2	1.0
	% of Total	0.0%	0.0%	0.5%	0.0%	0.5%
	Std. Residual	-.5	-.4	1.1	-.5	
KA21	Count	3	5	5	3	16
	Expected Count	3.6	2.7	5.8	3.9	16.0
	% of Total	1.4%	2.4%	2.4%	1.4%	7.7%
	Std. Residual	-.3	1.4	-.3	-.4	
KA22	Count	1	1	3	0	5
	Expected Count	1.1	.8	1.8	1.2	5.0
	% of Total	0.5%	0.5%	1.4%	0.0%	2.4%
	Std. Residual	-.1	.2	.9	-1.1	
KA23	Count	3	2	8	0	13
	Expected Count	3.0	2.2	4.7	3.1	13.0
	% of Total	1.4%	1.0%	3.9%	0.0%	6.3%
	Std. Residual	.0	-.1	1.5	-1.8	
KA24	Count	1	0	2	0	3

		Expected Count	.7	.5	1.1	.7	3.0
		% of Total	0.5%	0.0%	1.0%	0.0%	1.4%
		Std. Residual	.4	-.7	.9	-.9	
	KA25	Count	3	2	4	7	16
		Expected Count	3.6	2.7	5.8	3.9	16.0
		% of Total	1.4%	1.0%	1.9%	3.4%	7.7%
		Std. Residual	-.3	-.4	-.7	1.6	
	KA26	Count	2	1	1	2	6
		Expected Count	1.4	1.0	2.2	1.4	6.0
		% of Total	1.0%	0.5%	0.5%	1.0%	2.9%
		Std. Residual	.5	.0	-.8	.5	
	KA27	Count	0	2	1	0	3
		Expected Count	.7	.5	1.1	.7	3.0
		% of Total	0.0%	1.0%	0.5%	0.0%	1.4%
		Std. Residual	-.8	2.1	-.1	-.9	
Total		Count	47	35	75	50	207
		Expected Count	47.0	35.0	75.0	50.0	207.0
		% of Total	22.7%	16.9%	36.2%	24.2%	100.0%

Table 7-39. Chi-squared results for Table 7-38 above.

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	94.617[a]	66	.012
Likelihood Ratio	107.865	66	.001
N of Valid Cases	207		

a. 82 cells (89.1%) have expected count less than 5. The minimum expected count is .17.

There are two cells with equal chi-squared values that are most deviant: KA09: plates, bowls and KA15: beakers, cups, conical lamps. Neutralizing cell KA15: beakers, cups, conical lamps makes the p value insignificant at the 0.05 level (see Table 7-40 below).

Table 7-40. Final chi-squared results of Table 7-38 above after one cell is modified.

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	84.622[a]	65	.061
Likelihood Ratio	98.645	65	.006
N of Valid Cases	200		

a. 83 cells (90.2%) have expected count less than 5. The minimum expected count is .18.

7.8 Unit Types and Morphological Types

There does not seem to be a relationship between unit types and morphology. I conducted chi-squared using the different levels of form categories, but none yielded significant p values at the 0.05 level (see Table 7-41 below). All form types are found in relatively equal frequencies in trash deposits. In occupation layers, there are fewer bowls and plates than is expected.

Table 7-41. 4x4 contingency table of unit types and general morphological types

General Arch Context * general form Crosstabulation

			general form				
			beakers, cups, conical lamps	bottles, toilet bottles	jars, flasks	plates, bowls	Total
General Arch Context	Abandonment	Count	19	14	23	21	77
		Expected Count	18.3	13.2	26.8	18.7	77.0
		% of Total	9.6%	7.1%	11.6%	10.6%	38.9%
		Std. Residual	.2	.2	-.7	.5	
	Mixed	Count	14	6	19	8	47
		Expected Count	11.2	8.1	16.4	11.4	47.0
		% of Total	7.1%	3.0%	9.6%	4.0%	23.7%
		Std. Residual	.9	-.7	.6	-1.0	
	Occupational	Count	2	4	9	1	16
		Expected Count	3.8	2.7	5.6	3.9	16.0
		% of Total	1.0%	2.0%	4.5%	0.5%	8.1%
		Std. Residual	-.9	.8	1.5	-1.5	
	Trash	Count	12	10	18	18	58
		Expected Count	13.8	10.0	20.2	14.1	58.0
		% of Total	6.1%	5.1%	9.1%	9.1%	29.3%
		Std. Residual	-.5	.0	-.5	1.1	
Total		Count	47	34	69	48	198
		Expected Count	47.0	34.0	69.0	48.0	198.0
		% of Total	23.7%	17.2%	34.8%	24.2%	100.0%

Table 7-42. Chi-squared results for Table 7-41 above.

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	10.835[a]	9	.287
Likelihood Ratio	11.560	9	.239
N of Valid Cases	198		

a. 3 cells (18.8%) have expected count less than 5. The minimum expected count is 2.75.

7.9 Concluding Remarks

The important relationships among variables identified in this chapter are summarized here. In this glass assemblage, high-quality water clear colorless glass is ubiquitous during the Late Roman period (4th-6th centuries CE), but is also present in earlier periods (1st-4th centuries CE). High Mn/low Sb, Low Mn/low Sb, and Aqua glass groups are not represented in the 1st-3rd century samples. There are only 4 examples dating to this time period, however, so results must be interpreted cautiously. High Mn/low Sb glass and Low Mn/low Sb (if Levantine 1b) have been dated in other studies to the Late Roman period, so these results align well with those studies. Roman blue-green glass was a common composition in the 1st-3rd centuries CE; therefore, the fact that no Aqua glass dates to this period offers some support that it is distinct from Roman blue-green glass.

Karanis East (KAE) lacks High Mn/low Sb glass, but has a very high percentage of high quality antimony (Sb)-decolorized glass. Areas Karanis South (KAS) and Karanis Center (KAC) have more High Mn/low Sb glass than expected, but the stratigraphic units from which these samples were found are disturbed. Area KAS is an industrial area of the town, and perhaps this has something to do with the volume of High Mn/low Sb glass found there in Trench KA08.

There are more conical lamps found in area KAS than the expected values in the chi-squared analysis. *Unguentaria* are not present in areas KAS and Karanis West (KAW). Perhaps this is because there is less domestic architecture in these areas and more industrial buildings. These results will be discussed in more detail and interpreted in the following chapter.

Chapter 8

Value of Karanis Glass

8.1 Introduction and Chapter Summary

To explore the value of Karanis glass I employ a diverse, yet complementary set of research techniques. This chapter contextualizes the findings and research from previous chapters by explaining how these results relate to the value of glass objects. I first summarize how modern glassworkers and the middleman I interviewed from Cairo assess the value of their products and how the changing industry has influenced the products they make. I then discuss how this ethnoarchaeological study informs our interpretation of the relationship between value and ancient technology.

Since the *chaîne opératoire* of glass manufacturing I identify through ethnoarchaeology in Chapter 4 forms the foundation for this study of Roman glass from Karanis, the structure of the remainder of this chapter also follows the *chaîne opératoire* of glass manufacturing and object biographies. I explore factors affecting the value of glass objects during each phase of their manufacture, life, and discard. I discuss the results of the chemical analysis of glasses from Karanis and how the established compositional groups contribute to our understanding of the organization of the Roman glass industry as a whole. I then outline how certain types of glass may relate to object value. Following, is a discussion of the classification of Karanis glass and how relationships among variables, such as composition and morphology, contribute to our understanding of object value. I then interpret the patterns I identify in Chapter 7 regarding the archaeological context of artifacts to understand how object biographies contribute to value

studies. I compare results from my contextual analysis with inventories of hoards found during the University of Michigan excavations at Karanis.

Next, I describe the life histories of three morphological types—rectangular bottles, *unguentaria*, and oil flasks--in order to contextualize the current study's compositional and morphological results for these types as well as the spatial distribution and discard patterns of these types within the site of Karanis.

8.2 Ethnoarchaeological Study and Value: Workshop 2

During interviews with Workshop 2 owner as well as the middleman, I asked them to explain how they value and price their products as well as how they perceive their customers value their products. A summary of their responses and a discussion ensues.

As a general rule, to price his products, Mustafa adds 20% on top of the costs of making each piece. Workshop 2 actually uses an international assistant to help with their pricing. This international assistant does not act as a middleman, but deals with all the workshops and utilizes what Mustafa's son, Karim, refers to as the "Freidhoff" system. The assistant asks Mustafa the amount it costs him to make each item, he purchases these items at a slightly higher price than the cost of manufacturing, and he sells these items in his own shop at a 20% markup.

Further investigation revealed, however, that determining the selling price of a glass object is far more complicated than a simple 20% markup from the cost of manufacturing. When asked to identify materials, methods, shapes, or other characteristics that increase the value of a particular vessel, Mustafa gave several examples. Large vessels, for instance, require more work and skill to make. Thus, the purchase price is higher than simply a 20% markup from the cost of

raw materials and time spent on the object; rather, the skill involved in making large objects inflates their price.

Mustafa also pointed out particular shapes that are difficult to make, such as what he describes as a Mamluk-style teapot. This teapot has a very long spout, elongated pear-shaped body, and glass stopper to cover the opening of the vessel at the top. He says that no one else other than him can produce these because they are difficult to make and only he knows how to create them. Consequently, this type of vessel is more expensive to customers due to its complex design.

The type of glass used also determines its value. For instance, oxides, such as cobalt are expensive for Mustafa to buy. After purchasing the cobalt, he uses his secret recipe to formulate a cobalt oxide colorant, which he can then add to a particular batch of glass. Creating the cobalt blue color, then, requires extra cost for the manufacturer, as well as time and expertise. Therefore, vessels colored with cobalt oxide are more expensive than the green vessels, for instance, which are remelted 7-Up bottles that are already green in color.

The most expensive color is red, as it requires costly constituents that are added to the glass as well as knowledge of the proper kiln conditions to oxidize the color and make it red. Again, Mustafa claims only he knows how to produce red vessels. This specialized knowledge also encourages him to increase the price at which he sells these red products. Most of the red glass you find in shops in Egypt, he claims, are painted. The color is not actually inside the glass itself. They also sell painted red vessels in his shop at lower prices than the actual red vessels.

What Mustafa refers to as “opaline” glass is also more expensive than other types of glass, except for red glass. This is because its ingredients are expensive for Mustafa to buy and

he claims that he is the only glassworker who knows how to make opaline glass. Opaline glass is a term used for opaque glass of white or milky shades of other colors. It was a decorative style of glass made in France as early as 1820, containing powdered bone and oxides of antimony or arsenic (Hollister 1991). What Mustafa refers to as opaline glass is also opaque white or milky shades of green, blue, orange, or purple. It is unlikely that the composition is similar to that of French opaline glass, however, since Mustafa also claims that his products do not contain harmful heavy metals, like lead. An opacifier not containing lead (perhaps calcium antimonate), is most likely the expensive ingredient that drives up the prices of Mustafa's opaline glass.

Other factors that increases the price Mustafa charges his customers is the amount of time and skill involved. Lamps are generally more expensive, for instance, because they require a lot of time to assemble and/or are decorated. The most expensive lamps are those glass lamps blown into metal designs. Mustafa says only he can produce these lamps, as they are difficult to make. Lamps are more often purchased by local Egyptians rather than tourists. This could represent a local preference for these products, or merely the logistic difficulty of transporting larger products such as these abroad.

Mustafa explains that consumers buy two main types of products from him: tableware and decorative items. Lamps are included in the decorative item category. He says that one cannot determine the value of these objects merely by which of these two functional types they are. Rather, there are expensive pieces in both categories. Bowls made of red glass, for instance, would be more expensive than many of the decorative items of other colors.

The age of the glass can also affect its selling price. Mustafa has several antique glass objects, glass produced by either his father or grandfather. Although he still produces these same shapes and types of vessels, these older objects are much more expensive because they are

"antique". Nostalgia also raises the selling price of these and some additional objects in Mustafa's shop. Someone allegedly offered him 2000 Euro for the sign hanging behind his kiln but he refused to sell this because it held sentimental value for him. There are other objects that have sentimental value to him that he does not wish to sell in his shop. When customers attempt to purchase these items, he continues to raise the price of the item until they eventually give up.

Since the Egyptian Revolution in 2011, prices for gas to fuel the kilns and most other supplies (such as colorants) have risen. This rise in manufacturing costs has increased the price of all glass objects in Mustafa's shop. Tourism was declining in Egypt before the revolution, but has significantly dropped following it. This has negatively affected Mustafa's revenue. However, due to Mustafa's fame and exposure in several magazines, tourism books, interviews, and movies, he has managed to have a fairly steady stream of people visiting his shop. Fortunately, he does not rely solely on tourism for his income. The bulk of his profits are derived from large orders from commissioners or companies abroad, and these orders are not significantly impacted by tourism. Mustafa claims they are able to arrange many of these orders via E-mail, whereby the customers select the types of vessels they desire from a series of pictures Mustafa sends by E-mail. The importers contact Mustafa directly by E-mail, so Mustafa avoids having to use a middleman to complete these orders. Unfortunately, orders have been sparse since the revolution. He has only received one order of one thousand pieces from an American company. Therefore, his business has suffered significantly from the aftermath of the revolution. Other work Mustafa does unrelated to tourism are glass restorations in mosques and churches.

When asked how he thinks his customers value his glass products, he emphasized that his glass is hand-made and "natural". According to Mustafa, the numerous bubbles present in his products send an important message to the customer: these are hand-made products. To his

consumers, who are mainly tourists, hand-made glass is far more desirable than machine-made glass. These bubbles, which may be perceived as flaws to some, impart value to his products. He deliberately leaves gasses in the glass melt to create this effect, rather than to use a method he claims he knows to allow the gasses to escape prior to shaping. Mustafa also accentuates the recycled nature of the product and perceives this as a desirable quality to both types of his consumers, tourists and local Egyptians. By natural, he means that there are no harmful or poisonous heavy metals, such as lead, in the glass. Mustafa reported that an American group of researchers sampled his glass and found that it was free of harmful metals and other materials. Middleman, Hammam, confirmed this research was carried out and sent me a copy of the toxicity report (Wilson 2011).

Aid to Artisans, an organization that promotes ecologically sound practices among the artisan groups they assist, hired the company, Fuss &O'Neil, to test products from various ceramic and glass workshops in Egypt for toxic levels of certain compounds, such as lead and cadmium. They tested glass from Workshop 2 and another glass blowing workshop, presumably owned by Mustafa's brother. Glass from both workshops did not contain significant concentrations of lead or cadmium (Wilson 2011). It was safe to use as tableware and any other function that involves food consumed by humans coming into contact with the glass.

Unfortunately, the follow-up interview with Workshop 1 owners, including their assessment of value, could not be carried out in 2012 due to safety concerns in Cairo. Therefore, only the value assessments by Workshop 2 owner, Mustafa, and middleman, Hammam, will be discussed in this study.

8.3 Ethnoarchaeological Study and Value: Middleman

The quality control that Hammam completes prior to shipping materials to his customers abroad involves following up with producers and inspecting every piece he orders. Hammam describes specific characteristics of glass vessels that signify a higher quality product more marketable to his customers.

For instance, glass objects should not have any sharp edges on which people can injure themselves. If pontil scars (where the pontil rod is broken off from the base of the vessel) are not fire-polished or ground down smooth, these sharp edges can be dangerous for customers.

To Hammam and his customers, uniformity in size and shape is important as well. In other words, he desires vessels of the same type to be close in size and shape. When vessels of the same type vary too much in size, "it is difficult because the buyer doesn't accept it," Hammam explains. "I am dealing with importers, companies that are importing in bulk. So they want 100 pieces that, when you put them in the shop, they all look the same on the shelf." Hammam understands these are hand-made products that cannot be exactly the same size and shape. Yet, he persists, "I can't have two glasses with a difference of 4 or 5 cm. That's too much. A half centimeter or maximum one centimeter is acceptable by the buyers." Hammam also adds the customers who buy from these importing companies also value uniformity. For example, they typically prefer a set of goblets or glasses for their dining table to be similar in size.

