IN FLUX:

Glass, Technology, and the Glassmaking Industry of the Middle Byzantine and Early Islamic (8th-12th centuries CE) Eastern Mediterranean—the Archaeology and Archaeometry of a High Temperature Craft

By

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LIST OF CHEMICAL AND ANALYTICAL ABBREVIATIONS

Symbols and Names of Pertinent Chemical Compounds or Elements:

Al_2O_3	Alumina	MnO	Manganese oxide
As_2O_5	Arsenic pentoxide	Na_2O	Soda
BaO	Barium oxide	NiO	Nickel oxide
CaO	Lime	P_2O_5	Phosphate
Cl	Chlorine	PbO	Lead oxide
CoO	Cobalt oxide	SO_3	Sulphur trioxide
Cr_2O_3	Chromium trioxide	Sb_2O_5	Antimony oxide
CuO	Copper oxide	SiO_2	Silica
Fe_2O_3	Iron oxide	SnO_2	Tin oxide
K_2O	Potash	TiO_2	Titanium oxide
MgO	Magnesia	ZnO	Zinc oxide

Symbols and Names of Pertinent Trace Elements:

Li	Lithium	Zn	Zinc	Ba	Barium
Be	Beryllium	As	Arsenic	La	Lanthanum
B	Boron	Rb	Rubidium	Ce	Cerium
Sc	Scandium	Sr	Strontium	Pr	Praseodymium
Ti	Titanium	Zr	Zirconium	Ta	Tantalum
V	Vanadium	Nb	Niobium	Au	Gold
Cr	Chromium	Ag	Silver	Y	Yttrium
Ni	Nickel	Sb	Antimony	Bi	Bismuth
Co	Cobalt	Cs	Cesium	U	Uranium
W	Tungsten	Gd	Gadolinium	Tm	Thulium
Mo	Molybdenum	Tb	Terbium	Yb	Ytterbium
Nd	Neodymium	Dy	Dysoprosium	Lu	Lutetium
Sm	Samarium	Ho	Holmium	Hf	Hafnium
Eu	Europium	Er	Erbium	Th	Thorium

Groups of Chemical Elements:

Alkali Metals	Li, Na, K, Rb, Ce
Alkaline Earth Metals	Be, Mg, Ca, Sr, Ba
Transition Metals	Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Y, Zr, Nb, Mo, Ag, Hf, Ta, W, Au
Other Metals	Al, Sn, Pb, Bi
Metalloids	B, Si, As, Sb
Rare Earth Elements (REE)	La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Th, U

Chemical Analytical Strategies:

AAS	Atomic absorption spectroscopy
BSE	Backscattered electron
EDS	Energy dispersive spectrometry
EMP	Electron microprobe
EPMA	Electron probe microanalysis
LA-ICPMS	Laser ablation inductively-coupled plasma mass spectrometry
NAA	Neutron activation analysis
OES	Optical emission spectroscopy
SEM	Scanning electron microscopy (or the microscope itself)
XRF	X-ray fluorescence
WDS	Wavelength dispersive spectrometry

LIST OF PERIODS AND POLITICAL AND/OR CULTURAL ENTITIES

General Chronological Periods:

- Early Byzantine Period — ca. mid-4th to early-7th centuries CE
- Middle Byzantine Period — ca. mid-9th to early-13th centuries CE
- Early Islamic Period — ca. early-7th to early-12th centuries CE
- Middle Islamic Period — ca. mid-12th to 14th centuries CE
- Late Islamic Period — ca. 15th to 18th centuries CE

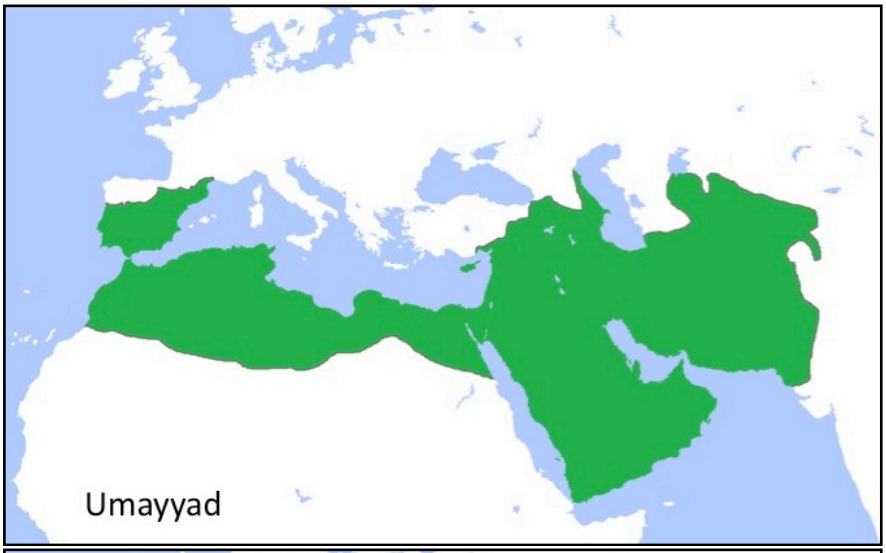
Political and/or Cultural Entities:

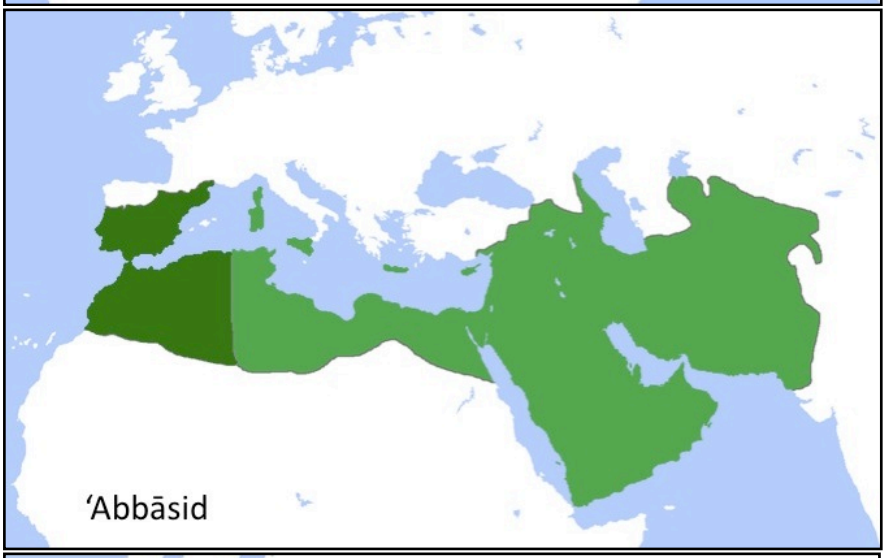
Name	Dates in power	Regional notes	Other notes
Byzantine Empire	ca. 395-1453 CE	Initially the eastern lands of the Roman Empire; by the 7th century CE limited to northwestern Anatolia and parts of Greece, Bulgaria, Italy	Most of Anatolia lost by 1071 CE to the Seljuks
First Bulgarian Empire	ca. 681-1018 CE	Northeastern Balkans; at height stretched from the Black Sea to the Adriatic Sea	Founded by the Bulgars, uniting with south Slavic tribes
Second Bulgarian Empire	ca. 1185-1396/1422 CE	Northeastern Balkans	
Umayyad Caliphate	661-750 CE	North Africa, the Near East (to southern Anatolia), the Arabian Peninsula, Persia	Green area on map, page xviii
ʻAbbāsid Caliphate	750-969 CE	North Africa, the Near East (to southern Anatolia), the Arabian Peninsula, Persia	Green area on map, page xviii (dark green is Spanish Umayyad caliphate)
Ṭūlūnid Dynasty	868-905 CE	Egypt (vassal of the ʻAbbāsid Caliphate)	Independent dynasty
Fāṭimid Caliphate	909-1171 CE	North Africa, southern portion of the Levant, western coast of the Arabian Peninsula	Green area on map, page xviii
Ayyūbid Dynasty	1171-1341 CE	Tunisia, Egypt, the Levant, the western half of the Arabian Peninsula	Centered on Egypt

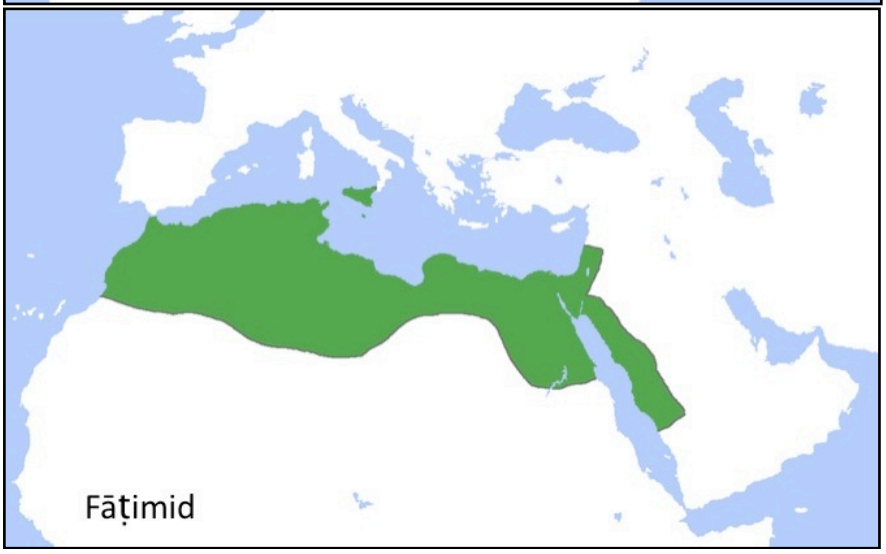
A Note on Transliteration:

An effort was made to use the appropriate diacritical marks for Arabic words and names throughout the text of this dissertation.

Maps showing the regions controlled by three pertinent Islamic caliphates:







CHAPTER ONE: INTRODUCTION

GLASS AS A SUBJECT, GLASS AS A MATERIAL, GLASS AS AN OBJECT

Glass is a truly miraculous material. It can be molded like pottery, cast like metal, and carved like stone, but by far the most exceptional property of glass is that it can be softened with heat and inflated with air to produce a vast number of vessel shapes and sizes—in the ancient world, simply no other material could do this. Invented in Mesopotamia in the third millennium BCE, glass was first used to make beads and small decorative objects, and in the mid-second millennium BCE vessels began to be made by first coating a clay core with hot glass and then scraping out this core to create a hollow object once the glass had cooled; the innovation of glassblowing was not introduced until the mid-first century BCE, but this technique quickly and irreversibly revolutionized the production and use of glass. For 5000 years glass has been an integral part of human life and a unique expression of material culture; even with the newly engineered materials of the present age (plastics in particular), the special position of glass has never truly been diminished.

The key to understanding and appreciating the history of glass is to recognize the close connection between glass structure, properties, and processing—in other words, the chemical components of glass, the qualities and characteristics or behavior of glass, and the manipulative possibilities of glass. When approaching glass as a subject of research it is imperative to investigate it as both a material and as an object, rather than as only one

or the other, in order to achieve a complete understanding and assessment of the role glass has played in human history. This may seem obvious and sensible, but it has only been in recent decades that scholarship has come to recognize the importance of acknowledging and discussing what I would call "the nature and culture of glass" together in concert.

Art historians have long dominated the field of glass studies, focusing on glass as a category of object and therefore on the extrinsic, or external, features such as form and style; chemists dominate another aspect of glass studies, focusing on glass as a category of material and therefore on the intrinsic features like chemical composition. The methods and findings of these two approaches should be compatible in theory (both figuratively and literally), but there remains a very real divide in the scholarship. This gap is accentuated and even compounded when scholars seek to understand issues of continuity and change in glass over time and across space; art historians are concerned with visual changes in glass and how these reflect and relate to cultural or social aspects, while chemists are concerned with material changes in glass and how these reflect and relate to technological aspects; neither of these perspectives take into full account the possibility that the extrinsic and intrinsic features of an artifact—the shapes, styles, and very fabric itself—form a unified whole within a narrative of continuity and change.

An integrated archaeological perspective can bridge the gap between art and science—and between objects and materials—by incorporating theories and methods from a variety of fields (art history, archaeology, anthropology, chemistry, and materials sciences) in such as way as to underscore the interrelationship of the history of the material itself with the history of the objects that were made using this material. In short,

an archaeological perspective that is concerned with the shared complexities of technology and artistry demonstrates that these two aspects are inextricably linked; archaeological research questions and methods can ultimately serve to illustrate, mediate, and promote this theoretical viewpoint.

Structures and Properties: What Is Glass?

The "glassy" state of matter is one that is neither truly a solid nor truly a liquid, but is somewhat similar to both. As a non-crystalline (or amorphous) solid, glass has the mechanical rigidity of crystals but lacks a regular, repeated crystalline structure; instead glass has the random, disordered arrangement of molecules that characterizes liquids. Moreover, glass does not have a true melting point, rather, glass becomes fluid at high temperatures and has a softening range of 700-1300 °C—depending on its chemical composition. These structural characteristics therefore directly impact and influence the properties of glass as a material:

- *Mechanical properties*: strong (weakened only by surface imperfections), hard, and elastic (it gives under stress, but to a breaking point)
- *Chemical properties*: corrosion resistant (resists chemical reaction)
- *Thermal properties*: shock-resistant (withstands intense heat or cold) and heat absorbent
- *Electrical properties*: insulating (not a conductor)
- *Optical properties*: reflects, bend, transmits, and absorbs light; transparent, translucent, or opaque (depending on additives)

In terms of composition, glass consists of three basic things: a network former, a network modifier, and a network stabilizer. As the majority of glass is formed from silica (60-80% SiO_2), typically in the form of sand or crushed quartz pebbles, this component is frequently termed the "network former." However, because the melting point of pure

silica is very high, 1600-1725 °C (beyond the range achievable by the fuels and furnaces of the ancient world, which was at least 1100 °C and possibly[1] in the range of 1100-1400 °C), it is necessary to add another ingredient—a "flux"—in order to lower the melting point of silica; the modifier also reduces the viscosity of the glass. This component is therefore known as the "network modifier," and the most common fluxes are alkaline compounds like soda (sodium carbonate, Na_2O) and potash (potassium carbonate, K_2O), or other compounds like lead oxide. However, once a flux is added the glass becomes soluble in water due to the weak chemical bonding of the network, and is thus easily susceptible to deterioration; a "network stabilizer" therefore becomes necessary, the most common of which are alkaline earth compounds such as lime (CaO) and magnesia (MgO). Although there are now many different types of glass in use,[2] soda-lime-silica glass (12-18% Na_2O, 5-12 % CaO, 60-75% SiO_2) or "SLS" glass was the most common type made in history, and even today accounts for some 90% of the glass made commercially.

From antiquity to the 18th century CE, glassmakers appear not to have known that three basic components were actually needed to produce glass, as only two raw materials (silica and a fluxing agent) are ever mentioned in documentary sources; the addition of a stabilizer was coincidental for much of glass history, provided indirectly by impurities in the silica or flux materials themselves—for example, lime could come from crushed beach shells or limestone mixed in with sand, or it could alternatively derive from the natural calcium component of plant ash soda. Because of the natural occurrence of lime

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[1] Henderson 2000: 39.

[2] According to Goffer (2007: 139), "one present-day glass manufacturer has more than 65,000 [glass] formulations on file."

and other impurities in the raw materials used to make glass, glassmakers had to take great care with the sourcing and processing of these materials—not all raw materials could be used together to successfully make glass, so a careful selection of ingredients based on their qualities (e.g., purities or impurities) and close control during the processing stages would have been necessary. For example, too much lime could result in a failed glassforming melt;[3] lime-rich sand was therefore rarely used together with lime-rich plant ash soda. As a result, the most common raw materials in antiquity were either [impure silica + pure soda] which was typically sand mixed with mineral soda, or [pure silica + impure soda] which was typically crushed quartz mixed with wood or plant ash soda. It is this basic principle that underlies much of the research into the history of glass technology and production.

Processing: Making Glass and Working With Glass

Artists or artisans today will readily tell you that the type of glass one uses has a direct impact on the capabilities of the material and the artistic possibilities of working with this particular medium. Glass is a manmade material, and as such its chemical and physical properties—and by extension, its working properties—can be to an extent manipulated or controlled by means of the raw materials and the methods of processing or manufacturing that are chosen and employed.

Some of the key material considerations for working with glass include the softening point, viscosity, stiffness, and working time of the glass. Softening point refers

[3] The best example of such a glassforming failure due to excessive lime is the glass slab at Bet She'arim, which "either did not fully melt during the firing cycle, or extensively devitrified upon cooling" (Freestone and Gorin-Rosen 1999: 105).

to a range of temperatures at which glass flows.[4] Closely related to this is a glass's viscosity, which refers in essence to the "thickness" of glass and its fluidity (which is a continuous function of temperature); in short, viscosity is a measurement of a fluid's resistance: the less viscous a fluid, the greater its fluidity or ease of movement. Thus, the softening point is more specifically the temperature at which the viscosity of glass is reduced enough so as to be workable. Low viscosity glass flows more easily than a more viscous glass, and thus viscosity is a highly important consideration for how one ultimately works with hot glass (casting, blowing, slumping, etc.). The "stiffness" of glass is another way in which glassblowers indicate the viscosity of glass, meaning the degree of difficulty in tooling the glass; glassblowers often note that glass becomes too stiff if it is recycled too many times.[5] "Working time" refers to the length of time that the hot glass can be worked before it cools sufficiently (i.e., becomes increasingly more viscous) to necessitate reheating.

As is abundantly clear, these elements are highly interrelated (being both a function of the chemical and physical qualities of the glass itself, as well as a function of temperature) and affect the amount of time and effort necessary to produce an object (Figure 1.1). However, these properties of glass are not only important technological and artistic considerations, they also connect directly to other aspects like the economic cost

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[4] Examples of the various softening points of ancient glasses (according to Goffer 2007: 145 and Table 9.7) include 865 °C for 14th century BCE glasses from Amarna (Egypt), 770 °C for 1st century BCE Alexandria (Egypt), 805 °C for 3rd century CE glasses from Mainz (Germany), 720 °C for 4th century CE glasses from Köln (Germany), and 790 °C for 9th century CE glasses from Samarra (Iraq).

[5] "When the same glass is melted many times, the quality deteriorates. This is noticeable to the gaffer as the glass becomes more 'stiff' or difficult to tool. Clear glass from the Hot Glass Show is always re-melted in addition to new batch, so no difference in quality is noticed" (from the Corning Museum of Glass website, frequently asked questions about the Hot Glass Show: http://www.cmog.org/frequently-asked-questions#faq-108054).

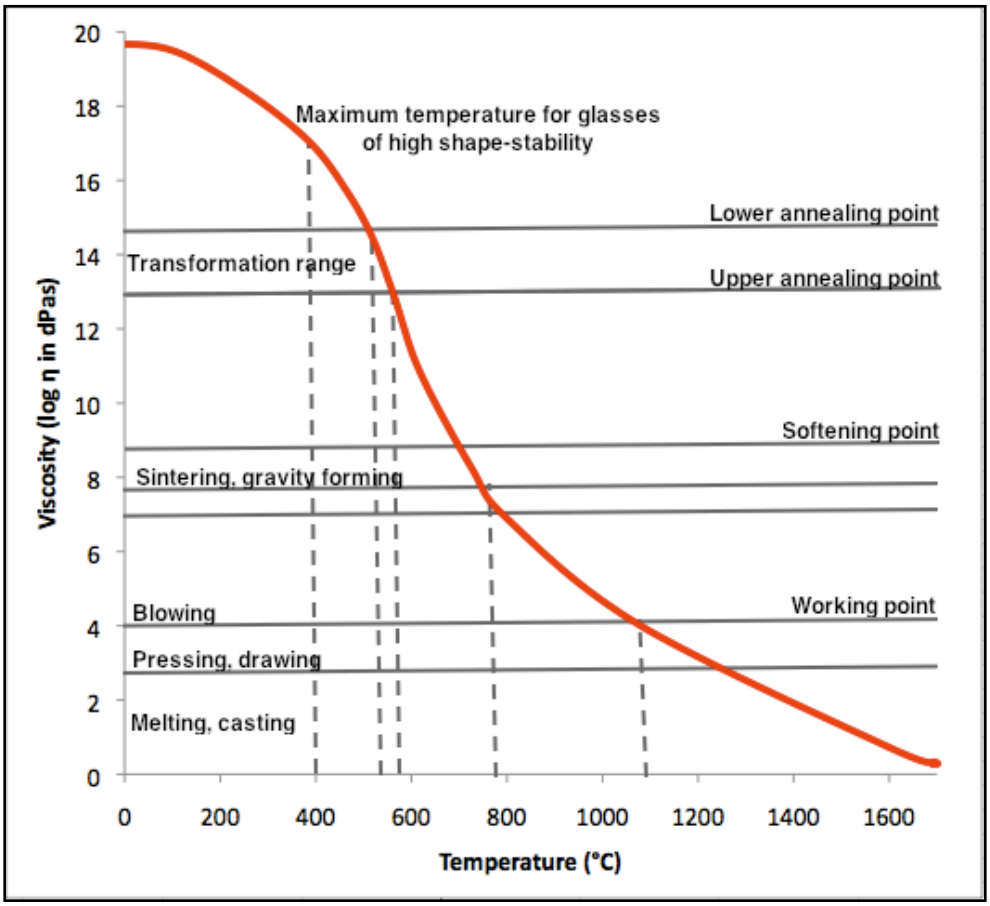

Figure 1.1: Example of a viscosity-temperature curve of a borosilicate glass, demonstrating the viscosity ranges for important several forming techniques, fixed viscosity points, and different temperature limits.[6]

and efficiency of producing a glass object: for example, the higher the softening point of a glass, the more fuel that is required to achieve an appropriate working range.

The very nature of glass quite clearly demonstrates that it is by no means a singular or static material. The history of glass production also demonstrates the dynamic life of glass. Glassmakers could change the sources, proportions, and combinations of the raw materials they used, which might reflect changing artistic or consumer needs as well

[6] This chart is adapted from the website of lab equipment provider Brand®: http://www.brand.de/en/tech-info/materials-glass/mechanical-resistance. For purposes of comparison, borosilicate glass has an upper annealing point of 560 °C and a lower annealing point of 510 °C; soda lime glass has an upper annealing point of 530 °C and a lower annealing point of 495 °C. Pyrex® is the brand name of Corning Incorporated's borosilicate glass.

as economic and technological systems; glassworkers could produce objects of an amazing variety of shape, size, color, opacity, decoration that might reflect changing social uses and cultural perceptions. These two halves of the glass industry—glassmaking and glassworking—are firmly linked, as any creative constraints, strategies, and solutions in one of these arenas would have acted as a feedback mechanism for the other.

GLASS AS A CASE STUDY: THE LINKS OF ARTISTRY AND TECHNOLOGY

The rigorous study of the structure, properties, and processing of ancient glasses began with the work of British chemist William E. S. Turner; his analyses showed there are observable differences in the bulk chemical composition of various ancient glasses, which correspond to the raw materials and technology that was used to make the glass (Turner 1954a, 1954b, 1956a, 1956b, and 1956c). In 1961, American chemist Edward V. Sayre and glass specialist/Egyptologist Ray Winfield Smith analyzed[7] 200 glass samples from Europe, Western Asia, and Africa dating to the 15th century BCE to the 12th century CE in order to "reveal any systematic compositional differentiations in ancient glass, whether based on regional or chronological classifications" (Sayre and Smith 1961: 1824). A very significant contribution of this study was Sayre and Smith's recognition that the magnesia (MgO) and potash (K_2O) content of a glass is a defining characteristic of the technology used to produce the glass. In short, low magnesia-low potash glass is indicative of the use of mineral soda as the glassmaking flux, while high magnesia-high

[7] A combination of three different techniques was used to generate the chemical data: arc spectrography, flame photometry, and colorimetry, "the spectrographic plates being read quantitatively by means of a photoelectric densitometer" (Sayre and Smith 1961: 1824).

potash glass is indicative of the use of plant ash soda;[8] the type of alkali flux of course also had a great impact on the other raw materials that were used during glass production. This basic recognition has prompted scholarly interest in questions of technology, technological transfer, and economic networks as well as resource provenance and procurement patterns for the glass made by different cultural groups.

Glassmaking technology clearly changed as craftspeople experimented with different raw ingredients and production processes, and scholars have been working towards defining just where and when these changes occurred. Chemical analyses show that alkali fluxes changed twice in the Eastern Mediterranean region: from plant ash soda to mineral soda during the first millennium BCE, and from mineral soda back to plant ash soda at the end of the first millennium CE. However, the historical picture of changing glass technology becomes even more intriguing when it is noted that these raw material changes largely occurred in the region west of the Euphrates River—glassmakers to the east did not follow glassmakers in the Levant and Egypt when the latter switched to using mineral soda as a fluxing agent.[9]

While the precise dates and conditions for the first millennium BCE transition has proved quite difficult to study,[10] the first millennium CE provides ample material for

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[8] These distinctions are often discussed in later published literature as LMG ("low magnesia") or LMLK ("low magnesia low potash") glass indicating the use of mineral soda, and HMG ("high magnesia") or HMHK ("high magnesia high potash") glass indicating the use of a plant ash soda.

[9] The question of *why* glassmakers to the east never employed mineral soda is an interesting one, and might be linked to the availability of raw materials, the preference of glass producers, or a combination of such factors. The region east of the Euphrates is of course quite large, and archaeological research on glass in this area has been somewhat more limited; future research would benefit from a survey of the types and sources of glassmaking raw materials, as well as where raw glass was being produced.

[10] As a whole the glass from this period has survived the archaeological record very poorly (Reade, Freestone, and Simpson 200: 23), and as a result the transition of plant ash soda to mineral soda fluxes that took place in the 10th-8th centuries BCE is still poorly understood (Freestone 2006: 208).

investigation. Sayre and Smith first observed that Roman and Islamic glasses straddle the very period of this second transformation: Roman glasses are made with mineral soda while Islamic glasses are made with plant ash soda (1961: 1825-1826 and Table 1). The chemical characterization of the difference between Roman and Islamic glasses would thus appear to confirm cultural-stylistic characterizations that have been so common in art historical publications, supporting the notion that Islamic art was something completely new and different from what came before. However, a closer look questions this narrative of dichotomy for the nature and culture of Roman and Islamic glass.

Background to Current Research

In 2003, I investigated a set of glass artifacts from a 5th-6th century CE Byzantine church in Petra (Swan 2004). This project had two objectives: first, to chemically analyze the fragments in order to deduce the raw materials and production processes used to make the glass; and second, to set these findings in a sociocultural context by comparing the Petra fragments with glass from two other sites in southern Jordan, 1st century BCE-1st century CE Nabataean glass from Khirbat al-Nawafla, and 8th-9th century CE Islamic glass from Ayla (modern Aqaba). I assumed that my findings would confirm the picture painted by previous generations of glass scholarship: Greek, Roman, and Byzantine glasses were made using mineral soda as a fluxing agent, while Islamic and medieval glasses use (respectively) plant ash soda and potash-rich wood ash instead. These assumptions, however, quickly proved to be erroneous: the Nabataean and Byzantine glasses did indeed contain mineral soda—but the Islamic glass from Ayla did as well,

which quickly threw into question the prevailing dichotomy of the technological differences between Roman and Islamic glass.

Searching for possible interpretations and explanations for the observations noted above, it is unlikely that the Ayla samples were Byzantine glasses mistakenly attributed to a later period—the cobalt blue color and scratched geometric decorations of the fragments were distinctly Islamic features. It instead appeared that there must have been *some degree of industrial continuity*, despite the fact that significant political and cultural changes were taking place for several centuries after the mid-7th century CE, as the Eastern Mediterranean transitioned from a Greco-Roman to an Arab-Persian sphere of influence. However, while glassmakers continued to use traditional raw materials and practices for at least two more centuries after the Arab conquest of the main glassmaking regions in the Levant and Egypt, the use of new colors, styles, and decorative methods show that *change was taking place on other levels*—perhaps in aesthetics and taste, object use and perception, or the identity of the glassmakers and customers themselves.

This study demonstrated the fact that as glass scholars, we cannot necessarily predict the raw materials and techniques used to make glass based on temporal, spatial, or stylistic information alone; in addition, glassmaking traditions appear to have been able to survive, thrive, integrate, and overlap in the face of larger socio-cultural and political changes (Swan 2004). When glassmaking raw materials and technology did finally begin to change from mineral soda to plant ash soda in the mid-9th century CE, this change must have been due to something more than the effects of external influences (like the Arab conquest) alone.

SCOPE AND SCALE OF THIS PROJECT

The unexpected results and ambiguous nature of the Early Islamic glass from Ayla are intriguing, and so this dissertation begins where the previous project left off. I selected more glass artifacts from Ayla for study, as well as samples from the contemporary site of Ḥiṣn al-Tīnāt in southern Turkey as a comparative assemblage. Both of these settlements were founded in the Early Islamic era and occupied during the 8th-12th centuries CE; they were also port cities, Ḥiṣn al-Tīnāt participating in the Mediterranean trade and Ayla taking part in the Red Sea and Indian Ocean trade. Although similar in many ways, Aqaba and Ḥiṣn al-Tīnāt had very different histories due to the fact that the former was located in the heart of the Islamic territories, while the latter was on the northern Islamic-Byzantine frontier and spent half of its history under Byzantine control.

These two archaeological sites present an important opportunity to explore the similarities and differences in the glass artifacts recovered during excavation, both their chemical composition and typological elements. As the Byzantine Empire and Islamic Caliphates were the inheritors of a well-established glassmaking tradition and industry, a comparison of the trajectory of the glass made and used by in the regions controlled by these two cultural entities makes this project even more important, as it may be able to link artistry and technology to more obvious social and cultural aspects. In general, the glass made and used during the 8th-12th centuries CE is still poorly characterized and understood, which is problematic for scholarship, considering that this was the very period in which glassmaking technology and practice fundamentally changed.

Research Questions

The overall purpose of this project is to investigate glass as both a material and an object in order to address some important archaeological, art historical, technological, and ultimately social questions. These include the following considerations:

- What is the character of the glass (as both a material and as an object) produced in the Eastern Mediterranean during the 8th-12th centuries CE? Are there obvious or only slight regional differences, or is there a larger shared *koiné* of glass? Is this characteristic of areas sharing cultural histories or only for those sharing political boundaries?
- What are the visible and invisible changes in the quantity, types, styles, distribution, and function of glass vessels over time and/or across space?
- Can chemical compositional groups and subgroups (of glass materials) be linked to particular typological groups and subgroups (of glass objects)?
- What is the relationship between chemical groups and specific regions, raw material sources, or workshops? Are such relationships even observable?
- What does chemical data suggest about the nature of the glassmaking industry in this period? Does it indicate centralized or decentralized workshops, or differences in primary and secondary production centers? Great continuity or great change?
- Can the mineral to plant ash soda shift be clearly seen? If so, is there a clear spatial or temporal pattern to this shift? What local factors might contribute to such a shift?
- If technological changes can be clearly demonstrated for the mid-9th century CE, how might they reflect or inform other changes (economic, social, cultural, religious, political) taking place during this period of time?

In addition, there are some questions that are of particular interest for the two sites under consideration:

- How do Ḥiṣn al-Tīnāt and Ayla compare in terms of the glass that was used at these sites?
- Are there notable typological differences between the two sample sets (object forms, styles, decorations, and functions)? If so, what is the degree of difference and is it uniform across all vessel types?
- Are there notable chemical differences between the two samples sets (raw materials, colorants, and/or opacifiers)? If so, what might this indicate about technology and economics?

- What were the particular economic, social, and political histories of these two sites? Do these histories shape glass production and consumption, or is the former shaped by the latter?

Goals and Objectives

The qualities of a material—i.e., its structures and properties—have a critical effect upon the creation, use, and perception of artifacts; this is a fundamental point, but it has been pointed out that there is not enough emphasis in exploring how these material properties interrelate with the social and cultural lives of people who made, exchanged, used, and deposited artifacts (Jones 2004). The goal of this dissertation is to address this deficiency by incorporating analytically-derived data with theoretical argument in order to answer broader questions about society, culture, and technology in a particular historical moment and location. In light of this, the objectives of this project are:

a) To investigate glassmaking raw materials, production technology, and relational networks (economic, technologic, social, cultural) of the Eastern Mediterranean region during the 8th-12th centuries CE (i.e., the Early Islamic and Middle Byzantine periods)
b) To interpret the nature and organization of the glass industry in this period, as well as how it related to the Late Roman-Early Byzantine (4th-7th centuries CE) and Late Byzantine-Late Islamic (post-12th centuries CE) industries
c) To consider how and why technological stability or change might occur in a given time or place
d) To discuss what glass technological change might indicate about the society and culture of the producers and consumers of glass products

The scientific investigation of archaeological objects is essential for some research topics; the use of chemical analysis is not done simply because it can be done, rather it provides essential information that is not attainable through traditional forms of object analysis alone. The goal is to illustrate by example how rigorous scientific analysis can

be effectively integrated with art historical observation to address the social and cultural concerns of archaeological theory and practice.

Structure of the Dissertation

The chapter structure of this project is as follows:

- **Chapter 2** sets up the pertinent historical background and relevant contexts of glass technology and production in the post-Roman world, building a reference point from which to proceed with a more focused case study of the Near East during the 8th-12th centuries CE.
- **Chapter 3** introduces the materials and methods used in this project to address the research questions outlined above. Samples of glass artifacts from two archaeological sites, Ḥiṣn al-Tīnāt (in southern Turkey) and Ayla (in southern Jordan), are analyzed and compared using traditional art historical/archaeological strategies as well as scientific strategies. In this chapter a brief background of the location and history of these two archaeological sites, and the specifics of the analytical techniques used will be set out, namely typological-chronological analysis and chemical analysis.
- **Chapters 4, 5, and 6** describe and discuss in detail the results for both the typological and chemical analysis of the glass fragments studied in this project; Chapters 4 and 5 focus on the glass vessels and jewelry (respectively) from Ḥiṣn al-Tīnāt and Chapter 6 focuses on the glass vessels from Ayla.
- **Chapter 7** brings the analytical results together with the observations and results of previous studies in order to synthesize and contextualize the results. How the findings of this study change our understanding of glass in this particular period of time is discussed.
- **Chapter 8** concludes the study by summarizing the main observations, significance, and contribution of this project. The strengths and limitations of this project are discussed, and suggestions for future directions for research are then offered.

A list of the archaeological sites mentioned throughout this dissertation may be found in Appendix A. In addition, because glass is a highly specialized craft and research topic, Appendix B provides a glossary of terms related specifically to glass and glassmaking. Finally, a catalog of samples and a table of the chemical analytical data are included as

Appendices C and D (respectively), and are ordered by sample number for easy reference.

In summary, this dissertation focuses on one particular moment and place in the long history and wide geography of glass production: the 8th-12th centuries CE Eastern Mediterranean. Using this particular period and region as a case study underscores the close connection of artistry and technology, as this was an important moment in which new glassmaking and glassworking practices were emerging within a region with a very old tradition of glass production and use. Moreover, social, cultural, political, and religious changes—some slow and subtle, some quick and blatant—were taking place in the Near East, which would also ultimately involve the production and consumption of glass.

CHAPTER TWO: GLASS IN THE LATE ANTIQUE-EARLY MEDIEVAL EASTERN MEDITERRANEAN, 4th-12th c. CE

INTRODUCTION

The contextual starting point of this study of glass is the Roman era, because it was during this time that the structure of a virtually "global" network and system of glass production and consumption was established, and it must be against this backdrop that the Late Antique and Early Medieval industrial successors are examined.[1] Two developments during the Roman period enabled glass to change from an exotic or luxury object available only in certain places for the wealthy to a common product available for all levels of society: the invention of glassblowing and the growth of the Empire.

These two elements laid the foundation for the production of glass in the Near East on a truly industrial scale during the Early Byzantine period, a scale that continued into the Early Islamic period as well. The variety and quantity of glass vessels reached a new level in the 4th century CE with glass all but ousting other forms of material culture for some purposes, such as ceramic drinking vessels (Stern 1999). Imperial legislation from the 4th-6th centuries CE that included provisions for the protection and promotion of glassworkers underscores the increasingly important role of glassmaking (Triantafyllidis

[1] This echoes the sentiments of Chris Wickham in his opening discussion of the Mediterranean in 400-1000 CE, which he begins "with a still-thriving Roman empire, *but only to set out the building-blocks with which post-Roman polities inevitably had to construct their environments*: certainly not to lament failure, or to present a model which successor states failed to live up to" (2009: 11, my italic emphasis).

2007: 262).[2] Raw glass also began to be produced in truly enormous quantities in the Near East from the 4th to at least the 11th century CE; although there may have been many continuities of practice in terms of the scale of production and trade, the raw materials and technologies of glassmaking certainly did change, for a complex set of reasons that still need to be explored.

ROMAN PRECEDENTS AND UNDERPINNINGS

In the second half of the 1st century BCE, glassworkers in Syria-Palestine learned to inflate a glass bubble by means of a hollow pipe and to turn this bubble into a variety of vessel forms (Avigad 1980; Israeli 1991), and by the 1st century CE blowing had become the dominant technique of glass manufacture (Grose 1986). Free-blowing and mold-blowing revolutionized the craft in that these techniques allowed workers to produce vessels quickly and easily, transforming glass into a much more widely available, affordable, and useful commodity. The incorporation of the Levant—with its long history of glassmaking—into the Empire took place in the 1st centuries BCE and CE, but it was the overall expansion of the Roman world with its trade relations, infrastructure, and unified political-economic administration that created the conditions for the spread and flourishing of glassworking throughout the Empire. Glass went from being a local Syro-Palestinian craft to an "empire-wide enterprise" (Stern 1999: 442), and by the mid-1st century glassblowing facilities were springing up across the empire (Isings 1957).

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[2] For example, the edicts of Constantine the Great in 337 CE and Theodosius II in 438 CE, and the 6th-century CE *Codex Justinianus* make references to tax reductions for craftsmen.

Improved forming techniques and an efficient, widespread system of transport and exchange are the most frequently cited reasons for the growth and success of Roman glass production. These elements did play an essential role in the creation of the Roman glass industry, but they are not the only factors that impacted glass production at this time. Of enormous significance was the standardized recipe and stabilized technology of Roman glassmaking in terms of both raw materials and actual processing, which in turn suggests a relatively organized or centralized production model.

The Shaping of an Industry

Roman glass was essentially homogenous in the 1st-3rd centuries CE across the Empire, suggesting the raw glass was being made either in a relatively few locations and/or by using the same or a similar suite of raw materials (Fiori and Vandini 2004). Roman authors frequently mention the Eastern Mediterranean as the premier glassmaking region, having both skilled workers and very high quality raw ingredients. Pliny the Elder (*Naturalis Historia* 36.190-194), Tacitus (*Historiae* 5.7), and Josephus (*Bellum Iudaicum* 2.189-190) all note that the best sand for glassmaking comes from the Belus River[3] while Strabo (*Geographica* 3.25, 16.756) makes a clear distinction between the "vitreous" sand of Sidon and that of Alexandria (i.e., between the sands of the Levantine and Egyptian coastlines). Pliny also mentions the mineral soda source of Wadi Natrūn in Egypt as an important source of this glassmaking raw material (*Naturalis Historia* 31.106, 109, 100).

[3] The Belus River is now called the Nahr Na'aman, flowing from the highlands near the Carmel range (Har Carmel) to the Mediterranean coast between Akko and Haifa in northern Israel. A 1960 study of Mediterranean beach sands shows the Bay of Haifa has the lowest color saturation (i.e., the palest sand which indicates a low iron content), which likely enabled glassmakers to select their raw materials by sight (Freestone 2006: 206); Brill has conducted extensive chemical study of the Belus River sand in comparison to the Jalame glass workshop (1988).

Chemical evidence indicates that glassmakers worked with a well-defined recipe and indeed used raw materials derived primarily from the Syro-Palestinian coast and Egypt (Nenna *et al.* 1997). This enabled craftsmen to closely control the composition of their glass (Freestone *et al.* 2000: 74).[4] However, a recipe or list of ingredients alone would not have been enough information to make glass of good quality or consistency, and would have had to be augmented by first-hand knowledge and experience of "the oxidizing and reducing conditions of furnaces and the effects these atmospheres would have had on the glass melts, as well as the optimum time and temperature needed to melt and refine a glass batch" (Lemke 1998: 269).

That glassmakers could control the color of their glass has been recognized as a "particularly masterful" feat of technology (Jackson 2005: 763). Glassmakers and glassworkers had to specifically select their ingredients (either in the raw form or as recycled glass cullet) and know how to manipulate the natural hues that result from the raw materials by means of additives and/or a tight control of the furnace parameters. For some 800 years Roman glassmakers used mineral soda—often identified as *natron* or *trona*[5] in both primary and secondary sources—as their principal fluxing ingredient, with

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[4] Recent studies using isotope analysis have demonstrated that 1st-3rd century CE Roman glass produced in Western Europe and in the Eastern Mediterranean can be differentiated by their Sr-Nd signatures, which indicates the probable use of different silica sources (Degryse and Schneider 2008; Degryse and Shortland 2009) in combination with mineral soda from the Near East.

[5] The word *natron* derives from the Greek work *νιτρων*, which is itself derived from the ancient Egyptian word *nṯry*; other derivatives of the Egyptian word include Akkadian *nit(i)ru* and Hittite *nitri* (Griffith 1994), as well as Hebrew נטרן (*natruna*). *Trona* derives from this same etymology. Although natron and trona are distinguished today by their chemistry (natron is sodium carbonate decahydrate, or $Na_2CO_3 \cdot 10H_2O$, while trona is trisodium hydrogendicarbonate dihydrate, or $Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$) it is unclear whether there these two words distinguished different materials in antiquity as well or whether they were used interchangeably. "Mineral soda" is used throughout this project, as it is not possible to specifically identify whether natron or trona were used to produce particular glasses.

a few specialist exceptions,[6] and this choice had a significant impact on the nature of the glass industry. As one research group has put it, "[mineral soda] seems to have fed the prodigious growth of the Roman glass industry" (Shortland *et al.* 2006: 523) and enabled the glassmaking industry to function on an unprecedented scale.

Like many other staple products (grain, oil, and wine) mineral soda was an export product of the provinces of Africa, coming specifically from Egypt and probably sent out from the port of Alexandria. Several evaporitic lakes in the eastern Mediterranean region were exploited in Antiquity[7] (Figure 2.1), but it is currently argued that the primary exploitable and exportable sources of mineral soda were the salt lakes of Egypt located west of the Nile Delta (Shortland *et al.* 2006; Shortland *et al.* 2011) and 100-150 km northwest of Cairo in a place appropriately called the Wadi Natrūn.[8] That glassmakers exploited these lakes is clearly illustrated by the Early Roman site of Bani Salama (Nenna 2003), where a glassmaking factory was situated directly on the edge of Lake Fazda and "the salt deposits would have extended to within a few meters of the factory" (Shortland *et al.* 2011: 924).

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[6] Lemke (1998) does show that soda-rich plant ash was used in the western provinces during the Early Roman period for the production of some highly colored glasses, which may suggest a small, localized, and specialized production of this type of glass.

[7] These include Lake Pikrolimni in northern Greece, Lake Van in Armenia, and Lake Jabbul in northern Syria. There is textual evidence that Pikrolimni was used as a natron source in the 1st-7th centuries CE, Van was used in the 1st-2nd centuries CE, and Al-Jabbul was used in the 6th century CE; however, it is argued that the small size of Pikrolimni and the relative inaccessibility of Van make the lakes of Egypt much more likely to be the *primary* producers, and it is still uncertain whether Jabbul was exploited for anything more than halite, common salt (Shortland *et al.* 2006: 526-527). Recent research has reassessed Pikrolimni as a viable glassmaking raw material source (Dotsika *et al.* 2009).

[8] The precise number and names of the Wadi Natrūn lakes are difficult to determine due to seasonality and climate change; currently there are eight lakes: Ga'ar, Khadra, Beida, Zug, Hamra, Ruzunia, Umrisha, and Fazda (Shortland 2004: 504); other probable sources in Egypt include the lake at el-Barnuj (Shortland *et al.* 2006: 526). The area seems to have extended over ~50 km (Saguí 2007: 212).

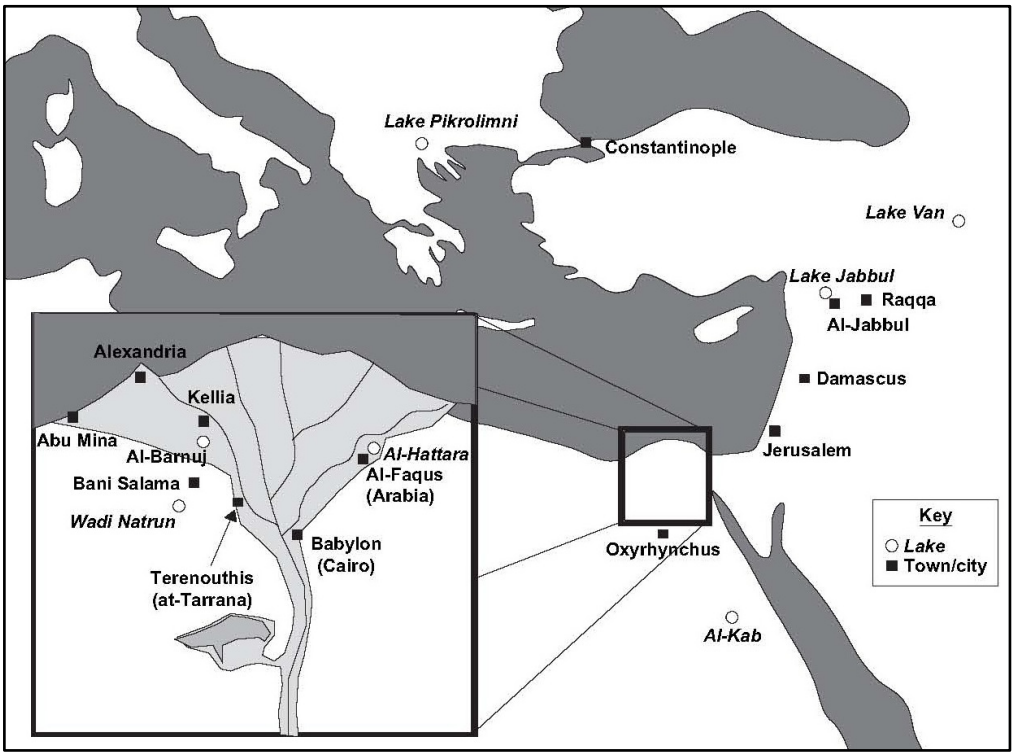

Figure 2.1: Map of the Eastern Mediterranean region showing the known evaporitic lakes that were exploited for sodium minerals in Antiquity (Shortland *et al.* 2006: 524, Fig. 1).

Figure 2.2: (Left) View of the evaporitic lakes of the Wadi Natrūn (photo taken by geologist Yvon Maurice and downloaded from http://www.flickr.com/photos/19787482@N04/6322425543/); (Right) detail view of natron (photo downloaded from www.visualphotos.com).

Evaporitic lakes can simultaneously produce several types of sodium-rich minerals (Figure 2.2),[9] but not all of these may have been collected for glassmaking purposes in the past. Chlorides and sulphates, for example, "are likely to have a deleterious effect on the [glassmaking] process, perhaps even to the extent of preventing glass formation altogether" (Shortland 2004: 514). However, sodium carbonate or sodium bicarbonate may have been rarely or never present in abundant supply at some sources due to the complexities of climate and groundwater composition (Shortland 2004: 514; Shortland *et al.* 2006a),[10] and recent studies suggest that sulphate-rich deposits perhaps may in fact have undergone some form of processing in order to convert sulphates to carbonates. The glass factory at Lake Fazda is a good example of this possibility, as contemporary chemical evidence suggests the mineral soda that was exploited by this factory was heavily contaminated with sulphates and chlorides rather being than the carbonate-rich system that has typically been assumed (Shortland *et al.* 2011: 924-925).[11] Such reassessments call into question the notion that Egypt was the primary source of mineral soda for the Near Eastern glassmaking industry; if other mineral soda sources were indeed exploited, this may significantly affect or alter our understanding of larger issues like economic systems and the mechanisms of technological and industrial change.

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[9] Listed in Table 1 of Shortland 2004: Natron ($Na_2CO_3 \cdot 10H_2O$), Thermonatrite ($Na_2CO_3 \cdot H_2O$), Trona ($Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$), Nahcolite ($NaHCO_3$), Burkeite ($Na_6CO_3 \cdot 2SO_4$), Thenardite ($Na_2SO_4$), Mirabilite ($Na_2SO_4 \cdot 10H_2O$), Halite (NaCl), and Pirsonnite ($Na_2CO_3 \cdot CaCO_3 \cdot 2H_2O$). Sodium carbonate and sodium bicarbonate may have been the most common minerals used for glassmaking.

[10] For example, "halite is by far the most dominant mineral in most of the [other Wadi Natrūn] lakes throughout most of the year" (Shortland 2004: 514).

[11] "Virtually all glass of this period contains 0.5-1.2 % Cl and 0.2-0.5 % SO4, which are likely to have been close to the solubilities of these components in the glass when it was made;" excess sodium chloride and sulphate may have separated as a "scum" that could be skimmed off the top of the melt and discarded (Freestone 2006: 204).

WORKINGS OF THE INDUSTRY DURING LATE ANTIQUITY

A fundamental change to the Roman glass industry occurred in the 4th century CE in terms of the composition and origin of glass that was made, which is why Late Antiquity might be considered a new period in glassmaking history. Chemical analysis has shown that starting in the 4th century CE, glass begins to have a slightly higher lime and alumina content than it did before although it was still made using mineral soda and sand, which suggests a slight change in glassmaking technology and raw material sources (Fiori and Vandini 2004: 160). In addition, very large quantities of raw glass began to be being made in Syria-Palestine and Egypt, presumably because these areas were closer to the favored sources of raw materials (Freestone *et al.* 2000: 66; Freestone *et al.* 2002a: 167),[12] and this Near Eastern raw glass dominated production for several centuries.

Primary and Secondary Production

Glass is made by first mixing the raw materials—silica and an alkali flux—together to form the glassmaking "batch." Simply put, the raw materials are first crushed, mixed, and fritted (partially reacted by heating in order to drive off gases) to produce the batch; these processes are probably repeated as often as necessary before the batch is finally melted to form the homogenous glass. Cullet (broken glass) is often added to the

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[12] In the Hellenistic and Roman periods, raw glass may have been manufactured in many parts of the Mediterranean world, including Europe, rather than exclusively in the Near East as it was in Late Antiquity (Degryse and Shortland 2009: 136; Wedepohl *et al.* 2011: 93). However, no primary production facilities dating to the 1st-3rd centuries CE have yet been found (Freestone 2006: 206).

Other parts of the Roman world may have imported mineral soda and combined it with local sand, which, even if not good quality, would have been more economical than importing sand. Pliny mentions the sands of Italy, Gaul, and Spain as also serving local glassmaking supply (Trowbridge 1930), and experimental archaeology has confirmed that sand from near the Volturno River in Italy can be used with the help of selective grinding, a process that "can be applied to any quartz-feldspar-carbonate sand" (Silvestri *et al.* 2006: 427).

glass batch in order to lower the melting temperature of the batch, as the cullet softens first; "the fluid cullet helps the still solid batch granules to move around the mix with each other" (Goffer 2007: 143).

The "primary production" of glass from its raw materials (i.e., glass*making*)[13] was an activity that took place separately from the "secondary production" of glass objects from raw glass by blowing, casting, etc. (i.e., glass*working*). As a result, two specialized branches of the craft emerged that would work in tandem to determine the structure of the overall glass industry (Fischer and McCray 1999: 895; Stern 1999: 441). Primary glass workshops could produce large amounts of raw glass—on the scale of tons per batch during Late Antiquity and the Early Medieval period—that was then broken up into chunks and sent to secondary workshops. The coloring of glass could have occurred at either point in the production cycle, although during this period it appears to have more commonly taken place in the secondary workshops.[14]

It seems reasonable to suppose that certain specialized decorative techniques were activities removed from the secondary working of raw glass into object. As such, perhaps a "tertiary production" category should be included in our consideration of the overall workings of the glass industry. For example, Roman cameo glasses and *diatreta* (cage cups) were almost certainly decorated by gem carvers or lapidaries using a blank that had been prepared by other glassworkers who specialized in the casting or blowing of

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[13] Such glass is termed "primary glass," "chunk glass," or "raw glass."

[14] Cobalt blue glass ingots from the Uluburun shipwreck indicate that glass was often colored at the point of primary production during the Late Bronze Age (Jackson and Nicholson 2010). However, when the glass industry expanded in the Roman period, in most cases it would have been more economical to produce uncolored glass in bulk for distribution and let glassworkers decide how much of their own glass to color.

vessels.[15] Enameling and relief cutting are other examples of decorative techniques that could reflect specializations beyond the common repertoire of the secondary glassworkers.

Defining Primary Production

The almost uniform[16] chemical composition Late Antique glass (Baxter *et al.* 1995; Nenna *et al.* 1997; Stern 1999; Nenna *et al.* 2000; Picon and Vichy 2003) and the archaeological remains of primary production facilities in Syria-Palestine and Egypt strongly support the notion that raw glass in this period was principally being made in the Near East (Foy 2000a; Freestone *et al.* 2000; Freestone *et al.* 2002a) and then shipped to glasshouses around Mediterranean world for secondary production.[17] Figure 2.3 illustrates this relationship of raw materials, primary and secondary workshops, and glass composition: the diagram on the left illustrates an early model in which glassmakers used

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[15] A passage from Ulpian's *Digest* (9.2.27.29) is telling: "if you handed over the blank for a *diatretum* cup to be made up and someone broke it through inexperience, he is liable for the extent of the loss. But if he did not break it through inexperience, but it already had flaws which made it susceptible to cracking, he can be acquitted. Consequently, most craftsmen, when given material of this sort, are accustomed to make an undertaking not to work it at their own risk" (Humphrey *et al.* 2006: 380).

[16] "Uniform" in terms of the major elements, but compositions will of course never be exactly the same even for glasses of the same type, due to natural variations in the raw materials and/or slightly different ratios of materials used during processing. Moreover, if raw materials were added to the furnace in batches, this could result in chemically distinct "regions" of the cooled melt; for example, raw glass made in one melt at Bet She'arim "showed some compositional layering, with more soda-rich glass towards the top of the slab" (Freestone *et al.* 2000: 71).

[17] A 4th century CE workshop at Hambach in Germania is believed by the excavators to be a primary glassmaking facility (Gaitzsch *et al.* 2000), and a tank furnace at a site of glass production at military camp at Bonn has also been noted (Wedepohl *et al.* 2011: 93). Chemical analyses of Roman period glasses from Germany are also believed to indicate the use of local sand sources from the River Rur (Wedepohl and Baumann 2000). Although this evidence might suggest the production of raw glass in the Late Antique period was much more widespread than just the Near East, scholars are not completely convinced, as the argument is based on compositional grounds rather than direct archaeological evidence (Freestone *et al.* 2002b: 258): "numerous remains of glass furnaces elsewhere in western Europe and Britain have been identified almost without exception as secondary workshops" (Stern 2008: 520) and "unambiguous evidence for glass making (as opposed to glass working) has not been forthcoming from detailed archaeological investigations of peripheral areas such as Britain" (Freestone *et al.* 2000: 66).

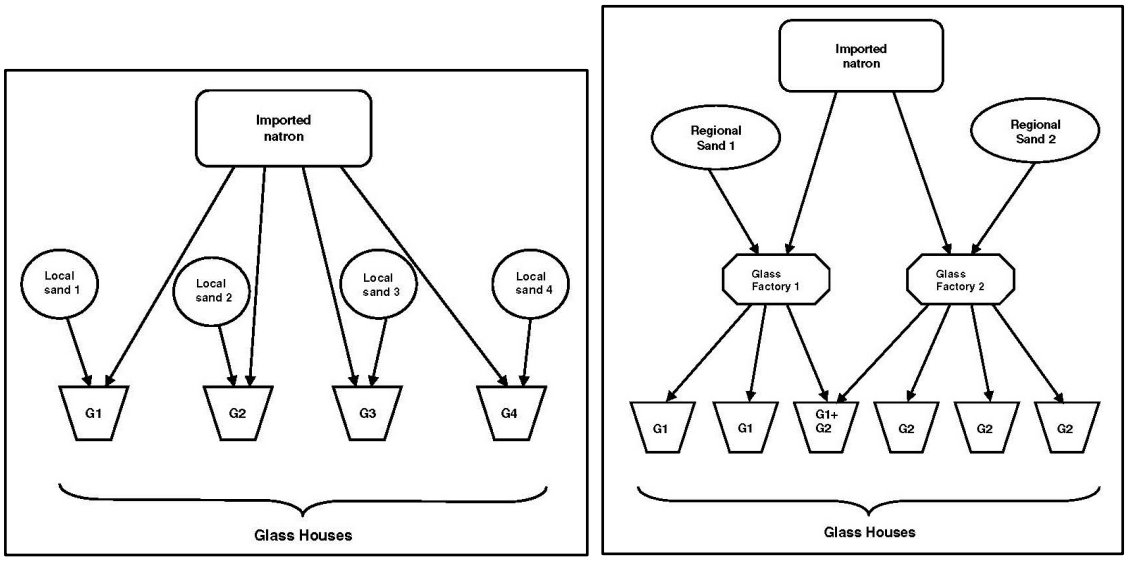

Figure 2.3: Schematic diagrams representing the relationship of raw materials, primary and secondary workshops, and glass composition: (left) production model in which individual workshops mix imported mineral soda with local sand, resulting in individual workshop "signatures" (Freestone *et al.* 2002b: 258, Fig. 1); (right) production model in which raw glass is first made primary workshops and then shipped in built to secondary workshops, which might mix the raw glasses (Freestone *et al.* 2002b: 259, Fig. 2).

imported mineral soda and local silica sources as their raw materials (each glass workshop would thus produce objects with a distinctive, workshop-specific glass composition); the diagram on the right illustrates the *revised* model showing the division of primary and secondary production workshops on a more industrial scale, which would explain the rather homogenous chemical profile of glasses from this period around the Mediterranean world. The second model can, however, also be complicated by the use of raw glass from more than one source by a secondary workshop (Freestone *et al.* 2002b: 258).

Several very large primary glass furnaces dating from the 6th-11th centuries CE have been excavated in the Near East (Figure 2.4), primarily along the Levantine coast in modern Israel and Lebanon but also in Syria; the similarity in design and capacity of these furnaces suggests continuity in raw glassmaking over the course of this period

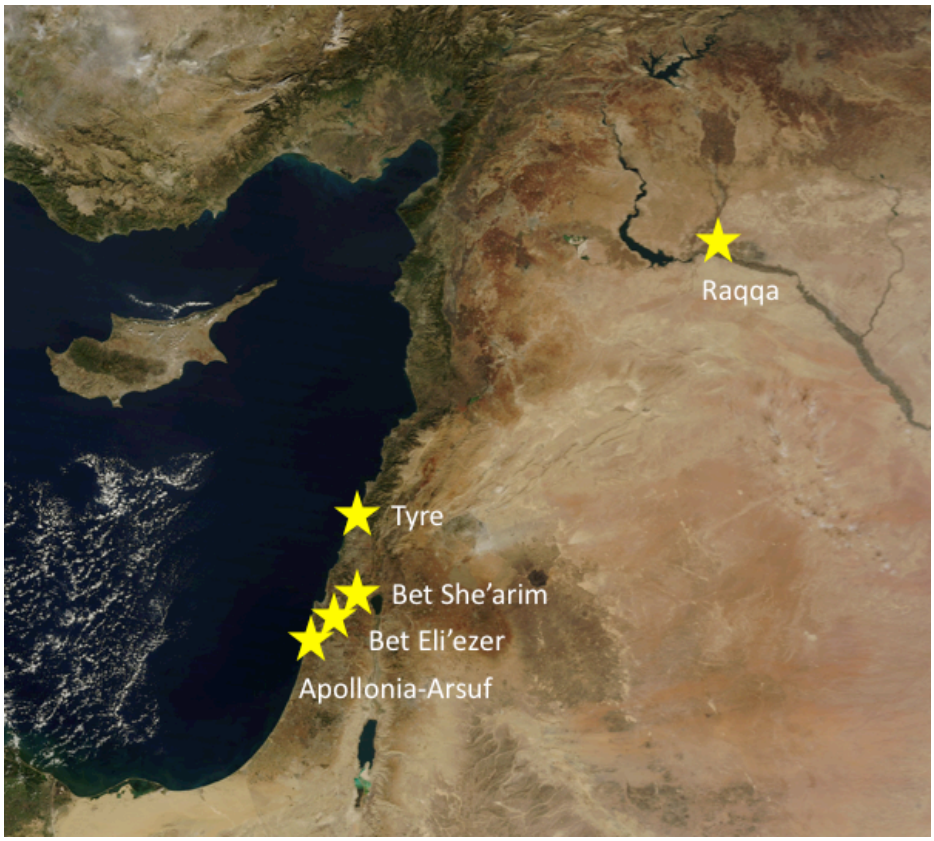

Figure 2.4: Location of several 6th-11th century CE glassmaking furnaces that have been excavated in the Near East to date (image from NASA, The Visible Earth, http://visibleearth.nasa.gov/).

(Keller 2010: 11). Three 6th-7th century CE rectangular tank furnaces have been identified at Apollonia-Arsuf (Tal *et al.* 2004; Freestone *et al.* 2008b).[18] One 9th century CE tank furnace was found at Bet She'arim in Israel, while 17 tank furnaces of similar dimensions have been identified in excavations at Bet Eli'ezer-Hadera and are dated to the late 7th and early 8th centuries CE (Gorin-Rosen 1995). Four glassmaking furnaces have been identified at Tyre and date to the 10th-13th centuries CE (Aldsworth *et al.* 2002; Freestone 2002; Carboni *et al.* 2003). Primary production of glass has also been identified in Syria, including one tank furnace and three bee-hive furnaces dating to the 8th-9th, 11th, and 12th

[18] Additional glassmaking furnaces will likely be identified at Apollonia in the future; when I visited the site in 2009 the excavation team was actually digging one such furnace.

centuries CE at Raqqa/Rafiqa (Henderson *et al.* 2004). While there is archaeological evidence for the primary production of glass in Egypt during the Roman Imperial period, there is no similar evidence, to date, of furnaces in operation after the 4th century CE;[19] however, chemical analysis of glass vessels indicates primary glass production was indeed taking place in Egypt during the 4th-9th centuries CE and it is hoped that future excavations will locate these primary workshops.

The enormous output of primary glass producers in this period is easily illustrated by the sheer size of the tank furnaces found at these sites. The Bet She'arim furnace could produce nine tons of raw glass at one time (Freestone and Gorin-Rosen 1999). Glassmakers appear to have charged such a large tank in several batches in order to reduce the amount of time needed to completely heat the raw materials from top to bottom (Freestone *et al.* 2000: 71), a practice that has been ethnographically observed in India as well (Sode and Kock 2001: 165). The Bet Eli'ezer furnaces are similar in size to the one at Bet She'arim, and "even if each furnace had been fired only once, the amount of glass produced would have been sufficient for the order of one million glass vessels of typical weight around 150g" (Freestone *et al.* 2000: 67). One large furnace at Tyre could produce more than 37 tons of raw glass at each firing, which would have been enough to make some 250,000 glass vessels, and two slightly smaller furnaces at the same site could produce 13 and 16 tons of glass at each firing (Aldsworth *et al.* 2002). It is unclear whether glass furnaces were used for more than one melting event (Freestone *et al.* 2000: 67), but repeated use of the same foundation stones may have been possible even if the

[19] Three Roman-period furnaces have been excavated near the Wadi Natrūn (located at Beni Salama, Zakik, and Bir Hooker) and two at Mareotis near Alexandria (located at Taposiris Magna and Philoxenite) in Egypt (Foy and Nenna 2001: 34; Nenna 2008: 127). A furnace with blocks of raw glass was also identified at Carthage (Foy 2003).

furnace was partially demolished to remove the raw glass (Sode and Kock 2001: 158). Regardless, it is clear that glass production in the Near East in Late Antiquity and the Early Medieval period took place on an unprecedented scale.

Small glassmaking furnaces appear to have been adequate for the glass industry until perhaps "the need for more rapid production on a larger scale brought larger furnaces—tank furnaces—into existence," which were capable of melting tons of glass in a single firing event (Brill 2009: 461). The sheer size and capacity for raw glass output of the tank furnaces that have been discovered to date indicate that the scale of the Near Eastern glassmaking industry in the Late Roman, Byzantine, and Early Islamic periods was massive; to melt a cubic foot of glass, approximately two hundreds pounds of batch would have been required. Perhaps "the enormous jump in scale accompanying the change over from melting pounds of batch to melting tons of batch might have affected the choice of raw materials used" (Brill 2009: 461).

Unlike glassworking, glassmaking did not usually occur within heavily settled areas. As a high-temperature industry, glassmaking carried with it the risk of spreading fire[20] and it was also often more convenient for primary glass workshops to be located close to the sources of fuels and batch components. Archaeological evidence supports these basic premises, as known primary production sites are commonly located on outlying foothills and close to wood and raw materials resources (Gorin-Rosen 2000: 62).

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[20] The 6th century CE Palestinian lawyer Julian of Ascalon (Ashkalon) refers to an edict that notes: "workers in glass and iron should not carry on their business in the city, but, if that is necessary, the workshops should be in remote and sparsely populated parts of the city to prevent sickness and the destruction of property by fire" (Trowbridge 1930: 119).

Defining Secondary Production

Glassworkers typically used small, circular kilns to remelt small batches of raw glass in ceramic crucibles in order blow or otherwise manufacture vessels and other glass objects. Secondary workshops could be located almost anywhere, but were typically situated in close proximity to where there was a demand for glass vessels. As such, it was common for glassworkers to set up shop within a city's limits and close to markets so that clients could quickly and easily obtain glass items (vessels, lamps, and window panes). In the post-Roman period, it was common for public spaces that had fallen out of use to be turned into workshops and shops:[21] the Roman theater of Jerash/Geresa was reused for glassworking (Meyer 1987), as were the agora spaces of Corinth (Weinberg 1940) and Tyre (Aldsworth *et al.* 2002), and the Roman baths of Tarsus (Adak-Adibelli 2007).

Secondary workshops from many sites in the Eastern Mediterranean dating to the Late Roman, Early Byzantine and Early Islamic periods have been identified, although many have not been studied or published in detail (Keller 2010: 11). In Israel-Palestine, glass workshops have been found in the Jewish Quarter of Jerusalem (Engle 1984; Israeli 1991), Jalame (Weinberg 1988; Slane and Magness 2005), Sepphoris/Diocaesarea (Longstaff and Keller 1994; Keller 1994; Fischer and McCray 1999; Fischer 2008), Samaria-Sebaste (Crowfoot 1957), Khirbet Ni'ana (Gorin-Rosen and Katsnelson 2007), Ramla (Tal *et al.* 2008), Bet She'an/Scythopolis (Fitzgerald 1931; Gorin-Rosen 1998; Gorin-Rosen and Winter 2010), Somelaria/Sumeiriya/Give'at Yasaf (Weinberg 1987),

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[21] This pattern fits with the larger urban transformation of Near Eastern cities that has been observed and characterized as a transition "from *polis* to *madina*" (Kennedy 1985; e.g. a transition from the Classical to Islamic city in terms of both the urban form and functional spaces), as the urban environment was increasingly industrialized: "industrial complexes were commonly inserted into the existing infrastructure, often at the expense off public space […] and by commandeering defunct civic monuments" (Walmsley 2000: 305).

Horvat Raqit (Jacobson 2004), Castra (Gorin-Rosen and Katsnelson 1999), Kafr Yasif (Weinberg 1964; Gorin-Rosen 2000), and Bet She'arim (Gorin-Rosen 2000). In Lebanon, a workshop has been identified in Beirut (Gratuze 2000; Foy 2000c; Jennings 2006) and at Tyre (Aldsworth *et al.* 2002). Few glass workshops have been noted in Jordan, including Pella (O'Hea 1992) and Jerash (Meyer 1988); only one post-Roman secondary glass workshop has been yet been identified in Egypt, at Tell el-Ashmunein (Bimson and Freestone 1987 and 1991).

In Anatolia, Early Byzantine secondary glass production workshops have been discovered at Anemourion (Russell 1972; Stern 1984 and 1989), Aphrodisias (Smith and Ratté 1998), and Ephesus (Czurda-Ruth 2007) but again none of these have been studied or published in detail (Keller 2010: 11). A glass workshop from the late 8th-early 9th centuries CE at Paphos on Cyprus is mentioned in passing (Megaw 1971 and 1972); debris and raw lumps and glass cullet has been found at Sardis dating to Early and Middle Byzantine periods (von Saldern 1980) suggest glassworking although no remains of a workshop have been discovered. At Tarsus, glass kilns were built inside the former Roman baths, and appear to have been used in the 9th-10th centuries CE (Olcay 1998; Adak-Adibelli 2007). A workshop has also been suggested for Sagalassos (Lauwers *et al.* 2007). In Greece too, evidence for secondary working in the form of cullet, chunks, and debris rather than physical workshop facilities have been identified at Philippi and Thessaloniki (Antonaras 2007 and 2010). A glassworking factory from the medieval period has been excavated at Corinth (Weinberg 1940 and 1975; Whitehouse 1991 and 1993).

Characterizing Glass to Understand Industrial and Economic Networks

Because of the separation of the glass industry into primary producers of raw glass and secondary producers of finished glass objects, the compositions of glass objects found on consumer sites "should closely resemble those of major primary glass suppliers, rather than producing workshop-specific fingerprints" (Freestone *et al.* 2002b: 258). At least five primary glass types made using mineral soda mixed with distinct silica sources have thus far been distinguished, which were made during the 4th-9th centuries CE in the Eastern Mediterranean.[22] These groups have been labeled Levantine I, Levantine II, Egyptian I, Egyptian II, and HIMT[23] (Tables 2.1 and 2.2).

Typical Roman glass compositions of the 1st-3rd centuries CE are distinct from these types, and it has been suggested that Levantine I and HIMT replaced them sometime in the 4th century CE (Freestone *et al.* 2002a: 172). The Egyptian II and Levantine II groups begin to appear at a slightly later in date than the Levantine I group, and it has been suggested that Levantine II production replaced that of Levantine I at the beginning of the Islamic era (Fiori and Gandini 2004: 165). However, the information presented in Table 2.1 should be considered flexible and preliminary, as future compositional analyses of glass from archaeological sites in the Near East may modify our understanding of the chronological and geographic distribution of these glass types.

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[22] This is not to say that each of these groups represents a single compositionally-distinct type of glass, or that these were the only chemical groups in circulation. For example, evidence from Raqqa has shown that "a single primary glassmaking site can manufacture a wide range of glass compositions" so it would be inaccurate to think of a production site as making only one glass type (Henderson *et al.* 2004: 466).

[23] HIMT stands for "high iron, magnesium, manganese, and titanium;" these transition metal oxides are elevated and "strongly intercorrelated," and are also strongly correlated with alumina (Freestone *et al.* 2002a: 167-168).

Glass group	Probable origin	Possible silica source	Production evidence dates (characteristic sites)	Characteristics
Levantine I	Levant	Belus River or Bay of Haifa coastal sand	5th-7th centuries CE (Apollonia, Bet She'an, Dor Israel)	Higher lime and soda, lower silica
Levantine II	Levant	Coastal sand (south of the Belus River?)	7th-8th centuries CE (Bet Eli'ezer, Israel)	Lower lime and soda, higher silica
Egyptian I	Northern Egypt?	Coastal sand	8th-9th centuries CE (Wadi Natrūn, Egypt)	Low lime, high alumina
Egyptian II	Middle Egypt?	Inland sand	8th-9th centuries CE (Tell el-Ashmunein, Egypt)	High lime, low alumina
HIMT	Egypt or North Sinai	Sand	Post-4th century CE (Tunisia, England, Germany, Italy)	High Fe, Mg, Mn, and Ti

Table 2.1: The main mineral soda glass production groups from the Late Antique-Early Medieval Near East that have been identified to date (Freestone *et al.* 2002a).

Glass group	Flux	SiO2	Na2O	K2O	CaO	MgO	Al2O3	Fe2O3	MnO
Late Bronze	Plant ash	64.30	17.90	2.30	8.40	4.20	1.10	0.67	n.g.
Roman	Mineral	n.g.	18.40	0.69	6.43	0.55	2.33	0.67	0.26
Levantine I	Mineral	70.60	15.20	0.71	8.07	0.63	3.05	0.39	<0.10
Levantine II	Mineral	74.90	12.10	0.46	7.16	0.63	3.32	0.58	<0.10
Egyptian I	Mineral	66.50	21.40	0.34	3.70	0.90	2.70	1.11	<0.10
Egyptian II	Mineral	68.20	15.00	0.20	10.80	0.50	2.10	0.78	0.20
HIMT	Mineral	64.80	18.70	0.44	5.24	1.29	3.18	2.30	2.66
Islamic	Plant ash	70.50	12.5	1.89	8.55	2.72	1.06	0.44	1.00
Medieval European	Plant ash	68.78	12.21	2.04	8.30	2.73	1.59	n.g.	n.g.

Table 2.2: Mean compositions (in wt%) of several groups of soda-lime-silica glass, showing change over time (data from Nenna *et al.* 2000, Freestone 2005, Freestone 2006, Tite *et al.* 2006, Rehren *et al.* 2010, and Arletti *et al.* 2010); n.g. indicates "not given."[24]

[24] The data sets for the chemical groups in this table are as follows: Late Bronze Age (14th century BCE Amarna, Egypt), Roman (1st-3rd century CE Leicester, England), Levantine I (5th-7th c. Apollonia, Israel), Levantine II (ca. 8th century CE Bet Eli'ezer, Israel), Egyptian I (8th-9th century CE Wadi Natrūn, Egypt), Egyptian II (8th-9th century CE Tell el-Ashmunein, Egypt), HIMT (4th century CE and later Carthage, Tunisia), Islamic (10th-13th century CE Banias, Israel), Medieval European (10th-13th century CE Hosios Loukos, Greece).

It should be noted that regarding the dates for the Levantine II glass, excavators have suggested a 6th-7th century date for the furnaces at Bet Eli'ezer and note they were possibly used into the early 8th century CE as well; however, "the limited occurrence or absence of this glass from assemblages dating to before the 8th century CE supports the view based upon the Ramla glass [8th century CE] that it represents early Islamic production" (Freestone *et al.* 2002a: 173).

It might be expected that these compositional types would dominate glass assemblages within the region local to a particular production group (Freestone *et al.* 2002a: 172). For example, there is an apparent restriction of the Egypt I type glasses to Egypt (Freestone *et al.* 2002a: 173). However, these five glass types can often be found simultaneously at a given site in the Mediterranean, which suggests glassworkers obtained their raw glass from a variety of suppliers or sources; even so, there may have been differential or preferential access to raw glass supplies, so the patterns of distribution should certainly be studied. Levantine I glasses, which are associated with Belus River sand sources, seem to have dominated the glass market in northern Israel; HIMT was possibly produced in Egypt and was abundant all around the Mediterranean and especially in the Sinai, but it "has yet to be identified in any quantity in northern Israel" (Freestone *et al.* 2002a: 173). Where both HIMT and Levantine I glasses are found together, HIMT dominates over Levantine I "outside the immediate Levantine area" (Freestone *et al.* 2002a: 173). Such details might suggest these two particular types were involved in a sort of supply competition; interestingly, HIMT glass has more soda and less silica than Levantine I type glass, which makes it easier to melt and therefore a more fuel-efficient glass (Freestone *et al.* 2002a: 173).

Economies of Glass: Cullet, Recycling, and Value

The movement of raw glass, raw materials, cullet (broken fragments of glass vessels that are intended for recycling), finished objects, ideas, and the glassworkers themselves are obviously important factors for understanding the nature of the glass industry. However, "movement" is just one facet of the larger network of glass

production and consumption; other aspects like glass recycling and the value of glass materials and objects are also central elements of the "economies of glass." Economic aspects are essential for a full consideration of the nature and culture of glass, because such aspects directly impacted glass production and consumption.