Additionally, the stability of the glass form is of importance. During quality control, Hammam rejects vessels that lean to one side or wobble when resting on a flat surface. He desires stable forms and either rejects these flawed vessels or demands the producer replaces them with quality pieces.

Hammam also explains how the manner of coloring the glass can dictate value. “The good quality is when they mix in the colors. The color should be inside the glass.” Sometimes glass is painted instead, especially in the case of red glass, since glass of this color is very expensive to produce. Hammam states, “I don’t do painted glass. I only do painting with the Pyrex glass.”

Lastly, Hammam explains how bubbles relate to the value of the glass. Like Mustafa, he agrees that consumers equate the tiny pin-prick-sized bubbles as signatures of a hand-made product. Without doubt, he says, “of course bubbles are attractive to buyers. Many small bubbles, this is the perfect item. Because people like the bubbly product. Usually they like it because recycled glass has bubbles. They feel this is really hand-made and this is really recycled glass. Plus these bubbles really look nice.”

Hammam qualifies his statement about bubbles, however, because he states that the presence of large bubbles in the glass actually decreases the value of the glass significantly. “If they are too big, the glass is unstable and it will crack before it even is shipped.” Large bubbles create weaknesses in the glass and increase the chance of breakage. Therefore, even if the piece arrives to the importer whole, it may break soon after the consumer buys the piece. When asked the price ranges for glass objects Hammam sells, he said there is a wide range. “It depends on how big it is and how difficult it is to do,” he says.

8.4 Recent Changes in the Glass Industry

"Change does not occur independently but is always related to other aspects of life, emulation, stylistic expression, economic efficiency, organization of production, and so on" (David and Kramer 2001: 165).

Cairene glass workers were first documented by Napoleon's savants, who illustrated a kiln and workshop of the early 1800s. This was published in Description de l'Egypte (Plate XXIII of the Etat Moderne section, 1809). During the 19th Century, local consumption of Egyptian glass declined. According to Metz (1990), "artisans, suffered from the influx of cheaply made European imports. Whereas some crafts, like basketry, pottery, and rug weaving, survived, others such as textiles and glass blowing were virtually eliminated." Crafts that survived included those like basketry, which remained cheaper to make in Egypt than in Europe. Then, as the industries in Egypt became more mechanized and developed in the early 20th century, there was a significant decrease of certain imported goods to Egypt, including glass (Schatz 1940 in: Mountjoy 1952) (See Table 1 below).

Table 8-1. Items of Egyptian Import in 1938 as a Percentage of 1913 Imports (Mountjoy 1952: 213 after Schatz 1940)

Machinery and Raw Materials	Per Cent		Finished Goods	Per Cent
Mineral Oils and Lubricants	1,403		Iron Bedsteads (value)	2
Silk Yarn	1,012		Leather Shoes	6
Precision Instruments	629		Furniture (value)	11
Mazout (fuel oil)	590		Tanned Leather	22
Vegetable Oils for Industry	516		Cement	24
Iron Bars	331		Cotton Yarn	29
Machines (value)	313		Glassware	45
Cast Iron	281		Soap	51
Woolen Yarn	180		Cotton Piece Goods	58

During World War II (1939-1945), foreign imports virtually ceased, and Egypt underwent intense industrial development. Although Egyptian industries began to dominate the local market at this time, the cement, sugar, and glass industries among others became monopolised by large-scale producers. These few, but fully mechanized firms accounted for the majority of the output of Egyptian industry (Mountjoy 1952). Mechanized establishments such as the Sayyid Yassin Factory built in Shubra (a suburb of Cairo) in the late 1940's or early 1950's, contributed to the growth of the glass industry, which now supplied the local market with light bulbs, tumblers, and bottles for the pharmaceutical, chemical, and fruit-juice industries (Mountjoy 1952).

Since these mechanized factories further marginalised the market for glass produced by small workshops, they shifted focus to tourists rather than local consumers. Mosques, churches

and building conservation projects in Cairo continued to employ glassworkers to produce lamps and stained glass windows. This notable shift in the consumers targeted by small workshops is an important change in the glass industry. Currently, tourists buy the majority of Cairene glass or it is exported to foreign countries.

This ethnoarchaeological study as well as the observations of several researchers who have studied the same Cairene workshop (Workshop 1) over the course of forty years allow a diachronic evaluation of the glass Cairene glass industry, including the manufacturing methods and quality of glass produced. In 1972, the first modern study of Cairene glass workers was undertaken by Nessim Henein and Jean-Francois Gout. They published their research on the technology and products of these glass workers along with information regarding daily life and rituals associated with the glass industry (1974). Alysia Fischer visited a Cairene workshop in 1999 as part of her dissertation research on the Byzantine Period glass industry in Israel (2001). Paul Nicholson and Caroline Jackson observed Workshop 1 in the early 1990's.

Henein and Gout (1974) identify the range of objects produced as largely utilitarian and in traditional Islamic shapes. They describe the decline in products appealing to a local market and thus, a shift in the type of consumers.

> However, this is a production that plays hardly any role in Egyptian life. The seller tells us that, already forty years ago, the only objects bought by the Egyptians for their personal use were the receptacles for kohl (Makhal), suction cups,[16] oil lamps for lighting and funnels for extracting rose water and orange flower water. But now he no longer manufactures oil lamps because the electric lighting made them unnecessary. Today, the dissemination of such glass is even more limited: only a small part of the urban Egyptian society, and tourists, use it. For the entire country, only five workshops have survived (Henein and Gout 1974: 39, Trans. by Dr. Paul Nicholson).

[16] These are suction cups presumably used for medicinal purposes.

Fischer also documents that the primary market of the glass workshops in Egypt was tourism but that the industry was undergoing some drastic changes. She visited Workshop 1 in 1996 and found that the majority of Workshop 1‘s glass was sold by middlemen in shops located in the Old City nearby. By 1999, Workshop 1 had opened its own retail shop and was not only selling its own products, but was also able to store enough glass to supply orders from foreign customers. The workshop owners were also able to charge more to these customers than middlemen in Egypt. She confirms, however, that these developments and increase in profits did not affect the production process or technology of the glass workshop, which remained unchanged in all respects other than the addition of a television near the kiln (Fischer 2008: 104).

Whereas Egyptians continued a trend of consuming machine-manufactured glass, tourists, in contrast, desire locally produced glass from small workshops largely due to its hand-made and recycled qualities. So instead of attempting to produce glass of higher quality glass free of bubbles and impurities to compete with mechanized factories for the local market, small workshops instead focused on manufacturing products that would appeal to tourists.

8.5 Technology and Value

The assumption is often made that ancient advances in technology resulted in higher-valued products in the past. For instance, the Lycurgus Cup, produced during the Roman Period, contains minute particles of silver and gold in the glass that give it unique optical effects (Tatton-Brown 1991). The chalice is referred to as dichroic glass because it appears jade green in reflected light and magenta in transmitted light. The technology used to produce these effects was not identified until 1965 (Brill 1965; Barber and Freestone 1990). This chalice most definitely was a luxury item, prized for its unique properties.

The technology of glass blowing and mold blowing, however, had the opposite effect on value, as these advances allowed for the mass production of glass. Mass production eventually led to cheaper products, most likely for multiple reasons. Many identical versions of the same product would potentially lessen its value, products were available to a wider population, and manufacturing was potentially cheaper.

What this ethnographic study reveals, is that sometimes a lack of technology or skill level can result in a more valuable product. Prior to this study, I had made the assumption that the numerous bubbles present in Cairene glass were a result of the use of recycled glass and a lack of technology, knowledge, and/or skill to diminish the gasses present in the melt. Why would one produce an inferior product if they had the technology and know-how to manufacture something of higher quality? As the interviews with Cairene glass blowers revealed, glass workers claim to know how to remove these bubbles prior to shaping the vessels by melting the glass at a high temperature and holding it there for a long period of time to allow the gasses to escape. However, they deliberately choose not to take these measures. This finding is in line with what Henein and Gout observed at Workshop 1 in 1972. The glass workers intentionally added or maintained impurities and bubbles in the glass through a variety of means: stirring back the melt and raising it above the hearth to introduce air bubbles into the melt, throwing a (sweet) potato into the melt, dipping a wooden core into the melt, using the melt before it is completely liquified, and introducing a large amount of wood into the furnace to produce charred fragments in the air that mix in with the cullet while it is melting to cause air bubbles (1974).

The reason why these glass workers desire bubbles in the glass is related to consumer demand and the changes in the glass industry over time. Although Cairene workshops primarily sold to local Egyptians in the distant past, their current consumers are primarily tourists.

According to the glass workers, tourists want to buy hand-made glass, not machine manufactured glass. Bubbles identify their products as hand-made, and thus, their bubbly vessels appeal to their primary customer, tourists. Rather than being seen as flaws and a mark of an inferior product, bubbles impart value to the vessel.

As established in the above discussion concerning the veracity of statements made by counterparts in this study, Mustafa may not have answered honestly to the question of whether or not he knows how to remove excessive gasses or bubbles in the glass. He may not want to admit that he does not know how to do this, fearing that we would lose respect for him or this potential weakness would somehow become known to others. This possibility of an untruthful answer cannot be excluded. However, this does not discount the conclusions drawn from Mustafa's statement: the point is that he would perceive the removal of these bubbles as diminishing the value of his product to his consumers. Thus, he either does not pursue learning how to remove these bubbles or already knows how to remove the gasses and chooses not to do so. As a result of either of these choices, his glass products continue to be filled with tiny bubbles, which his consumers seek and admire.

This is a prime example of how ethnoarchaeology can improve the interpretation of archaeological data by exposing the researcher to alternative theories to which he/she would not have arrived through logic alone. However, direct analogy does not apply here since machined glass did not exist during Roman times, and therefore, the presence of bubbles in Roman glass at Karanis cannot be interpreted in a parallel manner. Nonetheless, this ethnographic example has shown that there are alternative reasons, often social, as to why a technology is implemented to produce a given product. It is not sufficient to assume that a lack of technological acumen used

to produce a given object signifies a lack of knowledge or skill. Identifying the consumers and their desires is at least one other means to explain different levels of technological applications.

"Consumption is a creative process that is determined both by the cultural perceptions of the consuming group and by the kinds of identities that consumers wish to construct for themselves" (Jones 2002: 96). Thus, consumption need not be driven by rationality, efficiency, or necessity (Douglas and Isherwood 1979 in: Jones 2002: 96). Appadurai stipulates that one should treat "demand, hence consumption, as an aspect of the overall political economy of societies" (1986: 29).

> Demand, that is, emerges as a function of a variety of social practices and classifications, rather than a mysterious emanation of human needs, a mechanical response to social manipulation… or the narrowing down of a universal and voracious desire for objects to whatever happens to be available (Appadurai 1986: 29).

However, there is a reciprocal relationship between consumption and production: social and economic forces dictate the demand, but also demand has the potential to manipulate, to some degree, these social and economic pressures (Appadurai 1986: 31). Consumption is affected by social structures and also must be discussed as a mode for studying ancient trade and economics. For instance, consumption of objects in certain contexts can assist in legitimizing political structures or in displaying a consumer's social identity and/or compliance to a certain set of values (Morely 2007).

8.6 Ethnoarchaeology and Value: Concluding Remarks

There are two main goals of this ethnoarchaeological study. One is to explore modern relationships between glass value and technology to aid in the interpretation of archaeological material from Karanis. Diachronic changes in the modern Cairene glass industry may clarify

variables driving change in the glass industry or in the products manufactured during the Roman Period. Although mechanization and industrialization of the glass industry worldwide have not greatly affected the technology and methods used in the two modern glass workshops in Cairo investigated in this study, these and other changes in the glass industry have drastically influenced the type of consumers who buy Cairene glass products and consequently, the products themselves. In the 19th and 20th centuries, mechanized glass factories abroad and eventually within Egypt marginalized the local market for glass produced by small workshops. As a result, these workshops shifted focus to tourists rather than local consumers. Since tourists desire hand-made glass from Egypt rather than machine-made, these workshops continued to produce glass full of bubbles that act as clear markers of a hand-made product. Although a direct analogy does not apply here since machined glass did not exist during Roman times, these findings demonstrate how a lack of technology does not always represent a lack of knowledge, but rather, producers can make choices to omit a technology due to social and/or economic reasons. When evaluating archaeological material, then, we must ask, are there indications in the ancient glass assemblage that consumer demand differs from what we might expect?

Technology, can often impart value to an object. Certain technologies, such as those implemented to produce the dichroic glass of the Lycurgus Cup, greatly increase the value of an object. According to Oppenheim (1970), the manufacture and coloration of glass was an elusive process in past societies in which ritual played an important part. "Secrecy and ritual would have led to there being restricted communication of technological information about glass making (including the construction of glass furnaces and the manufacture of crucibles from the appropriate clays)" (Henderson 2000: 60). Technological knowledge possesses "both a transformative and political potential" (Dobres 2000:4-5). Since "technology always has the

possibility of being about relations of power, the diffusion of technical knowledge was also dependent on what Costin refers to as the context" (Dobres 2000:4-5; Costin 1991).

Cairene glass workers' assessments concerning the value of their products also informs the complicated relationship between technology and value. Mustafa emphasized frequently that he was the sole person in Egypt, and in some cases the world, who could produce a certain type of glass. He priced these items higher than a 20% markup from production and labor costs because they demonstrate his secret knowledge, which renders these vessels more valuable. Other technologies, such as those required to make certain colors, such as red, deep blue, and opaque colors, impart value not only because they require a specialized knowledge, but also because they require ingredients or processes that add additional manufacturing costs (ingredients and/or time).

8.7 Glass Manufacturing: Chemical Analysis, Morphology, and Value

The pXRF analysis and EPMA analysis I conducted is a crucial component to this research on the value of Karanis glass. Glass composition results from the initial phase of glass manufacturing: the selection of raw materials and the making of glass. In this section, I will explain the implications of the compositional groups I establish in Chapter 5, and how these various compositional types may have been valued differently by the makers and users of these glass objects. I give particular attention to what I refer to as "Aqua" glass and "Mixed Mn/Sb" glass, as the composition of these two types strongly suggest they represent recycled glass. I address how this study contributes to the debate regarding the location, organization, and scale of glass manufacturing during the Roman Period. I also discuss life histories of rectangular bottles,

unguentaria, and oil flasks to place the Karanis glass assemblage in better overall context within Roman Period glass consumption.

8.7.1 Colorless Glass

Colorless glass comprises the majority of samples included in this study. As mentioned, selection bias may play a small role in the inflation of colorless glass samples compared to other types, but there is no doubt that colorless glass is ubiquitous at Karanis during the Late Roman period (4th-6th centuries CE). Antimony-decolorized glass comprises over 50% of the total glass sample population. Harden states that Colourless wares a and b (Fabrics 1 and 2) are typically earlier wares (1936). In Chapter 5, I demonstrate through Read's recursive method that there is an association between Harden's fabrics 1 and 2 and antimony (Sb)-decolorized glass. Therefore, the present study negates Harden's claim, because over 91.5% of the datable glass dates to the Late Roman period and 53.6% of these datable finds are Sb-decolorized glasses (see repeat table below, Table 8-2). The frequency of Sb-decolorized glass in this assemblage also contrasts with compositional studies of glass from other sites in Egypt. Antimony-decolorized glass only comprises less than 22% of the glass sampled from Bubastis, and none of these samples have been stylistically dated to the Late Roman period, but only to the 1st-3rd centuries CE).