A special material property that glass shares with metal is the ability to be remelted and used again to produce new objects. When a glass vessel breaks, little can be done to repair it, but the broken pieces can be recycled. Glass recycling initially occurred on a small scale; it did not involve the actual remelting of fragments (broken glass was instead reused as inlays, mosaics, etc.) until after the discovery of blowing, but by the late 1st century CE recycling had become almost synonymous with the practice of remelting (Stern 1999: 441). Remelting broken cullet was economically and technically very sound practice, as melting glass requires significantly lower temperatures than melting raw materials to make glass from batch (1094˚C compared to 1426˚C). However, recycling glass over and over again gradually makes it more difficult to work with due to an increasing stiffness, which is why it was common practice to mix glass cullet with batch materials to make glass rather than remelting cullet alone.

If the development of blowing glass revolutionized the glass industry in the Augustan period, then the innovation of large-scale recycling had a considerable impact on the industry during the Flavian period; in fact, "recycling became a poetical *topos* for Flavian poets, such as Martial (*Epigrammata* I, 41) and Statius (*Silvae* I, 6), who mentions peddlers hawking sulphur in exchange for broken glass" (Silvestri *et al.* 2008: 332). By the late 2nd-early 3rd centuries CE, recycling was so common that authors like Dio Casius (*Historia Romana* 60.17.6) used the phrase "broken glass" as an idiomatic

expression to indicate the cheapness of something (Stern 1999: 451, note 38). Recycling continued to be an integral part of the network of glass production and consumption in the post-Roman period—and is of course still practiced today.

The realization that remelting broken glass fragments was much easier and less labor-intensive than making glass from its raw materials likely led to the deliberate and selective collection of broken glass, and to a change in the very color of the glass being produced. By the end of the 1st century CE intensely colored glass was largely replaced by naturally-colored or colorless glass—this may be directly linked to the increased practice of glass recycling, as there would have been a risk of producing an "indistinct muddy color" by mixing colored glasses (Stern 1999: 451; Silvestri 2008: 1489). "Uncolored" glass can take two forms: the first is glass that has no intentional colorizing additives but takes on a range of yellow-green-blue hues due to the natural impurities (especially iron) of the raw materials (Verità 1995), which is often called "naturally" or "unintentionally" colored; the second form is glass in which the natural color chemistry has been intentionally manipulated through the addition of a decolorizing agent like antimony and manganese oxides into the batch (Sayre 1962), which is called "decolorized" or "colorless" glass.

The practice of recycling could also have enhanced the overall trade of glass, as it would have been more economical to produce natural glass that could then be turned into a variety of colors rather than to produce specialized colors at the outset. If a strong color was desired for a vessel or individual decorative details, glassworkers themselves could color the raw glass by adding metallic scrap or mineral ores. Window glass may have made up the bulk of recycled glass (Lauwers *et al.* 2007: 42), possibly because it was

cheaper than vessel glass (Erim and Reynolds 1973) or because it was of lower overall quality (Jackson *et al.* 1998: 61), but all colors and qualities of glass were recycled.

Recycling is an activity that is often very difficult to identify in the archaeological record, but on occasion evidence for the intentional collection of broken glass has been found. One interesting example of this is the monastery at Jabal Harun in southern Jordan, which shows different "glass economies" in action. The monastery's church burned down in the mid-late 6th century CE, but there is no indication that the broken glass from these structures (windows, lamps, and tablewares) was collected; however, when the church was destroyed a second time in the early-mid 7th century CE, the associated broken glass was collected and recycled. Archaeologists have interpreted the changing pattern of glass cullet use at Jabal Harun as indicating the economic differences between these two periods: the lack of cullet collection in the 6th century CE indicates the monastery was relying on a functioning local or regional glass workshop within a well organized economy, whereas the collection of cullet in the 7th century CE reflects either the fact that the local workshop was short of raw material or that it was cheaper and more convenient for the monastery to collect cullet (Keller 2010b: 195). There is evidence for the same sort of changing glass-recycling activities from the nearby Petra church as well (Marii 2001; 2008).

The chemical analysis of vessel fragments has shown that recycling can be identified by the elevated levels (more than 10 ppm) of transition metals like Cu, Co, Pb, Mn, Sb, Sn, Ag, and Zn (Freestone 2006; Silvestri 2008a, 2008b; Silvestri and Marcante 2011). These particular elements are linked to the additives that were used for colorizing, decolorizing, and opacifying glass, which may indicate the careless or unavoidable

contamination of a recycled batch of glass by colored glass (e.g., the colored blobs and trails that decorated uncolored glass); alternatively, this might reflect a "confidence that the inclusion of a small amount of colored glass would not affect the color of the batch" (Freestone 2006: 210).

An obvious concern for chemical analytical studies is that the recycling process may have blurred the compositional differences between the various primary production groups. Fortunately, this does not seem to be the case; "the *random* mixing of the glasses clearly did not take place on large scale or these relatively discrete groupings […] would not be discernable" (Henderson 2004: 112). This may be because "for significant periods of time, glass working in a region tended to depend on a single production center for the supply of raw glass" so recycling probably occurred on an intra-regional basis and thus only mixed together glasses of the same basic type during the recycling process (Freestone 2006: 210). It is also possible that glassworkers were familiar with the source of the cullet and simply did not mix together different types of glass because of differing working properties.

Glass scholars have also noticed that there is often a correlation between the composition and color, which suggests that glassworkers could use color "as a means of identifying glass of a compositional type that had its own characteristic (predictable) working properties" (Henderson *et al.* 2004: 465). The cargo of the *Iulia Felix*, a late 3rd century CE ship that sank off the coast of northern Italy, shows that the glass cullet was carefully selected for particular colors and types (Silvestri *et al.* 2008; Silvestri 2008). Selection is still practiced today; for example, in 2010 I interviewed the Khalife family of glassworkers in the town of Sarafand (located on the coast of Lebanon between Tyre and

Sidon), who take great care to only melt together glass of like colors by extensive sorting of recycled materials.

The recycling of glass can also provide important glimpses into the relative costs of the different types of glasses produced in the Roman and post-Roman world. The *Iulia Felix* was carrying some 11,000 fragments of glass cullet as part of its cargo (Silvestri *et al.* 2008; Silvestri 2008). The excavators of the ship found that cullet with a blue-green hue (i.e., naturally colored glass) was proportionally more abundant than colorless glass or glass with a green color, which may possibly be explained by the greater cost of colorless glass with respect to colored glass (Silvestri *et al.* 2008b: 332). Such an interpretation is supported both by typological and by chemical evidence: the blue-green glass cullet mostly came from bottles, while colorless glass had been used to made higher-quality objects like plates and cups[25] (Silvestri *et al.* 2008: 332). Contemporary documentary evidence for the variable cost of glass based on color comes from the Price Edict of Diocletian, prepared in Antioch ca. 301 CE. This Price Edict lists the maximum prices for six types of glass; both vessel glass and raw glass (presumably in the form of both raw chunks and cullet) were sold by the pound,[26] "at 24 and 13 denarii per pound, depending on whether the raw glass was colorless (*vitri alexandrini*) or blue-green (*vitri*

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[25] Colorless glass was also used for "more ordinary vessels like bottles" (Silvestri *et al.* 2008: 332), but it is unclear whether these bottles are of the same form and function as the blue-green glass bottles or are instead more specialized (e.g., small bottles for luxury products like oils?).

[26] This is apparent from the words used in the Price Edict to indicate weight: *libra* (or the Greek *litra*) referring to raw glass, and *pondo* to vessel glass. "The choice of the word probably reflects the reality of transactions: raw glass was sold in multiples of one pound (libra), whereas the merchant needed to use a balance with a weight (pondus) to calculate the price of a glass vessel" (Stern 1999: 461). However, Stern points out is that despite this practice, "luxury glass and decorated vessels were always sold per piece" rather than by pound (1999: 462).

Iudaicis virdis)" (Silvestri *et al.*. 2008: 332).[27] The colorless "Alexandrian" glass was more expensive precisely because it had been manipulated in order to counter the natural blue-green hue of glass; the naturally colored "Judaean" glass was therefore less expensive.

A close chemical study of colorless Roman glass from 1st-4th centuries CE Britain has shown that the primary production of colorless glass was closely controlled in terms of the selection of raw materials, and that glasses made using better quality raw materials are often linked to "the more elaborate and 'high-status' vessels, such as the facet-cut beakers and cage cups" (Jackson 2005: 770). Jackson demonstrates that glass decolorized using antimony was made using a high-quality sand (with low levels of iron, alumina and other impurities), while glass decolorized using manganese was made with the same "impure" sands used to produce the typical naturally aqua glass; of additional significance is the fact that antimony is a stronger decolorizer than manganese (Jackson 2005: 771 and Fig. 1) and therefore was the more valuable additive. Pliny and Strabo both comment on "technical improvements for making clear (decolorized glass) glass" (Stern 2008: 528), while Freestone has shown that sand from the Belus River—which was prized as a high-quality glassmaking raw ingredient because it contained a low level of impurities like iron—could be selected by visual means alone (Figure 2.5). These various studies certainly seem to support the conclusion that colorless glass was more

[27] Dan Barag has convincingly argued that the modifiers "Alexandrian" and "Judaean" do not in fact refer to the regional origin of the glass, but to generic qualities or types of glass (Barag 1987: 113-114). Stern also remarks that these designations may have begun in the 1st century CE, but certainly were in use before the year 135 CE when Hadrian officially abolished the province of Judaea and renamed the region Syria Palestina (1999: 461). It is interesting that the association of glass types had ceased to be geographically meaningful by the start of the 4th century CE, and that they had been replaced material-specific meanings.

expensive than natural glass, and that certain types of colorless glasses were more costly than others.

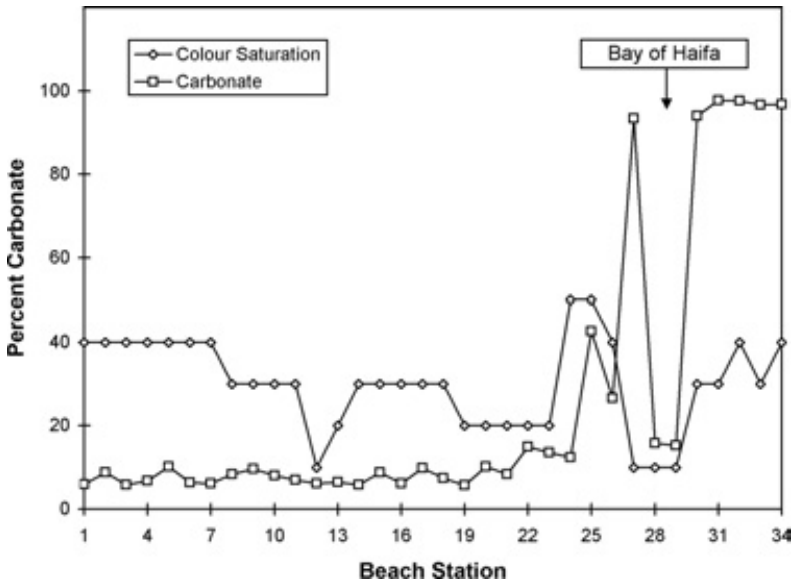

Figure 2.5: Color saturation and the calcium carbonate content of beach sands from the coast of modern Israel. The lower the color saturation, the paler the sand: the Belus River sand (near the Bay of Haifa) would have been very pale compared to adjacent sands and thus could be specifically selected (Freestone 2006: 206, Fig. 5).

Economies of Glass: Shipwrecks and Transport

Studying the "economies of glass" is not limited to a consideration of the sources of raw materials or to aspects of the production of raw glass and finished vessels, including the recycling of cullet. An important—and often intangible—element is the larger regional movement of the various components of the glass network: raw materials, raw glass, cullet, finished vessels, and even the glassworkers themselves. All of these components were transported long and short distances by both land and sea, but our understanding of trade patterns typically derives from an analysis of the objects themselves, working backwards from the artifact to determine their origins based on stylistic or chemical characteristics and then comparing the distribution patterns of the finds.

Documentary sources provide some helpful insight into patterns of movement. For example, the ca. 3rd-6th centuries CE Babylonian Talmud gives an indication of the trade of cullet and raw glass from primary to secondary workshops that took place, referring to glass cullet being bought in bulk and conveyed along with finished products in sacks and baskets on the backs of donkeys in order to be reworked elsewhere (Shabbath, 154b; cited by Keller 1994).

Shipwrecks around the Mediterranean region show that the importation of raw glass from the Near East to other parts of the Mediterranean has a very long history, extending back to the Bronze Age.[28] An extremely important piece of direct evidence for glass trade is a small, shallow ship[29] that sank in the Serçe Liman harbor off the southern coast of Anatolia (Figure 2.6), which has been dubbed the Serçe Limanı "glass shipwreck." The ship has been closely dated by means of Byzantine and Islamic coins and coin weights[30] to the period of 1022/1022 to 1024/1025 CE, and a typological and chemical comparison of the glass, ceramic, and metal objects in the cargo suggests the ship loaded most of their products at or near to the Levantine port of Caesarea (Figure 2.7).

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[28] There is evidence of raw glass cakes being transported from Egypt in the mid-14th century BCE on board the vessel known today from the Uluburun shipwreck (Jackson and Nicholson 2010). Hellenistic period evidence of ships transporting raw glass, cullet, or finished vessels includes: a 3rd century BCE shipwreck off Corsica, a 3rd century BCE shipwreck off the coast of France, and a 1st century BCE shipwreck off the coast of France (Bass *et al.* 2009: 499-500). Roman-Byzantine period evidence includes: a 2nd century CE shipwreck off the coast of France, a 3rd century CE shipwreck off the coast of Italy, a 3rd century CE shipwreck near Malta, and a 5th century CE shipwreck off the coast of France.

[29] Nautical archaeologists from Texas A&M University excavated the wreck in 1977-1979; the ship is 15.6m long and is described as "a very small two-masted lateener with an overall length of only 15 meters and a cargo capacity of some 30 metric tons. Since her bottom was extremely flat and her keel projected only slightly below the bottom, she was very shallow draughted" (von Doorninck 1990: 58).

[30] These include coins of Byzantine emperor Basil II (958-1025 CE), and glass and metal coin weights and coins issued by Fāṭimid caliph al-Ḥākim[30] (996-1021 CE) and his son al-Ẓāhir[30] (1021-1036).

Figure 2.6: (Left) A 3D reconstruction of the Serçe Limanı ship (by Ryan Curtiss Lee, Texas A&M University, image from http://people.tamu.edu/~ryanlee/serce11th.html); (right) map showing the site of the shipwreck and the possible port it took cargo (base image from Google Maps).

Figure 2.7: Glass vessels and cullet recovered from the Serçe Limanı shipwreck (images from the Institute of Nautical Archaeology's website: http://inadiscover.com/projects/all/southern_europe _mediterranean_aegean/serce_limani_turkey/full_report/).

The Serçe Limanı ship[31] was carrying some 80 vessels of intact glassware as part of her cargo and was ballasted in part by approximately 3 tons of glass cullet that was

[31] There are technically several Serçe Limanı shipwrecks, as Serçe Liman is the name of the harbor itself in which the ships sank, but in this study the Serçe Limanı shipwreck will refer exclusively to the 11th century CE ship carrying glass cargo.

likely carried in baskets (Figure 2.7);[32] two tons of this was broken-up raw glass chunks and one ton was true cullet (e.g., broken glass vessels and glassworking debris[33] meant for recycling), which was destined to be sold to secondary glass workshops for melting and shaping into vessels by means of casting or blowing (von Doorninck 1990: 58; Bass *et al.* 2009: 500 and notes 27-29). Based on the pattern of fragment concretion, von Doorninck estimated that the glass was carried in 32 baskets, each of these "about 40 cm on a side and perhaps half a meter high" and carrying approximately 93.75 kg of glass—which works out to the weight of the cullet recovered from the wreck (Bass *et al.* 2009: 500). This estimation is an interesting calculation on the part of von Doorninck, as a Hebrew document from the Cairo Genizah[34] dating to 1011 CE—roughly contemporary to the Serçe Limanı ship—records a shipment of glass[35] from Tyre to Fusṭāṭ consisting of 37 baskets (Carboni *et al.* 2003: 143).

While there was no apparent sorting of the Serçe Limanı cullet baskets by glass color or type, in one case moil[36] fragments "were carried in baskets that contained little if

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[32] The half a million to a million fragments of glass in the Serçe Limanı cargo (Bass *et al.* 2009: 15) is staggering in comparison to other shipwrecks; for example, the 3rd century CE *Iulia Felix* contained only one barrel "originally about 1.40 m high, filled with more than 11,000 fragments of glass vessels, for a total weight of 140 kg" (Silvestri *et al.* 2008: 331).

[33] Such glassworking debris or waste is identifiable because it is "misshapen or otherwise defective or unfinished" and also includes partially used colored rods for making trailed decorations as well as pontil crack-offs (von Doorninck 1990: 58-59). The debris itself and its chemical similarity to the vessel fragments are evidence that all the glass came from workshop contexts rather than the widespread gathering of fragments for recycling.

[34] The Cairo Genizah is a repository of discarded writings inside the Ezra Synagogue in Old Cairo (Fusṭāṭ), which was discovered by scholars in the late 19th century.

[35] It is not certain what kind of glass this cargo actually was—whether finished vessels or raw chunks and cullet—as "the text speaks of glass (*zekûkît*) only in general terms," although raw glass "appears to be more probable" (Carboni *et al.* 2003: 144).

[36] A glass moil is a waste product from glass blowing, being a small collar or cylinder of glass that is left on the blowing iron after the vessel has been detached; one moil is direct evidence for one blown vessel. Elsewhere in the same volume, Bass notes that slightly more moils than Brill's count were actually found, 13,360 by one count (Bass *et al.* 2009: 501).

anything else, implying that they had been collected directly into the baskets at the glassworks that produced them" (Bass *et al.* 2009: 501). The conservative estimate for the number of vessels represented by the cullet is between 10,000 and 20,000 vessels, representing over 200 different vessel types and shapes (von Doorninck 1990: 59)—this is by far the largest assemblage of medieval Islamic glass that has ever been discovered.[37] The shapes and designs of the 80 examples of intact glassware are similar to that of the cullet, suggesting these are contemporary rather than older vessel cullet recycled at a later time.

Brill estimates that the 10,000-20,000 vessels making up the cullet could represent the output of two glassblowers working at the same furnace over the course of two to three months, although "if all of the fragments were from wasters, and one assumes a 15% rejection rate, they would represent about one and a half year's production." The 11,000 moil fragments "by the same mathematics would have required about five months to produce" (Brill 2009: 464). As the majority of the glass vessels from the Serçe Limanı shipwreck actually appear to be of good quality (as opposed to wasters), it may be that they cracked upon cooling and for this reason were disposed (Bass *et al.* 2009: 502).

CHANGES IN THE INDUSTRY DURING THE EARLY MEDIEVAL PERIOD

The cultural, technological, and economic patterns of the 4th-9th centuries CE characterize the Near Eastern glassmaking industry as a healthy and highly successful

[37] These include common wares as well as higher quality tablewares: beakers, dishes, bowls, bottles, jugs, ewers, flasks, jars, lamps, cupping vessels, and circular window panes. The vessels are plain or are decorated by threading, wheel-cutting, or mold-blowing—relief-cut decoration is rare.

Figure 2.8: (Left) Example of the halophytic species of plant used in glassmaking, *Salicornia Europaea* (photo by Marco Schmidt, http://da.wikipedia.org/wiki/Fil:Salicornia_europaea_MS_0802.JPG); (right) making plant ash in modern Korea using traditional methods (photo by Aimee Lee, http://www.flickr.com/photos/moonaimee/3224718404/in/photostream/).

network. In the Early Medieval period, however, mineral soda slowly began to be replaced by the soda-rich ashes of halophytic plants of the Chenopodiaceae or Amaranthacacceae family[38] (Figure 2.8) as the primary source of alkali. The ashes of such plants are naturally rich in calcium, so when plant ash soda was used as a flux it was combined with the lime-free silica of crushed quartz. This change in the two basic raw materials of glassmaking is first observed in Syria-Palestine beginning in the mid-9th century CE, and although the process of change was not a rapid or uniform, it appears to have become a universal and stabilized technology over the course of the 10th-11th centuries CE.

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[38] These plants are notably salt and drought tolerant, growing primarily in coastal areas, salt marshes, and semi-desert regions. There is a wide range of halophytic genera that could have been exploited by ancient glassmakers, including *Anabasis, Arthrocnemum, Halopeplis, Hammada, (Haloxylon), Salicornia,* and *Salsola* (Barkoudah and Henderson 2008: 297)—the last two are the genera typically discussed in glassmaking scholarship (Brill 1970; Iluz and Amar 2008), and common species include saltworts and tamarisks.

This family of plants has high soda because it concentrates alkaline salts (sodium carbonate) in their tissues by means of photosynthesis (Barkoudah and Henderson 2008: 297). Another species, called "wall pellitory" or *Parietaria judaica*, was recently found to have similar or occasionally higher potassium and soda levels than *Salsola kali* (Iluz and Amar 2008).

New Sources of Soda and Silica

A failed glass melt in a tank furnace at the site of Bet She'arim in Israel is the most direct evidence we have for ancient glassmakers' experimentation with new raw materials and recipes. The 3.4 x 1.95 x 0.45 meter, nine-ton slab of vitrified material was discovered *in situ* in a Jewish necropolis, inside a cave that had been used first as a tomb, then as a cistern, and finally as a workshop space (Figure 2.9). At first it seemed unbelievable to excavators that glassmakers simply abandoned the raw glass, but chemical analysis has shown that the melt was a complete failure: either the ingredients did not fully melt or the mass underwent extensive devitrification upon cooling (Freestone and Gorin-Rosen1999: 105).

The cause of this failure was the extremely high lime content—15.9 wt% CaO (Brill and Wosinski 1965: 219.5), which is double the 7-9 wt% CaO that is typical for Roman-Byzantine and Islamic glasses—this indicates that two high lime ingredients were used: calcium-rich sand and calcium-rich plant ash.[39] The relationship between the raw materials for soda-lime-silica glasses and reasons for the failed Bet She'arim melt are best illustrated in Figure 2.10.[40] The date of this experiment with raw material combinations is highly important for understanding the chronology of glass technology

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[39] Recall that calcium-rich sand was traditionally paired with pure natron, while pure quartz was paired with calcium-rich plant ash. The Bet She'arim slab had elevated levels of potash and magnesium, which confirm the use of plant ash, while elevated levels of alumina indicate a sand silica source. The result of this combination was that the working properties "were outside the range acceptable to glassworkers… indeed, its liquidus may have been so high that it did not melt completely when fired under standard conditions" (Freestone and Gorin-Rosen 1999: 115); moreover, glasses with excess amounts of lime cool very slowly and become partially crystallized.

[40] Three of these sites correspond to the mineral soda primary production groups identified by Freestone (Bet Eli'ezer corresponds to Levantine II while Apollonia and Dor correspond to Levantine I), Banias represents a typical plant ash glass, and Bet She'arim is the failed glass melt—the tie-lines visually indicate where glass compositions need to be situated in terms of ratios of silica, lime, and soda in order to produce a viable glass; the Bet She'arim mixture is not on the same line as the others, because it has more lime.

and production. Initially, the slab was dated to the 4th-7th centuries CE (Brill and Wosinki 1965; Brill 1967), but this has been adjusted this to a post-Byzantine date of the early 9th century CE based upon the technological study and an archaeological reassessment of the site (Freestone and Gorin-Rosen 1999: 113; Vitto 1996: 136-141).

Figure 2.9: The failed 9th century CE glass melt from the tank furnace at Bet She'arim. Left: the block of vitrified glass *in situ* (photo from the Corning Museum of Glass website, http://www.cmg.org); right: close-up of the surface (photo by author).

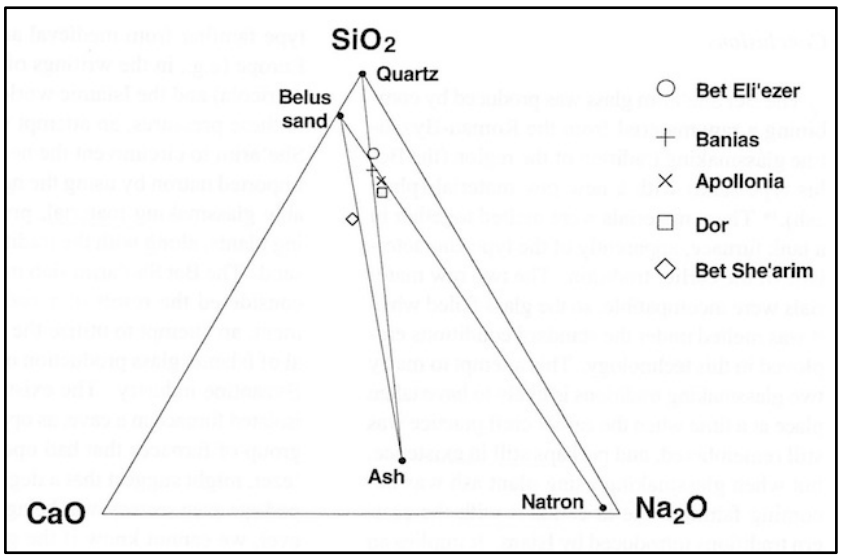

Figure 2.10: Triangular diagram showing the relationship between raw materials and glasses from several sites in modern Israel, all of which (glasses made using mineral soda and plant ash soda alike) fall on a similar line *except* for Bet She'arim (from Freestone and Gorin-Rosen 1999: 115 and Fig. 6).

The site of Raqqa-Rafiqa in Syria provides additional important evidence for the chronology of glass technology (Henderson 1999 and 2004; Henderson *et al.* 2004 and 2005). Six locations in and around this site have been excavated, and three of these show evidence for glass production and experimentation (Henderson 2004): Tell Zujaj in the 8th-9th centuries CE, Tell Fukhkhar in the 11th century CE, and Tell Belor in the 11th-12th centuries CE. Tell Zujaj[41] includes a complete glassmaking workshop with the remains of four beehive-type glass furnaces *in situ*; although there are no furnaces at Tell Fukhkhar, extensive production debris has been recovered, including evidence for the fritting, melting, and working of glass.

Both mineral soda and plant ash soda glasses (in the form of raw chunks and finished vessel fragments) were found together at Tell Zujaj in dumps dated to a short, possibly 30-year period in the late 8th-early 9th centuries CE, suggesting that both technological types were being used contemporaneously at the site. The mineral soda glass "shows very little spread in values, indicating a repeatedly well-controlled process" and was probably imported for secondary working from the Levantine coast (Henderson *et al.* 2004: 439 and 465). The plant ash glasses were made on the site during the same period, but these had a more diffuse compositional range that can be divided into three distinct groups; one of these is believed to be the result of experimentation with new combinations of raw materials (Henderson *et al.* 2004: 457). Such experimentation may have been similar to that taking place at Bet She'arim during the same period; sand was used in combination with plant ash soda, although the shell content of the sand appears to have been removed to avoid the excess-lime difficulties experienced at Bet She'arim

[41] It must be noted that *zujaj* is the Arabic word for glass, which is suggestive of the significant amount of glass recovered from this site.

(Henderson 2002: 600). Over 75% of the glasses recovered from 11th century CE Tell Fukhkhar at Raqqa were made of plant ash soda that had a low level of compositional variety (Henderson *et al.* 2004: 452), which suggests that by this time the new technological processes had stabilized.

The third testament to the technological changes taking place during this period are the glass coin weights that were made in Egypt during the Umayyad to Fāṭimid periods (Figure 2.11). These objects are important evidence for establishing a more precise chronology of the change in glassmaking flux, because they were stamped with the names of known officials[42] who can be associated with a specific range of dates (Balog 1976; Bates 1981). Since the 1970s, several researchers have chemically analyzed Islamic glass coin weights, the results of which are shown below (Table 2.3). Matson, Sayre and Smith analyzed only a small number of samples, but they were the first to indicate that mineral soda continued to be used in Egyptian glass into the 9th century CE. Gratuze and Barrandon (1990) analyzed 70 examples of coin weights from the Umayyad to Mamluk periods, and defined four distinct chemical groups based on their alkali and silica characteristics; three of these dating from the Umayyad, ʻAbbāsid, and Ṭūlūnid periods used natron as an alkali while the fourth dates to the Fāṭimid period and likely used plant ash soda as the flux. Kato, Shindo, and Nakai (forthcoming) have recently undertaken a large-scale study of glass coin weights; the authors have presented their preliminary results at the AIHV 18 Congress and their findings support Gratuze and Barrandon's observation that in the mid-8th century CE there was a minor change in the

[42] "The right of emission of glass was only exceptionally exercised by the caliph himself… the caliphs generally delegated the issuing of the glass to the governor, or when there was a viceroy, to him, or to the finance director, or to both jointly" (Balag 1976: 4).

silica sources used for the mineral soda glass, and also shows that the coin weights are similar in composition to the glass vessels used in Fusṭāṭ (specifically, they were produced from the same silica source). Although these studies of glass coin weights have shown that there is no evidence for plant ash being used by Egyptian glassmakers to make coin weights before 968/9 CE, there remains a large 100-year gap in the data set for coin weights dating between 868-968 CE (Whitehouse 2002: 195); analyzing coins from the late 9th-early 10th centuries CE is therefore critical for a more complete and clear understanding of the chronology of the glassmaking technological changes that were taking place.

Figure 2.11: Examples of glass coin weights from the Fāṭimid period (Institute of Nautical Archaeology: http://inadiscover.com/projects/all/southern_europe_mediterranean_ aegean/serce_limani_turkey/full_report/).

Coin weight (no. and date)	Alkali	Publication
One weight (737-747 CE)	Natron	Matson 1948
Five 8th century weights and one 9th century weight (833-842 CE)	Natron	Sayre 1965; Sayre and Smith 1974
Seven weights (ca. 10th century CE)	Plant ash	Sayre 1965; Sayre and Smith 1974
Unspecified number of weights (latest dates to 868-883/4 CE)	Natron	Gratuze and Barrandon 1990
Unspecified number of weights (earliest dates to 968-969 CE)	Plant ash	Gratuze and Barrandon 1990
Unspecified number of weights (dating to ca. 714/717-787/796 CE and ca. 760/772-850/852 CE)	Natron	Kato, Shindo, Nakai (forthcoming)

Table 2.3: Summary of the results of chemical analyses of Egyptian glass coin weights, emphasizing the soda ingredient used as an alkali (low magnesium/potassium levels correspond to natron and high magnesium/potassium oxide levels correspond to plant ash).

SUMMARY

Although this project is primarily concerned with the Eastern Mediterranean glassmaking industry of the 8th-12th centuries CE, the contextual starting point is irrefutably the Roman era, during which time the structure of a "global" network and system of glass production and consumption based on the use of mineral soda fluxes was established. Significant changes began in the 4th century CE, and these laid the foundation for the large-scale primary production of glass in Egypt and the Levant and the shipping of raw glass throughout the Mediterranean region. This network remained healthy and successful for centuries, even after the basic glassmaking raw materials began to change. The process of replacing mineral soda with soda-rich plant ash began in the 9th century CE and appears to have been completed by the 11th century CE.

CHAPTER THREE: METHODS AND THEORY

INTRODUCTION

This chapter discusses the methods and theories used in this dissertation to study and interpret samples of archaeological glass recovered during the excavations of two sites in the Near East, each with occupation sequences spanning the 8th to 12th centuries CE. An overview of these archaeological sites is first discussed to sketch out and compare the geographic, historical, and cultural context of the sites. The methods of artifact analysis are then outlined, which includes a typo-chronological and chemical assessment of the glass artifacts, together with a synthesis of this information with other glass studies from the region. Finally, a theoretical framework that combines strategies for thinking about aspects like materials, economics, craft, technology, and society is suggested for shaping a discussion of the overall meaning and significance of the data and findings.

ARCHAEOLOGICAL SITES

This study focuses on materials from two sites located at opposite ends of the Levantine region: Ḥiṣn al-Tīnāt in modern Turkey and Ayla in modern Jordan (Figure 3.1). Both of these sites were built as new foundations during the Early Islamic period and follow a Near Eastern architectural type linked to the *amṣār, quṣūr*, *caravanserai, ribāṭāt,* and *khānāt* of Umayyad and ʻAbbāsid-period form (Eger 2010: 72; Whitcomb

1995a; Wheatley 2001). In addition, both of these settlements were located at the crossroads of important overland caravan routes and served as ports of trade on busy maritime waterways. Each site has a continuous occupation sequence of four centuries spanning the 8th to 12th centuries CE, which includes the Umayyad and ‘Abbāsid periods as well as the early Fāṭimid period in the south and the Middle Byzantine period in the north. Although to date neither site has exhibited any evidence of glass production (specialized workshops, glass furnaces, wasters, moils, slag, or other production debris), they do have a significant amount of glass vessel fragments that could shed light on the nature of glass production and consumption in the Near East during this particular period of time.

Figure 3.1: Map of the Near East showing the location of Ḥiṣn al-Tīnāt and Ayla, with the zone in between the two sites being the study region of this project (image from NASA, The Visible Earth, http://visibleearth.nasa.gov/).

Ḥiṣn al-Tīnāt (near modern Dörtyol in Hatay Province, southern Turkey)

Ḥiṣn al-Tīnāt[1] is a small, fortified settlement located on the Mediterranean coast of south-central Anatolia and was occupied in the Early Islamic and Middle Byzantine[2] periods (ca. 8th-mid 12th centuries CE). This region was known in antiquity as Black Cilicia (Tobin 2004) and features several plains and mountain chains, including the Cilician Plain, the Plain of Issos, the Plain of Antioch[3], and the Amanus Mountains. Historically this area has been of key importance because of its coastline, very fertile landscape, and access points through the mountainous terrain. In addition to linking the region to the Mediterranean, the plains served as a crossroads for the trade routes connecting greater Anatolia to northwestern Syria (*al-ʻAwāṣim*) and northern Mesopotamia (*al-Jazira*).

In Late Antiquity and the medieval period, Cilicia was a border zone between Byzantium to the north and the Islamic caliphates to the southeast. The Islamic-Byzantine frontier (*al-thugūr*) is the subject of current research by A. Asa Eger of University of North Carolina, Greensboro, who has shown that this region was not a militarized "no

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[1] "Castle of the Figs" in Arabic (*ḥiṣn* = fortress/castle; *al-tīnāt* = of the figs).

[2] Terms denoting chronology and/or cultural affinity ("Byzantine," "Islamic," or "Frankish") get rather messy when referring to this particular region during the medieval period, as political control shifted several times and the area was continuously comprised of both Christian and Muslim communities. See Eger notes that this scenario holds true for the larger region as well: "the Amuq Valley and the city of Antioch were under political control of the Byzantines and the Franks," although culturally "the region has much in common with the areas that were under Muslim control. The material culture of the Middle Byzantine period shows very little sign of Byzantine influence" (Gerritsen *et al.* 2008: 274). See Eger 2005 for his discussion of the "imagined" frontier and the impact a 'frontier model' has had on scholarship.

In the northern areas of the Byzantine Empire (Greece, Bulgaria, Constantinople) the "Middle Byzantine" period includes the 9th-12th centuries CE; however, in publications about Ḥiṣn al-Tīnāt the term "Early Islamic" is applied to 9th-early 10th century occupation sequence while "Middle Byzantine" refers to the late 10th-12th centuries because the area was predominantly controlled by non-Islamic populations (Byzantium or the Armenian kingdoms) at that time. The period is contemporary with the "Middle Islamic" period of regions to the south of the site and is therefore chronologically synonymous.

[3] Now known as the Amuq Valley.

man's land" as is often believed, but rather was multi-cultural, populated area that was part of an interconnected economic trade network (Eger 2010: 67). Eger's work has led to the discovery and initial excavation of Ḥiṣn al-Tīnāt.[4]

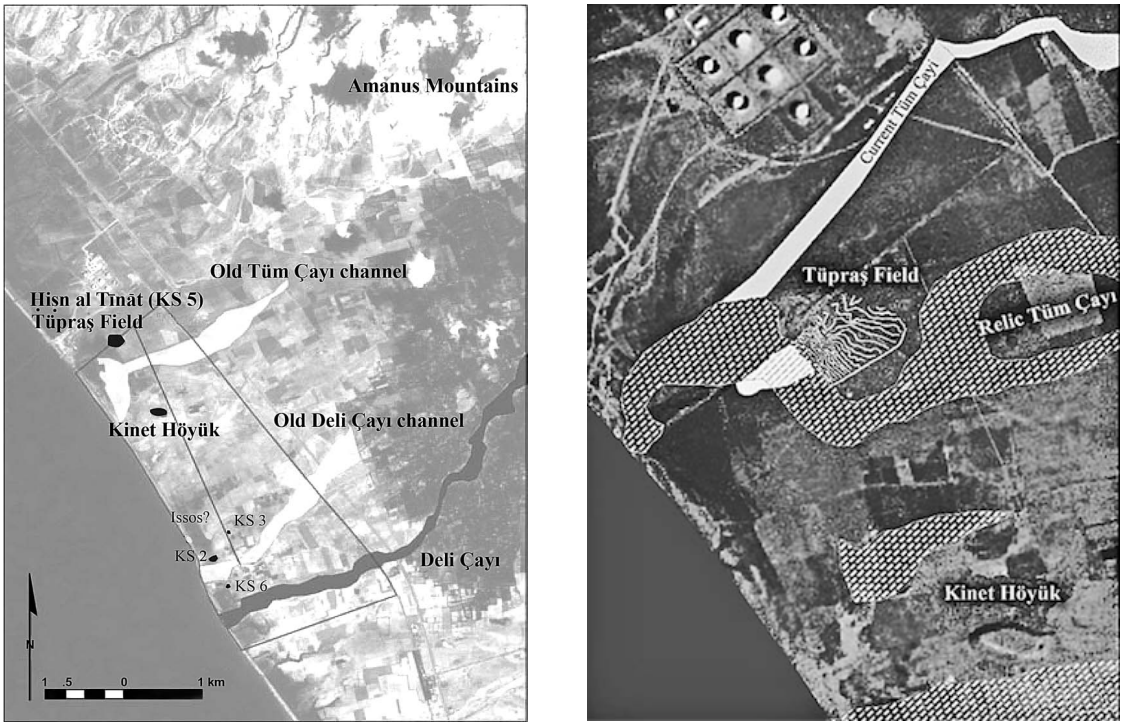

Figure 3.2: (Left) The Kırıkköprü Survey area, showing Kinet Höyük in relation to the new sites including the KS5 Tüpraş Field site, Ḥiṣn al-Tīnāt (Eger 2010: 56, Fig. 3); (right) CORONA satellite imagery of Tüpraş Field and Kinet Höyük (Eger 2010: 53, Fig. 2).

Investigation of the area along the coast near Dörtyl began in 1992 with the excavation of the mound site known as Kinet Höyük by Marie-Henriette Gates of Bilkent University. This mound was continuously inhabited from the ceramic Neolithic to the late Hellenistic period in the mid-1st century BCE (Gates 2002; 2009)[5] and then abandoned,

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[4] Early Islamic geographers including Aḥmad b. al-Ṭayyib al Sarakhsī (ca. 9th century CE, Transoxiana), Ibn Ḥawqal (ca. 10th century CE, Nusaybin/Nisibis in modern Turkey), Istakhrī (ca. 10th century CE, Iran), and Idrīsī (ca. 11th century CE, Spain) list a successive line of settlements along Cilicia's coastal route, including Ḥiṣn al-Tīnāt (Eger 2010: 50) but until now the location of this site had not been identified.

[5] Gates has published annual season reports from 1994 to 2009 in *Kazı Sonuçları Toplantısı*, and is currently writing the final reports for the publication of a final monograph.

but was later resettled in the late 12th century CE (Redford *et al.* 2001). The Kırıkköprü Survey,[6] carried out by Eger and A. U. di Giorgi in 2005, greatly contributed to the understanding of the vicinity of Kinet Höyük; this survey explored a 2km long corridor along the coast near the mound (Figure 3.2), identifying previously unknown sites as well as clarifying the occupation sequence of the mound itself.

In the Roman period the local population abandoned the mound and resettled about 2km to the southeast, a change that was probably due to the movement of the Deli Çayl River. This Roman settlement is likely the city of Issos (Hellenkemper 1984), and was re-identified as such by the discovery of a north-south coastal road, bridge, cemetery, and bathhouse as well as scattered ceramic and architectural remains in Kırıkköprü Survey units KS2, KS3, and KS6. Ceramic evidence at Issos suggests that occupation lasted from the 1st century BCE to the 7th centuries CE, although it may have extended into the early Umayyad period (the second half of the 7th century CE) as well. The locus of population then moved to a site northwest of the Kinet mound; this early Islamic settlement is the site that has been identified by Eger as Ḥiṣn al-Tīnāt and is located just north of the Tüm Çayl River and lagoon (of which a relic streambed remains), along the Late Roman coastal road. The site was identified by its distinctive Early Islamic ceramic assemblage in Kırıkköprü Survey units KS5 (known as Tüpraş Field and labeled TF)[7] and during later excavation of its stone fortification walls. A thick layer of burning associated with the main structure is visible in excavation units TF1 and TF11, which indicates

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[6] The survey is unpublished, although it is refereed to in other publications (Eger 2010: 55-58).

[7] "No single site surveyed in the Amuq or Kahramanmaraş Plains on the other side of the Amanus Mountains exhibited quite the amount, range, and value of both local and imported Early Islamic pottery, and indeed no site in either plain survey came close to showing a total dominance of Early Islamic pottery as compared with other periods" (Eger 2010: 71).

destruction by fire; this is not surprising, as the last quarter of the 11th century CE was quite unstable as Byzantines, Seljuqs, Armenians, and Crusaders vied for control of the region.[8] The population resettled the Kinet Höyük mound (directly on top of the Hellenistic period remains) in the late 12th century CE—probably to take advantage of the site's elevation—and occupation there continued into the early 14th century CE (Redford *et al.* 2001).

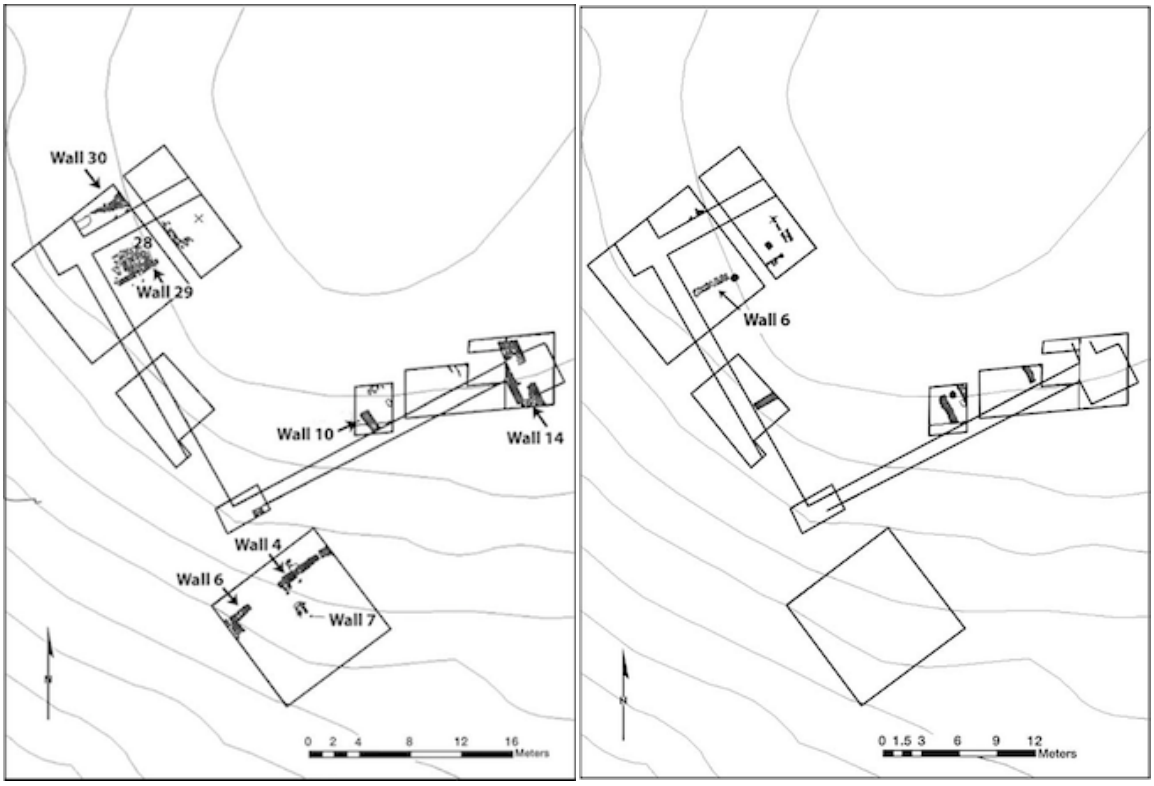

Figure 3.3: (Left) Plan of Ḥiṣn al-Tīnāt Phase IV Early Islamic period remains (Eger 2010: 60, Fig. 5) and (right) Phase III Early Islamic period remains (Eger 2010: 63, Fig. 60).

[8] Cilicia and Antioch were conquered by the Arabs in 637 CE and reconquered by Byzantine Emperor Nicephorus II Phocas in 969 CE (Eger 2010: 73) and remained in Byzantine control for over 100 years; Antioch was conquered by the Armenians in 1078, then by the Seljuqs in 1084, and then by the Crusaders in 1098.

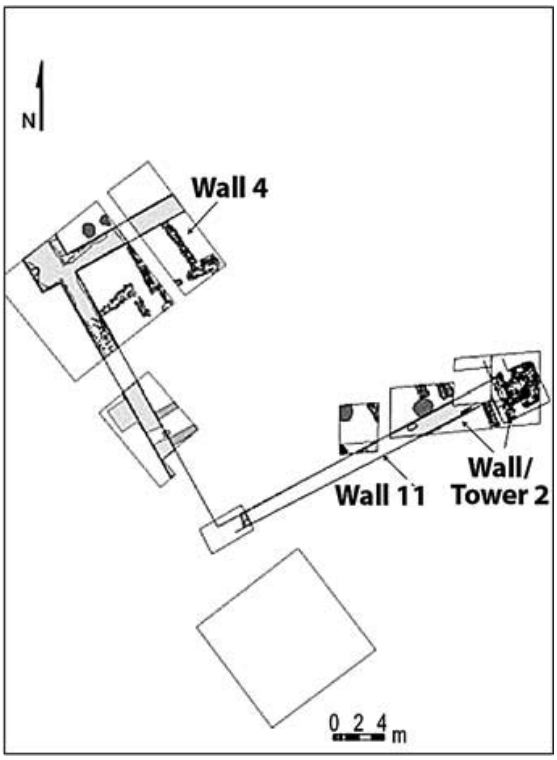

Figure 3.4: Phase I/II Middle Byzantine and later remains (Eger 2010: 64, Fig. 7).

Asa Eger has led three short excavation seasons at Ḥiṣn al-Tīnāt, in 2006, 2008, and 2011. Surface survey has defined an area of approximately 400m x 400m (16 ha), with finds becoming denser in a 50m x 50m (0.25 ha) portion. Excavation has uncovered a large fortified structure with corner towers and perpendicular internal walls that date from the Early Islamic and the Middle Byzantine periods (Figures 3.3 and 3.4). The site's chronology has been preliminarily divided into four architectural phases based on ceramic analysis:

- Phase IV: Early Islamic – 8th-centuries CE (fortified enclosure built)
- Phase IIIA/B: Early Islamic – late 9th-10th centuries CE (fortified enclosure built; occupation and construction of internal walls and external buildings)
- Phase II: Middle Byzantine – 11th-early 12th century CE (reuse of fortified enclosure)
- Phase I: Late Byzantine to modern – post-12th century CE

In addition to the fortified structure, there is evidence for a domestic building to the south, which consists of rooms possibly arranged around a central courtyard. Documentary sources indicate that Ḥiṣn al-Tīnāt was a timber depot and port involved in Mediterranean trade to Syria and Egypt (Eger 2010: 51); about 50m southwest and down-slope of the core excavation units, evidence was found in TF10 to suggest that this was once the edge of the river and coastline. The architectural features, Early Islamic cream-buff amphorae, and timber found here might in fact be the remains of the site's harbor facilities.

Ayla (in modern Aqaba, southern Jordan)

Ayla[9] is a walled port city situated on a coastal plain at the southern tip of the Wadi 'Arabah and at the head of the Gulf of Aqaba, which was occupied in the Early and Middle Islamic periods[10] (ca. mid-7th-late 12th centuries CE). In contrast to the fertile plains and upland forests of southern Anatolia, Ayla lies in an arid landscape flanked by mountains and bordered by deserts: the Sinai to the west, the Negev to the north, and the Ḥismā to the east. The harsh climate and topography of this landscape has led some scholars to describe it as primarily a "transit area" more suited for nomadic populations

[9] Names are particularly confusing for historical Aqaba because different variations have been used since antiquity—including Aila, Aileh, Aela, Ailana, Aelana, Elana, Haila, and Ailath (Parker 1997: 20)—possibly derived from the Biblical Hebrew place name of "Elath." Moreover, there are three chronologically distinct sites in the vicinity of the modern city, all of which were called some variation of the same name; the earliest observation of this confusion comes from the 10th-century geographer Muqaddasi who wrote "the city is usually called Ayla, but the true Ayla is in ruins nearby" (Whitcomb 1988: 3). Modern excavators have agreed to use a specific and unique spelling for the various excavation areas in order to distinguish the sites from one another and indicate their different occupation periods and/or cultural affinities; these agreed-upon spellings (Aila, Ayla, and Aylah) are used for the individual sites, and "Aqaba" is used as a collective reference (See Figure 3.4).

[10] Specifically, the Umayyad to Fāṭimid periods. As mentioned previously, "Middle Islamic" coincides chronologically with "Middle Byzantine" elsewhere in the Near East.

(Mayerson 1964: 168), but in actuality Aqaba and its hinterland have a very long settlement history.[11] An ample water supply made Aqaba a veritable "oasis by the sea" (Whitcomb 1994b: 4), and its strategic position on the coastline and at the juncture of key overland routes (running north to Palestine and the Levantine coast, northeast to Transjordan and Syria, and west to Sinai and Egypt) made Aqaba a thriving commercial center and international port as well as a busy way station for Christian and Muslim pilgrims on their way to St. Catherine's Monastery, Jerusalem, Mecca, and Medina.

Excavations within modern Aqaba began in earnest during the 1980s as a response to the rapid expansion and development of the city, which is the only seaport of the Hashemite Kingdom of Jordan and a popular tourist resort of luxury beachfront hotels. Archaeological research has shown ancient Aqaba's overall settlement pattern to be one of progressive movement southward down the coastline, resulting in at least four different archaeological sites within the boundaries of the modern city (Figure 3.5). The earliest of these is Tell el-Kheleifeh ($9^{th}/8^{th}$-4th centuries BCE), situated 550 m north of the modern shoreline and roughly equidistant from the modern city centers of Eilat (in Israel) and Aqaba (Glueck 1940; Pratico 1993). Two kilometers southeast of Tell el-Kheleifeh is the Nabataean, Roman, and Byzantine city of "Aila" or "Ailana" (1st century BCE-7th century CE) and 500 m to the southeast of Aila is the Early Islamic city of "Ayla" (7th-12th centuries CE). The later medieval settlement and castle (13th-14th centuries CE) are located one kilometer beyond Ayla to the southeast and is typically called "medieval Aqaba."

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[11] Occupation of Aqaba's hinterland begins in the Middle Palaeolithic and continues, with some interruption during 4th-1st century BCE, to the modern period (Parker 1997: 39). The earliest settlements in the area are Tell Maqass and Hujayrat al-Ghuzlan, located 4 km north of the modern coastline and dating to the mid-5th to mid-4th millennium BCE (Khalil and Eichmann 2001).

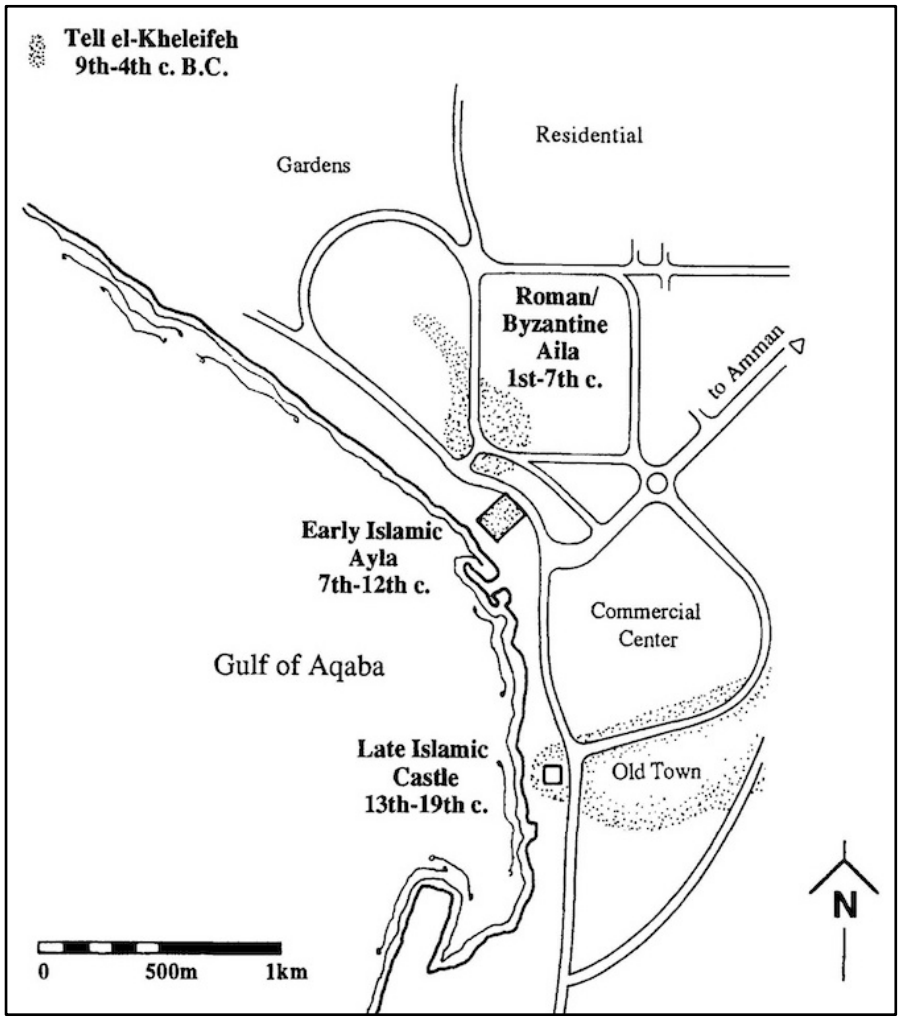

Figure 3.5: Plan of the major archaeological remains within modern Aqaba, including (from north to south) Tell el-Kheleifeh, Aila, Ayla, and Aylah (Parker 1997: 23, Fig. 2).

Aila was discovered by survey in 1990 by the Aqaba Geomorphological and Archaeological Reconnaissance Project (Meloy 1991) and thereafter excavated in 1994-2002 as part of the Roman Aqaba Project, directed by S. Thomas Parker of North Carolina State University (Parker 1996, 1998a, 2000, and 2003).[12] The primary goal of the project was to investigate the economic role of the city in the Roman Empire, and to examine the origins and development of the town and its relationship to the hinterland.

[12] A final report has not yet been published.

Excavations show a Nabataean city housing a substantial population was founded here by the 1st century BCE, with an economy based on pastoralism and long-distance overland trade between Arabia and the Mediterranean (Parker 1997: 22; Damgaard 2010: 5).

Aila continued to flourish after Roman annexation in 106 CE[13] and with the construction the *via nova Traiana* in 111-114 CE, the city became the southern terminus of an imperial highway stretching 267 miles north to Bostra in Syria that likely "improved both physical infrastructure and security for commercial traffic" (Parker 1997: 40). During Roman hegemony, maritime trade increased and expanded and the Red Sea trade "blossomed for more than 500 years" (Damgaard 2010: 6). In the late 3rd-early 4th century CE, the *Legio X Fretensis* was transferred from Jerusalem to the vicinity of Aila[14] where it remained until the mid-5th century. A significant Arab Christian population inhabited Aila from an early stage, as evidenced by bishops[15] and a possible 4th century CE church (Parker 1998b). In the Byzantine period, the center of the city shifted southward and a stone curtain wall with towers was constructed;[16] large quantities of imported objects and documentary evidence show that the city continued to be a thriving commercial center.

Aila surrendered peacefully by treaty (*sulh)* to Muslim forces in 630 CE (Mayerson 1964). The treaty guaranteed the safety and property of the city's inhabitants,

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[13] Initially part of the *Provincia Arabia,* the area became part of the province of *Palaestina Tertia* in the mid-4th century (Bowerstock 1983: 143).

[14] Some scholars have proposed that Islamic Ayla was constructed on top of this legionary fortress, based on the shape and layout of the site (Knauf and Brooker 1988); this theory has been disproved (Whitcomb 1994a and 2006) but the whereabouts of the legionary fortification remain uncertain.

[15] Bishops of Aila were present at the councils of Nicaea in 325 CE, Chalcedon in 451 CE, and Constantinople in 536 CE and their names are known until the early 7th century (Whitcomb 1989a: 164-165).

[16] Built in the late-4th century and reinforced with towers in the 6th century, the wall went out of use by the late 6th or 7th century (Parker 1997: 36-37; Damgaard 2009: 87).

which in effect "limited the possibility of simply appropriating the urban environment" (Damgaard 2009: 86) and contributed to the construction of a new settlement called Ayla, probably around 650 CE during the caliphate of 'Uthman b. 'Affan (Whitcomb 1995: 266). The pre-existing Byzantine city continued to be occupied, with no evidence of commercial decline. By the 8th century CE there were attempts to merge the two cityscapes, "by camouflaging the gates with markets" (Whitcomb 1995b: 503-507; Damgaard 2009: 87, note 12) and by integrating the street plans of the two settlements (Damgaard 2009: 87).[17]

The remains of Ayla were first identified in 1986 through a series of soundings made on the beachfront by Donald Whitcomb of the University of Chicago's Oriental Institute. Extensive excavations were conducted in 1987-1995 as part of the Islamic Aqaba Project,[18] the goal of which was to investigate the character and development of one of the earliest known Islamic urban foundations as well as the city's relationship with the urban centers of Egypt, Palestine, and Jordan (Whitcomb 1989a: 164). Excavations revealed a rectangular walled enclosure (145m x 175m) with towers and four main gates, within which were domestic structures and a mosque. This walled area may have acted as an urban core surrounded by an extensive extramural industrial and domestic settlement

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[17] A street laid out in the Roman period in Area K that continued to be in use at least until the early 10th century "crosses at an exactly perpendicular angle to the line created by the central *decumanus* at Ayla," which could indeed show an "integrated orthogonal planning" for Aila and Ayla.

[18] There is no final report for this project, although seasonal reports appear in the *Annual of the Department of Antiquities of Jordan* and the Oriental Institute's online *Annual Report*, as there are various articles and book chapters describing the history and significance of the site (Whitcomb 1988, 1989, 1994a, 1994b, 1995a, 1995b, 1998, 2001, 2006, and 2009).

Renewed investigations of Ayla were undertaken briefly by the University of Ghent's Islamic Aqaba Project (as a reconceptualization of the Aqaba Castle Project), which conducted a short 2008 season within the southwest quadrant of the walled enclosure and just outside the Egyptian Gate (Damgaard 2008). The unexpected death of IAP director Johnny De Meulemeester in 2009 shifted this research to the Aylah Archaeological Project (AAP) directed by Kristoffer Damgaard of the University of Copenhagen, which is continuing excavations in the southwest quadrant (Damgaard 2010).

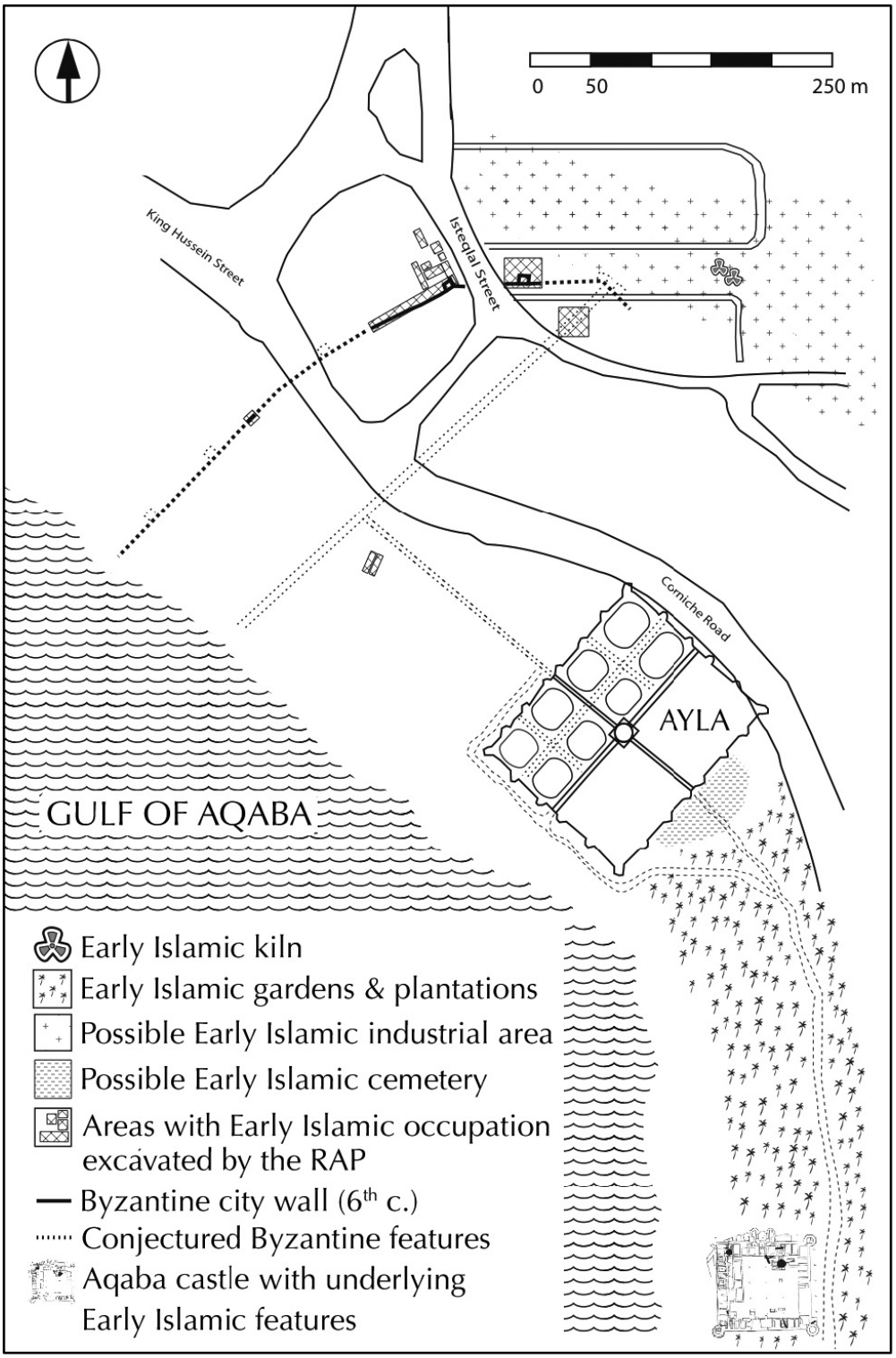

Figure 3.6: Plan of modern Aqaba highlighting Ayla and the Early Islamic remains from the surrounding area (Damgaard 2008a: 86, Fig. 10.2).

(Parker 1997: 41), as Early Islamic strata were also found inside and around Byzantine Aila (Figure 3.6).[19] Whitcomb has divided Ayla's occupation sequence into five major phases:

- Phase A (650-750 CE, Rashidun and Umayyad): first construction
- Phase B (750-850 CE, Early 'Abbāsid): reconstruction and expansion
- Phase C (850-950 CE, Middle 'Abbāsid): continuity
- Phase D (950-1050 CE, Late 'Abbāsid or Fāṭimid): intensification
- Phase E (1050-1116 CE, Fāṭimid): decline

The period of greatest prosperity at Ayla appears to be the late 8th-late 10th centuries CE, which saw extensive architectural restructuring of the city; an earthquake in 748 CE initiated a "serious investment of capital in the form of rebuilding, expansion, and re-organization of architectural space" and at this time the mosque was rebuilt and the areas outside the city walls were expanded (Cobb 1995: 420). Ayla's prosperity began to wane as the region became more insecure in the 11th century CE due to Bedouin raids and even more earthquakes,[20] but the 12th century CE might be considered the moment of "ultimate decline" due to conflicts between the Ayyubids and Crusaders. King Baldwin of Jerusalem took the city in 1116 CE, and "much of the population at Ayla is said to have taken to their boats and fled at Baldwin's approach" (Cobb 1995: 419).

Ayla remained abandoned and settlement shifted south once again to an area around a castle, which was founded in the 12th century by the Crusaders or Ayyubids and

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[19] The Roman Aqaba Project dug test trenches 150 m west of Ayla's fortification walls in an attempt to locate the Classical port (Areas L); stone walls and artifacts dating primarily to the Umayyad and late 'Abbāsid period were recovered from Areas A, K, and L (Parker 1997: 38). This occupation was limited to the 7th-8th centuries in Areas A and K, which thereafter were abandoned or became dumps; "the domestic occupation in Area L, closest of all these areas to both the shoreline and the Early Islamic town, continued well into the 'Abbāsid period, after which it, too, was used as a dump by the 10th century" (Parker 1997: 41).

[20] Ayla was sacked by the Banu Jarrah in 1024 CE and parts of the town collapsed and subsided during the earthquakes of 1068 and 1071 CE (Whitcomb 1994: 7).

was enlarged by the Mamluks in the 13th-14th centuries. The late Islamic town was called Aqabat Ayla ("pass of Ayla," later contracted to Aqaba) and included the castle, date palm plantations, and a fishing village. The castle was the focus of the Aqaba Castle Project in 2000-2008, led by Denys Pringle of the University of Cardiff and Johnny De Meulemeester of Ghent University; this project aimed to explore the history and morphology of the Mamluk-Ottoman phases of the site, but the remains of structures from the early 8th century CE were also discovered (De Meulemeester and Pringle 2004; 2005) and a high artifact density of 8th-11th century CE material suggests this area was quite active during this period, again attesting to the fact that "the geographic scope of the Early Islamic settlement was not limited to the walled town and pre-existing settlement, but was a widely dispersed and presumably growing phenomenon" (Damgaard 2009: 88).

ANALYTICAL METHODS

The typological and chronological characteristics of glass artifacts are traditionally assessed on a site-by-site basis for inclusion in the final excavation report[21] or for publication in a separate volume.[22] On some occasions, site assemblages—particularly those with evidence of glass production—also undergo a chemical analysis for inclusion as an Appendix in a longer site report[23] or as a short article for publication

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[21] Examples include various publications of excavations carried out by the Israel Antiquities Authority, such as Bet Eli'ezer (Gorin-Rosen 1993), Ramla (Gorin-Rosen 2010a and 2010b), Sepphoris/Zippori (Gorin-Rosen 2010c) and Bet She'an (Gorin-Rosen 2010d).

[22] Examples include Beirut (Jennings 2006), Nishapur (Kröger 1995), Fusṭāṭ (Scanlon and Pinder-Wilson 2001), and Serçe Limani (Bass *et al.* 2010).

[23] Examples include Jalame (Brill 1988), Nishapur (Brill 1995), Fusṭāṭ (Kato *et al.* 2010b), and Beirut (Paynter 2006).

in a specialist journal like the *Journal of Archaeological Science* or *Archaeometry*.[24] On other occasions archaeometrists publish chemical analyses of glasses from many different archaeological sites to build a general and comparative picture of glass technology at a given period of history or over time in a particular region.[25]

Glass scholarship is still largely segregated by typo-chronological assessment on one hand and geochemical assessment on the other, but the two can be combined into a coherent whole that allows a more critical analysis of the nature and culture of ancient glass. A typo-chronological approach alone is not enough to address questions about the details of glass technology and production, but a study that focuses exclusively on chemical data without addressing specificities like the physical appearance and historical period of the samples in question is also of limited value. The analytical strategy of the present study involves a close combination typological and chemical data—considered alongside the cultural, historical, and archaeological context of the material. This strategy is outlined below in more detail.

Sampling Strategy and Sample Set

The glass artifacts from Ḥiṣn al-Tīnāt and Ayla have never before been studied or published.[26] No production debris has been recorded from either excavation, which could

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[24] Examples include Raqqa (Henderson *et al.* 2004), Raya/al-Tur (Kato *et al.* 2009 and 2010a), and Beit Ras (Abd-Allah 2010).

[25] The earliest publication of this type is an article about ancient glass (Sayre and Smith 1961). More recent examples include appendices to catalogs about Islamic glass (Brill 2001), Sasanian glass (Brill 2005a), and medieval glass (Wedepohl 2010), as well as independent volumes about ancient Mediterranean and Near Eastern glass from all periods (Brill 1999a; 1999b).

[26] I surveyed the Ḥiṣn al-Tīnāt glass in July 2010 and will contribute an analysis of glass from the site in a future report. Carol Meyer of the University of Chicago's Oriental Institute served as the glass specialist for the 1986-1995 excavation of Ayla, although her observations have not been published nor has a full study of the material been conducted; I am very grateful to Meyer for providing copies of her drawings of some

suggest there were no glassmaking activities taking place at these sites,[27] although it should be noted that there has been almost no extramural excavation at either site. While it would be advantageous to study glassmaking or glassworking debris directly when addressing questions of production and technology, it is rare to identify glass production facilities in the archaeological record so it becomes necessary to work with what material is available; fortunately there is much that can be understood about technological processes by studying finished glass objects themselves.

The amount of glass recovered from Ayla is vastly greater than that from Ḥiṣn al-Tīnāt. While this could be a function of the size/location/etc. of each settlement or a reflection of the reality of the population's glass consumption, it is definitely also due to the different excavation histories of the sites. Nine long seasons of excavation by a large team at Ayla has produced enough glass to fill about 20 large (24"x12"x4") cardboard boxes and should be estimated as consisting of several thousands of fragments; two short seasons at Ḥiṣn al-Tīnāt by a very small team has produced only a few hundred fragments of glass in comparison. Because of these differences in assemblage size, and the different publication history for each excavation, the sampling strategy used to select fragments for inclusion in this study has been adjusted for each site.

A total of 249 samples of glass— 135 from Ḥiṣn al-Tīnāt/Kinet Höyük and 114 from Ayla—are included in this study. The question of sample size is important.

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of the Ayla materials. I did conduct a chemical analysis of six samples of cobalt blue glass from Ayla as part of my MSc dissertation (Swan 2004), but the results of this analysis have not yet been published.

[27] The small size of Ḥiṣn al-Tīnāt and the amount of imported goods suggests it was not involved in production activities; the later medieval phases on top of the Kinet Höyük mound have shown evidence for other production activities, including iron and glazed Port Saint Symeon-type *sgraffito* ceramics (Redford *et al.* 2001: 69). Ayla has evidence for transport amphora production (Melkawi *et al.* 1994), but no other recognizable industries; glass may have been produced in or around the Roman-Byzantine city of Aila, but no strong evidence has yet come to light (Janet Jones, personal communication).

Although no discussion has ever been made about how many samples are "necessary" for a representative analysis of an assemblage, this number must depend on the overall population size and the goals of an individual study, as well as upon sampling strategies. A survey of the published literature show a serious range in sample sizes, particularly for chemical analysis, from 19 samples (Degryse and Shortland 2009), 41 samples (Van der Lindon *et al.* 2009), 100 samples (Lankton *et al.* 2009a), 247 samples (Dussubieux *et al.* 2008), 312 samples (Popelka *et al.* 2005), to 1,121 samples (Lankton *et al.* 2009b). In his monumental two-volume 1999 publication of chemical analyses, Brill often includes only six to 12 samples but he notes that he is "fully aware that such small sample numbers are not statistically sufficient for characterizing the glass found at most archaeological sites—especially large or complex sites where glasses of different dates are found. One must be careful not to try to read too much into the results for small groups of samples […] they nevertheless can serve as guidelines or what to expect" (Brill 1999a: 8).

Some 202 fragments of glass were recovered from Ḥiṣn al-Tīnāt during the 2006, 2008, and 2010 seasons.[28] More than half of these are analyzed in this dissertation, as well as four fragments excavated from the late 12th-14th centuries CE medieval phase of nearby Kinet Höyük in order to make general comparisons. The provenance of the samples from Ḥiṣn al-Tīnāt and Kinet Höyük includes the following excavation areas and loci (Figures 3.7 and 3.8):[29]

- **TF8**: The extramural building(s) to the south of the fortified structure with rooms around a possible courtyard. Loci 2-5, 7-8, 12-13.

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[28] More glass was recovered during the summer of 2011, although I was not present during this season to determine the exact quantity or quality of the material.

[29] "TF" denotes the Tüpraş Field site near Kinet Höyük (i.e., Ḥiṣn al-Tīnāt) while "K" indicates Kinet Höyük.

- **TF9**: The area around the northwest corner of the walled structure, including the north and west fortification walls and corner tower; loci are located both within the fortification walls and outside the structure. Loci 2, 4, 6-9, 13, 15-19, 23, 28.
- **TF10**: The river or coastline area 50m southwest and down slope of the other units (perhaps the remains of harbor facilities). Loci 1-2.
- **TF11**: Extension to the east of TF9, showing a continuation of the northern fortification wall as well as perpendicular internal walls. Loci 1-3, 6, 8.
- **TF12**: The central section of the western fortification wall. Loci 1-2, 4, 7, 13.
- **TF15**: Possible residential area to the east of the fortified structure (not shown on plan). Loci 2-3.
- **K/K2/K3**: Area of residential structures located on the eastern terrace of the later medieval mound. Loci 122-123, 125, 128.

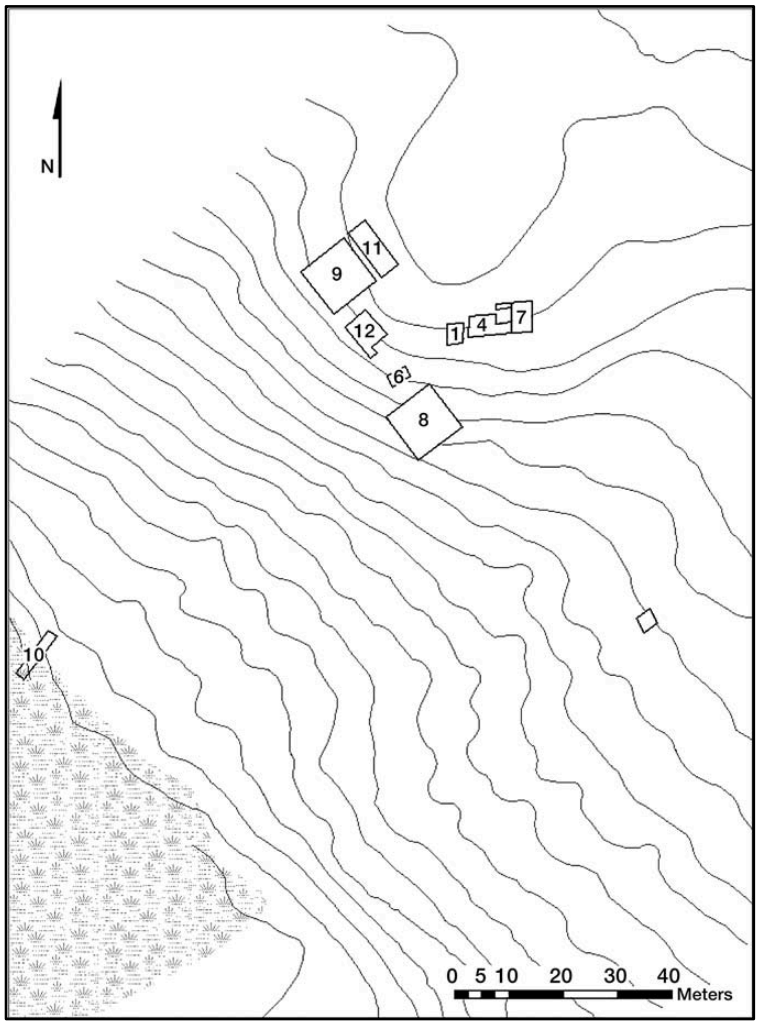

Figure 3.7: Plan showing the excavation units in Tüpraş Field (from Eger 2010: 59, Fig. 4; unit TF 15 does not appear on this map because it was excavated in 2010).