Table 8-2. Descriptive statistics of datable finds, n=153

Date * Basic Chem Grp Crosstabulation

		Basic Chem Grp					
		Aqua	High Mn/low Sb	Low Mn/low Sb	Mixed Mn/Sb	Sb Decol Glass	Total
Date C1-C3	Frequency	0	0	0	1	3	4

		Expected Count	.5	1.0	.1	.4	2.1	4.0
		% of Total	0.0%	0.0%	0.0%	0.7%	2.0%	2.6%
		Std. Residual	-.7	-1.0	-.2	1.0	.6	
	C3-C4	Count	1	0	0	1	7	9
		Expected Count	1.1	2.2	.1	.8	4.8	9.0
		% of Total	0.7%	0.0%	0.0%	0.7%	4.6%	5.9%
		Std. Residual	-.1	-1.5	-.3	.2	1.0	
	C4-C6	Count	17	37	2	12	72	140
		Expected Count	16.5	33.9	1.8	12.8	75.0	140.0
		% of Total	11.1%	24.2%	1.3%	7.8%	47.1%	91.5%
		Std. Residual	.1	.5	.1	-.2	-.4	
Total		Count	18	37	2	14	82	153
		Expected Count	18.0	37.0	2.0	14.0	82.0	153.0
		% of Total	11.8%	24.2%	1.3%	9.2%	53.6%	100.0%

So why would the Karanis assemblage from the Late Roman period include unusually high quantities of colorless wares? One possibility is that these wares were selectively recycled so that their composition was only slightly altered through the process of recycling. Perhaps these difference are too subtle to detect with pXRF, or the higher manganese (Mn) group (1.1.2) represents recycled Sb-decolorized glass. More than likely, however, the slightly elevated manganese (Mn) levels characteristic of Group 1.1.2 are merely due to impurities in the sand from which the glass was made. Therefore, this group could be the product of a slightly less pure sand source rather than representative of earlier glass that has been recycled and made into new objects during the Late Roman period. However, since I was able to identify several antimony (Sb)-decolorized groups, some with higher manganese (Mn) and iron (Fe) levels than 1.1.1.1, for

instance, this may suggest that these compositional types were produced through the recycling of colorless wares and the careful selection of recycled cullet in the melt.

It is possible that in general, the inhabitants of Karanis were quite affluent and could afford high-quality colorless glass. Perhaps the demographics of this town included a more wealthy percentage of the population than other towns in Egypt, such as Bubastis.

Another explanation for the elevated antimony (Sb) decolorized glasses in the Karanis assemblage is that colorless glass was highly valued and kept more frequently as heirlooms. Heirlooms are not to be considered as commodities. Kopytoff defines a non-commodity as something which is "'priceless" in the full possible sense of the term, ranging from the uniquely valuable to the uniquely worthless" (1986: 75). Heirlooms can be classified as inalienable objects, ones that are not meant to be exchanged. Inalienable possessions are those that are "imbued with intrinsic and ineffable identities of their owners" (Weiner 1992: 6). Ideally, these inalienable possessions stay within the closed context of family or lineage, from one generation to the next (Weiner 1992: 6).

Inalienable possessions often reflect and speak for a person or group's social identity (Arnould *et al.* 2004: 210). Therefore, objects that stand for the person and for the person's survival in the memory of others can often have heirloom potential (Marcoux 2001: 222). Objects have the power to "provide iconic symbols of descendants' relationships with deceased kinsfolk" and provide a means for developing, sustaining, and shaping memories (Arnould et al 2004: 212).

Lillios (1999) affirms that a proper anthropological evaluation of heirlooms necessitates both a life history/biographical approach (Appadurai 1986; Kopytoff 1986) and a contextual approach. The latter identifies and compares the various contexts in which the artifacts were

found within the archaeological record. This provenance information is crucial in the recognition and interpretation of heirlooms along with other cultural material recovered. Consequently, a holistic approach of studying material culture includes both "diachronic and synchronic perspectives" (Lillios 1999: 241).

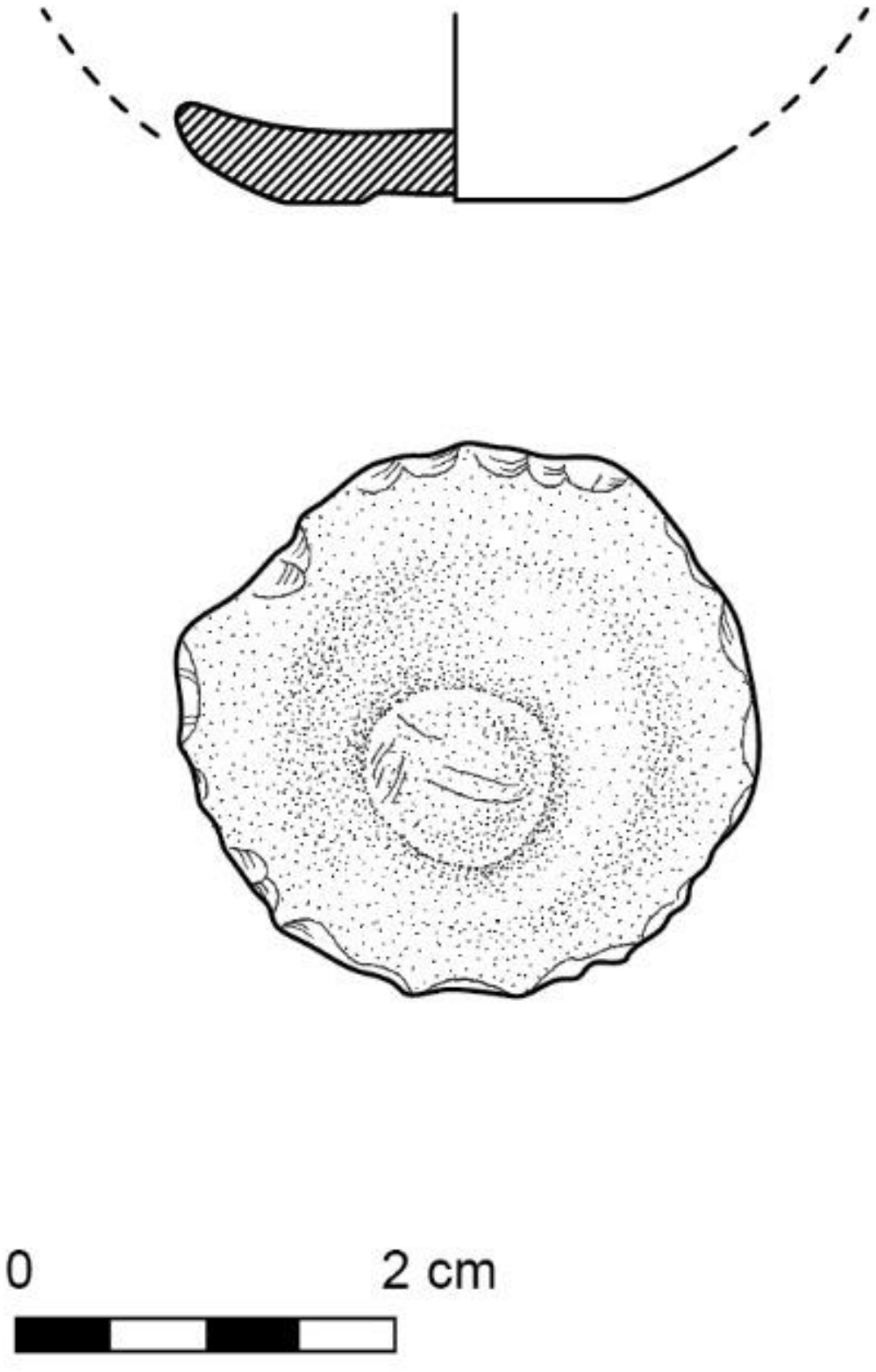
Harden (1936: 25) asserts, "glass in Roman Egypt was a luxury—at any rate till the fourth century—and was likely to be carefully preserved and handed down from generation to generation, even when a vessel was broken it was sometimes refashioned and re-used." If blown glass became commoditized around the fourth century as Harden suggests, did certain types of glass maintain their prestige? Was colorless glass valued over other types due to the skill, expertise, and decolorizers often needed to make it? Was colorless glass, then, kept more often as heirlooms?

My contextual analysis did not result in the identification of heirlooms. Harden, however, identified some examples and also inventories items found in various hoards from Karanis (see Table 8-3 in section 8.9 below). A comparison of these items and the archaeological context of the recently excavated material, however, sheds light on the value of various types of objects as well as the identification of potential heirlooms found in hoards (see section 8.9 below).

Yet another explanation for the large percentage of Antimony-decolorized glass at the site is that colorless objects were reused after being damaged or completely broken. Highly valued glass objects sometimes were repaired or used in their broken state after being damaged. Harden, for example, identifies two examples of nearly colorless bowl bases that had been broken accidentally, and then subsequently chipped off the bowl body to be used again independently (1936, numbers 176 and 177). One of these bases was painted, perhaps after

broken off the original vessel (Harden 1936). One water clear colorless base (Group 1.1.1.1, Antimony-decolorized glass) found in Area KAE during URU excavations also shows evidence of reuse. It appears to be a base of a flask that was intentionally chipped away from the rest of the vessel. The edges are chipped finely to produce a nearly round piece of glass, resembling an inlay for jewelry (see Figure 8-1 below).

Figure 8-1. Base of a colorless flask, SPEC ID 573, showing evidence of secondary use. Notice chipped and retouched edges. Drawing by Susak Pitzer and rendering by Jennifer Dillon.



8.7.2 Aqua Glass

I refer to Group 1.3.1.1 as "aqua" to distinguish it from Roman blue-green glass of the 1st-3rd centuries as well as the samples identified in Foster and Jackson (2009). Blue-green glass was a very common fabric type during the 1st-3rd centuries CE (Paynter 2006; Silvestri 2008). Blue-green glass is missing completely from the analyzed assemblage from Bubastis (Rosenow and Rehren 2014). Since Bubastis was occupied during the 1st-3rd centuries CE, the absence of this type is remarkable (Rosenow and Rehren 2014).

Since the Karanis glass corpus analyzed in this study primarily dates to the Late Roman period, it is unclear whether or not blue-green glass is common at Karanis during the 1st-3rd centuries CE. Harden notes that a glass, which he identifies as "Fabric 9" is found in both early and late archaeological contexts and that the manufacture of this type of glass spanned the entire occupation period of Karanis (1936). However, it is not entirely clear if Fabric 9 glass from this earlier period identified by Harden represents Roman blue-green glass or another compositional group yet unidentified. I have demonstrated through chi-squared analysis and Read's (2007, 2015) recursive method that Group 1.3.1.1 is associated with Harden's Fabric 9, bottle ware. This means that this compositional group can be identified fairly accurately through an evaluation of the outward appearance of the material. Further chemical analysis of aqua colored glass dating to earlier periods (1st-3rd centuries CE) from Karanis is needed to test if they are the same compositional group as these Late Roman period glasses I have identified, or if they are compositionally distinct.

Group 1.3.1.1 and its derivatives I have identified in Chapter 5 may represent recycled blue-green glass from earlier periods (1st-3rd centuries CE) mixed with antimony-decolorized

glass. Perhaps earlier blue-green glass was mixed with the antimony-decolorized glass to extend its volume (as suggested by Jackson and Paynter 2015). This would explain why some of the Aqua glass is virtually colorless and high in antimony. Electron microprobe of one aqua-colored rectangular bottle from the Kelsey Museum yielded remarkable results. SPEC ID 823 presumably dates to the late 2nd to early 3rd century CE, according to Harden's proposed dating of 5000 houses excavated by the University of Michigan (1936). As mentioned in chapter 5, the unique composition of this sample suggests that it may be a plant ash based, rather than natron based glass. Plant ash based glasses are quite rare during the Roman Period, when natron was almost exclusively used as a fluxing agent. It must be noted that there are other explanations for the high P_20_5 and MgO characterizing this sample: fuel and/or crucible contamination cannot be discounted as a possibility (Jackson and Paynter 2015; Mark Walton, Personal Communication, April 2015).

However, if this glass represents a plant ash based glass it is possible that some or all of Group 1.3.1.1 is also of this type, or contain amounts of these plant ash based glasses in a recycled melt. SPEC ID 823 was chosen for electron probe micro-analysis (EPMA) because it was thought to represent the same compositional type as Group 1.3.1.1 based on its outward appearance. It may date earlier (late 2nd-early 3rd centuries CE), however, based on the dates for houses given in Harden (1936). Further chemical analysis of a large sample population of these Aqua glasses using EPMA or LA-ICP-MS is necessary. These methods can measure manganese (Mg), phosphorus (P), and sodium (Na) levels and can yield absolute values for concentrations of elements so that results can be compared with other published studies.

Regardless of whether or not Group 1.3.1.1 and its derivatives represent recycled glass and/or plant ash based glass, I have shown that it can be isolated as a distinct compositional

group through quantitative analysis of pXRF raw counts. A chi-squared analysis of compositional type and form also reveals that toilet bottles made from Group 1.3.1.1 and Mixed manganese-antimony (Mn Sb) glass are preferred types. This means that there was a strong preference for using these recycled wares for toilet bottles. A chi-squared with more generalized form categories also shows that rectangular bottles and toilet bottles both were commonly made from Aqua glass. Harden also noted the pattern that rectangular bottles and toilet bottles are the most common forms for Fabric 9, hence, the reason why he referred to this fabric type as "bottle ware" (1936).

Roman blue-green glass seems to be a common compositional type for rectangular bottles and *unguentaria* throughout the Roman Empire during the 1st-3rd centuries CE. Rectangular bottles made from blue-green glass belong to one of the most commonly occurring vessel types during the 1st and 2nd centuries CE (Bingham and Jackson 2008; Foster and Jackson 2009), most likely used to store and transport liquids, such as olive oil and wine (Charlesworth 1966; Harden 1936). Blue-green glass vessels dating to the Late Roman period are less common, however. Foster and Jackson (2009) identify 8 samples dating to the 3rd-4th centuries CE out of 376 naturally colored glass specimen in their dataset. They tentatively suggest that this glass represents manufacturing on a more local scale, perhaps even in the north-western provinces where it was found. They note that the composition of these glasses are similar to the 3rd century blue-green glass was found at Leicester (Jackson 1994) and blue-green glass from Aosta in Italy (Mirti et al 1993) because there are elevated levels of copper, antimony, and manganese (Foster and Jackson 2009).

There is an ongoing debate regarding the manufacturing origins of blue-green glasses of the 1st-3rd centuries CE. Foy *et al.* (2000) and Nenna *et al.* (1997) suggest that these earlier blue-

green glasses have Levantine origins and that Egyptian natron was used as the fluxing agent. Freestone *et al.* (2000), however, reject this theory based on the ratio of lime to alumina. Because of oxygen and neodymium isotopes, some suggest even a Western Roman Empire origin for these earlier blue-green glasses (Brill 1999; Leslie *et al.* 2006; Degryse and Schneider 2008).

Group 1.3.1.1 glasses have elevated levels of manganese (Mn) and antimony (Sb); therefore, it is possible that they represent a similar group as Foster and Jackson's (2009) blue-green glasses. However, the EPMA sample (SPEC ID 823) shows significant differences in composition, such as higher titanium (Ti), iron (Fe), and potassium (K), and lower lime content. The most notable differences, however, are the elevated magnesium and phosphorus (given as oxides, MgO and P_2O_5, for EPMA results) levels of this sample, as mentioned above and in Chapter 5. Rosenow and Rehren (2014) identify 4 samples of blue-green colored glass that have elevated P2O5 and MgO, and moderate to high levels of Mn and Sb. Three of the four samples are stylistically dated to the 1st-2nd centuries CE. They conjecture that these represent plant ash based glasses. SPEC ID 823 matches the composition of these glasses more closely than other previously identified glass types. Since Group 1.3.1.1 glasses date to the Late Roman period, however, no published glass studies seem to have identified a similar group.