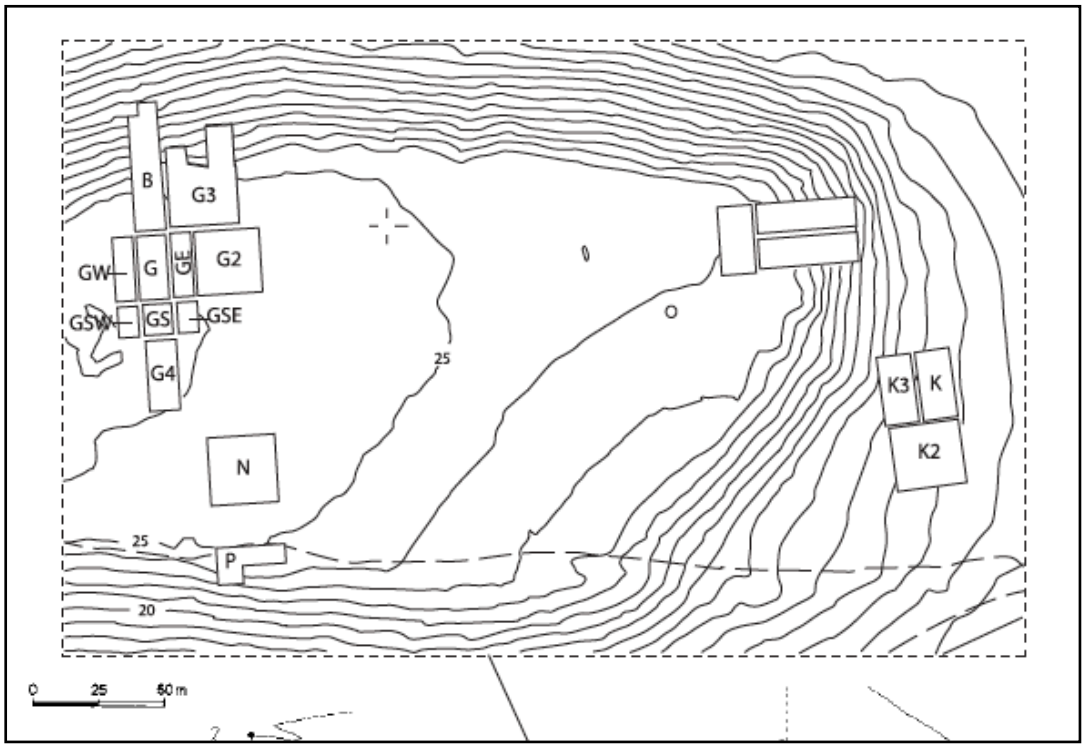

Figure 3.8: Plan showing the lettered excavation units used for the excavation of Kinet Höyük (from Redford *et al.* 2001: 93, Fig. 2).

551 fragments of glass from Ayla were initially selected for examination, and 135 of these were sampled for this project. The choice of these samples relied on advice of the excavation director, Donald Whitcomb, who identified the best-excavated areas or those with the longest stratigraphic sequence. These areas included three city gates and several internal structures that were most likely residential buildings. The archaeological context of the samples from Ayla includes the following excavation areas and loci (Figure 3.9):[30]

- **E8b**: Area within Tower 2, which flanks the Egyptian Gate in the northwest fortification wall of the city (in area D). Loci 2, 18-19, 31, 33-34.

[30] Area B (including B1d and B2b contexts) was excavated in 1986 before the grid system was set up; the location of these units was described by Whitcomb (personal communication) and is indicated only roughly in Figure 3.8.

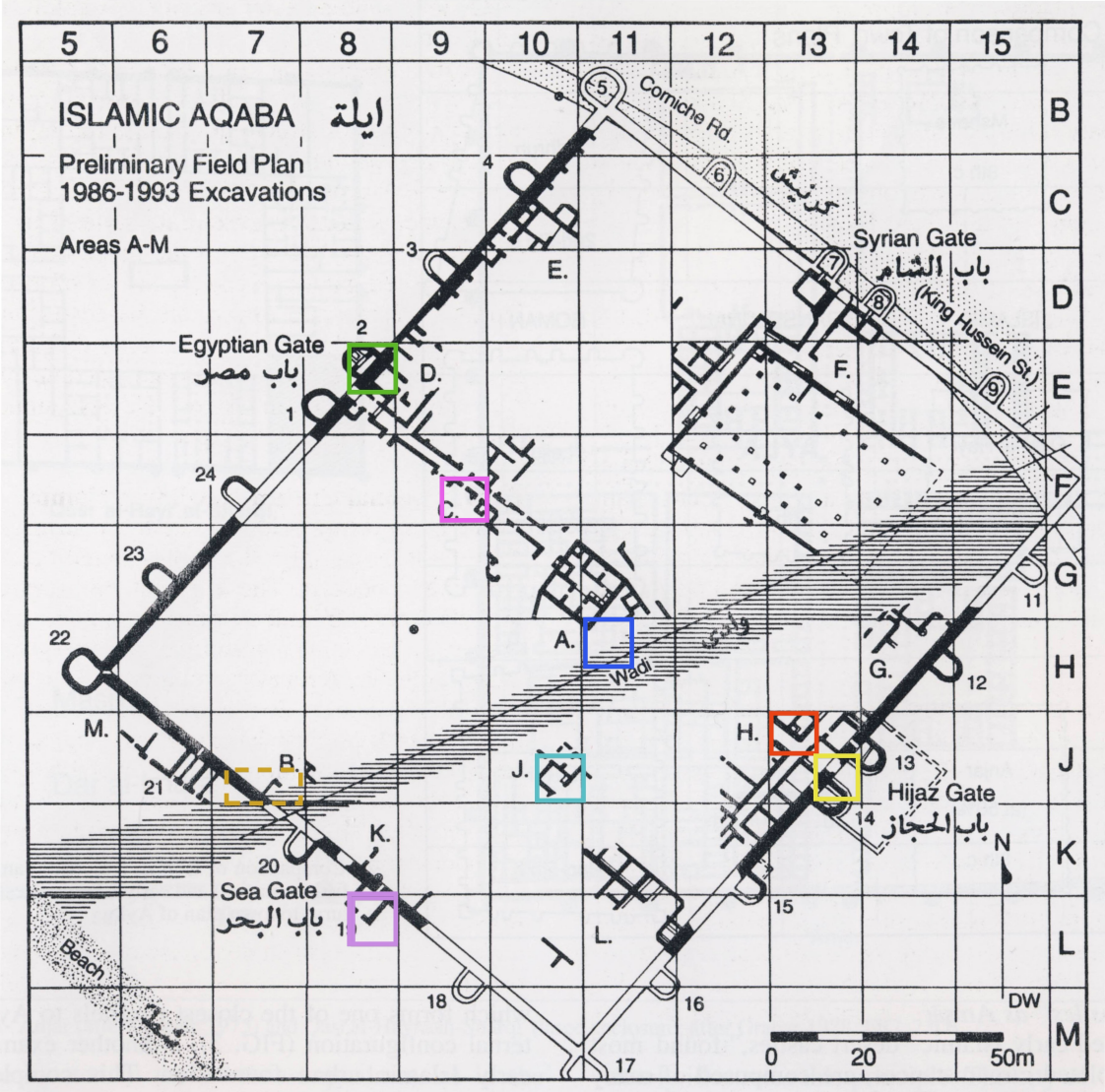

Figure 3.9: Plan of Ayla (Whitcomb 1995a: 279 and Fig. 1) showing the archaeological contexts of the glass samples in this study: E8b (green), F9d (dark pink), B1d and B2b (tan dashed), L8b (light purple), J10d (light blue), H11a (dark blue), J13a (red), and J13d (yellow).

- **F9d**: Area on one of the two major roads within the fort (in area C). Locus 18.
- **B1d**: Trench on the inner edge of the city wall located on the north edge of the wadi near the sea (hypothesized dock facility area). Loci 30-31, 35, 38.
- **B2b**: Step trench on the north edge of the wadi, near the sea (hypothesized dock facility area). Loci 18-19.
- **L8b**: The "Square Tower" flanking the Sea Gate in the southwest fortification wall of the city (area K). Loci 2-5, 7, 10-16, 21, 27, 34-34, 40-41.
- **J10d**: The "'Abbāsid house," south of the wadi and city center (in area J). Loci 12, 40-41, 46-53.
- **H11a**: Area near the "Fāṭimid house" in the center of the city (in area A), on the north edge of the wadi; one of the deepest soundings at the site. Locus 16.

- **J13a**: Structures near the Hijaz Gate (in area H). Many samples were taken from this unit, although it has been identified as a pit context; although the material can often be dated on the basis of style, this residual material should still be treated with caution.
- **J13d**: Area in front of and including the Hijaz Gate in the southeast fortification wall of the city (in area H). J13d is called the "Hijazi room" and is located inside the tower of the Hijaz Gate. Locus 18.

When choosing samples from Ḥiṣn al-Tīnāt and Ayla, a careful attempt was made to select vessels made from naturally-colored glass (that is, glass on the blue-green color spectrum due to the natural iron impurities of the raw materials rather than any intentional additives) because these would be the most representative of the bulk characteristics of the raw glass and thus more comparable. Some highly colored and colorless examples were included as well to provide an indication of the coloring and decolorizing techniques in use at the time. Although the main focus of this study is on vessels, the bracelet fragments recovered from Ḥiṣn al-Tīnāt were also included; the 8th-12th centuries CE is a poorly understood chronological period and bracelets are not commonly studied,[31] so these objects were also considered in the hope that they might provide a good comparison for contemporary vessel production so we can see the larger picture of glass use in this period.

Typological and Chronological Analysis and Assessment

A typo-chronological analysis records the different types of objects found at a site, but it may also provide insight into changing social and economic patterns of glass

[31] There have been studies done on the typology of glass bracelets from the Levant and Egypt, but few studies on the chemical composition (an exception is Boulogne and Henderson 2009, although the samples are of a rather late period of time, deriving from the Mamluk and Ottoman periods). Very little work has been done on glass bracelets in the Byzantine world.

production and use. A comparison of typological features of glass finds from Ḥiṣn al-Tīnāt and Ayla to other sites in the region may also help answer questions of provenance, production workshops, and trade. However, the analysis of glass fragments recovered from archaeological sites is often quite challenging. The extremely fragmentary nature of archaeological glass often makes it very difficult if not outright impossible to determine the type or size and shape of a vessel, and weathering often greatly changes the appearance of the glass in terms of color, clarity, and even the thickness of vessel walls.

Form and function

Glass typological analysis shares many of the same principles of ceramic analysis. For example, the terminology of vessel shapes (piriform, conical, globular, cylindrical, lenticular), vessel parts (shoulder, mouth, lip, base, body, handle, neck, rim), and descriptions of the formal details (outsplayed, concave, convex, vertical, squat, flattened) is similar to pottery because glass vessels frequently mimicked (or were mimicked by) their ceramic counterparts. However, there are some elements that are specific to glass due to the very nature of the material, making the study of glass a separate specialization (see the glossary in Appendix B for specific definitions). The treatment of a vessel's rim (unworked, cracked-off, ground, folded, fire-rounded, thickened, or tubular) and base (pushed-in, tubular ring, trail ring, disk, knob, or second bubble) are specific to glass because of the particular ways in which the material can be treated. Decorative techniques also share some common features with ceramics (scratching, appliqués, impressions, wheel-cutting, mold-forming, painting, or luster), but there are many

techniques that are again unique to glass (blowing, faceting, indenting, pinching, or tonging).

Dating glass vessels on the basis of typological features is a fundamental problem for glass, because "unlike pottery, which can be dated by rim-types, glass ware has only slight variations in the manufacture of rims and bases because of the limitations of this material," and everyday household wares "did not change materially in shape or type over a long period of time" (Isings 1957: 163). Glassblowing techniques were long-lasting, and similar rim and base finishing methods were used for the various vessel types. This poses another particular difficulty for glass specialists, who cannot always rely on the rim or base diameter and stance to determine the original appearance of a vessel when only a small fragment survives; a cup or beaker might have the exact same rim diameter, stance, lip finishing, and wall thickness as a wide-mouth flask, so a small "diagnostic" fragment cannot always be used confidently to reconstruct the original form of the vessel (Figure 3.10).

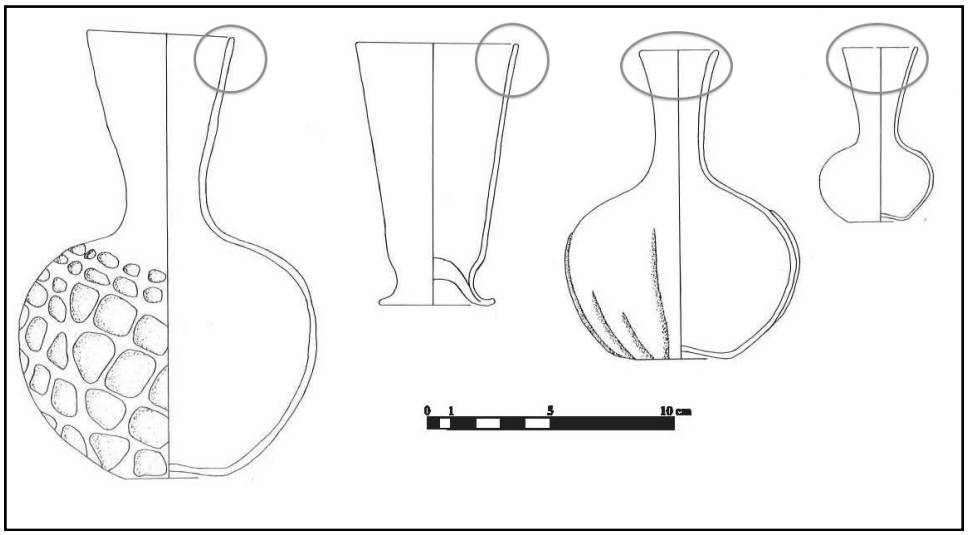

Figure 3.10: Examples of glass vessels with different forms and sizes (and in one case, functions); if the portion of the vessel within the circles and ellipses were the only fragment remaining of these particular vessels, the difficulty of reconstructing the original form is clear (individual drawings from Dussart 1998: 264, 273, and 285).

Diagnostic fragments

RIMS: Bowl rim diameters are typically over 8 cm. Beaker rim diameters can be similar to that of small bowls, cups, and lamps, so it is often difficult to distinguish between open vessels with medium rim diameters. Bottles and flasks are easier to identify because of the narrow diameter of the necks and mouths, although flasks during this period often do have wide mouths. In some cases the treatment of the lip can provide an independent indication of the form or function of the vessel.

BASES: Thick-walled glass has a better post-depositional survival rate, so it is no surprise that the center portions of bases often survive while the walls do not. Bottle bases typically retain at least some of their curvature where the sidewalls meet the bottom, and flatten where the vessel rests on ground. Another diagnostic feature for identifying vessel bases is a mark left on the bottom surface of a vessel when it is cracked off the pontil rod during the manufacturing process (the "punty scar");[32] an indentation in the bottom of the base called the "kick,"[33] a base ring, or a foot are other common features of glass vessel bases.

HANDLES: Handles are not typically found on open vessels, except for bowl-like lamps with multiple looped handles or for some types of cup. Handles are of course typical for jugs and ewers, containers with narrow necks and small mouths (with or without a spout), designed to hold and pour liquids. The portion of a handle that typically

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[32] A hot "bit" of glass allows a metal rod to be temporarily attached to the bottom of the vessel so that the object can be removed from the blow pipe, thereby enabling the mouth to be shaped; an irregular or ring-like mark or scar of varying size is sometimes left when the pontil itself is removed from the vessel when the piece is completed.

[33] A "kick" refers to a concavity in the very bottom of a vessel that is typically formed by being pushed in by a pontil. Although this finishing technique reduces the liquid capacity of the container, it also strengthens the base and can make the vessel more stable by preventing it from tipping over.

survives is the part where hot glass would have first attached to the body of the vessel and then been pulled away and reattached to another place on the vessel body. The rounded cross-sections of handle can sometimes be confused with bracelets if the anchor point of the handle does not survive. The thickness and shape of a handle can sometimes indicate the type and size of vessel even if the vessel itself does not survive.

DECORATED BODY FRAGMENTS: There are certain decorative techniques that are diagnostic in that they can be linked to particular vessel forms, regions of manufacturing, or popular periods of production. One example is the dark blue, purple, or greenish trails of hot glass that were wound around colored or uncolored vessels, a technique that was common in the Early Byzantine and Umayyad periods; trails were often left unmarvered but sometimes were incorporated into the vessel wall by additional heating and inflation. Incised geometric designs on the exterior surface of dark blue, purple, or colorless beakers, bowls, and bottles are an example of diagnostic decoration of Early Islamic glass during the 9th and 10th centuries CE. Dark blue or purple "prunts" or "blobs,"[34] relief-carving, and mould-blown geometric patterns are some other examples of diagnostic decorative types.

Color and clarity

Most glass vessels in this region after the 4th century CE are translucent (depending, of course, upon the thickness of the vessel walls) and unintentionally colored hues on the blue-green spectrum (Meyer 1987: 188). Light green, yellow-green, light

[34] These are indeed the technical terms to indicate the application of a small amount of hot colored glass to the surface of a vessel. I distinguish between blob and prunt by the degree to which the applied glass is flush to the surface of the vessel (prunts stand proud, and blobs are lower in relief).

blue, blue-green, green-blue, and aqua are the typical palette, and it is possible to produce all these colors without the addition of a coloring agent (hence descriptors like "unintentionally-colored" and "naturally-aqua"); the natural iron impurities in the glass raw materials can create these various hues through the manipulation of the atmosphere and temperature of the glass furnace. Yellow, brown, and deep blue glass were also made at this time, but only the latter color would have required a special additive (Harden 1971: 80), which was typically cobalt or copper. Nearly colorless glass could be achieved by a careful selection of the raw materials and close control of the furnace atmosphere, or by the addition of manganese to the batch as a decolorizer.

Color is perhaps the most challenging aspect of glass typological analysis because the precise hue and degree of opacity of a glass vessel look different depending on the thickness of the walls and the state of preservation of the fragments. Moreover, glass color descriptions are highly subjective: two specialists might describe the same blue-green hue in very different ways (for example, the same fragment might be considered light blue or blue-green).

Typological comparison

The glass fragments in this study are assessed in terms of their vessel form (open or closed), function (cups/bowls, dishes/plates, jars, flasks, jugs, bottles, and other objects), color (unintentionally colored, intentionally colored or decolored), decoration (appliqués, trails, prunts/blobs, tooling, painting, scratching, and other techniques), method of manufacture (blowing, mold-blowing, and casting), and use (drinking, storage,

serving, or toiletry vessels). This analysis is made in reference to glass finds from contemporary sites in the Eastern Mediterranean.

Comparative sites in Greece include Athens (Weinberg and Stern 2009; Stern 2010), Thessaloniki (Antonaras 2006, 2010, 2011), and Corinth (Davidson 1952; Matson 1940; Weinberg 1940, 1975; Whitehouse 1991, 1993). In Anatolia these include Constantinople (Henderson and Mango 1995), Saraçhane in modern Istanbul (Haye 1986), Perrhe (Höpken 2010), Sagalassos (Degryse *et al.* 2005, 2006; Lauwers *et al.* 2010), Amorium (Gill 2002; Lightfoot and Ivison 2002; Lightfoot 2005), Ephesus (Czurda-Ruth 2007; Uhlir *et al.* 2009, 2010), Sardis (von Saldern 1980), Mezraa Höyük (Derviş 2006), and Mersin-Yumuktepe (Köruğlu 1998, 2009, 2010) in Anatolia. The Serçe Limanı shipwreck off the coast of southern Turkey also provides an important comparative assemblage (Brill *et al.* 2010).

In Syria comparative glass assemblages come from the sites of al-Mina (Lane 1938), Ḥamā (Riis 1957), Resafa-Sergiopolis (Mackensen 1984), Qasr al-Hayr as-Sharki (Salam-Liebich 1978), Raqqa (Henderson 1999, 2002; Henderson *et al.* 2004, 2005), and Qal'at Sem'an (Dussart *et al.* 2004). In modern Lebanon these include Tyre (Aldsworth *et al.* 2002) and Beirut (Jennings 2006; Paynter 2006) in Lebanon. In modern Israel-Palestine comparative sites include Akko (Gorin-Rosen 1997), Yoqne'am (Lester 1996), Ramla (Gorin-Rosen 2010a, 2010b; Gorin-Rosen and Katsnelson 2005; Pollak 2005), Bet She'an (Hadad 1998, 2002, 2005; Gorin-Rosen 2010d), Sepphoris (Fischer and McCray 1999; Gorin-Rosen 2010c), Hammat-Gader (Cohen 1997; Lester 1997), and Caesarea (Pollak 2003). Finally, in Jordan these sites include Jerash (Baur 1938; Meyer 1988, 1989), Tall Jawa (Siemens 2010), and Aila (Dodge 1998). Glass finds from an additional

number of sites from a wider geographic area and longer timescale were also sometimes considered for purposes of chemical comparison, including sites in Africa, Sri Lanka, and India.

Problems of preservation and interpretation

Glass is highly prone to post-depositional disintegration and weathers very heavily due to the leaching of the alkali content when the object is buried (al-Sa'ad 1996 and 1997). Glass corrosion and weathering is the result of complex chemical processes activated by extreme burial conditions (fluctuations in temperature, pH, and ground water), the unique chemistry of the soil, and likely also by the chemistry of the glass objects (e.g., low-quality glass corrodes more quickly). These factors act as a catalyst for the leaching of important components of the glass matrix—specifically the alkali (Na_2O and K_2O) and lime (CaO)—and their replacement by hydrates in a process that is similar to iron corrosion. Hydrated silica layers take the place of the original glassy matrix, a process that begins at the outer surface of the object and progresses inwards, leaving a glass core of reduced thickness. This results in chemically-altered laminar products that are often iridescent, brown, or black in color and range from a flakey to a cement-like consistency; these weathering layers easily obscure the color and clarity of a fragment and makes identification and interpretation even more challenging (Figure 3.10).

A major problem of glass preservation is that in most cases the corrosion layers so completely obscure the original glass that it is nearly impossible to identify such details as the color, clarity, and quality of the fabric or the manufacturing technique—key

Figure 3.10: Glass fragments from Ḥiṣn al-Tīnāt, showing the degree of deterioration of the samples and examples of the results of the weathering process.

elements for determining the date, type, or possible provenance of glass artifacts. Even when weathering layers are mechanically removed to reveal the underlying glass, the fragment is often too far corroded to determine the color or clarity; the weathered surfaces themselves are also deceptive, as the iridescent turquoise, green, and yellow hues are due to the refraction of light from the pitted and layered surfaces rather than the original coloration of the glass. It is also difficult to comment about the quality of the fabric by noting the presence or absence of air bubbles within the matrix because, again, the weathering process and corrosion and layers can obscure these details. Finally, it is nearly impossible to determine the manufacturing or finishing method of the vessels through an analysis of the texture of the inner and outer surfaces.

The fragmentary and weathered condition of the artifacts often makes identification and interpretation extremely challenging, especially when trying to determine the original form of a vessel from a small fragment of a rim or base and especially from a body shard. There are few complete vessels included in this study, and the remaining samples are very small fragments typically covered by layers of weathering products. However, some important observations could still be made about the form,

style, and function of the glass objects recovered Ḥiṣn al-Tīnāt and Ayla, and chemical analyses were conducted on the unweathered portions of the samples.

Chemical Analysis and Assessment

A comparison of typo-chronological information within and between the Ḥiṣn al-Tīnāt and Ayla assemblages may be revealing in itself, but such an analysis will become even more powerful when combined with chemical data. The application of materials science methods allows archaeologists to go far beyond a traditional analysis of artifacts based on the extrinsic features of an object (i.e., form, style, and decoration). Investigating the intrinsic features of artifacts allows us to ask more detailed questions about the materials, practices, and knowledge that people in the past had at their disposal to create the objects that participated in their lives and experiences. Little can be said for certain about the raw ingredients, recipes, and technical processes used in glassmaking based on macroscopic visual examination of glass artifacts alone; it is the chemical composition that provides details about the practical workings of the glass industry and highlights the complexities of glass as a material.

In the 1960s, scientists began to differentiate glasses according to their chemical composition and to divide them into broad technological, temporal, and/or regional groups. In their seminal paper in the journal *Science*, Sayre and Smith (1961) showed that there are relatively minor variations in the basic composition of the soda-lime-silica glass commonly produced in Western antiquity, with the exception of five oxides that do show clear differences: MgO, K_2O, MnO, Sb_2O_3 or Sb_2O_5, and PbO_2. Scholars today typically rely on seven major and minor oxides as having this discriminatory power, including

MgO, K_2O, Na_2O, CaO, MnO, Al_2O_3, and FeO or Fe_2O_3. From these oxides, scholars have distinguished two basic glassmaking technologies by the use of mineral soda or plant ash as a fluxing agent; mineral soda flux produces glass with MgO and K_2O levels below 1.5 wt% whereas plant ash soda glasses have concentrations often well above this level.[35]

The chemical differences between these groups are actually often quite small or indistinct. A fuller and much more detailed interpretation of glass and glassmaking technology can be achieved by analyzing trace element composition of ancient glasses. For example, trace element analysis has defined discrete subgroups that distinguish Late Bronze Age glass produced in Mesopotamia from glass produced in Egypt (Shortland *et al.* 2007), and has also isolated two different trading regions and periods for glass beads found in eastern Africa (Dussubieux *et al.* 2008); distinctions and observations such as these are essential when making interpretations about economic or cultural interactions and relationships, or about object provenance and trade patterns.

Choice of analytical method

There are a wide variety of analytical methods available to the researcher interested in investigating the chemical composition of glass. Some of these include X-ray fluorescence or XRF (Kato *et al.* 2009), optical emission spectroscopy or OES (Brill 1999), scanning electron microscopy or SEM (Fischer and McCray 1999), electron microprobe analysis or EMPA (Schibille *et al.* 2007), laser ablation inductively coupled plasma mass spectrometry or LA-ICP-MS (Dussubieux *et al.* 2008), strontium or

[35] The former is typically called low magnesium glass (LMG) and the latter called high magnesium glass (HMG) in previous publications.

neodymium isotope analysis (Freestone *et al.* 2003; Degryse and Shortland 2009; Degryse *et al.* 2010a), and neutron tomography (Fiori *et al.* 2006). The choice of method involves weighing the combined pros and cons of availability, cost, sample preparation time, analysis time, repeatability, accuracy, precision, and data interpretability.

The three most widely used methods are currently XRF, SEM, and EMPA; the former is favored because of its availability as a portable hand-held device,[36] while the two latter are favored because of their wide availability in laboratories. These methods, however, are not suitable for trace element analysis. XRF, SEM, and EMPA are unable to reliably detect concentrations below 0.01 to 0.1 wt%; this is problematic, as trace elements are typically present in concentrations well below the 0.01 wt% level. In contrast, LA-ICP-MS is capable of measuring elements present in the low parts per million and even parts per billion (Gratuze 1999; Gratuze *et al.* 2001; Lankton *et al.* 2009a). This method has gained popularity in archaeology over the past 15 years (Speakman and Neff 2005), especially when applied to questions about artifact technology and provenance, such as obsidian (Gratuze 1999; Pereira *et al.* 2001), iron (Devos *et al.* 2000), and more recently glass (Shortland *et al.* 2007; Dussubieux *et al.* 2008; van der Linden *et al.* 2009).

Another advantage of LA-ICP-MS is the fact that it is virtually non-destructive in that it requires no sample preparation and leaves a mark on the glass that is virtually invisible to the naked eye (50-100 microns in diameter and 100-200 microns deep); by comparison, SEM and EMPA are highly invasive, as sample preparation involves imbedding a sample of glass in a resin matrix and grinding and polishing a flat, scratch-

[36] Some countries like Israel and Egypt do not allow export of archaeological material, which makes on-site analysis advantageous.

free surface. While XRF can also be non-destructive, this technique has interference problems with the weathered layers of the glass surface (Cox *et al.* 1997). Studies have shown that there can be a significant difference in the concentration of an element at the surface of a sample and within the core; for example, LA-ICP-MS analysis a glass bead from Thailand showed that the potash content of the glass was only 1 wt% at the surface but was 14 wt% at points 100-200 microns beneath the surface (Lankton *et al.* 2009b: 4). Because the XRF only measures the outer 20 microns of a sample, analytical results may thus be misleading or prove difficult to interpret. LA-ICP-MS results are not adversely affected by surface weathering because the composition begins to be measured several seconds after the laser starts to ablate the sample, which means the weathering surface is not included in the count.[37]

Analytical procedure and parameters

All analyses were conducted in the Anthropology Department of the Field Museum in Chicago, using a high sensitivity Varian quadrupole inductively coupled plasma mass spectrometer (ICP-MS) connected to a New Wave UP213 laser ablation system.[38] Laser ablation analysis involves using a laser to ablate a small amount of material in a helium atmosphere;[39] the material is then re-ionized and the ICP-MS

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[37] The weathered surface of a glass can be highly misleading for an accurate chemical analysis, as "corroded glass is typically depleted in K, Na, Ca, and Mg, but enriched in Si, Al, Ti, and Fe, with the alkaline elements being always heavily leached out" (Robertshaw *et al.* 2010: 1902). A study by Kato *et al.* shows that there are significant differences between XRF analyses made on weathered versus polished surfaces (2009: 1702-1703 and Table 4).

[38] Although there was also the option to analyze material as a solution by means of acid digestion, this method is long, dangerous, and expensive. The New Wave UP-213 is a high performance Nd:YAG deep UV [213 nm] laser ablation system, that provides flat craters and high absorption.

[39] A helium atmosphere "minimizes sample re-condensation during ablation about the target site and thereby maximizes sample transport to the ICP" (Vicenza *et al.* 2002: 722).

measures elements as separate ions, identifying these elements by their mass. A total of 58 glass-forming elements and impurities were selected for analysis;[40] the Varian ICP-MS Expert software automatically chooses the best isotopes for each element, with the exception of iron, which is specified as Fe57.[41] The detection limits range from 10 ppb to 1 ppm for most of the elements, and accuracy ranges from 5-10% depending on the elements and their concentrations.

A 55 µm laser beam pulses at 15 Hz and 70% output for 1.40 minutes and with a spot size of 50-80 microns in diameter.[42] The laser removes material from a very small area, typically leaving a 50-100 µm diameter and 100-200 µm deep crater in the sample. The ICP-MS then measures one point per peak, scanning for each element three times and then averaging these scans; this procedure is replicated nine times and these replicates are averaged together, although the first three replicates are not factored in because the sample surface may be contaminated and chemically altered or depleted. Four analyses were made for each sample, on spots that were chosen based on the overall size and surface character of the sample; the raw data is given in cps (counts per second), so the unknown oxide concentrations are calculated as wt%, ppm, or ppb using a Macros

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[40] Including Li7, Be9, B11, Na23, Mg24, Al27, Si29, P31, Cl35, K39, Ca44, Sc45, Ti49, V51, Cr53, Mn55, Fe57, Co59, Ni60, Cu65, Zn66, As75, Se78, Rb85, Sr88, Y89, Zr90, Nb93, Mo98, Ag107, Cd111, In115, Sn118, Sb121, Cs133, Ba137, La139, Ce140, Pr141, Nd146, Sm147, Eu153, Gd157, Tb159, Dy163, Ho165, Er166, Tm169, Yb172, Lu175, Hf178, Ta181, W182, Au197, Pb, Bi209, Th232, and U238. O, N, C, H, Ar, S, and F cannot be analyzed, and other elements on the periodic table are not relevant for such studies; Cl is measured but may not be visible if it is present in very low concentrations (Laure Dussubieux, personal communication).

[41] Although Fe56 is present in the greatest abundance (91.72%) there can be interference from argon (mass 40) and oxygen (mass 60), because when they are combined as ArO+ this also has a mass of 56; a similar interference problem occurs for Fe54 and Fe58, as Cr has a mass 54 and Ni has a mass of 58 (Laure Dussubieux, personal communication).

[42] A spot size of 50µm was used for analyses made on 16-17 August 2010, but the spot size was changed to 80µm for tests run 18-27 August 2010; this change should not affect the comparability of the analytical results (Laure Dussubieux, personal communication).

program designed by Laure Dussubieux and based on the procedures and formulas outlined by Bernard Gratuze (described in Gratuze 1999 and Gratuze *et al.* 2001).

Accuracy, Precision, and Comparability

In a study where conclusions are made using quantitative data generated through instrumental means, a key consideration must be the accuracy and precision[43] of the data produced, as well as the comparability of tests done on different instruments or by other laboratories. Accuracy and precision contribute significantly to the observed elemental variation and are controllable factors (Bishop *et al.* 1990: 540). As sample preparation is a very important component of assuring the accuracy and precision of chemical analytical research, it is highly significant that LA-ICP-MS requires no sample preparation.

Reference glasses of known composition allow researchers to check their results against these known compositions, thus ensuring the accuracy and precision of the instrument and methods that are used, and also facilitating inter-laboratory comparisons. The quality of the data produced at the Field Museum was controlled by checking the accuracy and precision of the instruments through the use of the ^{29}Si isotope as an internal standard and synthesized glasses and certified reference materials as external standards. One such set included three of the four synthetic glasses developed by the Corning Museum of Glass in Corning, New York.[44] The chemical compositions of these

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[43] "Accuracy is a statement of how close a measurement of an element is to its actual concentration in a sample" and this is assessed by also using a standard of known elemental concentrations (Bishop *et al.* 1990: 539). "Analytical precision is a statement of how well we can repeat the analysis and obtain the same results" (Bishop *et al.* 1990: 540).

[44] Devised by W. E. S. Turner and Robert Brill in 1963, designed by Brill, and prepared by August A. Erickson of Corning Glass Works in 1964. The theoretical and recommended compositions of the four glasses were calculated from the batches and are given in Appendix B and D of Brill 1999b; a chemical "round-robin" to check the comparability of data obtained from different laboratories was carried out

glasses were engineered so as to represent the composition of common glass varieties in antiquity (Brill 1965, 1971, 1999a, and 1999b) and were "doped with 29 to 31 elements at the major, minor, and trace levels" (Vicenzi *et al.* 2002: 720).[45]

Corning Standards B, C, and D were available for use at the Elemental Analysis Facility of the Field Museum. Corning Standard B typifies soda- and calcium-bearing silicates resembling the composition of the soda-lime glasses of the first millennium CE, while Corning Standard D is a potassium- and calcium-rich silicate resembling the potash-lime glasses of the 17th-19th century CE; these two standards were alternately analyzed after tests were made on a set of five glass samples of unknown composition. In addition, Corning Standard C was analyzed after running any unknown samples that proved to have a high lead content (greater than 1 million cps), as this standard is barium-rich and lead-rich. In addition to controlling for instrumental drift, the Corning standards "show promise for use as secondary standards for minor and trace element analyses of insulating materials such as synthetic ceramics, minerals, and silicate glasses" (Vicenzi *et al.* 2002: 719).

Because the Corning reference glasses do not contain certain trace elements, as they were designed with XRF analysis in mind (Brill 1971), a second set of reference glasses was also used during analysis. This second set of standard reference material (SRM) used was developed by the National Institute of Standards and Technology. These standards, SRM 610 and SRM 612, are doped with trace elements and have been

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between 1965 and 1972, and this data formed the basis for the recommended compositions. A description of the raw materials and process of making these glasses is available in Vicenzi *et al.* 2002: 720.

[45] Including SiO_2, Al_2O_3, Fe_2O_3, MgO, CaO, Na_2O, K_2O, MnO, P_2O_5, TiO_2, Sb_2O_5, CuO, PbO_2, CoO, BaO, SnO_2, SrO, ZnO, B_2O_3, Li_2O, Cl, SO_3, Rb_2O, V_2O_5, Cr_2O_3, NiO, ZrO_2, Ag_2O, and Bi_2O_3.

characterized in the journal *Geostandards and Geoanalytical Research* (Rocholl *et al.* 1997; Gao *et al.* 2002; Eggins and Shelley 2002).

The comparability of analyses is of course an important consideration for a project that aims to compare newly generated data with previously published data. There are often real differences in the sensitivity, precision, and accuracy of different methods, instruments, and/or laboratories (Bishop *et al.* 1990; Hancock and Carter 2010). To that end, the information presented above about the analytical parameters, sample size, and counting statistics are essential so that future analysts can assess the quality of the date presented herein, or can use this information to replicate the analyses that have been made. The practices of combining and comparing compositional chemical analytical data have been the subject of scrutiny; although in one study it was found that *combining* different data sets without some form of statistical adjustment is problematic, *comparing* different data sets is indeed feasible and desirable (Baxter *et al.* 2006: 413).

Interpretation of the Analytical Results

The results of the chemical analysis done in this study are presented in full in the Appendix and summarized in tables and charts throughout Chapter 4 (glass vessels from Ḥiṣn al-Tīnāt), Chapter 5 (glass bracelets from Ḥiṣn al-Tīnāt), Chapter 6 (glass vessels from Ayla, and Chapter 7 (a synthesis of these sites). These results are assessed and compared by means of simple descriptive statistics. The major and minor constituents are discussed in terms of bulk composition in wt% oxides, which elucidates the basic raw materials, colorants or decolorants, and overall technological tradition or recipe based on the use of a mineral soda or plant ash soda fluxing agent; trace elements patterns are also

discussed, as they enable the more general characteristics of the glasses to be further refined. Grouping and comparing the analytical results helps characterize the glass and find patterns within and between the site data. A basic comparison using bivariate scatter plots is enough to show the correlations between elements as well as to identify average compositions, groups and subgroups, and any outliers. In some cases the composition of the samples shown in the charts are shown as reduced compositional values,[46] as this method of reporting removes many of the compositional effects of additives (like colorants and decolorants) so that the main components of the glass are more comparable.

Multivariate statistical methods were initially considered but are not used in this study, primarily because the choice and number of variables to include in a statistical analysis of glass is by no means straightforward and there are additional issues of background noise and contamination. David Hurst Thomas has cautioned "unless thoughtfully applied, multivariate statistics hold a far greater specter of error, confusion, and outright abuse than do all of the univariate and bivariate techniques combined" (1978: 238), and multivariate statistical treatment of glass compositional data has not been shown to be any more advantageous than more simple methods of data analysis.