Considering the chemical composition of SPEC ID 823 as well as the relative glass composition of Group 1.3.1.1 compared to other types identified through pXRF, it is possible that Group 1.3.1.1 and its subgroups represent manufacturing on a more local scale. The preferred types identified through chi-squared analyses and Read's (2007, 2015) recursive method—rectangular and *unguentaria* made from Aqua glass--also support this theory. Since rectangular bottles and *unguentaria* were most likely valued for the commodities they contained,

rather than for the vessel themselves, they were made from lower quality, and most likely, recycled glass. Rectangular bottles would have been especially cheaper to manufacture, since they are typically mold blown, which is a technique that can speed up the process of manufacture as well as ensure standardization in vessel volume and dimensions. Based on Mark Taylor's experimental archaeological research, he estimates that one glassblower can produce five rectangular bottles an hour and 7500 bottles per year, if working 6 hours a day, five days a week (1997).

It is probably that these rectangular bottles and *unguentaria* were manufactured in the same general region in which the commodities they contained were produced to avoid the high cost of importing glass containers to house and transport oils and liquids. Alexander Severus (222-35 CE) imposed taxes on glass exports[17] which were reinstated by Aurelian (270-5 CE),[18] and later remitted by Constantine (306-37 CE)[19] (Harden 1936; Isings 1957; Trowbridge 1930). These taxes would have encouraged local manufacturing of glass to use as containers for liquid commodities.

Archaeobotanical and other archaeological remains recovered by the URU Project provide strong evidence that Karanis had a substantial olive oil production industry. Kandace Pansire surveyed and documented stone implements used for pressing olives and other oil plants, including limestone olive press bases, large rotary grinding stones, and limestone round topped weights and/or crushing rockers (Cappers *et al.* 2013). Large amounts of olive pits and safflower seeds have been recovered from the site during the URU Project as well, supporting a thriving

[17] Lamprid. *Alex. Severus,* 24,5

[18] *Vopiscus, Aurelianus*, 45, 1

[19] *Codex Theod.* 13, 4, 2

industry (Barnard *et al.* in press). In addition, remains of olives (No.0285) and safflower seeds (No. 2694) from Karanis are curated at the Agricultural Museum in Dokki, Cairo (Cappers and Hamdy 2007).

Harden remarks that toilet bottles and rectangular bottles made from Fabric 9 date more commonly to the earlier, second-century houses at Karanis (1936). My research, however, confirms that these types are still prevalent in the 4th-6th centuries CE. Therefore, future URU excavations of earlier stratigraphic layers at Karanis may yield an even higher volume of aqua colored *unguentaria* and rectangular bottles. Given that there are few published samples of blue-green glass potentially similar to Group 1.3.1.1 glass, the large amount of vessel fragments belonging to this group (n=83) in this study are quite astounding. The volume at Karanis suggests that vessels made from Aqua glass were either disproportionately consumed by denizens of Karanis compared to other areas of Egypt and the Roman Empire. Or, another explanation could be that these vessels were tied to a commodity produced at Karanis, such as olive and/or safflower oil. There is textual evidence that olive oil was exported from Egypt to other areas of the Roman Empire (*Periplus Maris Erythraei*, section 6, Trans. Schoff 1912). This could account for the few examples found in the western provinces. Harden states that "the occasional examples of dark green cylindrical and rectangular bottles and variegated toilet bottles of Alexandrian type and fabric that occur in the west denote not so much a trade in glass as a trade in the commodities they contained" (1936:44).

Harden suggests an Alexandrian origin for these types. However, given that there is textual evidence that Oxyrhynchus had a glass workshop (see Chapter 2), it is quite possible that there is an even closer source of manufacturing of these aqua vessels. Although I suggest that the Oxyrhynchus glass workshop would have been a secondary glass workshop, this does not

negate the possibility that they were recycling broken glass vessels and remelting them to make new and relatively cheap vessels. The preferred type, Mixed manganese/antimony (Mn Sb) glass and toilet bottles also suggests that these morphological types were made from recycled material.

If SPEC ID 823 is, indeed, plant ash based glass and Group 1.3.1.1 are also of this type, then this would suggest a local primary workshop somewhere in Egypt. Rosenow and Rehren (2014) also suggest that the potential plant ash based glasses form Bubastis may have Egyptian origins. Without evidence linking these plant ash based glasses to a particular primary glass manufacturing site, further chemical analysis of this glass type may shed light on its manufacturing origin.

8.7.3 Mixed Manganese/Antimony Glass

The Mixed Manganese/antimony Group identified in this study most likely represents recycled glass. What sets this group apart from the aqua group is that these glasses are quite heterogeneous in composition compared to the aqua group. This may signify that the glass types recycled and combined were not as carefully sorted and selected as they were to produce the Aqua glass. The composition of each batch of recycled glass varied quite a bit depending on which types were combined in the melt. The fact that they were making *unguentaria* and other toilet bottles from this mixed group further support that this compositional group represents recycled glass generally used for lower value glass objects.

8.7.4 High Manganese/Low Antimony Glass

This study identifies only 16.8% of the glass sample population as High manganese (Mn)/low antimony (Sb), and only a small percentage of those are tentatively identified as high manganese, iron, and titanium (HIMT) glass. My analysis in Chapter 6 shows that all conical vessels in the study were made with High Mn/low Sb glass; this is identified as a preferred type based on chi-squared analysis. Since conical vessels were not frequently chosen for compositional analysis in this study, however, the High Mn/low Sb glass may be underrepresented in the sample population. HIMT (high iron, manganese, and titanium) glass, on the other hand, dominates the Bubastis assemblage, comprising approximately 66% of the total glass sampled (Rosenow and Rehren 2014) and dating primarily to the Late Roman period.

My analysis in Chapter 6 also demonstrates that bowls made from High Mn/low Sb glass represent a preferred type. Chapter 7 confirms that High Mn/low Sb typically dates to the 4th-6th centuries CE (see Table 7-1, all 37 High Mn/low Sb samples date to Late Roman period). Harden notes that Fabrics 3, 4, and 5 are later fabrics and calls them "table ware a, b, and c" respectively because they are the common fabric type associated with dishes, bowls, flasks, and other items commonly used at the table (1936). More than likely, these three fabrics identified by Harden do not represent compositionally distinct groups; rather, the parameters he uses to distinguish the types are more based on the quality of the material, which could be due to the skill of the glass worker, kiln conditions, and other factors.

8.8 Assessing the Value of Rectangular Bottles, *Unguentaria*, and Oil Flasks

Comparing the preferred type, rectangular bottles and *unguentaria* made from Aqua glass, with oil flasks it should be pointed out that objects with presumably similar functions are

made with glass of different compositions. I offer an explanation for why these choices were made by exploring the social function of these objects and where these objects would have been used.

As mentioned, rectangular bottles and *unguentaria* are typically made from low-quality Aqua glass. Both morphological types have been linked to the function of storing oils or other precious liquids. *Unguentaria* often are designed to protect the liquids inside them: they have thick walls, small interior cavities (see Figures 8-2 and 8-3 below), and sometimes very thick, heavy bases to stabilize the vessel when it is placed on a surface (Figure 8-2). These characteristics suggest *unguentaria* typically contained high-value liquids. Due to their robust design, they are often heavy and not very portable, meaning the owner of the toilet bottle would most likely use it in the home rather than carry it on him/herself to the public bath or other relatively short distances. This is perhaps supported by the fact that *unguentaria* are not present in Karanis south (KAS) and Karanis west (KAW). These two areas are considered industrial areas, as they both contain pottery kilns and less domestic architecture.

Rectangular bottles, as mentioned, are thought to have stored olive oil and wine (see Figure 8-4 below). Both containers seemed to have been valued for the liquids they contained, rather than for the glass itself.

Figure 8-2. *Unguentaria* base from Karanis, SPEC ID 600, showing thick, heavy base. Compositional Group 1.3.1.1.1, Aqua glass. Drawing by Susak Pitzer and rendering by Jennifer Dillon.

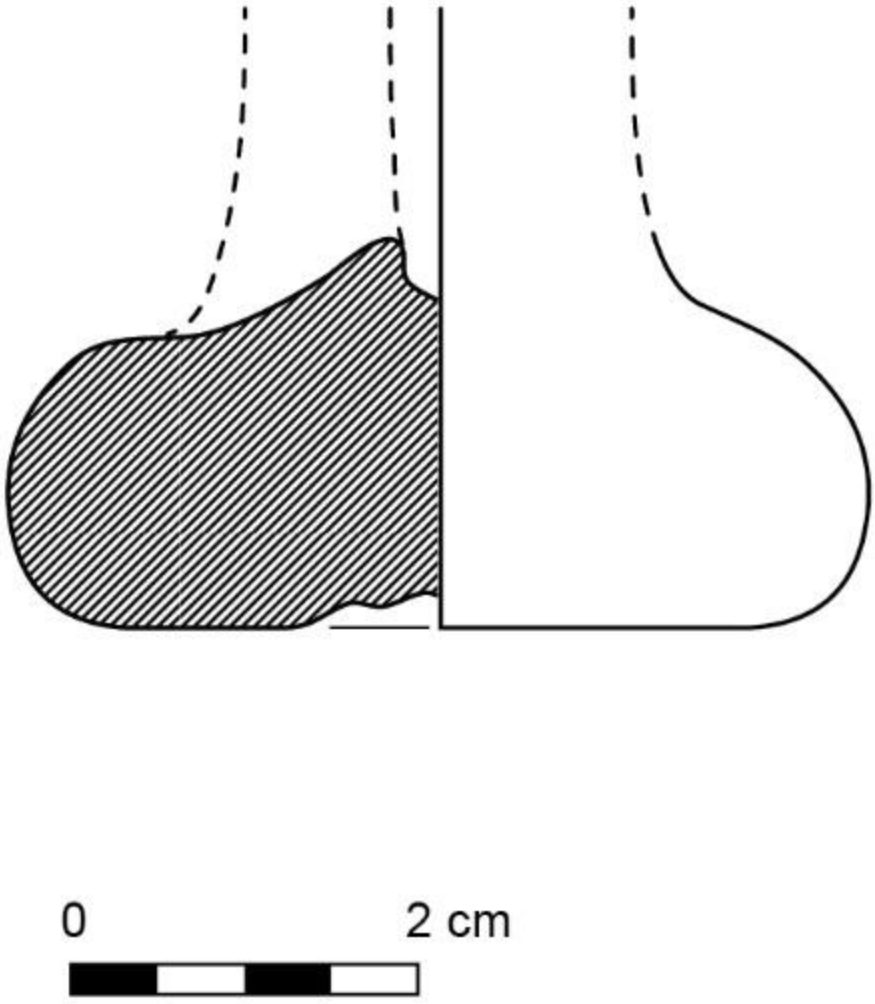
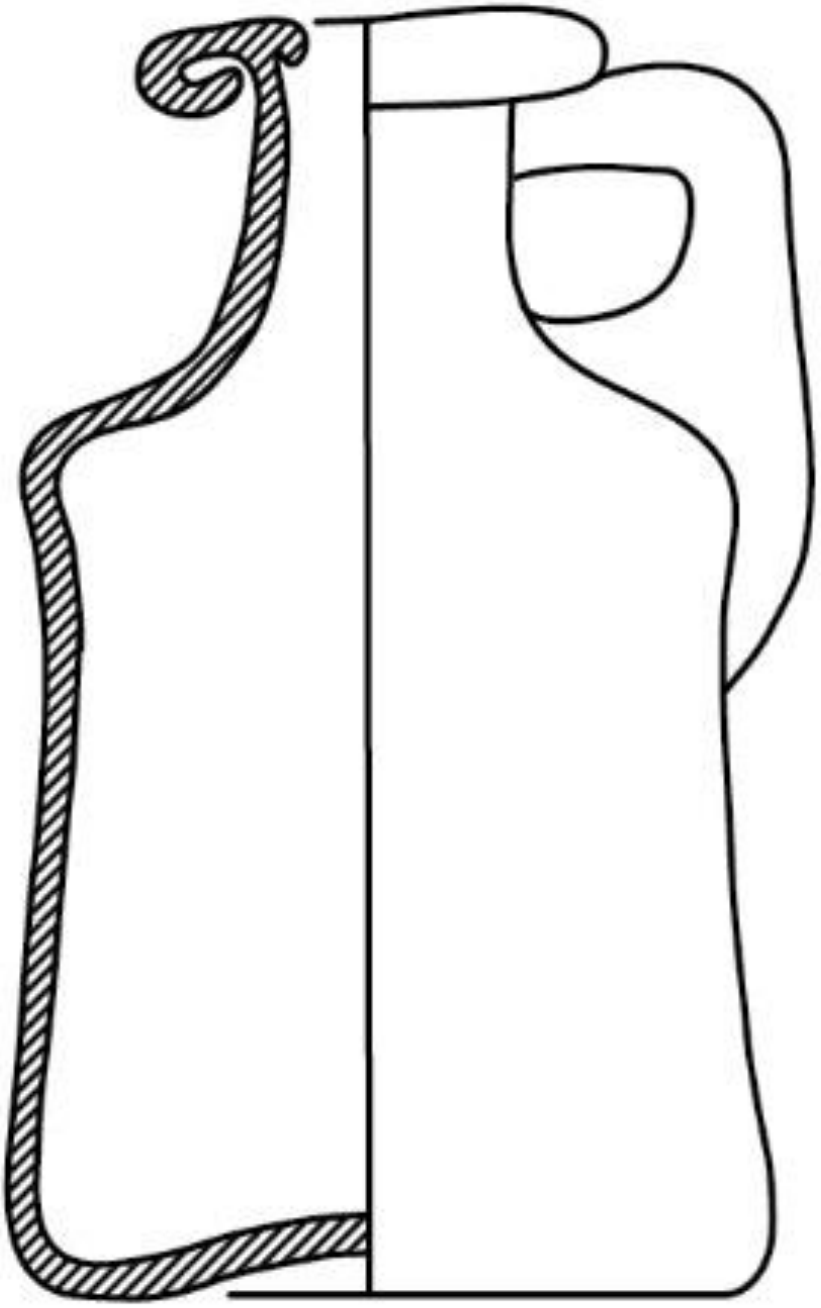


Figure 8-3. *Unguentaria* base from Karanis (not analyzed with pXRF). Shows small cavity and thickness of base and walls. Photograph by Seppi Lehner, courtesy of URU Fayum Project.



Figure 8-4. Free-blown rectangular bottle found at Karanis during University of Michigan excavations and dating to the 3rd-4th centuries CE (redrawn by Jennifer Dillon, after Harden 1936, number 757, Pl. XX). Fragments of rectangular bottles identified among recently excavated glass from Karanis are all mold blown. Therefore, the sides are flat, instead of slightly indented like those of the free-blown example below. Note, drawing is not to scale.



In contrast, all oil flasks found at Karanis were made of high-quality antimony (Sb) decolorized glass. This did not show up as a preferred type in the chi-squared analysis in Chapter 6 because the chi-squared analysis takes into account that more than half of the total glass samples are Sb-decolorized; therefore, just by chance, many two-handled flasks (Form 12) will be made from Sb-decolorized glass (Read, personal communication, 2015). Since there are 12 examples of oil flasks made with Sb-decolorized glass and no other compositional type, however, I think this trend is worth noting.