Because glass is a manmade material rather than a geological material, there are deliberate choices and manipulations that may be misinterpreted by a statistical treatment of the data. An example may best serve to make this particular point. The chemical analysis of glass samples all taken from the same tank furnace at Bet Eli'ezer showed that

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[46] Reduced compositions are marked by an asterisk (*) and were calculated by normalizing the seven major and minor oxides to 100%. The rationale and process is described by Brill (1999b: 8-11). If considering P_2O_3 in addition to these seven oxides, a double asterisk (**) indicates that these eight oxides were normalized to 100%.

90% of the results were tightly distributed around a typical composition, but the remaining 10% had significantly higher soda and lower silica:

> This may be a reflection of glassmaking practice, where the glassmakers are inferred to have added raw materials to the furnace in batches, and added natron to the last batch, to ensure complete melting as the furnace cooled. *Cluster analysis does not allow for the effects of such behavior.* (Freestone *et al.* 2002a: 169, my italic emphasis)

If the elements associated with the intentional addition by glassmakers of colorants or decolorizers are not taken into account when performing a statistical analysis, this can also be problematic. For example, in a study where differently colored glasses were included in the same Cluster Analysis, the investigators found that "they do not group together, although produced in one workshop, due to differences in chemical composition coming from added colorants" (Kuleff *et al.* 1985: 190).

Statistical treatment of raw chemical data can additionally create patterns or groupings that are not real or meaningful, making data interpretation more difficult or even inaccurate:

> Statistical analyses can be dominated by small subsets of the minor or trace elements and can give rise to *results that have little substantive meaning and/or ignore much of the information in the data*. No satisfactory and simply applied resolution of this problem appears to have been proposed. (Baxter 1992: 267, my italic emphasis)

In addition, some approaches (for example, Discriminate Analysis) "assume that all possible compositional reference groups of glass have been identified and will assign an unknown to the closest reference group, even if this is, in reality, compositionally distinct" (Freestone *et al.* 2002a: 170).

A recent study investigated how chemical groups and outliers are established and defined, testing various methods of statistical analysis to determine whether geochemistry

is more important than data dispersion in the assessment of data (Michelaki and Hancock 2011). This study found that commonly used statistical analysis procedures (like Principle Components Analysis) can overlook existing chemical groups and outliers, while the very choice of the elements included in the statistical analysis can bias the results and obscure any actual patterns (Michelaki and Hancock 2011: 1259). Methods like PCA assume independent variables but the compounds and elements making up glass are not independent variables, they are linked in a complex geochemical ways. Simple bivariate plots of the data have been found to perform better than statistical treatment of the same data: "chemistry, as represented by bivariate plots of specific elements, trumps data dispersion, as represented by PCA and CLR-PCA" (Michelaki and Hancock 2011: 1277).

Although some glass compositional studies have used statistical analysis as part of their analytical methods, such analysis doesn't add much additional detail or clarify the findings for this study. Countless archaeometric studies have confirmed that descriptive statistics are enough to show relationships of the compounds and the relevance to the types or provenance of raw materials, production processes, or production zones. For example, Robert Brill used two approaches to study data obtained from the glass cargo of the 11th century CE Serçe Limanı shipwreck—the first was to inspect standard bivariate graphs of the seven major and minor oxides, and the second was to do three multivariate statistical calculations (Principle Components Analysis, Cluster Analysis, and Discriminate Analysis); significantly, "the two approaches yielded generally consistent findings" (Brill 2009: 480).

THEORETICAL FRAMEWORKS

A central aim of this project is to understand glass and glassmaking within the particular historical, cultural, and technological context of the 8th-12th century CE Eastern Mediterranean region, using glass as a case study to explore issues of technological stability and variability. Material culture can be approached from a number of different perspectives: art historical, material, social, and economic, to name but a few. An important goal of this study is to link qualitative and quantitative analyses with larger social considerations; to that end, an archaeological research agenda is combined with theories and methods gathered from the sciences and social sciences. There are two theoretical perspectives that have been particularly influential for shaping the approaches and interpretations of this project: the anthropological studies of technology and technological change by Michael Schiffer and James Skibo, and the study of the link between materials, materials science, and materiality by Andrew Jones.

Anthropology of Technology and Technological Change

Anthropological interpretation can perhaps provide fuller explanations for the reasons behind episodes of stability and change in production activities that are suggested by chemical data, because "human behavior, in all its glorious complexity and irrationality, is almost always involved somewhere along the line" (Pollard and Heron 2008: 408). Anthropology shows that technology is part of complex behavioral and social practice. Scholars have aimed to approach technology as a *practice*—viewing it not only as a way of doing or making something, but also as a way of organizing work and people into systems involving new words and new mindsets, as well as new tools and products;

"that is, we do add not only hands but also faces and minds to our study of the way things are made" (Miller 2007: 4). In short, "a technology is a corpus of artifacts, behaviors, and knowledge" (Schiffer and Skibo 1987: 595) and we must be aware of this combination of elements—rather than only one element—when discussing the practice and products of glassmaking, or how and why these changed over time.

Materials science and materiality

The qualities of a material—i.e., their structures and properties—have a critical affect upon the creation, use, and perception of objects (Tite *et al.* 2001; Jones 2004: 331). This is a fundamental point, and an emphasis is needed in exploring how material properties interrelate with the social and cultural lives of the people who made, exchanged, used, and deposited glass objects. Scientific analysis of archaeological materials has traditionally focused on the properties of materials and technological advances as explanations for change rather than on people and choices that may have been involved.

Materiality is a concept that observes the interwoven nature of the social and the material. It encompasses the view that material or physical components of the environment and the social practices enacted in that environment are mutually reinforcing: "the material world, and the social practices that take place in that world, bring each other into being and are therefore analytically indivisible" (Jones 2004: 330). Early Postprocessualist archaeologists borrowed a linguistic metaphor for material cultural that ultimately derived from a cross-discipline shift in discourse that occurred in the late 1960s: the "Linguistic Turn." The result of this metaphor was to approach to

material culture as a code whose logic could be decoded; Jones critiques this approach, noting that "it treats the material world as a mere substratum onto which humans lay their ideas and concepts" (2004: 328). Unlike the arbitrary relationship of signifier and sign in language, the meaning of material culture is not arbitrary because it is at least partly determined by its material qualities.

Although the intention of early Postprocessualists was to conjoin the material and social worlds, "due to a close adherence to linguistic models, the physical aspects of material culture remain relatively passive in their accounts of the past" (Jones 2004: 328). Jones's most important observation is that at both the practical and theoretical level archaeologists are required to consider simultaneously how it is that artifacts are socially and culturally constructed, while also taking into account the physical and mechanical construction of artifacts; we do not need to study these two aspects of artifacts as separate and distinct entities, "because materials science and material culture studies are engaged in the same project of inquiry" (Jones 2004: 329).

These two approaches—the anthropological consideration of technology and technological change, and the merging of materials science with materiality—intersect in very interesting ways. Schiffer and Skibo discuss how technological choices determine the attributes (or formal properties) of an artifact, which in turn affects the behavioral capabilities (performance characteristics) of that artifact; they also observe that technological choices often have polar effects, as "some performance characteristics are enhanced while others are degraded," and also that there is a difference between *fundamental* technical choices and *derivative* technological choices (Schiffer and Skibo 1987: 599). This link between "formal properties and behavioral capabilities" is another

way of emphasizing the connection between a material's structure, properties, and processing—a key analytical principle of materials science and a key structuring principle for the consideration of the combined nature and culture of glass.

SUMMARY

The most common way archaeologists have attempted to deal with the social dimension of material culture has been to separate out three discrete aspects of an object—style, technology, or function—and then to selectively study one of these (Dietler and Herbich 1998: 236). This dissertation aims to incorporate historically and culturally contextualized, analytically-derived data with theoretical argument in order to address broader questions of society, culture, and technology at a particular location and moment in time. By choosing two sites at opposite ends of the Near East, this study is in effect sampling the entire geographic region in a manageable way; limiting work to two sites additionally makes it possible to go into more depth in their historical, geographic, cultural, and material analysis. The glass from Ḥiṣn al-Tīnāt and Ayla can then be compared and contrasted with the finds from numerous other sites in the Near East or from further abroad to make more in-depth observations and conclusions about glassmaking and glassworking in the Eastern Mediterranean region during the 8th-12th centuries CE.

This next three chapters present the results of the typological, chronological, and chemical analyses of the 249 fragments of glass selected from the 8th-12th century CE contexts of Ayla and Ḥiṣn al-Tīnāt. A detailed list of all samples is given in the Appendix and some of the more significant objects are illustrated in photographs or line drawings in

Chapters 4-6. Sequential sample numbers were assigned to the fragments in order to avoid lengthy site-specific registration numbers like KT025689; for the correspondence of the sample numbers used here to the original site registration numbers of the artifacts, see the sample list in the Appendix.

CHAPTER FOUR: GLASS VESSELS FROM ḤISN AL-TĪNĀT, ANALYTICAL RESULTS

INTRODUCTION

This chapter presents the results of the typological and chemical analyses of glass vessels from the site of Ḥiṣn al-Tīnāt in southern Turkey. Of the 202 glass fragments that were initially assessed in the field, 135 fragments were chosen for further analysis in this study. 115 of these are vessel fragments from the 8th-12th century CE phases at Ḥiṣn al-Tīnāt proper, 16 are fragments of glass jewelry (which will be discussed separately in Chapter 5), and four are vessel fragments from the late 12th-14th century CE phases of the medieval settlement at nearby Kinet Höyük; the latter samples were included to facilitate general intra-site observations and to make diachronic comparisons. Because it is so rare for complete glass objects to be recovered during archaeological excavation, the discussion that follows is based on the information than can be revealed using fragments alone. In both the typological and chemical assessments, these fragments are organized and discussed by diagnostic type in order to more easily organize and highlight the observations made in this study.

TYPOLOGICAL ANALYSIS

Three of the Ḥiṣn al-Tīnāt vessel fragments proved through chemical analysis to be modern (see note 15 below) and will therefore not be included in the following

typological discussion. Of the 112 ancient vessel fragments, 42 of these (38% of the total) are plain or decorated wall fragments, 33 (30%) are base fragments, 23 (21%) are rim fragments, eight (7%) are handle fragments, and four (4%) are neck fragments; two nearly complete vessels were also analyzed. The four Kinet Höyük fragments include two wall fragments, one rim and one base fragment.

Nearly complete vessels

A total of four nearly complete vessels were recovered from the field in 2008, three of which also happen to be among the most elaborate and diagnostic of the assemblage and are most likely imports from Islamic lands. Only two of these (Nos. 208 and 225) could be examined in 2010 and sampled for chemical analysis, but all four objects are presented here because they offer important insight into the range of glass used at the site, in both geographic and stylistic terms.

Nine fragments join together to reconstruct most of vessel **No. 208**, a small, squat jar of light purplish glass (Figure 4.1) standing approximately 6 cm tall with a 3.5 cm rim diameter and 4.0 base diameter; ceramic evidence dates the excavation context of this object to the 11th-12th centuries CE. The vessel has a mold-blown honeycomb pattern of rounded indents, a short neck and a slightly flared rim that was tooled while the vessel was on a pontil rod; a faint trace of a punty scar remains on the bottom center of the vessel and the lip may have been cracked off and ground. Examples of 11th-13th century brass dip-molds (Carboni and Whitehouse 2001: 85, No. 11; von Folsach and Whitehouse 1993) show how glassmakers achieved such a honeycombed surface, and similar mold-

Figure 4.1: No. 208 from Ḥiṣn al-Tīnāt (photograph at the left is courtesy of A. Eger 2010).

Figure 4.2: (Left) Jar from the Israel Museum, collection no. 77.12.439 (Brosh 2003: 356); (right) jar from the Gemeentemuseum (Institut du Monde Arab 1996: 147).

blown patterns are quite common among Islamic glass vessels.[1] Two slightly larger vessels are striking similar to No. 208 (Figure 4.2); one vessel in the Eliahu Dobkin Collection of the Israel Museum (Brosh 2003: 329 and 356, No. 479) is attributed to the

[1] Fragments from the 11th century Serçe Limanı shipwreck show that a range of vessel forms could be produced using the same dip-mold; bottles, bowls, dishes, cups with identical mold-blown patterns can thus be thought of as "mold siblings" (Lledó 1997; Bass *et al.* 2010).

Eastern Mediterranean and dated to the 11th-12th century, while a second vessel of the same style but even larger size in the Gemeentemuseum in the Netherlands is attributed to 12th century Iran (Institut du Monde Arabe 1996: 147, No. 68; Haags Gemeente-museum 1979). Curators have dubbed this vessel type an *albarello* because of its resemblance to a 12th-14th century type of ceramic vessel, and a medicinal function has been suggested: "such vessels were used in pharmacies to store powders and medicines… the narrow waist made it easy to pick them up off a shelf" (Brosh 2003: 356). If No. 208 and the museum parallels did indeed serve similar functions as their styles would suggest, then their findspots (one in Byzantine lands and two in Islamic regions) indicate "long distance trade in *materia medica* was maintained [during the Byzantine and Islamic periods] despite changes in the balance of power and political regime" (McCabe 2009: 292).

Another nearly complete object from the Ḥiṣn al-Tīnāt assemblage that was likely imported from Islamic lands is a small flask, **No. 225** (Figure 4.3), the neck and shoulder of which are still intact; ceramic evidence from the stratigraphic context of this fragment is dated to the 10th-12th centuries CE. This vessel was free-blown using dark blue glass decorated with a series of opaque white trails that were combed into a "festoon" pattern, which was then marvered flush against the body of the vessel. Flasks are the most common shape for marvered Islamic vessels, a decorative type that scholars attribute broadly to the 8th-13th centuries with a peak production period in the 11th-13th centuries; after this time, new decorative techniques—enamel painting in particular—became dominant (Hasson 1983: 112). However, most excavated examples appear to come from Fāṭimid, Ayyūbid, Mamluk, and Ottoman strata and thus largely date to the 12th/13th

Figure 4.3: (Left) Fragment No. 225 from Ḥiṣn al-Tīnāt; (center) flask in dark brown and opaque white glass from the Kofler collection, attributed to 7th-8th century Egypt or Syria and standing 9.5 cm tall (Carboni 2001: 316, no. 3.63a); (right) flask in dark blue and opaque white glass from the Corning Museum of Glass, attributed to 11th-12th century Egypt and standing 14.6 cm tall (Carboni and Whitehouse 2001: 139, No. 55).

centuries CE and later.[2] Numerous examples have been excavated at al-Ṭūr, Fusṭāṭ, Quseir al-Qadīm, Ḥamā, and Jerusalem.[3]

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[2] Lamm (1929: 95-104, Tf. 29 nos. 2-3, 7-10, Tf. 30 nos. 4, 6-8, 11, Tf. 32, nos. 4-7) dates marvered flasks to the 7th-8th centuries while Clairmont (1977, nos. 183-185) dates them to the 10th-12th centuries; however, these authors are the only ones to give such early dates, and it should be noted that their examples are drawn from museum collections rather than securely dated archaeological strata. Allan (1995) argues for an exclusively 12th-13th century CE date, because several of the sites where marvered glass was found have unreliable stratification while those with reliable stratification date to the Ayyūbid and Mamluk periods (Carboni 2001: 291).

[3] Examples from al-Ṭūr date to the 14th century and later, and most are dark blue but green, purple, black, and colorless examples are also present (Shindo 1993: 299-300, 302, and Figs. 7 and 8); the examples from Fusṭāṭ date to the Mamluk period, the 12th century and later, and 95% of are blue and 36% are purple glass (Shindo 1992; 1993: 300 and Fig. 3; 2000); examples from Quseir al-Qadim date to the 13th-14th centuries and are of purple, brown, black, or green glass (Whitcomb 1983: 102 and Fig. 2, Nos. cc, ee, mm, oo, nn, pp; Meyer 1992: 90 and Pl. 19, Nos. 548-553); examples from Ḥamā are ascribed to 1100-1400 CE and are typically deep purple although a few pieces were in brown, green, and blue glass (Riis and Poulsen 1957: 65-66, No. 201); translucent and opaque purple, opaque red, and translucent blue vessels of this shape and style were recovered from undated contexts in Jerusalem (Hasson 1983).

The large quantity of marvered glass fragments and wasters found in Jerusalem is particularly interesting; over 300 fragments of marvered purple glass suggests such vessels were made here, while marvered vessels of other colors were fewer in number and are thus thought to be made elsewhere (Hasson 1983: 111-112), the blue ones possibly in Damascus and Alexandria (Riis and Poulsen 1957: 62-69; Carboni and Whitehouse 2001: 106-107, 139, and Fig. 94). Based on the color distribution of excavated examples, it does seem plausible that blue marvered glasses were produced in Egypt while purple marvered glasses were produced in Syria-Palestine (Carboni 2001: 305). Only one fragment of this shape and decorative type was found at Samarra (Lamm 1928: 108) which supports the notion that this was a predominantly Levantine type. While these flasks may have contained unguents or perfumes, their primary contents may have been cosmetics; an example from al-Ṭūr actually retained traces of kohl and was found near a copper applicator rod (Shindo 1993: 302-304, Figs. 7-9; Satoh *et al.* 1994; Kawatoko and Shindo 2009: Pl. 29, Nos. 1-2).

The dating of Islamic marvered flasks not found in stratified excavation is usually based on the shape of the vessel bottom and sometimes also on color: "cylindrical flasks can be attributed to either the early Islamic or early medieval period but spear-like flasks only to the medieval" (Carboni and Whitehouse 2001: 139), and later flasks often have a bubble neck, like those from Quseir al-Qadim (Whitcomb 1983: 102 and Fig. 2, no. oo); marvered flasks are also more likely to be of "different colors and less regular tooling" in earlier periods while the later examples are predominately of dark blue and green glass. It is not possible to date No. 225 based on style alone, because it cannot be determined whether the vessel is spear-shaped or cylindrical with the base and most of its body

missing. The color does not help either because blue glass was used in all periods of manufacture, although the lack of festoons on the neck may perhaps suggest an earlier date.[4] Chemical analysis confirms a post-9th century date, more specifically the 10th-12th century CE date derived from ceramic analysis of the context.

The two other nearly complete vessels were not sampled for chemical analysis because they had been moved to the local museum, but they should be mentioned here as they attest to the variety of quality and provenance of the vessels present at the site. The first of these (KNH23501) is a very distinct type of bottle called a "molar flask" (Figure 4.4). It has a small, rectangular body (5-6 cm high) with four short wedge-shaped feet tapering to points (i.e., resembling the roots of a molar tooth) although its short, rounded neck is missing; this object was made by casting a solid block of glass which was then cold-worked by drilling out the center and cutting v-shaped facets into the walls and a grooved horizontal band around the midsection. This is the only vessel made in this manner in the Ḥiṣn al-Tīnāt assemblage—all other vessels were made by free- or mold-blowing hot glass. The color is also significant, as it is translucent and colorless, meant perhaps to look like rock crystal. Molar flasks date exclusively to the 9th-11th centuries; similar bottles in metal and ivory were common in the 9th-10th centuries CE but were not made after this time (Brosh 2003: 368). Scholars have suggested that molar flasks served as perfume containers; they are a common types of glass unguent container within

[4] Note the difference in the neck treatment of No. 225 compared to the parallel examples: the festoon does not continue up to the rim on the Ḥiṣn al-Tīnāt fragment, while this style is seen on virtually all parallels; the 7th-8th century vessel from the Kofler collection is one of the few parallels found that has a similarly plain neck, but it should be noted that the early dating of this piece is based on Lamm.

Figure 4.4: (Left) Unsampled fragment from Ḥiṣn al-Tīnāt, registration number KNH23501 (photograph courtesy of A. Eger); (right) a molar flask of similar size, color, and pattern dating to the 9th-10th century from the Dobkin Collection of the Israel Museum (Brosh 2003: 330 and 368, No. 503).

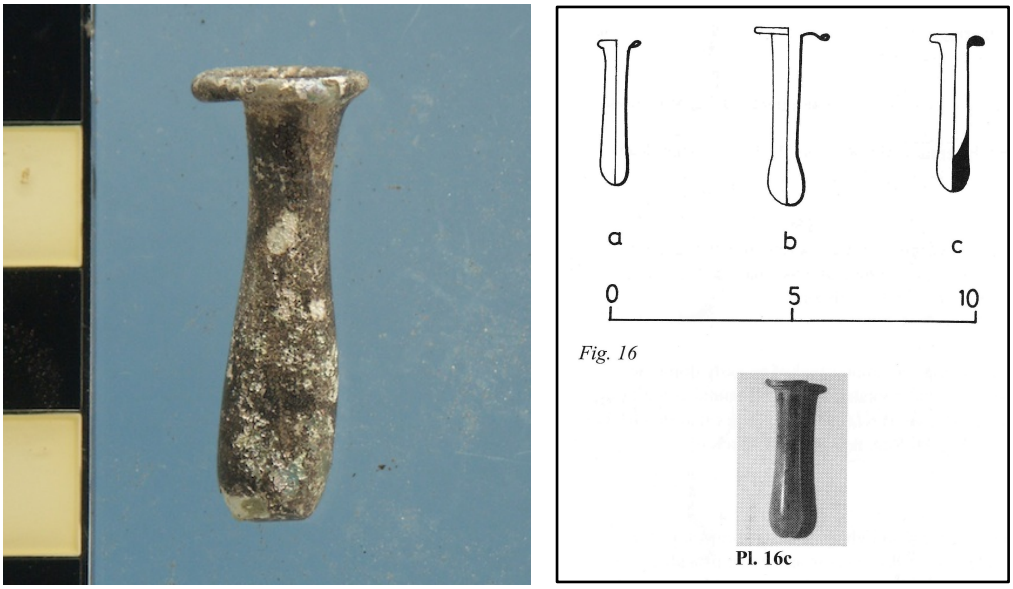

Figure 4.5: (Left) Unsampled fragment from Ḥiṣn al-Tīnāt, registration number KT026166/08 (photograph courtesy of A. Eger); (right) somewhat similar flasks from Fusṭāṭ, ca. 1000 CE (Scanlon and Pinder-Wilson 2001: 40 and Fig. 16).

Islamic contexts in the Near East,[5] but to my knowledge they are not commonly found in Anatolia. Margaret O'Hea has noted that on the basis of current publications, molar flasks are actually missing from the Transjordan repertoire (O'Hea 2001: 134).[6]

The second unsampled object (KT026166/08 from TF11) is a small, teardrop-shaped flask of a light olive green fabric; it has an irregular profile, a rounded bottom, a lopsided rim with a flattened and everted lip, and somewhat squeezed-in sides near the base (Figure 4.5). The overall irregularity and asymmetry suggests it was quickly or casually made. Miniature bottles have been found at many sites, but are believed to be "confined to the 'Abbasid-Fatimid periods" in the Near East (Hadad 2005: 39). It is typically ineffective to search for close parallels for such simple objects, although flasks of a similar shape and size were found at Amorium (Gill 2002: 58, 75, and Fig. 1/19, no. 280) and Tiberias (Lester 2004: 188 and Fig. 7.9, nos. 107-115). Examples also come from Fusṭāṭ (Figure 4.5), which "form a homogenous group and were made around 1000 CE" and are believed to be "intended for the storage of drugs or precious scents" (Scanlon and Pinder-Wilson 2001: 40-41 and Fig. 16, Nos. 16a-c). The volume of the phials from Tiberias were measured to help determine their use: "the results show that the tubular phials contain less than 1 cc of liquid" and when they are turned upside down they do not spill unless shaken "and then only in single drops;" from this test it was concluded that such phials contained liquids "that were dispensed in single drops or by measured quantity" (Lester 2004: 191-192).

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[5] Examples have been found in Egypt, Syria-Palestine, Iraq and Iran; however, "it is noteworthy that although present in both Egypt and Syro-Mesopotamia, [molar flasks] seem to have by-passed many Levantine sites" (O'Hea 1993: 224).

[6] With the exception of the regional capital of Bet She'an.

Vessel fragments

Undecorated wall fragments

Plain wall fragments are by far the most difficult artifacts to discuss in any great typological or chronological depth because they are so ambiguous; such fragments could belong to virtually any vessel type from any period and are therefore of little assistance to a typo-chronological analysis and interpretation. What may be said pertains to the color and clarity of the glass and the thickness of the walls. The 30 plain fragments in the assemblage include naturally aqua, almost colorless, yellowish, light purple, light blue, and light green glass, as well as one dark blue fragment (**No. 211**); all are transparent or translucent, depending on the thickness of the vessel. The majority of wall fragments are thin, indicating they came from small blown vessels rather than larger vessels; an exception to this is **No. 216**, a large and relatively thick wall fragment that attests to the presence of at least a few larger vessels, most likely bottles or jugs.

Decorated wall fragments

Much more diagnostic than the body fragments of plain vessels, decorated wall fragments can sometimes indicate the shape, function, provenance, and/or date range of a vessel. Only 14 of the 44 wall fragments found at Ḥiṣn al-Tīnāt have decorative features (Figures 4.6).

No. 135 is a fragment of nearly colorless glass decorated with two thumbprint-sized ovals of purple glass, from ca. 10th century CE stratigraphic contexts; **No. 194** would appear to be have an applied blob of yellow glass that has been marvered flush

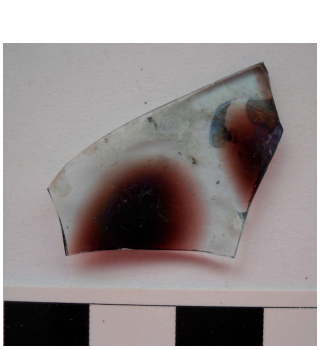
with the surface of the vessel.[7] Blobs of colored glass on pale blue-green, green-yellow, or colorless glass are very common for Byzantine beakers/goblets/lamps in the Near East from the 4th century CE onwards (Weinberg 1988: 87-93; Stern 2001: 293296, nos. 157-159; Israeli 2003: 154 and 195-197, nos. 229-236), although these blobs are usually blue or dark green in color and typically stand proud of the surface of the vessel wall. The blobs of the Ḥiṣn al-Tīnāt fragments are somewhat more unusual in their color and are flush to the surface rather than proud, indicating the vessel was reheated and marvered after the application of the blobs. Precise parallels are not easy to find looking at finds from Anatolia (for example, there are no colored blobs on the beakers/goblets/lamps from Amorium) and further south; in contrast, Weinberg notes that "some western examples have blobs of other colors in addition to blue, a feature that seems absent in the East" (1988: 89), so perhaps parallels should be sought to the north and west.

Fragment **No. 145** comes from 11th-12th century CE stratigraphic contexts and is a rounded wall fragment of naturally aqua glass, probably from a small jar or globular bottle, which has a small nipped or pinched fin on its exterior surface; **No. 196** has a similar but slightly longer pinched fin, and comes from ca. 10th century CE contexts. Pinched fins can be oriented either horizontally or vertically, but typically decorated globular vessel forms (bowls, beakers, jars, and bottles). The practice was popular in the Late Roman-Early Byzantine Near East, with 4th-7th century examples from Jalame (Weinberg 1988: 84; Slane and Magness 2005), Hammat Gader (Cohen 1997: 412-3 and

[7] There is a very remote possibility that this yellowish color is not an applied yellow glass, but rather part of a stained decoration; it is rare to see yellow blobs and the smoothness of the fragment gives one pause. However, the small size of the fragment and my lack of experience handling metallic-stained glass makes it very difficult to suggest this with certainty; if this fragment is indeed stained glass, this would be highly significant, another example of imported luxury glass (from Egypt or Syria). However, the chemical analysis show no elevated levels of copper or silver.

Pl. IV, nos. 5-6; 414-416 and Pl. V, no. 2), and Beirut (Jennings 2006: 159-163 and Figs. 7.4, 7.7, 7.8, nos. 4 and 7). However, the nipped or pinched decorative style seems to be "more characteristic of the second half of the 7th and 8th centuries than of the Byzantine period" (i.e., of the Umayyad period) in the Near East (Pollak 2003: 165; Barag 1985) but remained common among Islamic glass vessels into the 10th century (Lamm 1929-1930; Scanlon and Pinder-Wilson 2001: 66). Umayyad, 'Abbāsid, and Fāṭimid examples come from Caesarea (Pollak 2003: 166 and Fig. 1, no. 13), Tiberias (Lester 2004: 204-206, no. 171), Bet She'an (Hadad 2005: 96-97, Pl. 4, nos. 78-81; 112-113, Pl. 12, no. 222), Ramla (Gorin-Rosen), Qal'at Sem'an (Dussart *et al.* 2004: 74 and Fig. 4, no. 9), Jerash (Baur 1938: 522, 536, and Fig. 18, no. 244; Meyer 1987: 204, 206, and Fig. 10, no. A and B; Dussart 1998: BVII 251, Pl. 19), Pella (O'Hea 1993: 222, 226, and Fig. 25, nos. 2-4), Jabal Usais (Brisch 1965: 174-175 and Fig. 44), and Istabl 'Antar/Fusṭāṭ (Foy 2000b: 175 and Fig. 13, nos. 3-8). To my knowledge, parallels are lacking in regions outside of the Near East; for example, of the various methods used to decorate the vessels found at Amorium, pinched fins are absent.

Evidence for relief patterning produced by impressing or mold-blowing comes from several different fragments. Colorless fragment **No. 161** has a relatively deep and rounded external boss with a central rounded protrusion, while light blue fragment **No. 212** displays a circular protrusion in the center of a slightly raised circular line from which more circular protrusions radiate; these two patterns are likely the product of impressing the glass after its final shape was finished but before it was removed from the pontil rod.



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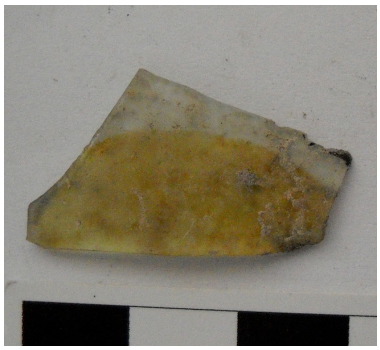

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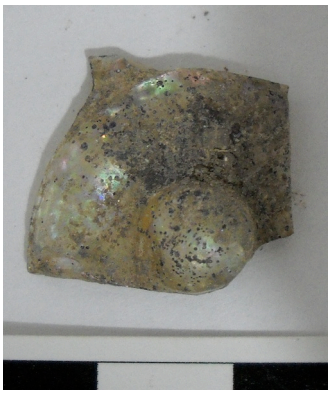

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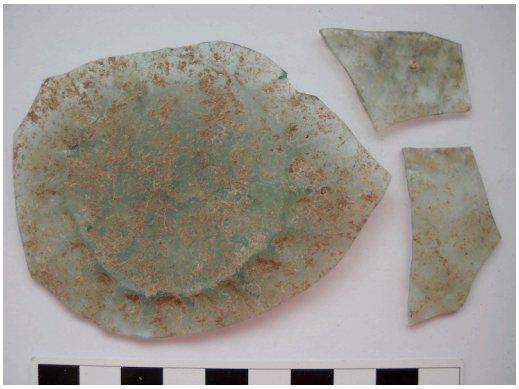

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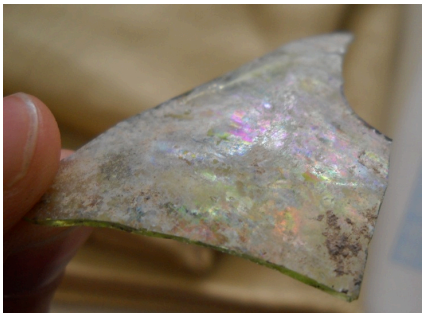

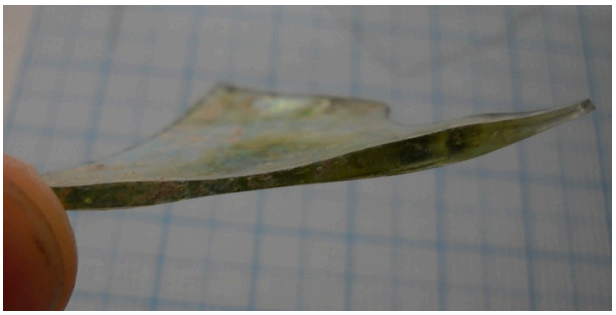

No. 193

Figure 4.6: Detail of the various decorative methods and effects used for the glass from Ḥiṣn al-Tīnāt; vessels with <u>colored blob appliqués</u>: No. 135 and No. 194; <u>pinched fins</u>: No. 145; <u>impressed</u> decoration: No. 161 and No. 212; <u>mold-blown</u> decoration: No. 131 and No. 193.

Figure 4.7: Detail of the various decorative methods and effects used for the glass from Ḥiṣn al-Tīnāt; <u>clamped or tonged</u> decoration: No. 164, No. 168, and No. 202; <u>mold-blown polygonal</u>: No. 158 and No. 171; <u>applied trails and tooled</u>: No. 165.

The patterning of the ca. 10th century CE fragment **No. 131** is certainly the result of mold-blowing: the ridged surface that can be achieved by using a mold can easily be seen in its base fragment, while the fainter ridges of its wall fragments show that the vessel was reheated and expanded once it was removed from the mold; a similar vessel in purple glass comes from Amorium (Gill 2002: 7, and Fig. 1/21, no. 318). Yellowish vessel **No. 193** also has a molded and reheated/expanded body; its wall thickness is irregular because of the pattern of the mold, which can best be felt but is easiest to see in the cross section.

Another technique for achieving a patterned surface involves clamping a tong-like tool down the wall of the vessel (Figure 4.7). This method (variously called impressing, pincering, or tonging) was used for three of vessels in the Ḥiṣn al-Tīnāt assemblage: **No. 164** is a small colorless wall fragment with short parallel dashes and a small triangle

shape, **No. 168** is a naturally aqua rim fragment from a beaker with a rounded lip and thick vertical walls decorated with a lozenge-shaped design, and **No. 202** is a naturally aqua wall fragment with an S-shaped or possibly bird-shaped design. Nos. 164 and 168 come from contexts dating to the 10th-12th centuries CE while No. 202 is from an 11th-12th century CE context. No. 164 is similar to examples from Bet She'an (Hadad 2005: 151 and Pl. 31, nos. 615, 618, and 622) while No. 202 has a very close design parallel with a ca. 9th-10th century CE bowl of "greenish colorless glass" in the Leo Mildenberg Collection (Carboni and Whitehouse 2001: 103 and Fig. 93) and also with blue-green examples from al-Mina also possibly dating to the 9th-10th centuries (Lane 1938: 68-70 and Fig. 12, Nos. A-B). Although only No. 168 can be associated with a specific vessel form (a beaker or bowl with vertical walls), it is likely that the other two examples are from similar forms; this technique was used on a vessel typically after its final shape was completed, and so was more likely to decorate open beakers/cups/bowls with short, vertical sides and slightly thicker walls so that the entire surface of the vessel could take the pattern of the clamp.

Tong-decorated objects are a ubiquitous type of fineware in Egypt and have been found throughout the Levant and Syria as well as in Iraq, Iran, and the Caucasus. Some scholars believe these vessels "can be attributed with some degree of confidence to Egyptian workshops" dating to the 9th-11th centuries (Carboni and Whitehouse 2001: 102-103), although others suggest "a shared *koiné* of pincered glassmaking throughout the caliphate" because "pincer-tongs could have traveled widely, needing little skill to produce cheaper local wares than the deeply cut Persian glass whose ornament they imitated" (O'Hea 1993: 225). This *koiné* should be extended to the Byzantine world as

well, because tonged vessels have been found in Amorium (Gill 2002: 60-61, 76, and Fig. 1/20, no. 304-308) and Corinth (Davidson 1952: 107, no. 687)—however, this fact does not appear to be widely known to scholars of Islamic glass; it would be fascinating to discover whether these Byzantine examples appear contemporaneously or at a slightly later period.

Facet-cut vessels are largely absent (the molar flask being the only example), although two 10th-12th century CE fragments of mold-blown polygonal vessels achieve a similar look (Figure 4.7), which might be thought of as "faux-faceted" perhaps. **No. 158** is probably a small bottle, and has several sharp changes of direction around its circumference but the thinness of the walls indicates it was blown rather than cold-worked. **No. 171** is the base of a small bottle or jar that also has polygonal sides, but the curved bottom and thin walls again suggest mold-blowing rather than facet cutting; short bottles dating to the 8th-10th century in the Israel Museum have similar polygonal sides (Brosh 2003: 352, Nos. 468-469).

The most unique decoration is from **No. 165,** a fragment with thick, irregular trails that are tooled into several horizontal projections (Figure 4.7). This fragment comes from contexts dated to the 10th-12th centuries CE. Possible parallels in technique rather than precise shape/style include Early Byzantine and Early Islamic jars and bottles with tooled trails[8] (Stern 2001: 313, No. 176; Carboni 2001: 26-27 and 38-39; Brosh 2003: 335-338; Hadad 2005: 116-117 and Pl. 14, nos. 270-281) or zoomorphic cage flasks of the Early Islamic period (Carboni 2001: 24-25). The closest parallel may be the base of a globular vessel from Bet She'an (Hadad 2005: 193 and Pl. 52, no. 1076).

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[8] Perhaps more appropriately described as ruffles, ribbon trails, or crimped trails.

Handle fragments

Eight handle fragments from jugs or juglets were recovered from the site (Figure 4.8). Most are naturally aqua or slightly colorless, and all were made by attaching a gather of hot glass to the body or shoulder of the vessel, pulling out the gather to the desired handle length and thickness, snipping the gather free from the rod and attaching the free end near the mouth of the vessel; as a result, all the handles are thickest where they were first attached to the vessel (forming a sort of blob) and typically have a rounded section. **Nos. 173** and **197** are two of the largest handles, each approximately 4.5 cm in length to the point of breakage and ~1 cm in diameter at their thickest point (KT25775/TF 8 is the largest example, which was not sampled). **No. 155** is similar in shape and style but is thinner and made of light purplish glass. **No. 119** is more complex, a gather of glass having been attached to the vessel and then pulled downwards and then upwards, with this fold then pressed flat against the vessel while the handle was pulled out horizontally and then vertically; the walls of this vessel might have been more vertical than those sporting the other handle type (which were probably jugs with more

No. 173 No. 119 No. 172 No. 231 No. 201

Figure 4.8: Examples of the different handle types.

narrowed necks). **Nos. 172**, **231**, and **201** are all distinct handles: the first is short and forms a tight curve, the second is thin and terminated by a blob where it meets the vessel rim, and the third seems to have three points at its end. **No. 238** is of yellowish glass and comes from where the glass blob was attached to the wall of the vessel, although the rest of the handle is missing.

Rim fragments

The 24 surviving rims are relatively simple in terms of both their form and finishing methods. Most have rolled, folded, or simply fire-rounded lips. Rim diameters, which give some indication of vessel function, range from 2-21 cm (Figures 4.9-4.11); most fragments are quite short, however, making it more difficult or impossible to identify the overall vessel shape.

Vessels with rim diameters over 10 cm are identified as bowls (Figure 4.9). **No. 132** (light greenish-aqua glass, 16 cm rim diameter) is a large bowl with an almost vertical rim with an externally folded lip. This fragment was recovered from ca. 10th century CE contexts, but this was a long-lasting vessel form in the Near East and parallels include Late Roman-Byzantine examples from Jalame (Weinberg 1988: 42-43 and Fig. 4-3, no. 19), Tirat-HaCarmel (Pollak 2005: 9-12 and Fig. 2, nos. 13-14), Caesarea (Pollak 2003), and Jerash (Meyer 1987: 190 and Fig. 6, no. H); Umayyad examples from Tall Jawa (Siemens 2010: 420-421) and Bet She'an (Hadad 2005: 95 and Pl. 3, nos. 57-68); and Ayyūbid-Mamluk examples from Bet She'an (Hadad 2005: 189 and Pl. 50, no. 1031). In the ''Abbāsid period "bowls with outfolded rims continued to be used alongside new forms, such as cylindrical bowls and large bowls with slanting walls and solid bases"

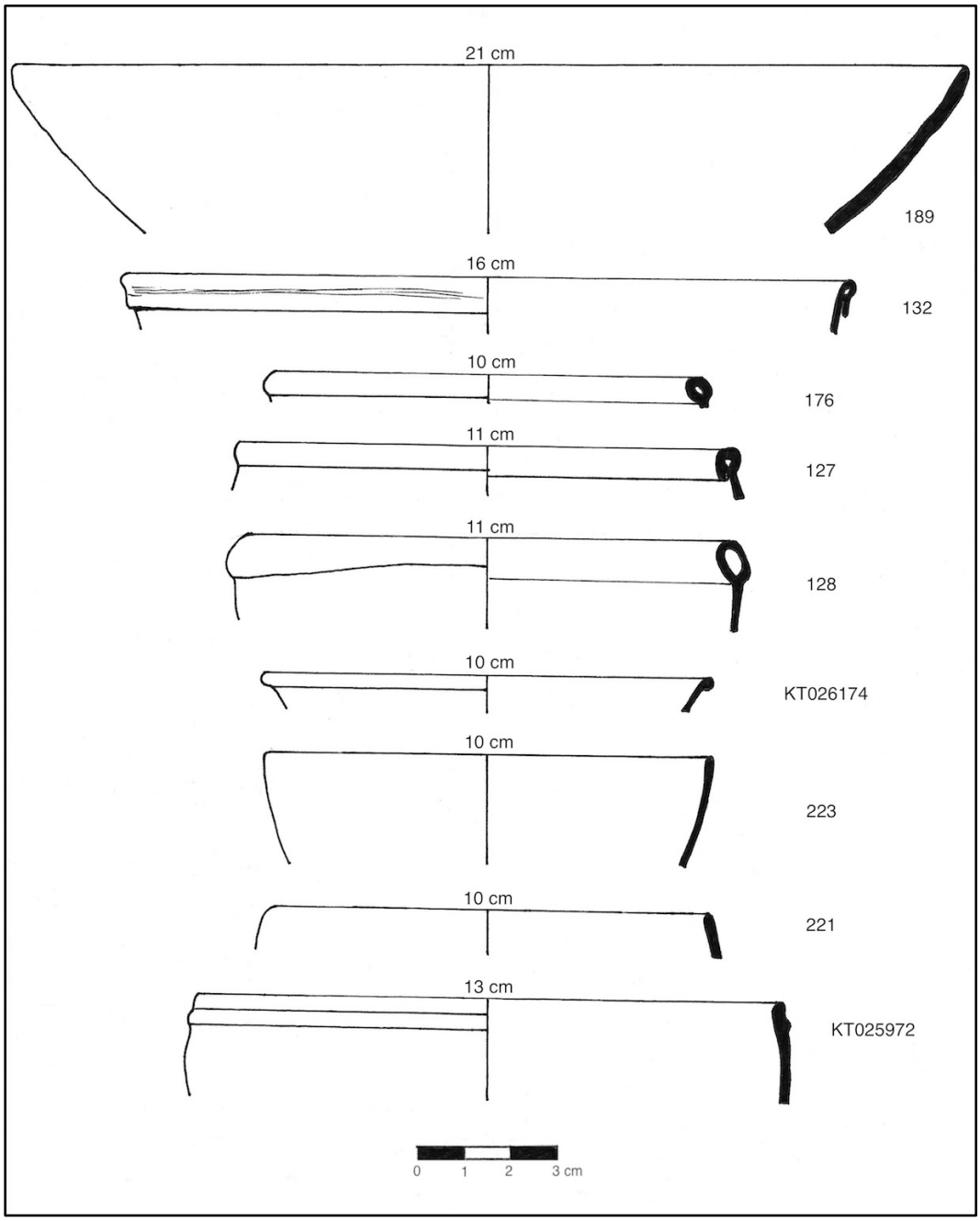

Figure 4.9: Line-drawings of rim fragments of bowls from Ḥiṣn al-Tīnāt; rim diameters are given at the top of each, and object numbers are shown (unless the fragment was not sampled for analysis, in which case the excavation finds number is given).

(Pollak 2003: 167); **No. 189** (colorless glass, 21 cm rim diameter) is a ca. 10th century CE example of a large shallow bowl with flaring walls and a plain rim, and similar examples come from Caesarea (Pollak 2003: 166-167 and Fig. 1, no. 19) and Bet She'an (Hadad

2005: 93 and Pl. 2, nos. 31 and 39; 11th century examples come from the Serçe Limanı ship (Bass *et al.* 2010: 134-141 and Figs. 12-2 to 12-5).

Several vessels with rim diameters ranging from 10-13 cm served as bowls or large hemispherical cups; although the vessel shape and rim treatments of these are similar to finds from Amorium (Gill 2002: 70 and Fig. 1/12; 72 and Fig. 1/14; 174 and Fig. 2/10; 175 and Figs. 2/11-2/12), the latter are smaller in size (typically being 8 cm in rim diameter). Vessels with incurved, rounded rims and a cylindrical body are a new dominant type in many ‘‘Abbāsid period assemblages in the Near East (Pollak 2003: 167) and examples come from Caesarea, Ramla, Hammat Gader, Bet She’an, and Fusṭāṭ. Nos. 176, 127, and 128 all have slightly turned-in rims with rolled lips and seem to have convex, globular body walls; these fragments were excavated from contexts dated to the 10th-12th centuries CE. **No. 127** (aqua glass, 11 cm rim diameter) has a thick and rounded lip that was formed by rolling the rim towards the interior of the vessel; **No. 176** (aqua glass, 10 cm rim diameter) is very similar; and **No. 128** (light green glass, 11 cm rim diameter) has an irregularly rolled lip with a large hollow. Nos. 221 and 223 are similar to these other vessels in size and general shape, but both have plain rims and they were recovered from stratigraphic contexts dated to the 11th-12th centuries CE. **No. 221** (light greenish-yellow glass, 10 cm rim diameter) has a slightly turned-in rim with a plain fire-rounded lip while **No. 223** (colorless glass, 10 cm rim diameter) has a similar but somewhat less inverted rim; this style is found for example in Umayyad loci at Jerash (Meyer 1987: 213-214 and Fig. 13, nos. E-F) and Tall Jawa (Siemens 2010: 419-420).

Two unsampled vessels are also included here because they illustrate two other rim styles present at the site. A rim fragment from KT026174 (indistinct color, 10 cm rim

diameter) has a slightly everted, fire-rounded lip, while a rim fragment from KT025972 (aqua glass, 13 cm rim diameter) has a slight bulging horizontal rib just below the lip on its exterior surface; the later finds parallels from 5th century CE Tirat-HaCarmel (Pollak 2005: 7-8 and Fig. 1, nos. 7-8) and Jalame but is noted as being a relatively uncommon shape in the Levant, Egypt, and Cyprus (Weinberg 1988: 45-47 and Fig. 4-6, nos. 50-70); the style seems more common in the Islamic periods, as Umayyad and ‘‘Abbāsid-Fāṭimid vessels with a horizontal rib were among the finds of Bet She’an (Hadad 2005: 91 and Pl. 1, nos. 28; 143 and Pl. 27, nos. 530-533), Qal’at Sem’an (Dussart *et al.* 2004: 75 and Fig. 5, no. 7), and the Serçe Limanı ship (Bass *et al.* 2010: 163-164 and Fig. 13-2, nos. 7-8).

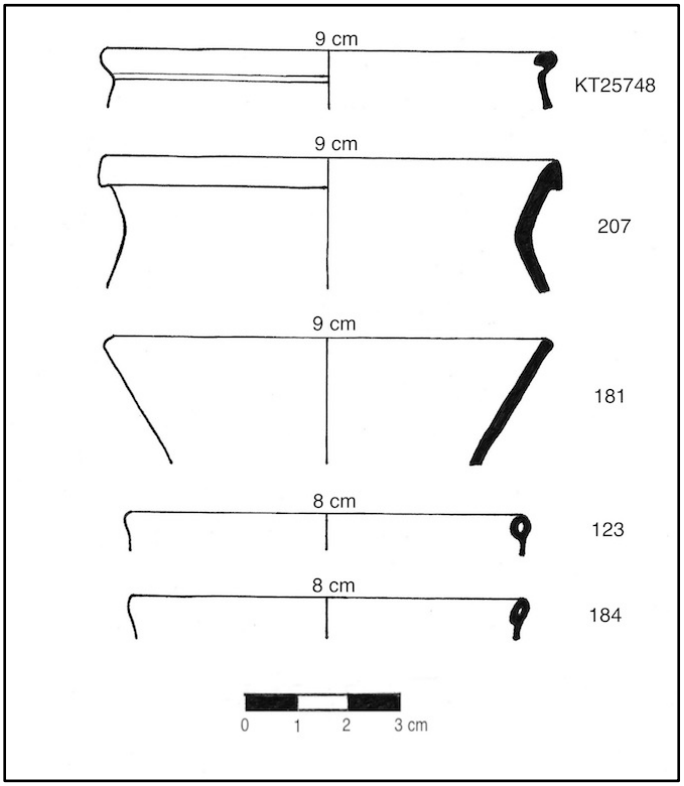

Figure 4.10: Line-drawings of rim fragments of bowls, jars, and beakers from Ḥiṣn al-Tīnāt; rim diameters are given at the top of each, and object numbers are shown (unless the fragment was not sampled for analysis, in which case the excavation finds number is given).

Vessels with rim diameters 7-9 cm (Figure 4.10) are more difficult to confidently identify, as the difference between some shapes simply cannot be determined without more of the vessel walls surviving; vessels in this size range could simultaneously function as cups, small bowls, beakers, goblets, or lamps but they could alternatively be wide-mouthed flasks or jars. Three fragments with 9 cm rim diameters illustrate this dilemma: one unsampled fragment from KT25748 (indistinct color) is likely to be a bowl, while the tapering walls of rim **Nos. 207** (aqua glass) and **181** (aqua glass) make it more likely these are wide-mouthed flasks or jars. No. 181 is from contexts dated to the mid-10th to mid-11th centuries CE, and it is similar to vessels found at Amorium (Gill 2002: 50-51, 71, and Fig. 1/13, nos. 169-172) and Bet She'an (Hadad 2005: 103 and Pl. 7, nos. 116-124, 134-136). No. 207 has a much more unusual rim profile and, interestingly, one that is definitely found at Ayla.[9] Two smaller vessels from ca. 10th century CE contexts are more likely to be cups: **No. 123** (aqua glass, 8 cm rim diameter) has a vertical rim with a hollow, rolled lip; **No. 184** is very similar in color, size, and overall appearance although the roll is slightly flattened on the interior. Vessels of this size and similar rim treatment from 7th-century Beirut have been identified as belonging to lamps, although there is a significant lack of the distinctive lamp bases or handles at Ḥiṣn al-Tīnāt; this makes such an identification questionable and suggests they may simply have been drinking vessels, as at Caesarea (Pollak 2003: 167-168 and Fig. 2, no. 22).

The form and function of vessels with small rim diameters (Figure 4.11) are more straightforward, as their small mouths indicate they were from storage or pouring vessels.

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[9] Several colorless or nearly colorless glass jar fragments—almost identical to No. 207—are among the objects drawn by Carol Myer in the late 1980s; these fragments were recovered from areas/loci G11c-7 RN497 and G10b-4 RN531 of the "Fāṭimid house" (Whitcomb 1988b), and seem to be largely from 10th-11th century CE contexts. A fragment of this type from L8b-5 is included in this study as sample No. 7 (see Chapter 6, page 239, note 9).

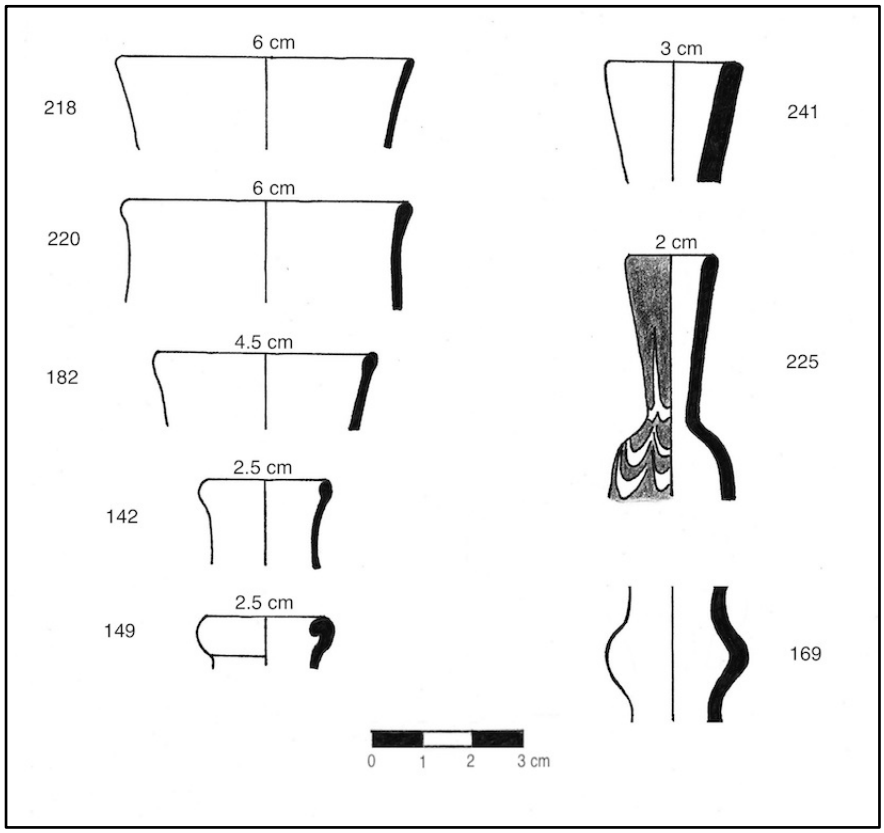

Figure 4.11: Line-drawings of rim fragments of jars, flasks, and bottles from Ḥiṣn al-Tīnāt; rim diameters are given at the top of each, and object numbers are shown.

While rims with 6 cm diameters could be from small cups, beakers, or lamps they are more likely bottles with straight mouths like examples from Tall Jawa (Siemens 2010: 433-434). Vessels with rim diameters that are less than 5 cm are certainly flasks, bottles, or jars. **No. 182** (aqua glass, 4.5 cm rim diameter) has a wide mouth that tapers, indicating it is probably a jar or a large flask. **Nos. 241** (light blue glass, 3 cm rim diameter) and **225**[10] (dark blue and white marvered glass, 2 cm rim diameter) are smaller flasks of the same general type although the walls of No. 241 are much thicker; both were found in 10th-12th century CE contexts. **Nos. 142** (aqua glass) and **149** (aqua glass) are

[10] This vessel is discussed above with the nearly complete vessels, but it is included again here to allow a comparison of vessel size and style with other bottles from the site.

two small bottles with a 2.5 cm rim diameter. The former has a short neck with a thickened, fire-rounded lip while the latter has thicker walls with a lip that is rolled towards the interior but not completely joined to the vessel walls. Bottles with an infolded rim was very common in all periods and are thus "almost undatable" because they go back to the 1st century CE (Bailey 1998: 151), but No. 149 is very similar to the "bubble rim" of bottles found onboard the 11th century CE Serçe Limanı ship (Bass *et al.* 2010: 214-221) which have short cylindrical necks and nearly globular bodies (either plain or mold-blown), and it was found in contexts dated to the 10th-12th centuries CE.

Neck fragments

The narrow diameter of two fragments, **Nos. 136** and **229**, show that they come from small bottles, although nothing more can be said about the vessel size or shape. On the other hand, **No. 169** (aqua glass) and **No. 203** (colorless-yellow, not illustrated) have the bulging collar of a "ring-neck" or "bubble-neck" type of flask or bottle; the former comes from 10th-12th century CE contexts. Vessels with bubble necks found on board the 11th century CE Serçe Limanı ship were consistently 3 cm in diameter at the bubble while the rims were frequently 3.3 cm in diameter, usually funnel-shaped with a simple fire-rounded lip (Bass *et al.* 2010: 223-235). Bubble-neck bottles in a wide variety of shapes have been found on both medieval sites including Corinth, al-Mina, Ḥamā, Qasr al-Hayr as-Sharki, Yoqne'am, Beirut, and Manda.

Base fragments

Fragments from vessel bottoms are numerous and typically identified by the

combination of a curved outer wall edge with a flattened bottom, a thickened center, a pushed-up center, and/or traces of a scar from the pontil rod; however, bases are also frequently the most fragmentary so in most cases the original shape and size of the base cannot be determined. Of 33 base fragments, 13 reconstructable examples are illustrated in Figure 4.12.

There were several fragments from thin-walled vessels that appeared to have a small base diameter and relatively flat bottom, which likely came from bottles. The most common type of base in the assemblage is of aqua glass and was formed by pushing the

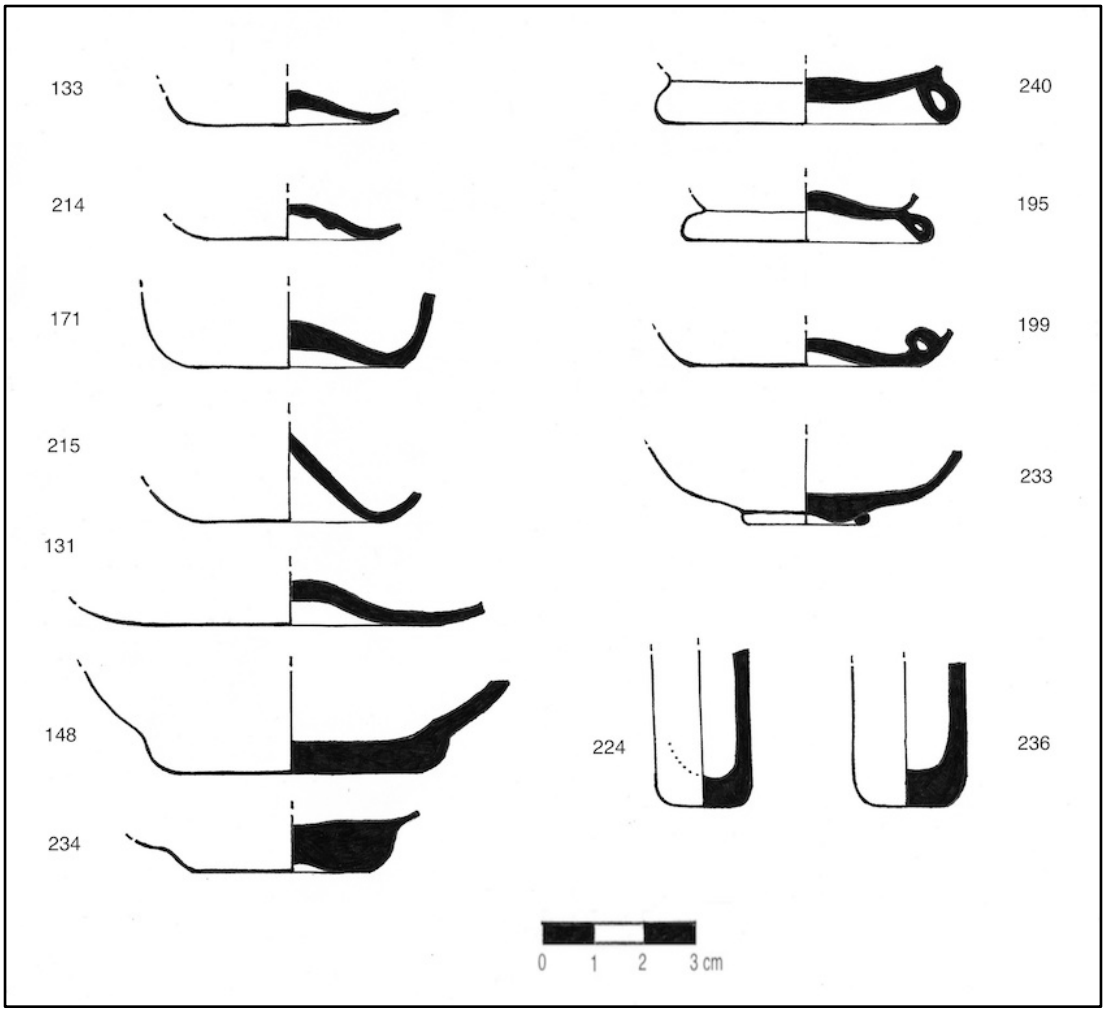

Figure 4.12: Line-drawings of base fragments from Ḥiṣn al-Tīnāt, including object numbers.

center of the base slightly upwards; examples of this type include **Nos. 131, 133, 171, 214**, and **215**. The relatively small base diameter (3-6 cm) suggests that most of these probably belonged to bottles; similar bases were found at Amorium (Gill 2002: 72 and Fig. 1/15, nos. 206-214; 176 and Fig. 2/13, nos. 202-222) but this type of base is essentially ubiquitous because it is the most simple to produce. **No. 131**[11] (aqua-green glass) is the largest of this type, and the only mold-blown example, possibly from a large bottle or a bowl. **No. 214** has a slightly off-center and rough punty scar. **No. 215** (green glass) and No. 122 (aqua glass, not illustrated) both have a high kick, which is typically a feature of later vessels.

Bases with a thickened and flattened bottom were formed using the original glass gather rather than from the application of an additional pad of glass; examples of this type include **Nos. 148** (aqua glass) and **234** (green glass), the remaining walls of which suggest the body of the vessel was probably somewhat globular. **No. 234** is also asymmetrical in terms of the thickness of the base pad and the rise of the vessel walls. Most parallels are identified as Early Byzantine, for example fragments at Jerash (Meyer 1987: 190, 193, and Fig. 6, nos. Z, aa-dd); however, No. 234 comes from contexts dated to the 11th-12th centuries CE and a similar base was also found in Middle Byzantine levels at Amorium (Gill 2002: 53, 72, Fig. 1/15, no. 201) and still others can be noted amongst miscellaneous bases from the 11th century CE Serçe Limanı shipwreck (Bass *et al.* 2010: 424 and Fig. 41-4).

A few bases have a pushed-in bottom that forms a hollow foot-ring; without more of the vessel wall remaining it is unclear whether this type of base belonged to a

[11] This vessel is discussed above with the decorated wall fragments, but it is also included here to allow a comparison of vessel size and style with other vessels from the site.

bottle/jug or to a bowl/cup/beaker. **Nos. 240** (colorless glass), **195** (aqua glass), 175 (aqua glass, not illustrated), and 213 (light blue, not illustrated) are all examples of this type; this method of creating a foot-ring is first seen in the Late Roman period and was a long-lasting type, as similar bases have been found at Amorium (Gill 2002: 55-56, 73, and Fig. 1/16, nos. 230-237; 176 and Fig. 2/14, nos. 242 and 246) and various Byzantine and Medieval sites in the Eastern Mediterranean including al-Mina, Yoqne'am, and the Serçe Limanı shipwreck (Bass *et al.* 2010: 429 and Fig. 41-5). **No. 199** is a unique variation of this type—the base-ring is internal rather than forming an external foot—but it is similar to the simple pushed-in bottle bases in overall shape and it comes from a context dated to "mainly the 9th-10th century CE;" parallels are difficult to find, but several miscellaneous bases from the 11th century CE Serçe Limanı shipwreck also have internal rolls and less prominent feet (Bass *et al.* 2010: 429-430 and Fig. 41-6, nos. BA 779 and BA 800).

Another method for creating a foot is by winding a trail of glass around the bottom center of the vessel, which also required less time and technical skill to create than the pushed-in base ring. Examples of this type include **No. 233** (indistinct color) and **No. 151** (indistinct color, not illustrated), which both have a thin ring of glass. Similar bases were found at Amorium (Gill 2002: 46, 69, Fig. 1/10, nos. 117-123).

Two small bottles with squared bases were also found. **Nos. 224** (yellow-amber glass) and **236** (aqua glass) each have straight walls with squared bases and would probably have had cylindrical necks and straight rims. Such small bottles served as containers for oils, perfumes, or medicines. This seems to be a widespread and long-lasting shape; examples include vessels from Bet She'an (Hadad 2005: 159 and Pl. 35,

nos. 695-697), Beirut (Jennings 2006: 214-215 and Fig. 9.17, nos. 1-15), and the Serçe Limanı shipwreck (Bass *et al.* 2010: 238 and Fig. 19-2).

Kinet Höyük fragments

Glass was spread across the 12th-14th century CE layers of Kinet Höyük, and fragments were common in almost all contexts (site conservator Fran Cole, personal communication). Eight such fragments were unintentionally included with the collection of Ḥiṣn al-Tīnāt glass, but it seemed an opportune moment to compare the material from the two different phases of the larger settlement.[12] Four of these eight fragments (**Nos. 246-249**) were sampled in order to provide a chemical comparison to the glass from the earlier Ḥiṣn al-Tīnāt.

No. 246 is a plain wall fragment of light purple glass; **No. 247** is a thin, fire-rounded and slightly everted rim fragment of naturally aqua glass; **No. 248** is a wall fragment of colorless glass with two thin and parallel threads applied to the exterior surface; and **No. 249** is a base fragment of light green glass with a rolled base ring, a high central kick, and straight walls. Nos. 248-249 are most likely fragments from a type of large cylindrical beaker. A hoard of similar beakers was found in a pit on the East Terrace of Kinet Höyük, and was interpreted as a cullet collection meant for recycling. The fragments included three bases and the upper bodies of some 30-40 individual vessels (Figure 4.13). A slightly different beaker, with a narrower body and a painted red and gold panel around the circumference, was also recovered from Kinet Höyük (Fran Cole, conservator, personal communication).

[12] Other medieval glass fragments were collected between 1995-2008, some of which likely came from pit contexts (A. Eger, personal communication).

Figure 4.13: (Left) Fragment No. 249 from Kinet Höyük; (right) example of one of many almost complete beakers recovered from a hoard in 12th-14th c. contexts at Kinet Höyük.

Similar vessels, described as goblets, have been found at Hama (Riis and Poulsen 1957: 57-59, Figs. 157-160 and 161-162) and ascribed to the 12th-13th century and Syrian manufacture, following Lamm (1929-1930). The flared shape is considered to be characteristic of Syrian glass produced during the Ayyūbid period, when "beakers shapes were adjusted to obtain the definitive forms that became the rule later in the period and during the early Mamluk era," and these beakers were widely exported throughout the Islamic world and have been found as far afield as Iran, Turkey, and the Crimea (Carboni 2001: 184). They additionally probably inspired the beaker shapes that were produced in Venice in the late 13th century (Carboni and Whitehouse 2001: 123-125 and Nos. 40-41).

CHEMICAL ANALYSIS

The vessel fragments from Ḥiṣn al-Tīnāt and Kinet Höyük are all soda-lime-

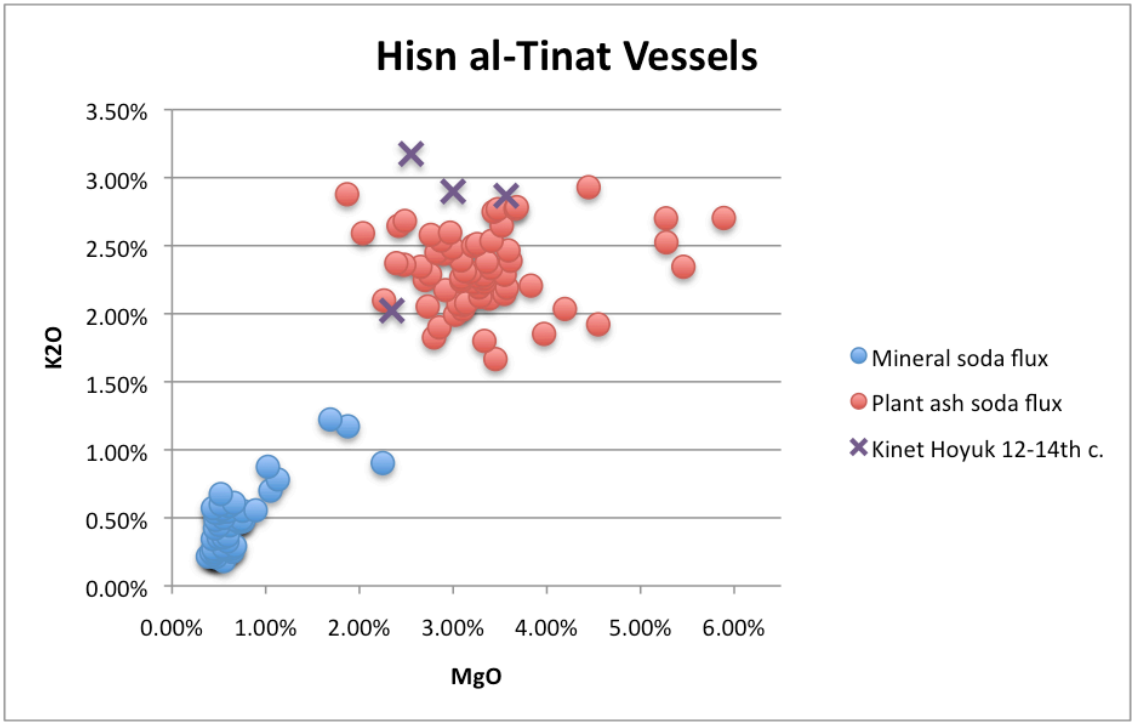

Figure 4.14: Bivariate scatter plot of magnesia and potash (two of the best discriminators) showing the two main technological groups of vessel glass from Ḥiṣn al-Tīnāt and Kinet Höyük.

silica[13] glasses, but two main technological traditions can easily be distinguished by the type of alkali that was used as a fluxing agent during production—mineral soda or plant ash soda when plotting their magnesia and potash levels (Figure 4.14).[14] The mineral soda glasses are easy to distinguish from the plant ash soda glasses, because the levels of magnesia and potash in the former are both typically below 1.5 wt% and well over 1.5 wt% in the latter.

Three samples (**Nos. 115, 200**, and **204**) were removed from further consideration and are not shown in Figure 4.14 because their compositions strongly suggest they are

[13] This type of glass is distinguished from other types of ancient glass, specifically potash glass and lead glass, because Na_2O (soda) is the dominant alkali; these glasses also have a relatively large amount of CaO (lime).

[14] This difference, between low potash-low magnesia (LMG or LMLK) mineral soda glasses and high potash-high magnesia (HMG or HMHK) plant ash soda glasses, was first recognized by Sayre and Smith (1961).

modern glasses,[15] a possibility that was first recognized in the field by their unusual coloring, decoration, and/or shape as well as because they were found in topsoil contexts. Of the 112 ancient vessel fragments from the Ḥiṣn al-Tīnāt assemblage, 49 (43%) were made using mineral soda as a flux and 64 (57%) were made using plant ash soda; the four samples from Kinet Höyük were all made using plant ash soda as a fluxing agent. In the following sections, the mineral soda and plant ash soda glasses will be discussed separately in order to highlight technological details and possible primary production group affiliations.

Mineral soda glasses

The Ḥiṣn al-Tīnāt samples include 49 fragments that were made using mineral soda and sand as the primary raw ingredients; the results for the major/minor elements are presented in Table 4.1 and for trace elements in Table 4.2. When we look in more detail at the mineral soda group (Figure 4.15) we can see that the vast majority of the samples plot in a cluster beneath the 1 wt% mark for each of these components, with a range of 0.4-0.9 wt% MgO and 0.2-0.7 wt% K_2O. There are six noticeable outliers to this cluster (which are circled in Figure 4.15); three of these (**Nos. 139, 220**, and **175**)[16] have noticeable but only slightly higher magnesia and potash levels (1.0-1.1 wt% MgO and

[15] The chemicals used in making modern glass are relatively pure, so the raw materials are typically much cleaner (i.e., free of impurities) than those used by glassmakers in antiquity. Low chlorine, low iron (~0.01 wt%) and low potash (~0.1 wt%) are usually indicative of modern glass; high arsenic (several hundred ppm) is also indicative of modern glass, as this only began to be added to the glass batch in the 18th century CE; these observations are typically reliable, but should be understood as tendencies rather than hard and fast rules (Thilo Rehren, personal communication).

[16] No. 139 is a small rim of aqua glass with a rolled (but not hollow lip), No. 220 is a plain rim in aqua glass, and No. 175 is an aqua fragment that looks to be part of small a tubular ring base; although the fragment is very small, it is vaguely possible that it is part of a foot for a goblet/lamp (see examples from Amorium in Gill 2002: 65 and Fig. 1/65, nos. 52-53 and 63-64; 66 and Fig. 1/6, nos. 74-80), which would be significant as no other evidence for such vessels were found at the site.

0.7-0.9 wt% K_2O, but both are still below 1.5 wt%), and three of these (**Nos. 237, 170**, and **222**)[17] have significantly higher magnesia and potash levels (1.7-2.3 wt% MgO and 0.9-1.2 wt% K_2O). All of these outliers have lower levels of silica and, with the exception of Nos. 175 and 237, higher levels of manganese (ranging 0.2-0.5 wt%, while most glasses have less than 0.1 wt% MnO); Nos. 175 and 220 also have higher levels of lime and alumina.

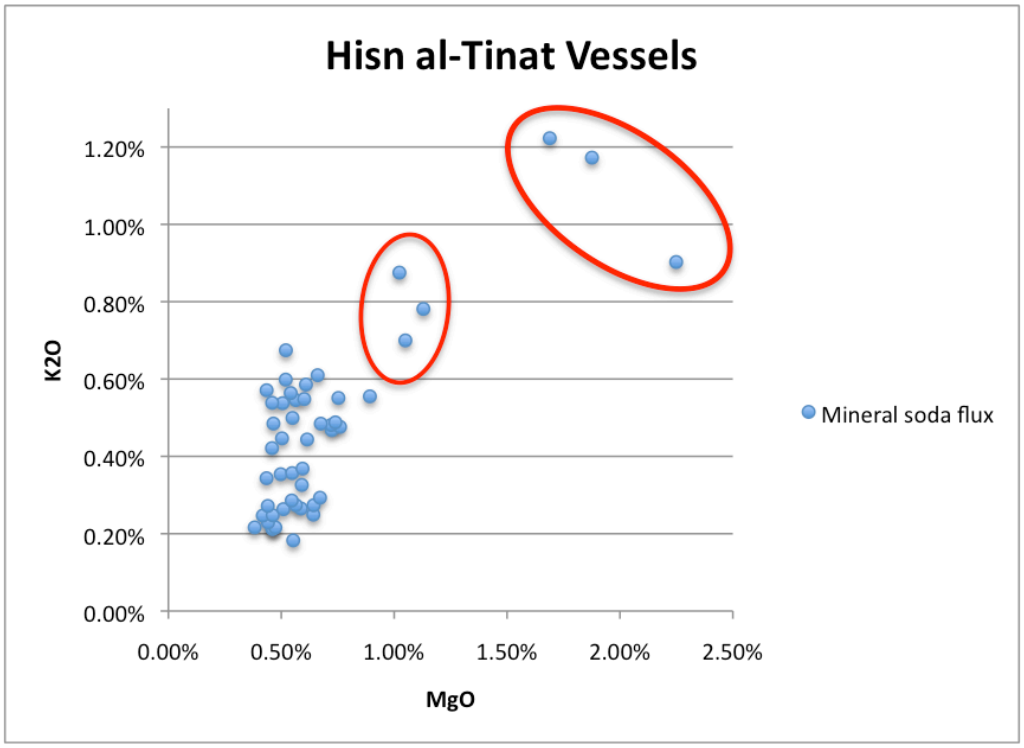

Figure 4.15: Bivariate scatter plot of magnesia and potash showing the mineral soda technological group, highlighting the main cluster and outliers (points circled in red).

[17] No. 170 is an aqua wall fragment that may be from the base of a large bottle, No. 237 is a brown-yellow wall fragment, and No. 222 is a curved fragment of blue glass that was classified as a bracelet fragment. If No. 222 is indeed a bracelet, then it is the only one not made with plant ash soda; the chemical results and the extreme regularity of the fragment in comparison to the other bracelets prompted me to consider the possibility that it may be a handle. However, as most of the handles from the site have a round cross-section and were trailed on, the identification is still not clear (see the commentary in Chapter 5 about the Ḥiṣn al-Tīnāt bracelets).

Table 4.1: HISN AL-TĪNĀT MINERAL SODA GLASSES: chemical results (major and minor oxides, and colorants/decolorants) given in wt% oxide.