Why would oil flasks exclusively be made of a higher quality glass than *unguentaria* and rectangular bottles, which also housed highly valued liquids? I believe the answer to this question lies in the way in which these objects were used. They share similar functions, storing oils, but they would have been used differently. These oil flasks have two handles, allowing this vessel to be conveniently portable by wearing it around one's neck or hanging it on the wall of a bath house. Sometimes metal chains or handles were attached to the glass handles of the vessel (see Figures 8-5 and 8-6), or simply twine or cordage was tied to the glass handles, as an example from Karanis shows (see Figures 8-7 and 8-8). The rims of the oil flasks recently found at Karanis are funnel-shaped, to slow the flow of liquids (see Figure 8-8).

Figure 8-5. Colorless oil flask, or aryballos, with dark blue handles, bronze chain, stopper, and suspension ring, 1st century CE (courtesy of Yale University Art Gallery, Acc. 2003.36.1)



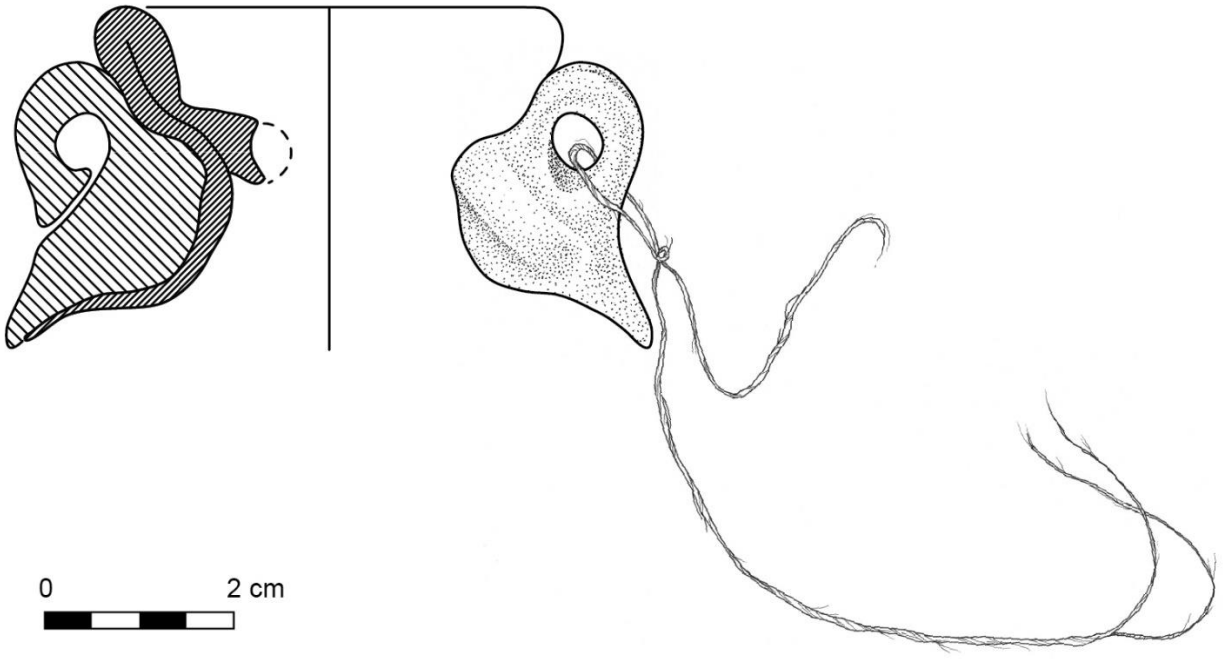
Figure 8-6. Oil flask, or aryballos, with bronze handle attached to glass handles, late 1st-2nd century CE (courtesy of Yale University Art Gallery, Acc. 1930.418)



Figure 8-7. Oil flask rim and handle with attached cordage, SPEC ID 292, (photograph by Christina Long, courtesy of URU Fayum Project)



Figure 8-8. Drawing of oil flask rim and handle with attached cordage, SPEC ID 292, (drawing by Susak Pitzer and rendering by Jennifer Dillon)



These vessels would have been used in the public sphere, since they were brought to public baths to use there, rather than exclusively in the home. The public usage of these vessels, I think, encourages conspicuous consumption of oil flasks. Therefore, denizens of Karanis purchased and used high-quality flasks made from colorless glass. Harden identifies fragment of convex bodies of vessels that have been decorated with wheel-cut or faceted designs and he presumes these to also belong to oil flasks (Harden 1936, number 774). These designs are produced through cold-cutting and require a lot of skill to execute. The bodies of these vessels were much more susceptible to breakage compared to their robust rim and handles. Consequently, the distinctive funnel rims and/or handles are the only portions identified in this study as belonging to oil flasks. Considering the high-quality glass used to make these items, the decoration sometimes carried out on these vessels, and the portability of oil flasks, it is clear they

would have functioned as a high quality prestige good to send the social message of high status or wealth. Additional support that oil flasks were highly valued items is the example of a repaired vessel noted in Harden (1936: 317, Acc. J46481). This oil flask was made from purple glass (perhaps intended to be colorless or intentionally colored with manganese). The neck had been broken, but repaired by placing a coil of glass around the broken edge to create a rim. According to Harden, the break around the neck underneath the rim coil could not have happened after the rim coil was added.

8.9 Contextual Analysis and Value

The distribution of High Mn/low Sb glass across the site of Karanis suggests there is a relationship between the industrial neighborhoods and these glass types. The chi-squared analysis of site area and basic compositional groups in Chapter 7 identifies the most deviant cells as those representing High manganese glass coming from Karanis south (KAS) and Karanis center (KAC). Since this compositional group seemed be used frequently to make bowls, one would expect to find these archaeological remains in a domestic context. Karanis "Area G" (KAG) at what presently is the highest part of the site, is a domestic area of town which also shows an association with High Mn/low Sb glass. The majority of stratigraphic units from which glass is derived in this area are trash deposits.

High Mn/low Sb glass is also tied to conical vessels, so perhaps the reason why this compositional type is disproportionately frequent in industrial areas of the site (KAS and KAC) is because these conical lamps were used as light sources more commonly in industrial areas compared to in the home. Higashi's (1990) study of conical vessels demonstrates that these lamps omitted substantially more light than terracotta lamps. So perhaps terracotta lamps were

used more frequently in the home, while brighter light sources were needed to continue industrial activities at night. I only tentatively interpret these results, however, since as mentioned, conical vessels were underrepresented in this sample population, and these industrial areas of the site, as well as the destroyed area (KAD), where High Mn/low Sb glass was also found, contain many disturbed layers.

Karanis East (KAE) on the other hand, shows a disproportionately low output of High Mn/low Sb glass in the chi-squared analysis in Chapter 7. Instead, there is a very high percentage of high quality antimony (Sb) decolorized glass found at KAE compared to other glass types (63.3% of total glass from KAE). Also, 33.4% of Sb-decolorized site recovered from the entire site is from KAE. Considering that almost all vessels in hoards found at Karanis were made from Harden's fabrics 3, 4, and 5, which most likely represents High Mn/low Sb glass, these fabrics and the vessels made from them were valued highly by the inhabitants of Karanis (see Table 8-3 below). In fact, only four out of 116 vessels found in hoard were not fabrics 3-5. These fabrics were also high quality glasses: fabric 2, colorless, and fabric 7, dark blue. The nature in which the glass was carefully stored and protected in hoards is a testament to the high value of these objects. Perhaps, then, the dearth of High Mn/low Sb glass in this study is also due to the fact that there are few samples derived from occupational layers. Instead, much of the glass comes from trash deposits, mixed fill deposits, or windblown sand deposits. Therefore, perhaps these highly valued objects were not disposed of as often in trash deposits because they continued to be used after being damaged or broken, or the broken glass was collected and recycled separately. There is evidence that HIMT (high manganese, iron, and titanium) glass, especially in later periods (4-6th centuries CE) was also recycled (Foster and Jackson 2009).

Table 8-3. Inventory of glass and other objects from hoards (Harden 1936)

Provenience	Storage of Glass Artifacts	Glass Objects/ Number of Objects	Other Objects/ Number of Objects	Fabrics
25/209 C/B-V and 27/209 C/FI-NI	20 glass objects in a ceramic pot buried beneath a floor of a room with wooden objects beneath the pot; 6 glass objects in a pot covered with a lid and buried under floor, 2 glass objects covered by palm-fiber matting.	Oval dishes-2 Shallow bowls-14 Deep bowls-2 Lamp-1 Cup on stem-1 Jars-3 Flasks-3 Cylindrical jug-1 Two-handled flask-1	Wood objects: Toy horses castanets pin	3, 4, 5
25/239 A/K X 2	2 glass bowls in a wooden box, along with three dishes of polished red pottery and a stone mortar.	Shallow bowls-2	Polished red pottery dishes-3 Stone mortar-1	3
25/293 A/A-J	9 glass vessels in a pot in a corner of a room	Lamps-2 Cup on stem-1 Jars-3 Flask-1 Bottle-flask-1 Two-handled flask-1		4
24/4029 G/F-W	11 glass objects in six wooden boxes in a room along with other objects and 1 dark blue glass flask nearby	Flasks-3 Deep bowls-5 Lamps-3 Dish-1	Wooden comb-1 Spindle whorls-2 Woven basket-1 Bronze boss-1 Bronze lamp-1	All are fabrics 3, 4, 5 except one flask is fabric 7
26/BC 61 D/B-F	6 glass vessels in a palm-leaf basket in a window of a room with other objects	Dish-1 Shallow bowl-1 Deep bowls-2 Jar-1 Flask-1	Spindle whorl-1 Wooden weavers' combs-2 Wooden hair comb-2 Stirring rod-1 Shell-1 Terracotta lamp-1 Reed basket/lid-1 Palm-leaf basket/lid-1	4
27/B 121 K/D-H, K, N, O	8 glass vessels in a large pithos covered with a stone mortar; one flask had a leather cover, one kohl pot contained 2 bone pins, and one lamp contained 4 dice	Flask -4 Kohl pot-1 Lamps-2 Cylindrical jug-1	Bone pins-2 Dice-4	All fabrics 3 or 5 except kohl pot is fabric 2

27/C 45 A/A-C	3 glass vessels near west wall	Deep bowl-1 Lamps-2		5
27/C 45 F/F, G	2 glass goblets in a hole in the sill of the niche in the west wall of a room; a pot lid covered the hole, held in place by mud plaster	Goblets-2		2
27/C 50 A/M-O	3 glass vessels below the level of the lintel of a blocked doorway in the east wall	Dish-1 Lamp-1 Flask-1		3, 5
27/C 56/G/LI-OI	4 glass vessels in a pot in SW corner of room with other objects	Shallow bowls-2 Lamp-1 Two-handled flask-1	Wooden box-1 Pottery dishes-3 Pot with cover-1	4, 3 (or 8), 5
28/B 158 A/F-H	3 glass vessels in a niche in west wall, at floor level	Shallow bowls-2 Flask-1		3
28/C 42 F/A-L	11 glass vessels in 3 separate deposits: flask leaning against east wall; 8 vessels in a pot on the floor near east wall; 2 vessels with other objects in a large *pithos* sunk below floor level near west wall; amulets, rings, and beads in wooden box near east wall	Dishes-2 Shallow bowls-3 Deep bowl-1 Bowl on stemm-1 Lamps-2 Flasks-2	*Pithos* contained: Terracotta lamps-2 Pottery Jugs-3 Wooden box contained objects of bone, glass, faience, and bronze: Amulets Rings Beads	3, 4, 5
28/C 42 J/A-AI	26 vessels in a cellar of house; some in 2 storage *pithoi*; shallow bowl propped up against wall with 2 red polished pottery dishes	Dishes-6 Shallow bowls-6 Deep bowls-4 Bowl on stem-1 Lamps-3 Cups on stem-2 Jars-2 Jugs-2	In two *pithoi*: Terracotta lamps, Bronze bells Amulets Against wall: Red polished pottery dishes-2	3, 4, 5

Karanis Areas G and Karanis east are both domestic areas of the town. Although both areas were occupied during the Late Roman period, during the fourth century CE, the eastern and western portions of the town were extensively expanded and developed (Barnard *et al.* in press). Since the majority of deposits from which samples are derived in KAG are trash deposits, the area may have fallen into disrepair or been abandoned, resulting in its use as a trash dump. The

differences in proportions of compositional types in area KAG and KAE may be due to a difference in functions of the areas excavated after the fourth century CE. What these two areas have in common is, however, that they are the only parts of the town where oil flasks were found. In general, KAE and KAG seem to yield higher valued items. Area G is a habitation area where excavation focused on a large court yard, adjacent to a three-room house with central stair well. Pig bone is frequent in the trash dumps, as well as ceramic imports, which were valuable compared to the ceramic assemblages from other areas of the site (Gupta-agarwal, personal communication, 2015).

A closer look at the nature of the archaeological deposits in which glass artifacts are found, reveals other patterns (see Ch. 7.5). The Aqua glass group most likely represents recycled glass, meaning that new vessels were formed from remelted broken glass. Aqua glass, however, is not absent from trash deposits. If this type was systematically collected and recycled at Karanis, one would expect this type of glass to be infrequently discarded in trash deposits and to occur more frequently in occupational layers than in trash deposits. Instead, Aqua glass makes up 1.5% of occupational deposit finds and 7.4% of trash deposit finds. Therefore, it is disproportionately found more frequently in trash deposits. Especially considering that the *unguentaria* and rectangular bottles, which make up a good portion (about 58%) of the total Aqua glass population, are more robust and resistant to breakage, it is significant that these types are found in greater proportions in trash deposits.

What this may indicate, however, is that this glass is not valued as highly, and therefore is discarded after being damaged or broken completely.

8.10 Concluding Remarks

Through the exploration of life histories of three types of glass objects-*unguentaria*, rectangular bottles, and oil flasks—and of object biographies of artifacts from Karanis, I demonstrate how chemical composition, morphology, use, and discard contribute to the value of glass objects. Artisans choosing to make vessels with similar functions with different compositional types are influenced by the demands of glass consumers, the social function of glass objects, and their use in the private versus public sphere.

Chapter 9

Summary and Conclusions

This multidisciplinary study employs three main approaches to assessing value of archaeological material: object biographies, contextual analysis, and life histories. Object biographies are investigated through the *chaîne opératoire* of glass manufacturing, and through chemical, morphological, and contextual analyses of recently excavated artifacts from Karanis. Analytical, historical, and archaeological evidence unveils the life history of certain glass vessel types--*unguentaria*, rectangular bottles, and oil flasks—demonstrating relationships among phases of the *chaîne opératoire* of glass manufacturing and the social function of objects.

By excavating these glass objects from Karanis, we have extended their biographies, and once again, their value changes in this modern context. The fragmented nature of this corpus from Karanis means that it may not be worth millions of dollars to a private collector or be a compelling addition to a museum. Instead, their modern value lies in the information they provide about the Roman glass industry, glass consumption at Karanis, and how value was assessed in the ancient world. They offer crucial insight into the technology, manufacturing location, mundane and social use, and discard of glass from Karanis. Secure provenance, the availability of an extensive reference collection, and minimal weathering enhance these objects' value to the field of archaeology and ancient glass, material culture, and value studies.

At least some of the glass used in Karanis was manufactured in Alexandria according to historical sources. A letter from a son living in Alexandria to his father in Karanis testifies that he was sending glass from Alexandria to Karanis. A papyrus document from Oxyrhynchus

attests that there was an organized guild of glass workers in Oxyrhynchus in the early 4th century CE. Since no primary evidence of glass working (i.e. remains of a glass furnace or glass working products) has been found at Karanis, the manufacturing location of the glass recovered from the site remains unclear.

Archaeological and chemical analysis provides indirect evidence for the origins of a specific glass types represented in the Karanis assemblage. Portable X-ray fluorescence (pXRF) spectrometry analysis of 464 samples of primarily Late Roman period vessel glass augmented by Electron probe micro-analysis of Karanis glass at the Kelsey Museum of Archaeology, aids in the discernment of two compositional groups that most likely represent recycled glass, meaning broken vessels remelted to manufacture new ones. Previous studies have identified glass recycling through chemical analysis, and recycling seems to have become a common practice by the Late Roman period, especially in the western provinces (Foster and Jackson 2009; Silvestri 2008). Evidence from a shipwreck off the coast of northern Italy in the first half of the 3rd century CE containing large amounts of cullet for glass recycling (Silvestri 2008), also suggests that recycling was occurring on a large scale. This study provides compelling evidence that recycling may also have occurred on a more local scale, in support of local industries such as olive oil production.

Archaeological evidence, such as stone implements for crushing and producing olive oil as well as archaeobotanical remains of olive pits and safflower seeds, supports a thriving olive oil industry at Karanis. The large amount of recycled Aqua glass commonly used for rectangular bottles and *unguentaria* points towards a local glass industry--in Egypt or perhaps even the Fayum—providing containers for oil products from Karanis. The Aqua glass group may correspond to Roman blue-green glass, but it has considerably lower levels of iron than the 3rd-

4th centuries CE blue-green glass identified by Foster and Jackson (2009).[20] Electron probe micro-analysis of one aqua-colored rectangular bottle from Karanis provides evidence that at least some of these Aqua glasses may be plant ash based glasses, which are quite rare during the Roman period. Although further chemical analysis is necessary to confidently identify this sample as plant-ash based rather than the product of fuel or crucible contamination, and to interrogate a larger sample size of Aqua glass, these findings have potentially crucial implications to the organization of the Roman glass industry as a whole and within Egypt as well as its potential ties to agricultural industries.

Life histories of both rectangular bottles and *unguentaria* reveals that these objects are designed to hold oils and precious liquids, and that the value of these vessels lies in the materials they contained, rather than the glass itself. It is no wonder, then, that they are produced from lower quality, recycled glass and take on suitable forms for their intended function. Through chi-squared analysis and Read's recursive method (2007, 2015), I identify toilet bottles made from aqua or mixed manganese antimony glass as preferred types (see Chapter 6). *Unguentaria* are often robustly designed with thick, heavy walls and bases, offering protection to the precious oils and liquids inside. Rectangular bottles are often mold-blown, resulting in a standard size and shape conducive for transport and large-scale consumption. Object biographies investigated through contextual analysis of glass recovered from Karanis provides clues about the use, discard, and value of objects produced from Aqua glass, including rectangular bottles and *unguentaria*.

Hoards of glass and other objects were recovered from the University of Michigan excavations in the late 1920s-30s. Objects from hoards were commonly found in wooden boxes

[20] Since absolute concentrations of elements as oxides are not attained through this pXRF analysis, these lower iron levels are determined by relative counts compared to other compositional groups identified.

or baskets, placed in niches, window sills, or holes dug into the floor. Karanidians carefully stored these glass items along with other treasured goods, accounting for the hundreds of whole, or nearly whole vessels housed at the Kelsey Museum of Archaeology. It is no coincidence that no Aqua glass was found among the 116 vessels found in hoards. There was clearly a preference to use glass belonging to this compositional group as utilitarian wares, rather than as objects to boast one's status in a social or public setting.

In contrast, a vessel type with a similar mundane function of containing oil, takes on not only a different form, but also a different composition, due at least in part to its important social function at Karanis. All of the 12 oil flasks in this corpus of recently excavated Karanis glass, are made from high-quality colorless glass. The design of this vessel form, namely the two dolphin handles and smaller, lighter body of the vessel, allows it to be portable. Oil flasks are known to have been used in public baths, so would have been transported short distances from the home to these public baths, such as the one near Area G (KAG) at Karanis. The larger handle used to carry the item either around the neck or clutched in hand means these objects would also have been in plain view while transported to the bath. The public use of these objects most likely dictates the consumers' preferred composition for these vessels, colorless glass. High-quality colorless glass not only resembles rock crystal, which was highly valued in antiquity, but also requires a specialized knowledge to produce and potentially scarce raw materials, such as antimony (a decolorizer) in conjunction with sand source(s) containing fewer impurities. Subgroups within these antimony-decolorized glasses at Karanis may represent selective recycling of colorless glasses, perhaps to continue the manufacturing of water-clear colorless glass during a time when antimony was difficult and/or expensive to obtain. That way, once broken, colorless glass maintained its value to be reformed into knew vessels that could still

be proudly shown in the public sphere. Manganese is a decolorizer that reportedly gradually replaced antimony, but it is not nearly as effective in creating a water clear colorless glass. This study indicates that water clear antimony-decolorized glass is ubiquitous during the Late Roman period (4th-6th centuries CE), but is also present in earlier periods (1st-4th centuries CE). The fact that antimony-decolorized glass comprises over half the total glass of this corpus lends support that overall, Karanis represents a fairly wealthy population, most likely the result of a thriving agricultural industry. This seems a logical assessment, given Africa, including Egypt, provided an important source of grain for Rome, especially during the early Empire (Rickman 1980). Another explanation for the large amount of colorless glass is that some colorless objects were retained as heirlooms due to their high value, or repurposed, such as the colorless base that has broken, retouched edges (see section 8.7.1 and Figure 8-1). Since Karanis east (KAE) yielded a disproportionately high percentage of antimony-decolorized glass compared to other compositional types, this may represent an affluent neighborhood at Karanis. Area G (KAG) also seems to represent an affluent neighborhood, given the amount of ceramic imports, pig bone, and colorless glass found in this area.

However, colorless glass was not the only way people could distinguish themselves through glass consumption. I fact, only 3 out of 116 vessels found in hoards were colorless, and the remaining belonged to Fabrics 3-5, what Harden calls late "table wares" (1936). These fabric types most likely correspond to High manganese (Mn)/low antimony (Sb) glass identified in this study, which includes high manganese, iron, and titanium (HIMT) glass. By definition, these wares were commonly used at the table and for entertaining guests, and comprise objects such as dishes, bowls, goblets, flasks, etc. Bowls and conical vessels made with High Mn/low Sb glass are identified as preferred types in this study through chi-squared analysis and Read's recursive

method (2007, 2015). Although these glasses often contain many impurities and bubbles, the fact that they are stored in hoards and probably used for social engagements in the home signifies that these were also objects of considerable value.

It is important, then, to consider the analogy of Cairene glass workers and their bubbly, recycled glass products. Interviews with Cairene glass workers reveal that a lack of technological acumen used to produce an object does not always signify a lack of knowledge or skill or an object of lower value. Instead, preferences of consumers can also explain different levels of technological applications and perceived quality. Since the mechanization of glass manufacturing in Egypt around the mid-20th century led to small glass workshops targeting tourists, rather than local consumers, their products changed to meet the demands and preferences of tourists. Tourists prefer to purchase crafts that are hand-made and appear to be environmentally friendly. This has encouraged the few surviving glass workshops in Cairo to manufacture bubbly glass products from recycled materials.

The geographic and cultural context of all subjects of this ethnoarchaeological study is crucial in discerning the ways in which they may serve as analogs to ancient glass workers. The Cairene glass workers use traditional furnaces and work exclusively with recycled glass. The Roman Glassmakers in the UK also use traditional furnaces, but base their furnace designs on experimental archaeological studies they executed. They also use traditional tools and techniques, and make their own glass based on modern compositional studies of Roman glass. The glass workers in Cairo and in the UK provide crucial insights into the *chaîne opératoire* of glass manufacturing, which forms the backbone of this research on Karanis glass. It aids in the discernment of decisions artisans made during the process representing shared notions of value. The four basic steps include: 1) furnace construction, 2) furnace maintenance and preparation, 3)

procurement of raw materials or cullet/glass making or melting of cullet, 5) glass working/shaping. This chain of events can be quite complicated, however, as the properties of glass allow various stages of production to occur at different locations.

Chemical analysis of the assemblage (see Chapter 5) enables the investigation of step 3 and 4, raw material procurement and the glass making process. Egyptian law prohibits researchers from removing artifacts from the country, necessitating on-site analysis; therefore, pXRF analysis is virtually the only means to interrogate the chemical composition of this recently excavated glass corpus. Through a quantitative analysis of results using raw counts, rather than calibrated results and through statistical analysis of quantitative data using Read's iterative approach (2007, 2015), I have discerned several compositional groups in addition to the two aforementioned recycled types. Considering all major and minor elements during this process, the elements upon which I subdivide the sample population are: antimony (Sb), manganese (Mn), iron (Fe), titanium (Ti), and potassium (K). Several of the groups I distinguish resemble previously identified glass groups such as: antimony decolorized (Foster and Jackson 2010; Foy *et al.* 2004; Gallo *et al.* 2013; Jackson 2005; Jackson and Price 2012; Paynter 2006; Paynter and Jackson n.p.; Silvestri *et al.* 2008), HIMT (Foster and Jackson 2009; Foy *et al.* 2003; Freestone *et al.* 2005; Jackson and Price 2012), mixed manganese antimony glass (Gallo *et al.* 2013; Foster and Jackson 2010; Jackson 1994, 2005; Paynter and Jackson n.p.; Silvestri *et al.* 2008), and Levantine 1b (Foster and Jackson 2009) (Jackson and Paynter 2015).

I follow the sequence of events involved in the fourth phase of the *chaîne opératoire* of glass manufacturing--the shaping and decorating of the vessel—while composing a morphological classification of Karanis. A case study of Karanis bowls housed at the Kelsey Museum of Archaeology demonstrated the need to refine aspects of Harden's (1936)

morphological classification of Karanis glass. Harden separates bowls into categories of "shallow", "deep", and "bowls on stem" (1936). I demonstrate the need to separate groups first according to qualitative body form differences (bell-shaped, irregular profile, convex-sided, straight-sided, etc.) before relying on quantitative dimensions (rim diameter, depth of body). Although there are quantitative grounds to separate bowls into shallow and deep categories, the bifurcation of the depth variable for these objects is essentially a product of their general shape. When groups are first divided according to qualitative differences following the *chaîne opératoire* of glass manufacturing, patterns are visible within subgroups that do not apply to the aggregate as a whole. For instance, all straight-sided bowls show a weak correlation between rim diameter and body height. When this group is subdivided first by base type, then by rim type, the correlation between rim diameter and body height becomes stronger for each of the subgroups.

Late Roman artisans preferred to use certain glass compositions for particular morphological types. Through Read's recursive method (2007, 2015) I distinguish possible functional types among the recently excavated Karanis glass assemblage. The preferred types, toilet bottles made from Aqua glass and toilet bottles made from Mixed manganese antimony glass together represent one functional type.

Through contextual analysis (see Chapter 7)I determine that high-quality, water clear colorless glass is ubiquitous during the Late Roman period (4th-6th centuries CE), but is also present in earlier periods (1st-4th centuries CE). High manganese/low antimony, Low manganese/low antimony, and Aqua glass groups are not represented in the 1st-3rd century samples; therefore, they appear to be later compositional types. Roman blue-green glass was a

common composition in the 1st-3rd centuries CE; therefore, the fact that no Aqua glass dates to this period lends some support that this group is distinct from Roman blue-green glass.

Patterns of geographic distribution of artifacts at Karanis are found through chi-squared analysis and Read's recursive method (2007, 2015). A very low percentage of High manganese/low antimony glass was recovered from Karanis East (KAE) compared to high-quality Antimony-decolorized glass. In contrast, the observed values of High manganese/low antimony glass found in areas KAC and KAS are much higher than the expected for chi-squared analysis of compositional types and site area. Since these are industrial areas of the site, more frequent use of conical lamps may account for a portion of this inflated value for High manganese/low antimony glasses. Five out of six conical vessels in this study are made from High manganese/low antimony glass and there are more conical lamps found in area KAS than the expected values in the chi-squared analysis. The stratigraphic units from which these samples in Area Karanis South (KAS) and Karanis Center (KAC) were found are primarily disturbed, however.

This study demonstrates that small fragments of material in large numbers can provide crucial insights about the society in which these artifacts were embedded when a multidisciplinary and holistic approach is employed. These diverse techniques have broader applications to the study of material culture, but are employed in this study to investigate several ways in which glass objects are valued. Chemical analysis of the assemblage enables the investigation of raw material procurement and manufacturing methods. Standing on the shoulders of an iconic glass specialist, Donald B. Harden, and comparing his assessments with the Karanis glass collection at the Kelsey Museum of Archaeology, allows me to glean the most information possible from glass fragments about their morphology and manufacturing techniques

employed. This relates to the skill involved in producing an object, the quality of the end product, as well as its intended function. I demonstrate that the manner in which objects are discarded can intimate their value and that geographic patterns of consumption in the town aid in the identification of affluent neighborhoods. By considering the *chaîne opératoire* of glass manufacturing as well as object biographies through contextual analysis, I have revealed social agency underwriting some of the decisions by artisans, including the glass composition preferred for certain vessel forms. Furthermore, a comparison of glass found in trash deposits versus those from hoards, reveals that certain object types, such as *unguentaria* and square bottles, were not typically included among the treasured items stored carefully in hoards. Nonetheless, they were commonly used by the denizens of Karanis, but discarded when broken rather than repaired or retained in a broken state. Colorless glass, on the other hand, is also not commonly found in hoards, but was sometimes repurposed and reused once damaged or broken. This indicates that colorless glass was of high value to Karanidians.

In an age when blown glass was commoditized and available to a broader demographic, fewer glass objects were considered luxury items. Karanidians tried to set themselves apart by using high-quality colorless oil flasks in the public sphere. But they did not ignore the utility of glass as a container for oils and other commodities. Glass was not just valued for its beauty and resemblance to rock crystal and semi-precious stones; rather, it was appreciated for more practical reasons, holding precious oils without tainting their scent or flavor.

Appendices

Appendix 1: Interview Questions for Cairene Glass Workers

Questions for Glass Workshop Employees and Owner

1. What is your full name?
2. How old are you?
3. How many years have you worked in the glass industry?
4. How many years at this workshop?
5. When was this workshop founded?
6. When did you start working at this workshop? How old were you?
7. Why did you choose to work at a glass workshop? How did you get involved in this line of work?
8. When did you leave school?
9. Where did you train?
10. Who trained you?
11. How were you trained? How soon after you began training did you work hands-on with the glass?
12. Did you make beads before you started blowing?
13. What kinds of vessels did you produce in the beginning stages of your training?
14. Do you enjoy working in the glass industry? Would you prefer to work in another industry?
15. Will your children follow as glass workers?
16. Why did you choose to work at this particular glass workshop?
17. What are your duties at the workshop?

18. What types of vessels do you produce at the shop?
19. Do you favor producing some vessel types over others? Why?
20. What is the most challenging thing about working with glass?
21. What techniques do you use to make certain vessels?
22. Can you and others see a difference in the glass you produce versus the glass someone else from the workshop produces? How can you tell?

Questions for Owner

1. Who is employed at the shop? Why did you employ them? Are any women/children employed?
2. How many people do you employ at the workshop? At the sales shop?
3. What are the health hazards of working in the glass industry?
4. How many hours per day do you work? Days per week?
5. Does everyone working in the shop blow glass?
6. Do people work in shifts or throughout the entire day?
7. Is there a reason for why people are assigned certain tasks? Do some jobs require more skills than others?
8. Do you have an apprentice?
9. Do you blow glass currently? If not, what role do you play now at the workshop?
10. Who selects the raw glass materials or recycled glass?
11. How do you acquire these raw materials?
12. What is the price ranges of your vessels?

Questions Regarding Products, Glass Industry, and Economy

1. Are there any other similar workshops in Cairo? How many? Do you know the people running them? Are you related to any of the other manufacturers?
2. How has the workshop changed in the last 15 years? Have you bought/made any new equipment? Any additions that have made work more efficient?
3. Is the glass industry more profitable than in the recent past? When has it been most profitable, and why do you think that was the case?
4. For whom do you intend your final products? What type of consumer do you have in mind: tourists, locals, international export? Have your customers changed over time? If so, how?
5. Have the demands/preferences of your customers changed the types of vessels you produce?
6. What kinds of vessels do you produce at the shop?
7. What are your raw materials? From where are these materials derived? Does the recycled glass only come from Egypt, or does it come from outside ever?
8. Why do you choose to use recycled glass over making your own glass or buying raw glass? What is glass made of? Are these materials difficult to access?
9. Do you always buy materials from the same supplier? How much do these materials cost approximately?
10. Are certain bottles/recycled glass easier to work with than others?
11. How do you separate the recycled glass? Is it only by color? Do you separate better quality glass out?
12. Do you clean the glass prior to remelting?
13. Why does the glass have a lot of bubbles in it? Could you remove the bubbles if you wanted? If so, don't you remove them? Have you tried different things to remove the bubbles?

14. Is this a desired characteristic? If so, desired by whom?
15. Is there an additive you can use to get rid of these bubbles or could you heat it longer to remove them?
16. Do you add anything else to the glass? Additional colors? Powdered glass? Why do you add these? How do you make your colorants?
17. How do you finish the vessels (foil over some, painting)? Who does this work?
18. What kinds of vessels do you make? What are they called?
19. From where do you get your inspiration for new ideas?
20. Where do you export your products? Do you have specific products just for export?
21. Are your export clients long-term?
22. What proportion of your products stays in Egypt vs. exported?
23. Do you customize orders? Produce new forms requested by clients?
24. Who distributes your final products, and to where do they distribute them?

Questions Regarding Furnace and Tools

1. When was the kiln constructed initially?
2. From where do you get your fuel? What percentage of your overhead costs does this comprise?
3. How often do you reline the furnace? Was it ever rebuilt entirely?
4. Can you identify the different parts of the furnace? Are certain portions meant for specific tasks/types of vessels or beads?
5. What kind of fuel do you use for the furnace?

1. Under what temperatures does your furnace operate? Are there different temperatures for different portions of the furnace?
6. Does each section of the furnace reach the same temperature?
7. Can you explain and name each part of the furnace?
8. How often does the furnace need to be repaired or rebuilt?
9. What furnace maintenance is necessary?
10. How long do you keep the furnace heated? Is it continuously on overnight?
11. How do you test the temperature of the different areas of the furnace?
12. Do temperatures fluctuate during the process of making one or many vessels? How do you cope with these fluctuations?
13. How does your annealing oven work? Do you cut off the heat at a certain point, or bring it down gradually? How long do you anneal for?
14. Do you experiment with techniques and/or kiln conditions?
15. Do these temperatures fluctuate during the process of making one or many vessels? How do you cope with these fluctuations?
16. What tools do you use? What are they called? Of what materials are these tools comprised?

Follow-Up Interview Questions

1. What is the most challenging thing about working with glass?
2. What techniques do you use to make certain vessels?
3. Do certain vessels require more skill? Which ones? Does this affect the pricing?
4. What vessels do you price highest and why?
5. Are any vessel prices affected by personal attachments you form with certain objects? Are there any heirlooms among your inventory?
6. How do you price your glass? What factors influence this price?
7. What are the ways in which you value the glass you produce? How do you think your customers value these products?
8. Who distributes your final products, and to where do they distribute them?
9. Has export of your products changed or suffered due to the recent political situation in Egypt?
10. Has the sales of your products been affected by the political situation? The production process, number or employees, or amount produced been affected?
11. For whom do you intend your final products? What type of consumer do you have in mind: tourists, locals, international export? Has the consumer of your products changed in the last two years?
12. What is your hope for the future of the glass industry as a whole as well as your business?
13. What other changes have happened over the last two years in the way in which you produce glass, the volume of glass produced, the number of employees, the type of glass produced, etc.? Why have these changes occurred?
14. Have your profits declined since the political situation changed in Egypt?

Appendix 2: Interview Questions for Roman Glassmakers

1. Describe the various steps involved in producing a Roman vessel.
2. Who constructed your furnaces? How are they built? Under what temperatures do they operate?
3. Do these temperatures fluctuate during the process of making one or many vessels? How do you cope with these fluctuations?
4. Describe your findings from the Roman Furnace Project?
5. What are the challenges of working with a wood burning kiln?
6. What fuel do you use for your wood burning kilns?
7. What research and experimentation have you undergone to arrive at the methods and tools you use to reproduce Roman vessels? How closely do you think these methods, equipment, and tools match those of ancient Roman times? From what materials are your equipment and tools made?
8. Do you make your own glass? Using what recipe? What materials? How do you produce it? Where? Do you use the same kiln to make glass as you do to work glass?
9. Who selects the raw glass materials or recycled glass? How do you acquire these raw materials?
10. Do you add anything to the raw materials? Colorants? Decolorizers, etc.?
11. What colors are most difficult to create?
12. Do you experiment with techniques and/or kiln conditions?
13. What measures can you take to increase the quality of the glass?
14. What are the limitations of working with recycled glass?

15. Which rim types are more difficult to produce and why?
16. Which forms are more difficult to produce and why?
17. What techniques do you use to make certain vessels?
18. Describe the steps involved in producing a Roman bath flask. Do you have video of the process?
19. What vessel type do you think would have been most valuable during Roman times and why?
20. What forms are more difficult to make and require more skill? Why?
21. What rim types are more difficult to make? What base types are more difficult to make?
22. Describe the process of making a Roman glass vessel and a mold blown Roman glass vessel?
23. How do you make your molds?
24. How long have you been blowing glass? Reproducing Roman vessels? Building kilns?
25. When did you start working on Roman glass reproductions?
26. How did you get involved in this line of work?
27. What are your duties at the workshop?
28. What types of vessels do you produce at the shop?
29. Do you favor producing some vessel types over others? Why?
30. Where did you learn your trade?
31. Did you have any experience in glass blowing or in the glass industry before starting work at the Roman Glassmakers workshop?
32. Who trained you in glass blowing? Where did they learn their trade?
33. Who distributes your final products, and to where do they distribute them?

34. For whom do you intend your final products? What type of consumer do you have in mind: tourists, locals, international export, museums, private collectors?

Appendix 3: Measurements and Data Collected For Glass Sample

1. SPEC ID (specialist ID)
2. Registry number
3. Excavation year
4. Provenance: area, trench, and unit number
5. Form, according to Harden's Classification
6. Form certainty
7. Fabric, according to Harden's fabric typology
8. Fabric certainty
9. Color of glass
10. Opacity
11. Portion of vessel
12. Primary technology employed
13. Secondary technology employed
14. Pontil or post technique
15. Decoration
16. Decoration color
17. Weathering, according to Harden's weathering categories
18. Dimensions of sample (length, width, thickness)
19. Rim type, if applicable
20. Rim type number (typology developed for this study)
21. Rim diameter
22. Preserved radius of rim

23. Base type, if applicable
24. Base type number (typology developed for this study)
25. Base diameter
26. Preserved radius of base
27. Body type, if applicable
28. Neck type, if applicable
29. Shoulder type, if applicable
30. Handle type, if applicable
31. Handle type number (typology developed for this study)
32. General Notes
33. pXRF Notes
34. Parallels in Harden or other publications

Additional Data Collected for Samples

1. Sketch/profile sketch
2. Photographs, including profile photographs
3. Drawings for certain samples
4. pXRF spectra and associated files

Appendix 4: Descriptive Statistics for Compositional Groups

Table A4-1. Descriptive statistics for compositional groups. Elements are given in counts/second.

Descriptive Statistics

Compositional Group		Al	Ca	Fe	K	Mn	Ti	Cu	Sb	Zr	Pb	Zn	Sr	Sn
1.1.1.1	N	126	126	126	126	126	126	126	126	126	126	126	126	126
	Minimum	.62	7.85	7.17	.02	.08	.01	.34	85.16	1.73	.24	.48	12.73	1.42
	Maximum	33.85	95.68	49.92	29.96	1.88	3.36	.91	551.46	8.62	9.09	1.14	61.36	9.29
	Mean	2.45	74.26	37.77	4.78	.87	1.64	.64	257.74	4.45	1.22	.78	28.88	5.61
	Std. Deviation	3.90	11.90	6.89	4.51	.27	.48	.10	105.19	.89	1.20	.13	5.34	1.70
1.1.1.2	N	51	51	51	51	51	51	51	51	51	51	51	51	51
	Minimum	1.37	17.66	52.06	1.67	.20	.92	.46	127.79	2.41	.42	.61	26.85	2.54
	Maximum	5.59	123.39	136.17	21.34	1.84	4.06	1.02	542.36	11.41	10.42	1.36	67.63	10.44
	Mean	2.13	88.53	67.42	7.64	1.11	2.05	.70	279.46	5.77	1.62	.90	45.16	5.81
	Std. Deviation	.55	20.45	15.13	4.61	.34	.53	.15	107.63	1.40	1.41	.16	10.60	1.75
1.1.2	N	58	58	58	58	58	58	58	58	58	58	58	58	58
	Minimum	1.14	58.23	38.97	1.81	2.06	.97	.50	62.42	3.22	.81	.40	18.96	2.50
	Maximum	7.86	139.31	116.73	14.94	4.74	3.85	1.98	569.01	16.64	3.99	1.08	59.91	8.59
	Mean	2.15	83.10	63.69	5.39	3.06	2.22	.74	270.73	5.69	2.33	.83	34.48	5.74
	Std. Deviation	.83	12.30	14.64	2.53	.75	.65	.21	81.78	2.00	.73	.13	6.36	1.61
1.2.1	N	6	6	6	6	6	6	6	6	6	6	6	6	6
	Minimum	.94	6.28	4.22	.10	-.03	.90	.59	1.33	.42	.06	.60	.16	1.17
	Maximum	2.21	73.23	113.16	29.30	17.08	5.14	.82	6.28	11.56	.61	.97	34.24	6.06
	Mean	1.78	46.44	66.49	8.52	7.61	2.34	.71	3.40	6.54	.33	.80	19.63	4.44
	Std. Deviation	.46	30.73	40.13	10.89	7.25	1.53	.09	1.73	3.66	.20	.15	12.58	1.83

1.2.2	N	3	3	3	3	3	3	3	3	3	3	3	3	3
	Minimum	1.73	27.76	34.04	2.99	46.63	1.43	.43	1.80	4.00	.04	.63	30.60	4.66
	Maximum	2.37	106.29	79.61	5.74	50.15	2.54	.77	3.83	5.99	1.08	.89	36.48	5.49
	Mean	2.00	67.71	58.58	4.46	48.01	2.05	.62	2.83	4.90	.53	.77	33.99	5.18
	Std. Deviation	.33	39.29	22.99	1.38	1.88	.57	.17	1.01	1.01	.52	.13	3.04	.46
1.2.3.1.1	N	18	18	18	18	18	18	18	18	18	18	18	18	18
	Minimum	1.78	45.44	58.57	2.16	72.86	1.66	.52	1.48	3.49	.08	.62	25.03	3.34
	Maximum	2.49	137.69	135.48	11.49	176.03	3.76	1.51	5.91	11.27	8.63	1.91	57.88	11.89
	Mean	2.18	91.78	89.72	5.06	104.92	2.66	.89	3.91	7.46	1.45	.95	42.59	6.03
	Std. Deviation	.21	19.34	19.90	2.05	29.70	.59	.24	1.28	2.15	2.12	.30	9.05	2.05
1.2.3.1.2	N	13	13	13	13	13	13	13	13	13	13	13	13	13
	Minimum	1.19	41.26	117.47	2.43	82.49	4.51	.68	.82	9.56	.36	.80	20.30	1.66
	Maximum	2.58	94.48	191.60	9.88	220.41	7.97	1.69	5.86	24.28	1.86	1.81	44.02	6.32
	Mean	2.04	71.57	155.24	5.38	141.84	6.24	1.17	3.96	18.62	1.14	1.04	35.19	4.68
	Std. Deviation	.34	15.89	22.73	2.10	33.38	.98	.31	1.70	4.46	.55	.32	6.86	1.37
1.2.3.1.3	N	3	3	3	3	3	3	3	3	3	3	3	3	3
	Minimum	2.04	51.99	189.16	1.66	82.66	3.54	.67	1.66	7.58	.42	.77	32.59	4.38
	Maximum	2.36	99.11	242.93	9.74	108.23	4.54	1.34	4.92	18.77	1.29	.97	39.38	6.33
	Mean	2.23	83.12	208.95	6.19	97.76	4.21	.96	3.11	13.20	.94	.88	37.02	5.33
	Std. Deviation	.17	26.96	29.56	4.13	13.40	.58	.34	1.66	5.60	.46	.10	3.84	.98
1.2.3.2	N	6	6	6	6	6	6	6	6	6	6	6	6	6
	Minimum	1.89	40.60	212.32	3.73	84.21	5.36	.96	1.48	15.92	.41	.68	27.96	4.44
	Maximum	2.39	88.27	343.35	18.04	191.10	10.92	1.22	3.27	36.80	4.33	1.82	37.63	7.16
	Mean	2.14	69.00	268.45	9.38	124.30	8.57	1.10	2.59	27.75	1.33	1.05	34.13	5.80
	Std. Deviation	.21	21.74	46.48	5.09	42.75	2.07	.09	.65	6.89	1.49	.41	4.10	.92
1.2.3.3	N	3	3	3	3	3	3	3	3	3	3	3	3	3
	Minimum	1.96	58.44	389.22	11.39	106.08	7.87	.87	2.35	23.18	.56	1.08	26.79	4.71
	Maximum	2.13	60.68	413.94	13.35	143.57	10.18	1.18	3.16	27.22	1.15	1.74	31.27	6.01
	Mean	2.07	59.71	399.85	12.31	124.41	8.88	1.01	2.78	25.17	.80	1.49	29.05	5.21
	Std. Deviation	.09	1.15	12.72	.98	18.76	1.19	.16	.41	2.02	.31	.36	2.24	.70

1.3.1.1.1	N	71	71	71	71	71	71	71	71	71	71	71	71	71
	Minimum	.78	23.42	42.70	.99	5.11	.72	.43	27.38	2.79	.83	.40	20.23	1.91
	Maximum	2.84	109.20	150.02	15.22	23.51	3.83	1.34	401.18	11.87	11.13	1.24	54.38	9.92
	Mean	1.99	76.74	93.54	8.09	12.70	2.40	.84	200.65	6.10	3.24	.86	35.31	5.77
	Std. Deviation	.31	18.73	21.55	3.55	5.17	.68	.17	83.55	1.30	1.99	.15	6.13	1.57
1.3.1.1.2	N	13	13	13	13	13	13	13	13	13	13	13	13	13
	Minimum	1.56	39.70	86.84	19.26	6.93	1.62	.74	45.02	4.61	1.36	.82	31.09	3.40
	Maximum	2.39	129.77	157.06	28.83	22.24	4.11	1.12	301.44	7.57	5.19	2.18	67.69	9.66
	Mean	2.06	89.26	120.99	22.36	14.79	2.64	.97	132.68	5.73	2.99	1.05	48.56	6.08
	Std. Deviation	.21	29.61	22.55	3.05	4.51	.81	.13	90.41	1.04	1.06	.36	11.13	1.83
1.3.1.2.1	N	6	6	6	6	6	6	6	6	6	6	6	6	6
	Minimum	1.58	63.39	123.15	14.35	28.52	2.11	.79	12.73	5.02	.61	.82	19.18	4.31
	Maximum	2.04	118.02	149.58	33.92	37.29	3.13	1.16	84.08	14.19	2.34	1.32	52.56	5.87
	Mean	1.84	91.49	137.10	21.19	30.61	2.52	.93	48.60	8.62	1.40	.95	40.03	5.07
	Std. Deviation	.21	22.17	11.79	6.79	3.41	.40	.14	29.55	3.34	.59	.19	11.54	.62
1.3.1.2.2	N	4	4	4	4	4	4	4	4	4	4	4	4	4
	Minimum	1.76	69.99	59.15	1.78	27.88	1.82	.65	197.28	5.45	3.81	.76	34.33	5.64
	Maximum	2.37	83.16	88.30	15.75	37.74	2.73	1.14	349.13	8.66	6.26	.96	44.43	8.52
	Mean	2.03	76.58	74.44	7.87	34.34	2.37	.93	281.52	6.93	4.74	.85	38.48	7.07
	Std. Deviation	.30	5.44	13.53	5.85	4.39	.43	.20	66.04	1.35	1.13	.08	4.46	1.23
1.3.2.1.1	N	25	25	25	25	25	25	25	25	25	25	25	25	25
	Minimum	1.74	33.44	39.63	.58	45.56	1.64	.61	7.87	4.26	.36	.59	31.86	1.93
	Maximum	18.21	112.20	271.09	30.08	125.31	3.25	4.27	27.47	10.91	3.64	1.39	62.00	8.96
	Mean	2.75	81.39	103.60	7.71	90.10	2.53	1.29	13.29	7.24	1.40	.86	47.27	4.88
	Std. Deviation	3.23	22.81	44.22	5.89	20.26	.46	.96	5.66	1.45	.75	.18	10.34	1.57
1.3.2.1.2	N	7	7	7	7	7	7	7	7	7	7	7	7	7
	Minimum	1.49	42.72	103.68	4.41	75.53	3.92	.84	7.14	9.61	.31	.60	31.17	3.35
	Maximum	3.01	112.84	206.91	14.02	159.39	6.96	1.56	25.88	22.12	2.32	2.41	43.67	7.52

	Mean	2.13	79.17	151.36	7.51	116.06	5.19	1.19	11.49	14.88	1.34	1.17	38.02	5.55
	Std. Deviation	.47	21.43	37.73	3.07	30.08	1.13	.30	6.95	4.29	.71	.64	3.94	1.35
1.3.2.2	N	12	12	12	12	12	12	12	12	12	12	12	12	12
	Minimum	1.38	34.24	84.94	3.66	45.57	1.78	.54	37.13	5.37	.99	.53	21.32	3.21
	Maximum	2.34	116.90	339.64	28.66	106.51	7.84	2.58	120.23	26.47	13.65	1.20	54.96	9.25
	Mean	1.96	80.24	144.83	14.28	73.12	3.56	1.29	71.85	9.65	4.12	.94	41.08	6.09
	Std. Deviation	.29	25.38	67.64	8.75	16.67	1.61	.60	29.50	5.66	3.96	.21	9.99	2.09
1.3.2.3	N	9	9	9	9	9	9	9	9	9	9	9	9	9
	Minimum	1.68	67.83	68.64	2.73	42.13	1.60	.71	172.64	4.87	1.21	.68	30.07	4.67
	Maximum	2.36	119.71	103.23	9.34	70.99	3.61	1.09	401.65	8.01	12.39	1.18	52.81	9.09
	Mean	2.04	86.60	85.24	5.79	58.46	2.61	.89	282.00	6.35	5.05	.90	38.19	6.90
	Std. Deviation	.20	16.31	13.03	2.07	11.28	.72	.14	80.71	.98	3.64	.14	7.82	1.69
2.1	N	4	4	4	4	4	4	4	4	4	4	4	4	4
	Minimum	2.01	53.19	136.07	4.12	3.38	1.89	.48	1.08	4.14	.09	.56	21.65	1.99
	Maximum	2.94	110.39	1236.96	13.02	81.83	7.77	5.07	82.17	16.06	12.57	.97	51.37	6.41
	Mean	2.35	85.91	625.19	8.92	37.29	4.16	2.47	24.66	8.66	4.19	.74	32.49	4.92
	Std. Deviation	.43	23.83	503.92	4.49	32.76	2.55	2.24	38.69	5.47	5.72	.20	13.34	1.99
2.2	N	3	3	3	3	3	3	3	3	3	3	3	3	3
	Minimum	1.98	65.46	81.02	3.73	168.99	2.61	.97	1.98	4.87	.22	.67	34.56	4.98
	Maximum	13.17	90.27	172.88	6.72	202.97	8.98	1.27	193.43	34.31	4.09	1.01	49.54	5.39
	Mean	5.83	81.43	139.23	4.89	186.82	6.30	1.07	66.29	19.58	1.56	.90	43.33	5.25
	Std. Deviation	6.36	13.86	50.61	1.61	17.05	3.31	.17	110.11	14.72	2.19	.19	7.81	.23
2.3	N	11	11	11	11	11	11	11	11	11	11	11	11	11
	Minimum	.01	25.30	27.65	1.80	.28	1.19	.51	4.17	2.28	19.50	.01	3.99	5.35
	Maximum	2.61	142.96	216.69	21.54	101.07	3.25	95.54	670.65	8.19	973.81	.74	58.96	41.23
	Mean	1.66	78.26	78.30	7.79	17.76	2.09	13.82	301.24	4.73	122.62	.52	29.37	14.77
	Std. Deviation	.70	32.52	55.25	5.95	30.86	.62	28.23	236.17	2.12	283.34	.20	15.34	11.90

2.4	N	4	4	4	4	4	4	4	4	4	4	4	4	4
	Minimum	1.12	86.61	185.68	34.25	2.73	5.74	.56	1.69	14.70	.17	.94	35.60	3.15
	Maximum	2.66	106.71	302.79	46.42	20.68	9.44	.69	23.72	34.54	.85	2.44	40.08	4.68
	Mean	1.82	96.91	250.68	40.57	7.75	7.58	.64	7.58	25.27	.39	1.60	37.86	3.91
	Std. Deviation	.80	8.47	48.56	5.03	8.65	1.53	.06	10.77	8.34	.31	.63	1.83	.68
2.5	N	3	3	3	3	3	3	3	3	3	3	3	3	3
	Minimum	1.93	3.58	3.83	.21	.01	1.34	.64	.29	.04	.05	.56	.11	1.30
	Maximum	2.12	7.81	32.03	.49	.28	2.62	.66	2.72	.12	.13	.79	.61	5.09
	Mean	2.04	6.11	13.38	.34	.10	1.92	.65	1.64	.07	.09	.65	.31	3.08
	Std. Deviation	.10	2.24	16.15	.14	.16	.65	.01	1.24	.05	.04	.12	.26	1.91
2.6	N	5	5	5	5	5	5	5	5	5	5	5	5	5
	Minimum	1.95	25.52	36.08	3.61	1.54	.71	.70	2.39	3.86	.54	.46	8.34	4.52
	Maximum	2.67	192.58	221.56	49.13	444.67	8.48	29.96	183.64	26.56	4.19	1.37	52.11	9.13
	Mean	2.34	97.23	145.03	18.95	124.14	3.51	7.87	51.04	10.73	1.93	.96	30.05	6.06
	Std. Deviation	.29	64.69	77.12	18.62	183.44	3.08	12.62	77.52	9.23	1.50	.33	15.60	2.08

Appendix 5: Harden's Basic Classification of Karanis Glass (1936)

I. Dishes and Plates

II. Shallow Bowls

III. Deep Bowls

IV. Bowls on Stem

V. Beakers and Goblets

VI. Conical Lamps

VII. Drinking cups and Goblets on Stem

VIII. Jars

IX. Flasks

X. Bottle-Flasks without Handles

XI. One-Handled Jugs and Bottles

XII. Two-Handled Flasks and Bottles

XIII. Toilet-Bottles

XIV. Miscellaneous Objects, Inlay, and Doubtful Fragments

Appendix 6: Chi-Squared Analysis of Dates and Body Types, Base Types, and Rim Types.

Table A6-1. 3x5 contingency table of general dates and body shape

Chi2 Dates * Body type Crosstabulation

			Body type					
			1	2	3	4	5	Total
Chi2 Dates	2C-3C	Count	3	4	4	4	3	18
		Expected Count	2.3	2.3	3.6	6.8	3.2	18.0
		% of Total	7.5%	10.0%	10.0%	10.0%	7.5%	45.0%
		Std. Residual	.5	1.2	.2	-1.1	-.1	
	2C-4C	Count	0	0	0	1	2	3
		Expected Count	.4	.4	.6	1.1	.5	3.0
		% of Total	0.0%	0.0%	0.0%	2.5%	5.0%	7.5%
		Std. Residual	-.6	-.6	-.8	-.1	2.0	
	4C-5C	Count	2	1	4	10	2	19
		Expected Count	2.4	2.4	3.8	7.1	3.3	19.0
		% of Total	5.0%	2.5%	10.0%	25.0%	5.0%	47.5%
		Std. Residual	-.2	-.9	.1	1.1	-.7	
Total		Count	5	5	8	15	7	40
		Expected Count	5.0	5.0	8.0	15.0	7.0	40.0
		% of Total	12.5%	12.5%	20.0%	37.5%	17.5%	100.0%

Table A6-2. Chi-squared results from Table A-1 above.

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	10.845[a]	8	.211
Likelihood Ratio	10.547	8	.229
N of Valid Cases	40		

a. 13 cells (86.7%) have expected count less than 5. The minimum expected count is .38.

Table A6-3. 3x4 contingency table of general dates and base class type

Chi2 Dates * Base Class Type # Crosstabulation

			Base Class Type #				
			2	3	4	9	Total
Chi2 Dates	2C-3C	Count	12	4	1	1	18
		Expected Count	13.5	3.6	.5	.5	18.0
		% of Total	30.0%	10.0%	2.5%	2.5%	45.0%
		Std. Residual	-.4	.2	.8	.8	
	2C-4C	Count	3	0	0	0	3
		Expected Count	2.3	.6	.1	.1	3.0
		% of Total	7.5%	0.0%	0.0%	0.0%	7.5%
		Std. Residual	.5	-.8	-.3	-.3	
	4C-5C	Count	15	4	0	0	19
		Expected Count	14.3	3.8	.5	.5	19.0
		% of Total	37.5%	10.0%	0.0%	0.0%	47.5%
		Std. Residual	.2	.1	-.7	-.7	
Total		Count	30	8	1	1	40
		Expected Count	30.0	8.0	1.0	1.0	40.0
		% of Total	75.0%	20.0%	2.5%	2.5%	100.0%

Table A6-4. Chi-squared results from Table A-3 above.

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	3.556[a]	6	.737
Likelihood Ratio	4.885	6	.559
N of Valid Cases	40		

a. 10 cells (83.3%) have expected count less than 5. The minimum expected count is .08.

Table A6-5. 3x5 contingency table of general dates and rim class type

Chi2 Dates * Rim Class Type # Crosstabulation

			Rim Class Type #					
			1	2	4	5	8	Total
Chi2 Dates	2C-3C	Count	1	14	1	1	1	18
		Expected Count	1.4	14.9	.5	.9	.5	18.0
		% of Total	2.5%	35.0%	2.5%	2.5%	2.5%	45.0%
		Std. Residual	-.3	-.2	.8	.1	.8	
	2C-4C	Count	0	3	0	0	0	3
		Expected Count	.2	2.5	.1	.2	.1	3.0
		% of Total	0.0%	7.5%	0.0%	0.0%	0.0%	7.5%
		Std. Residual	-.5	.3	-.3	-.4	-.3	
	4C-5C	Count	2	16	0	1	0	19
		Expected Count	1.4	15.7	.5	1.0	.5	19.0
		% of Total	5.0%	40.0%	0.0%	2.5%	0.0%	47.5%
		Std. Residual	.5	.1	-.7	.1	-.7	
Total		Count	3	33	1	2	1	40
		Expected Count	3.0	33.0	1.0	2.0	1.0	40.0
		% of Total	7.5%	82.5%	2.5%	5.0%	2.5%	100.0%

Table A6-6. Chi-squared results from Table A-5 above.

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	3.323[a]	8	.913
Likelihood Ratio	4.424	8	.817
N of Valid Cases	40		

a. 13 cells (86.7%) have expected count less than 5. The minimum expected count is .08.

Appendix 7: Base Categories

Table A8-1. Base Categories after Harden's base types (1936: 15-16) and Price and Cottam's descriptions (1998: 25-29).

#	Base Type	Short Description
1	Pushed-in	Open base rings are formed by making a constriction near the base edge and applying pressure to the underside of the base to make it concave; closed base rings are formed in a similar manner, only the underside joins with the constricted portion to form a tubular base ring
2	Padded	A base ring formed by applying a disk of glass to the bottom of the vessel and working the edges to form a ring
3	True base ring	A base ring formed by applying a ring of glass, knocked off a cylinder, to the underside of the vessel
4	Rounded/convex	Base is convex on the underside
5	Toed	Three or more small buds of glass have been pinched out from the glass to form "toes" on the underside of the vessel
6	Flat	Base is flat on the underside
7	Concave	Base is concave on the underside
8	Coiled	A coil or thread of glass is trailed on to form a ring on the underside of the vessel.
9	Stemmed	A base formed by either drawing out the glass at the bottom of the body into a twisted, solid stem and outsplaying it into a foot stand below (Harden 1936), or by applying a solid stem and then a separate disk of glass whose edges are worked to form a foot (Price and Cottam 1998).

Appendix 8: Harden's Classification of Bowls

Class II: Shallow Bowls

A. With base ring
    1. Folded Rim Outward
        a) Base ring with post technique-all true base rings
        b) Base ring with pontil technique-all padded base rings
            1. Almost rectangular contour
            2. Wide obtuse-angled contour
            3. Irregular, crooked contour
        c) Pushed-in base ring
    2. Folded rim, inward
    3. Rounded rim
    4. Coil Rim
    5. Moulded or polished rim
B. With rounded base
    1. Plain rim, rounded or polished
    2. Polished rim, with constriction at side just below
    3. Variant types of rim

Class III: Deep Bowls

A. With base ring
    1. Folded rim, outward
        a) Base ring with post technique-all true rings
        b) Base ring with pontil technique—all pad bases
            1. Bell-shaped body
            2. Convex-sided body
    2. Folded rim inward
        a) Base ring with post technique—all true rings
        b) Base ring with pontil technique—no examples
        c) Pushed-in base ring
    3. Rounded rim
        a) Base ring with post technique—all true rings
        b) Base ring with pontil technique—no examples
        c) Pushed-in base ring
    4. Coiled rim
    5. Polished rim
B. With rounded base
    1. Pillar-moulded type, with plain, rounded rim
    2. Plain rim, usually polished smooth, with constriction just below
C. With coil base
D. Flat or concave base, without ring
E. Rims from bowls of uncertain shape

Class IV: Bowls on Stem

A. Shallow bowls
B. Deep bowls

Appendix 9: Relationship between Context and Fabric Types

Table A9-1. Relationship between context and fabric types according to Harden (1936)

Excavation Date	Provenance	Date of House (CE)	Predomin-ant Fabrics	very common fabrics	common fabrics	rare fabrics	very rare fabrics
1926-27	Houses B I – B25	early second to early third century	1,2,8,9				3-7
1924-26	5000 Houses	mid-first to early third (disputably late second century to early third)	1,2,8,9				3-7
1927-29	C-Period Houses	early second to mid-third century (disputably late second century to mid-third)	1,2,8,9				3-7
1926-27	Houses B 26-B 59	late third to early fourth century		3, 5	2	1, 8, 9	4, 6
1927-29	B-period Houses	mid-third to mid-fourth century		3, 5	2	1, 8, 9	4, 6
1924-26	100 and 4000 Houses	fourth and fifth century	(2 in House 130 C)	3, 5 (8, 9 in House 130 C)	6, 7		1, 8, 9
1926-29	A-Period Houses	mid-fourth to mid-fifth century		3, 5	6, 7		1, 8, 9

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