Sample ID #	Color	SiO2	Na2O	K2O	CaO	MgO	Al2O3	Fe2O3	TiO2	MnO	P2O3	CuO	CoO	PbO2	Sb2O5	SnO2
GROUP 1: mineral soda glasses similar to the Egyptian II group																
120	Aqua	69.06	15.72	0.27	10.93	0.44	2.02	0.83	0.11	0.03	0.04	0.00	0.00	0.00	0.00	0.00
121	Deep blue	69.44	15.24	0.37	9.13	0.59	2.38	1.52	0.08	0.08	0.10	0.23	0.15	0.02	0.00	0.01
122	Aqua	70.53	15.81	0.26	9.14	0.51	2.19	0.80	0.08	0.03	0.07	0.00	0.00	0.00	0.00	0.00
125	Aqua	68.10	14.18	0.27	12.40	0.56	2.77	0.89	0.09	0.04	0.08	0.00	0.00	0.00	0.00	0.00
127	Aqua	73.05	13.05	0.18	9.11	0.55	2.53	0.95	0.10	0.03	0.06	0.00	0.00	0.00	0.00	0.00
129	Aq-green	70.79	14.91	0.33	9.12	0.59	2.35	0.90	0.08	0.18	0.10	0.01	0.00	0.02	0.00	0.00
130	Aqua	72.54	13.52	0.21	9.55	0.46	2.27	0.74	0.07	0.02	0.06	0.00	0.00	0.00	0.00	0.00
134	Aqua	69.62	16.28	0.22	10.01	0.38	1.96	0.80	0.10	0.02	0.05	0.00	0.00	0.00	0.00	0.00
135	Aqua/purple	68.44	16.02	0.35	8.99	0.50	2.26	0.98	0.09	1.62	0.07	0.00	0.00	0.00	0.00	0.00
136	Aqua	72.07	14.22	0.23	9.35	0.44	2.10	0.79	0.07	0.08	0.06	0.00	0.00	0.00	0.00	0.00
138	Aq-green	70.42	14.40	0.47	9.74	0.72	2.77	0.73	0.06	0.10	0.11	0.03	0.00	0.02	0.00	0.00
140	Aqua	73.16	13.81	0.22	8.32	0.47	2.37	0.82	0.07	0.02	0.07	0.00	0.00	0.00	0.00	0.00
141	Aqua	70.01	14.98	0.29	9.92	0.55	2.58	0.90	0.09	0.02	0.08	0.00	0.00	0.00	0.00	0.00
143	Aqua	72.04	13.34	0.21	9.79	0.46	2.52	0.85	0.08	0.02	0.07	0.00	0.00	0.00	0.00	0.00
192	Aqua	71.23	14.74	0.25	9.74	0.42	2.33	0.78	0.10	0.02	0.06	0.00	0.00	0.00	0.00	0.00
201	Aqua	72.13	14.61	0.25	9.17	0.46	2.15	0.68	0.08	0.02	0.10	0.00	0.00	0.00	0.00	0.00
206	Aq-green	69.68	15.71	0.27	9.63	0.64	2.50	0.87	0.11	0.03	0.10	0.00	0.00	0.00	0.00	0.00
209	Light green	69.82	14.11	0.44	9.65	0.61	2.42	1.08	0.11	1.19	0.12	0.00	0.00	0.00	0.00	0.00
214	Aqua	69.40	16.01	0.48	9.67	0.76	2.16	0.85	0.10	0.09	0.10	0.01	0.00	0.00	0.00	0.00
215	Green	72.81	16.73	0.27	6.29	0.59	1.82	0.78	0.09	0.02	0.05	0.00	0.00	0.00	0.00	0.00
221	Gr-yellow	69.83	14.63	0.25	10.12	0.64	2.75	0.96	0.14	0.02	0.07	0.00	0.00	0.00	0.00	0.00
AVERAGE (w/o 121)		**70.67**	**14.86**	**0.29**	**9.51**	**0.54**	**2.34**	**0.88**	**0.09**	**0.17**	**0.08**	**0.01**	**0.01**	**0.00**	**0.00**	**0.00**
Group 1 outliers																
170	Aqua	69.55	12.76	1.17	10.26	1.88	2.28	0.93	0.11	0.41	0.24	0.02	0.01	0.01	0.00	0.00
222	Blue	67.85	16.07	1.22	8.06	1.69	2.01	1.71	0.05	0.50	0.21	0.10	0.07	0.04	0.00	0.00
237	Br-yellow	71.06	13.85	0.90	9.93	2.25	1.69	0.24	0.07	0.01	0.01	0.00	0.00	0.00	0.00	0.00
154	Aqua	69.14	13.31	0.29	11.97	0.67	2.85	1.11	0.18	0.02	0.07	0.00	0.00	0.00	0.00	0.00
176	Aq-green	66.99	13.50	0.56	13.00	0.89	2.87	1.11	0.12	0.23	0.17	0.06	0.00	0.15	0.00	0.03
180	Aqua	66.81	15.79	0.36	11.61	0.55	3.41	1.07	0.14	0.02	0.03	0.00	0.00	0.00	0.00	0.00

Sample ID #	Color	SiO2	Na2O	K2O	CaO	MgO	Al2O3	Fe2O3	TiO2	MnO	P2O3	CuO	CoO	PbO2	Sb2O5	SnO2
GROUP 2: mineral soda glasses similar to the Levantine I group																
123	Aqua	70.71	13.65	0.49	10.22	0.74	3.09	0.56	0.03	0.03	0.10	0.00	0.00	0.00	0.00	0.00
124	Aqua	71.70	13.92	0.48	9.22	0.72	2.85	0.57	0.03	0.03	0.11	0.00	0.00	0.00	0.00	0.00
142	Aqua	70.56	16.86	0.54	7.89	0.51	2.70	0.40	0.02	0.02	0.09	0.00	0.00	0.00	0.00	0.00
145	Aqua	71.62	15.15	0.59	7.70	0.61	3.13	0.44	0.02	0.03	0.07	0.01	0.00	0.01	0.00	0.00
182	Aqua	70.56	15.45	0.50	9.13	0.55	2.74	0.35	0.03	0.03	0.10	0.00	0.00	0.00	0.00	0.00
184	Aqua	70.56	14.68	0.60	9.47	0.52	3.13	0.54	0.05	0.03	0.11	0.00	0.00	0.00	0.00	0.00
186	Aq-green	72.69	14.97	0.57	7.50	0.43	2.84	0.38	0.04	0.02	0.09	0.00	0.00	0.00	0.00	0.00
236	Aqua	71.33	13.75	0.61	9.20	0.66	3.38	0.45	0.04	0.07	0.13	0.07	0.00	0.01	0.00	0.00
AVERAGE		**71.22**	**14.80**	**0.55**	**8.79**	**0.59**	**2.98**	**0.46**	**0.03**	**0.03**	**0.10**	**0.01**	**0.00**	**0.00**	**0.00**	**0.00**
Group 2 outliers																
139	Aqua	69.48	13.98	0.70	9.97	1.05	3.07	0.81	0.05	0.21	0.14	0.03	0.00	0.10	0.00	0.01
175	Aqua	66.75	15.51	0.88	11.32	1.02	3.16	0.58	0.05	0.10	0.13	0.02	0.02	0.00	0.00	0.00
220	Aqua	66.30	13.90	0.78	12.62	1.13	3.20	0.98	0.07	0.23	0.14	0.07	0.00	0.20	0.00	0.04
166	Aqua	68.24	15.60	0.54	10.94	0.46	3.66	0.40	0.03	0.02	0.02	0.00	0.00	0.00	0.00	0.00

Sample ID #	Color	SiO2	Na2O	K2O	CaO	MgO	Al2O3	Fe2O3	TiO2	MnO	P2O3	CuO	CoO	PbO2	Sb2O5	SnO2
GROUP 3: mineral soda glasses similar to the Levantine II group																
116	Aqua	73.99	13.34	0.45	7.61	0.50	2.81	0.55	0.04	0.06	0.11	0.00	0.00	0.01	0.00	0.00
126	Aqua	73.60	14.30	0.67	7.13	0.52	2.63	0.52	0.03	0.02	0.13	0.00	0.00	0.00	0.00	0.00
128	Green	74.96	11.97	0.34	8.30	0.43	2.84	0.42	0.02	0.02	0.08	0.00	0.00	0.02	0.00	0.00
131	Aq-green	74.34	11.98	0.48	8.11	0.67	3.28	0.50	0.03	0.05	0.09	0.01	0.00	0.01	0.00	0.00
132	Aq-green	74.55	13.44	0.55	6.94	0.56	2.73	0.48	0.02	0.04	0.09	0.01	0.00	0.01	0.00	0.00
133	Aq-green	74.29	13.47	0.56	7.27	0.54	2.75	0.43	0.02	0.03	0.10	0.00	0.00	0.00	0.00	0.00
137	Aqua	73.84	13.54	0.48	7.67	0.47	2.98	0.38	0.02	0.02	0.08	0.00	0.00	0.00	0.00	0.00
193	Yel-green	72.78	13.41	0.55	8.72	0.60	3.06	0.41	0.03	0.02	0.07	0.00	0.00	0.00	0.00	0.00
194	CL-yellow	73.31	12.90	0.42	9.00	0.46	3.06	0.40	0.03	0.03	0.10	0.00	0.00	0.00	0.00	0.00
196	Aqua	72.86	12.96	0.55	8.80	0.75	3.16	0.41	0.03	0.02	0.07	0.00	0.00	0.00	0.00	0.00
AVERAGE		**73.85**	**13.13**	**0.51**	**7.96**	**0.55**	**2.93**	**0.45**	**0.03**	**0.03**	**0.09**	**0.00**	**0.00**	**0.01**	**0.00**	**0.00**

Table 4.2: HIṢN AL-TĪNĀT MINERAL SODA GLASSES: chemical results (trace elements) given in ppm.

Sample ID #	Color	Li	Be	B	Sc	Ti	V	Cr	Ni	Co	Zn	As	Rb	Sr	Zr	Nb	Ag	Sb	Cs	Ba
GROUP 1: mineral soda glasses similar to the Egyptian II group																				
120	Aqua	3.2	0.7	95.4	3.1	642.3	17.0	23.6	5.7	2.4	12.4	0.0	3.7	135.9	190.8	5.0	0.2	0.1	0.1	101.4
121	Deep blue	4.6	0.5	115.6	3.4	501.3	18.5	25.8	17.1	1152.0	2449.4	6.0	4.6	139.8	125.7	3.7	1.0	3.6	0.1	107.0
122	Aqua	3.9	0.5	148.6	3.1	478.1	17.2	23.3	5.9	10.1	27.7	3.4	3.6	124.4	120.8	3.8	0.1	0.2	0.0	102.4
125	Aqua	3.7	0.6	88.5	3.4	531.5	19.7	43.7	11.1	3.0	13.7	2.4	4.3	163.3	166.6	4.1	0.1	0.1	0.1	130.2
127	Aqua	2.8	0.5	70.7	3.5	570.3	20.1	28.0	6.7	3.2	13.9	6.9	3.3	119.9	161.8	4.4	0.1	0.2	0.0	90.4
129	Aq-green	4.0	0.6	92.3	3.2	487.6	19.2	27.9	13.4	5.9	38.3	8.6	4.3	146.6	129.9	3.8	0.4	0.9	0.1	125.8
130	Aqua	3.5	0.4	123.1	3.0	417.4	15.5	18.4	5.4	2.2	9.7	5.6	3.1	116.8	94.0	3.4	0.0	0.1	0.0	97.0
134	Aqua	3.2	0.6	111.5	2.9	584.6	15.7	25.4	4.6	2.3	11.6	0.0	3.4	120.1	174.9	4.8	0.1	0.3	0.0	96.6
135	Aqua/purple	4.8	0.7	127.4	3.2	520.9	23.7	25.5	9.8	5.2	112.1	2.1	4.7	160.4	121.2	4.0	0.0	0.5	0.1	275.8
136	Aqua	3.7	0.6	112.6	3.0	429.3	17.1	19.9	6.0	2.5	14.6	2.9	3.5	120.5	93.4	3.5	0.0	0.2	0.0	106.1
138	Aq-green	4.7	0.4	88.1	2.8	334.3	13.2	40.8	8.1	34.1	97.5	3.8	6.0	245.4	87.8	2.9	5.0	5.2	0.1	141.5
140	Aqua	3.4	0.6	61.1	3.2	438.6	18.8	24.6	6.6	2.6	10.7	1.6	3.4	126.8	98.5	3.4	0.0	0.1	0.0	110.1
141	Aqua	4.0	0.5	72.0	3.3	521.2	20.4	26.1	7.1	2.6	12.2	2.6	4.5	142.0	131.3	4.0	0.1	0.1	0.1	119.9
143	Aqua	2.8	0.5	55.9	3.1	466.4	18.4	24.7	5.6	2.5	13.0	1.6	3.7	151.4	124.5	4.0	0.1	0.2	0.1	139.4
192	Aqua	3.0	1.0	73.2	3.4	590.3	17.4	23.4	10.4	2.5	10.0	4.1	4.1	151.2	133.6	4.3	0.1	0.8	0.1	119.8
201	Aqua	6.6	0.5	110.6	2.9	489.0	15.7	20.0	6.0	2.3	11.1	19.9	3.2	118.6	85.9	3.0	0.1	0.2	0.0	92.9
206	Aq-green	4.5	0.5	79.7	3.6	684.6	22.0	28.8	9.2	4.1	15.1	4.6	4.0	154.9	162.4	4.4	0.1	0.2	0.0	131.2
209	Light green	5.0	0.7	55.8	3.4	663.2	24.7	28.5	10.1	5.3	154.5	8.0	6.7	166.0	151.0	4.2	0.1	0.1	0.1	292.2
214	Aqua	4.9	0.6	64.3	3.2	591.9	21.0	26.3	11.8	28.0	21.0	2.8	5.4	177.9	120.9	3.8	0.1	0.2	0.1	135.4
215	Green	4.2	0.5	97.8	3.6	556.8	16.2	15.3	7.7	2.8	11.2	2.5	3.9	150.0	81.9	3.7	0.1	0.1	0.1	102.0
221	Gr-yellow	4.1	0.4	68.8	4.3	840.8	21.3	28.0	6.5	3.0	11.7	1.6	4.4	160.3	178.9	4.6	0.1	0.1	0.0	141.8
AVERAGE (w/o 121)		**4.0**	**0.6**	**89.9**	**3.3**	**542.0**	**18.7**	**26.1**	**7.9**	**6.3**	**31.1**	**4.2**	**4.2**	**147.6**	**130.5**	**3.9**	**0.3**	**0.5**	**0.1**	**132.6**
Group 1 outliers																				
170	Aqua	7.5	0.7	92.6	3.0	685.0	20.1	27.6	20.1	41.8	71.0	4.3	9.5	349.3	128.0	3.6	0.2	4.4	0.1	174.9
222	Blue	45.1	0.6	571.3	3.1	289.8	17.6	20.0	23.6	512.9	130.1	37.3	16.2	389.6	36.3	2.2	0.3	11.0	3.9	148.8
237	Br-yellow	1.8	0.4	27.7	2.0	441.6	16.5	11.0	4.9	2.0	12.0	0.7	26.2	41.9	158.1	4.8	0.1	1.0	0.2	63.7
154	Aqua	3.3	0.6	94.4	4.1	1069.1	26.4	32.9	7.6	3.8	12.8	1.4	5.6	241.1	259.5	6.2	0.1	0.1	0.1	181.8
176	Aq-green	6.1	0.9	72.7	3.2	745.2	21.6	48.8	18.6	19.1	67.9	1.2	9.7	292.8	144.9	4.4	2.5	13.9	0.5	169.1
180	Aqua	2.9	1.8	30.2	4.9	828.9	27.0	32.2	9.7	4.0	12.9	0.0	7.4	224.9	253.0	7.1	0.2	0.2	0.1	205.3

Sample ID #	Color	La	Ce	Pr	Ta	Au	Y	Bi	U	W	Mo	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Th
GROUP 1: mineral soda glasses similar to the Egyptian II group – CONTINUED																								
120	Aqua	5.9	11.6	1.4	0.2	0.0	7.0	0.0	1.1	0.1	0.2	5.1	1.1	0.2	1.0	0.1	1.0	0.2	0.6	0.1	0.6	0.1	3.9	1.2
121	Deep blue	5.4	10.6	1.3	0.2	0.0	6.5	0.1	0.8	0.1	1.1	5.1	1.0	0.2	0.9	0.1	0.9	0.2	0.5	0.1	0.6	0.1	2.9	1.1
122	Aqua	5.2	10.4	1.3	0.2	0.3	6.0	0.2	1.0	0.1	0.2	4.8	1.0	0.2	0.8	0.1	0.9	0.2	0.5	0.1	0.5	0.1	2.7	1.1
125	Aqua	5.7	11.1	1.4	0.2	0.0	6.8	0.0	1.0	0.1	0.2	5.1	1.0	0.2	0.9	0.1	1.0	0.2	0.5	0.1	0.6	0.1	3.7	1.5
127	Aqua	5.7	11.3	1.5	0.2	0.0	6.5	0.0	0.7	0.1	0.1	5.4	1.0	0.2	1.1	0.1	0.9	0.2	0.6	0.1	0.6	0.1	3.6	1.3
129	Aq-green	5.3	11.2	1.3	0.2	1.5	6.0	0.0	0.9	0.1	0.2	4.9	1.0	0.2	1.0	0.1	0.9	0.2	0.5	0.1	0.5	0.1	2.9	1.1
130	Aqua	5.0	9.8	1.2	0.2	0.8	5.7	0.0	0.8	0.1	0.1	4.6	0.9	0.2	0.9	0.1	0.8	0.2	0.5	0.1	0.5	0.1	2.1	0.9
134	Aqua	5.5	10.9	1.4	0.2	1.4	6.6	0.0	1.0	0.1	0.1	5.0	1.0	0.2	1.0	0.1	0.9	0.2	0.6	0.1	0.6	0.1	3.8	1.2
135	Aqua/purple	5.3	11.2	1.4	0.2	0.0	6.3	0.0	1.4	0.1	0.5	5.1	1.0	0.2	1.0	0.1	0.9	0.2	0.5	0.1	0.5	0.1	2.7	1.1
136	Aqua	4.9	10.5	1.2	0.2	0.0	5.6	0.0	0.9	0.0	0.1	4.7	1.0	0.2	0.9	0.1	0.8	0.2	0.5	0.0	0.5	0.1	2.1	1.0
138	Aq-green	5.4	10.8	1.4	0.2	0.4	6.8	0.0	0.9	0.7	0.4	5.1	1.1	0.3	1.0	0.2	0.9	0.2	0.6	0.1	0.6	0.1	2.1	1.0
140	Aqua	4.7	10.0	1.2	0.1	0.0	5.4	0.0	0.8	0.0	0.1	4.2	0.9	0.2	0.8	0.1	0.7	0.2	0.4	0.1	0.5	0.1	2.2	0.9
141	Aqua	5.3	10.4	1.3	0.2	0.0	6.2	0.0	0.9	0.1	0.1	5.0	1.0	0.2	0.9	0.1	0.9	0.2	0.5	0.1	0.5	0.1	2.9	1.2
143	Aqua	6.2	12.1	1.6	0.3	0.6	6.8	0.1	1.2	0.4	0.1	5.8	1.3	0.3	1.2	0.2	1.0	0.2	0.7	0.1	0.8	0.1	3.0	2.1
192	Aqua	6.4	12.2	1.7	0.3	0.6	7.8	0.3	1.2	0.5	0.3	6.3	1.5	0.4	1.2	0.1	1.2	0.3	0.7	0.1	0.8	0.1	2.9	1.4
201	Aqua	4.5	9.5	1.1	0.2	0.0	5.0	0.0	0.8	0.1	0.2	4.4	0.9	0.3	0.8	0.1	0.8	0.2	0.4	0.1	0.6	0.1	2.0	0.9
206	Aq-green	6.0	12.1	1.5	0.2	0.0	6.4	0.0	0.8	0.1	0.2	5.8	1.1	0.3	1.0	0.2	1.0	0.2	0.6	0.1	0.7	0.1	4.1	1.4
209	Light green	5.7	12.4	1.5	0.2	0.0	6.3	0.0	0.9	0.2	0.5	5.4	1.1	0.3	0.9	0.1	1.0	0.2	0.5	0.1	0.5	0.1	3.5	1.2
214	Aqua	5.5	12.3	1.5	0.2	0.0	5.5	0.0	0.9	0.1	0.6	5.5	1.1	0.3	0.9	0.1	0.9	0.2	0.5	0.1	0.6	0.1	2.8	1.2
215	Green	5.2	11.1	1.4	0.2	0.0	6.3	0.1	0.8	0.1	0.4	5.2	1.4	0.3	1.0	0.2	0.8	0.2	0.5	0.1	0.5	0.1	1.8	0.9
221	Gr-yellow	6.4	11.8	1.5	0.2	0.0	7.4	0.0	0.6	0.1	0.1	5.8	1.3	0.3	1.0	0.2	1.0	0.2	0.6	0.1	0.7	0.1	4.1	1.4
AVERAGE (w/o 121)		**5.5**	**11.1**	**1.4**	**0.2**	**0.3**	**6.3**	**0.0**	**0.9**	**0.1**	**0.2**	**5.2**	**1.1**	**0.2**	**1.0**	**0.1**	**0.9**	**0.2**	**0.5**	**0.1**	**0.6**	**0.1**	**2.9**	**1.2**
Group 1 outliers																								
170	Aqua	6.1	12.1	1.6	0.2	0.1	6.7	0.0	0.8	0.2	1.4	5.8	1.3	0.3	1.1	0.2	1.1	0.2	0.6	0.1	0.6	0.1	3.1	1.4
222	Blue	4.7	9.4	1.2	0.2	0.1	5.6	0.1	1.9	0.4	3.7	4.4	0.9	0.2	0.8	0.1	0.8	0.2	0.5	0.1	0.5	0.1	0.9	1.1
237	Br-yellow	3.6	8.1	0.9	0.3	0.2	7.1	0.0	0.6	0.3	0.2	2.9	0.7	0.2	0.7	0.1	0.9	0.2	0.6	0.1	0.8	0.1	3.9	0.8
154	Aqua	8.5	16.0	2.1	0.4	0.0	10.3	0.0	1.0	0.2	0.3	8.2	1.7	0.3	1.4	0.3	1.4	0.3	0.9	0.1	1.0	0.1	5.7	2.0
176	Aq-green	7.2	13.4	1.8	0.2	0.2	8.4	0.3	0.9	0.4	0.9	6.8	1.4	0.4	1.2	0.2	1.1	0.3	0.7	0.0	0.8	0.1	3.5	1.6
180	Aqua	9.8	18.7	2.3	0.4	2.5	11.5	0.5	1.8	2.5	0.3	9.7	2.0	0.6	1.8	0.3	2.0	0.4	1.1	0.2	1.1	0.2	6.8	2.9

Sample ID #	Color	Li	Be	B	Sc	Ti	V	Cr	Ni	Co	Zn	As	Rb	Sr	Zr	Nb	Ag	Sb	Cs	Ba
GROUP 2: mineral soda glasses similar to the Levantine I group																				
123	Aqua	3.3	0.7	77.0	2.7	196.8	11.3	161.7	15.7	4.3	12.8	4.7	7.2	349.0	50.2	2.0	0.1	0.8	0.1	164.3
124	Aqua	3.3	0.6	79.3	2.6	187.9	11.5	155.1	12.1	3.5	11.8	3.5	7.3	335.4	42.7	1.9	0.0	0.8	0.1	163.9
142	Aqua	4.1	0.4	59.9	2.2	138.1	7.9	15.4	5.5	1.5	8.1	2.3	9.0	305.8	28.2	1.5	0.0	0.2	0.1	167.3
145	Aqua	3.8	0.5	52.7	2.2	145.3	8.9	15.7	5.8	2.5	12.3	1.4	11.5	402.0	36.9	1.8	0.2	0.4	0.1	232.5
182	Aqua	3.5	0.4	85.3	2.1	184.2	8.3	36.5	5.1	1.5	6.0	3.0	8.8	498.8	27.8	1.4	0.0	1.9	0.1	193.9
184	Aqua	6.1	0.5	56.1	2.4	296.8	11.8	19.1	5.8	1.9	10.0	3.9	10.7	357.6	40.1	2.2	0.0	0.3	0.2	199.3
186	Aq-green	3.3	0.4	46.4	2.0	220.1	6.6	13.2	10.0	2.2	7.6	2.8	10.7	348.3	34.1	1.7	0.1	0.3	0.1	180.0
236	Aqua	3.8	0.4	53.0	2.5	221.6	8.7	63.3	18.4	3.6	39.9	5.1	9.5	388.5	35.0	1.7	0.5	3.8	0.1	213.7
AVERAGE		**3.9**	**0.5**	**63.7**	**2.3**	**198.9**	**9.4**	**60.0**	**9.8**	**2.6**	**13.6**	**3.3**	**9.3**	**373.2**	**36.9**	**1.8**	**0.1**	**1.1**	**0.1**	**189.4**
Group 2 outliers																				
139	Aqua	5.7	0.7	80.9	2.9	299.7	15.0	54.9	16.8	13.6	46.8	4.9	8.0	298.9	85.7	2.9	2.4	11.4	0.1	167.2
175	Aqua	5.0	0.6	77.6	2.3	322.0	11.1	24.5	11.9	124.4	254.4	4.4	11.0	486.4	47.6	2.1	0.1	0.3	0.1	197.4
220	Aqua	5.8	0.4	63.6	3.1	436.2	16.7	37.7	14.3	11.2	69.0	2.2	9.6	433.5	72.9	3.0	0.9	14.2	0.1	222.5
166	Aqua	4.0	3.7	34.2	3.5	204.9	10.6	21.1	8.6	1.8	8.5	22.7	11.6	495.9	56.9	2.4	1.0	0.6	0.7	245.6

Sample ID #	Color	La	Ce	Pr	Ta	Au	Y	Bi	U	W	Mo	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Th
GROUP 2: mineral soda glasses similar to the Levantine I group – CONTINUED																								
123	Aqua	5.4	10.7	1.3	0.1	2.7	7.4	0.0	0.9	0.1	0.5	5.2	1.2	0.3	1.0	0.1	0.9	0.2	0.6	0.1	0.5	0.1	1.8	0.8
124	Aqua	5.0	10.7	1.3	0.1	0.0	6.3	0.0	0.9	0.0	0.5	5.0	1.0	0.2	0.9	0.1	0.9	0.2	0.5	0.1	0.5	0.1	1.1	0.8
142	Aqua	4.5	10.2	1.2	0.1	0.0	5.6	0.0	0.6	0.0	0.1	4.5	0.9	0.3	0.8	0.1	0.7	0.2	0.5	0.1	0.4	0.0	0.7	0.6
145	Aqua	6.4	12.9	1.7	0.1	1.0	7.7	0.3	1.5	0.1	0.5	6.4	1.3	0.3	1.3	0.2	1.2	0.2	0.7	0.1	0.6	0.1	1.3	1.5
182	Aqua	5.2	11.6	1.4	0.1	0.0	6.5	0.0	0.9	0.1	0.5	5.2	1.0	0.3	0.9	0.1	0.9	0.2	0.5	0.1	0.4	0.1	0.7	0.6
184	Aqua	5.9	12.2	1.5	0.1	0.0	6.9	0.0	0.8	0.1	0.3	5.7	1.2	0.3	1.1	0.1	1.0	0.2	0.5	0.1	0.5	0.1	1.0	0.8
186	Aq-green	4.8	9.8	1.2	0.1	0.0	5.8	0.0	0.5	0.1	0.2	4.8	1.0	0.3	0.8	0.1	0.8	0.2	0.5	0.1	0.4	0.1	0.9	0.7
236	Aqua	5.8	11.0	1.4	0.1	0.1	7.1	0.1	1.1	0.1	0.5	5.8	1.2	0.3	1.0	0.2	1.0	0.2	0.6	0.1	0.6	0.1	0.9	0.8
AVERAGE		**5.4**	**11.1**	**1.4**	**0.1**	**0.5**	**6.7**	**0.1**	**0.9**	**0.1**	**0.4**	**5.3**	**1.1**	**0.3**	**1.0**	**0.1**	**0.9**	**0.2**	**0.5**	**0.1**	**0.5**	**0.1**	**1.0**	**0.8**
Group 2 outliers																								
139	Aqua	5.9	11.2	1.4	0.2	0.1	7.4	0.1	0.7	0.1	0.8	5.7	1.2	0.3	1.1	0.2	1.0	0.2	0.6	0.1	0.6	0.1	2.0	1.1
175	Aqua	6.3	11.7	1.5	0.1	0.1	8.0	0.1	0.6	0.2	0.7	5.9	1.1	0.3	1.1	0.2	1.0	0.2	0.6	0.1	0.5	0.1	1.2	0.9
220	Aqua	7.2	13.1	1.8	0.2	0.3	8.7	0.3	0.8	0.2	1.1	6.6	1.4	0.4	1.3	0.2	1.3	0.3	0.7	0.1	0.6	0.1	1.8	1.3
166	Aqua	8.3	14.6	2.0	0.3	2.6	10.9	0.3	1.2	0.7	1.1	9.9	3.1	1.1	2.3	0.3	2.9	1.4	1.1	0.5	2.3	0.8	2.5	1.3

Sample ID #	Color	Li	Be	B	Sc	Ti	V	Cr	Ni	Co	Zn	As	Rb	Sr	Zr	Nb	Ag	Sb	Cs	Ba
GROUP 3: mineral soda glasses similar to the Levantine II group																				
116	Aqua	3.1	0.3	81.3	2.5	248.2	11.6	21.1	5.8	4.1	18.0	1.8	7.6	285.7	66.2	2.4	0.3	2.8	0.1	180.2
126	Aqua	3.6	0.4	83.7	2.4	180.9	9.6	56.3	12.4	2.3	11.3	1.6	11.6	304.0	39.6	2.0	0.1	0.6	0.1	200.5
128	Green	3.3	0.4	41.6	2.3	141.9	8.0	16.7	5.1	3.1	11.1	6.6	6.2	293.4	32.5	1.6	0.1	0.3	0.1	165.3
131	Aq-green	3.6	0.4	89.1	2.4	151.6	10.0	127.4	9.4	2.7	11.3	5.2	7.1	317.8	33.3	1.6	0.1	6.7	0.1	177.5
132	Aq-green	3.9	0.4	90.9	2.5	140.3	10.7	128.4	12.8	2.6	11.5	0.6	8.6	293.0	28.5	1.5	0.1	7.7	0.1	169.7
133	Aq-green	3.7	0.4	93.6	2.3	127.3	8.8	95.3	10.0	2.0	8.0	0.1	8.5	306.9	26.7	1.4	0.0	2.5	0.1	175.4
137	Aqua	3.1	0.5	51.3	2.3	128.6	7.6	60.2	7.4	1.5	7.3	1.3	8.6	328.0	32.4	1.5	0.1	0.9	0.1	204.0
193	Yel-green	3.5	0.7	58.1	2.4	181.2	10.8	14.3	5.6	1.7	5.9	3.3	10.1	402.3	33.2	1.8	0.1	0.3	0.1	216.5
194	CL-yellow	3.2	1.0	39.6	2.4	163.2	8.1	65.8	13.3	2.1	11.6	3.5	7.2	397.4	33.4	1.6	0.2	3.0	0.1	202.8
196	Aqua	4.3	1.5	70.8	2.3	174.0	8.9	14.6	14.9	3.9	8.9	5.5	9.9	425.2	33.0	1.7	0.2	0.3	0.1	198.4
AVERAGE		**3.5**	**0.6**	**70.0**	**2.4**	**163.7**	**9.4**	**60.0**	**9.7**	**2.6**	**10.5**	**3.0**	**8.5**	**335.4**	**35.9**	**1.7**	**0.1**	**2.5**	**0.1**	**189.0**

Sample ID #	Color	La	Ce	Pr	Ta	Au	Y	Bi	U	W	Mo	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Th
GROUP 3: mineral soda glasses similar to the Levantine II group – CONTINUED																								
116	Aqua	5.9	11.5	1.5	0.1	1.0	7.0	0.0	1.4	0.0	0.4	5.5	1.1	0.3	1.1	0.1	1.0	0.2	0.6	0.1	0.6	0.1	1.6	1.0
126	Aqua	5.1	12.4	1.4	0.1	2.9	5.8	0.3	0.9	0.1	0.5	4.9	1.0	0.3	0.9	0.1	0.9	0.2	0.4	0.1	0.5	0.1	1.1	0.9
128	Green	4.7	10.3	1.2	0.1	0.0	5.8	0.0	0.5	0.0	0.2	4.5	1.0	0.2	0.8	0.1	0.7	0.2	0.4	0.1	0.4	0.1	0.7	0.6
131	Aq-green	4.9	9.4	1.2	0.1	0.0	6.3	0.0	0.5	0.0	0.5	4.8	0.9	0.3	0.9	0.1	0.9	0.2	0.5	0.1	0.4	0.1	0.8	0.6
132	Aq-green	4.3	9.2	1.1	0.1	0.0	5.5	0.0	0.6	0.1	0.5	4.0	0.9	0.2	0.8	0.1	0.7	0.2	0.4	0.1	0.4	0.0	0.7	0.5
133	Aq-green	4.4	9.9	1.1	0.1	1.0	5.4	0.0	0.6	0.1	0.4	4.3	0.9	0.2	0.8	0.1	0.7	0.1	0.4	0.1	0.4	0.0	0.7	0.6
137	Aqua	5.1	11.0	1.4	0.1	0.3	6.3	0.2	1.0	0.1	0.2	5.3	1.1	0.3	0.9	0.1	0.9	0.2	0.5	0.1	0.5	0.1	0.8	1.4
193	Yel-green	5.6	11.7	1.4	0.1	0.1	6.5	0.0	0.7	0.3	0.7	5.2	1.1	0.4	1.1	0.2	0.9	0.2	0.5	0.1	0.6	0.1	0.8	0.7
194	CL-yellow	5.7	11.4	1.6	0.1	0.4	7.1	0.3	0.7	0.4	0.3	6.1	1.8	0.5	1.8	0.2	1.0	0.2	0.6	0.1	1.2	0.2	0.9	0.9
196	Aqua	5.8	11.7	1.4	0.1	0.0	7.1	0.0	0.6	0.1	0.7	5.3	1.1	0.3	1.2	0.2	1.0	0.2	0.6	0.1	0.5	0.1	0.9	0.8
AVERAGE		**5.2**	**10.9**	**1.3**	**0.1**	**0.6**	**6.3**	**0.1**	**0.8**	**0.1**	**0.4**	**5.0**	**1.1**	**0.3**	**1.0**	**0.1**	**0.9**	**0.2**	**0.5**	**0.1**	**0.5**	**0.1**	**0.9**	**0.8**

Despite these divergent characteristics, the outlier samples still fit comfortably within the chemical groups outlined in the sections below, but a closer look may help to explain their irregularities. The chemical compositions of Nos. 139, 170, 175, 220, and 222 are possibly the result of glass recycling. With the exception of No. 222,[18] all are naturally-aqua (i.e. unintentionally colored) glasses but they contain somewhat higher levels of the elements that are usually associated with coloration, decoloration, and opacifying processes: copper, cobalt, lead, manganese, antimony, silver, and zinc (Freestone 2006: 209), as well as iron and tin (Thilo Rehren, personal communication). This suggests that at some point in time, intentionally colored glass cullet was recycled and incorporated into the remelted batch from which these objects were made.

Although an attempt most certainly would have been made to keep colored and non-colored cullet separate, it would have been difficult to keep decorative elements of colored glass (like trails, blobs, and handles) separate (Freestone *et al.* 2002: 267). Trace levels of the transition metals "have little effect on the color of the [remelted] glass, but are clearly present at concentrations above those encountered in freshly made glass sampled from tank furnaces, or those expected in mature sands" (Freestone 2006: 209).[19] The recycling of intentionally decolorized glasses might also serve to explain the elevated levels of manganese that were observed in all the outlier samples, and the elevated magnesia and potash may further support the suggestion that most of these samples were

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[18] The high iron of No. 222 is likely the result of additives in order to make the darker blue color; copper, cobalt, lead, and manganese levels are also high, which together could indicate recycling—which would not be surprising if the fragment is indeed a bracelet.

[19] An excellent example of this is a comparison of No. 121 with No. 170. Both fragments fall within the same chemical group (Group 1, similar to Egypt II glasses) and both have elevated copper, cobalt, and lead levels; however, No. 121 is intentionally colored blue by additives while No. 170 is naturally aqua in color, which explains why No. 121 has higher levels of these elements while No. 170 has lower (but still significant) levels of these elements.

recycled.[20] No. 237 may simply be a unique glass type rather than made from recycled glass like the other outlier samples, as it does not share in an association with elevated transition metals. This fragment was found in topsoil contexts, and is distinct because it is one of the few fragments that is brown-yellow in color (although the other examples were made using plant ash soda); it has the lowest alumina (1.7 wt%) and iron levels (0.2 wt%), as well as the highest magnesia level (2.3 wt%) of the mineral soda glasses.

The levels of magnesia and potash for the Ḥiṣn al-Tīnāt mineral soda samples are both below 1.5 wt% because mineral soda is a relatively pure alkali source when compared to plant ash soda; this purity makes it difficult to differentiate production groups or zones that used mineral soda based on the soda itself. Thus, it is the characteristics of the sand[21] that was used in combination with the soda during production that may distinguish between primary production groups. Lime and alumina are two important components of the sand source and are excellent initial discriminators for the five commonly occurring primary production groups (Levantine I, Levantine II, Egyptian I, Egyptian II, and HIMT);[22] these are shown together with the Ḥiṣn al-Tīnāt mineral soda samples in the bivariate plot in Figure 4.16.

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[20] Dussart *et al.* suggest the following explanation: "a contemporary glassblower has informed us that in order to reuse cullet for glassblowing, it is *usually necessary to add alkali to the composition*. This could be because the old glass is often too rich in alumina as the result of contamination from refractory fusion pots, which increases the viscosity of when it is being worked" (2004: 81; my italic emphasis). However, the uptake of alumina during the recycling process is actually quite low, and if a flux were indeed added it would be soda (Thilo Rehren, personal communication); fuel ash contamination during recycling may perhaps better explain the increased levels of magnesia and potash in some recycled glasses (Paynter 2008 and Rehren *et al.* 2010).

[21] Or more precisely, the characteristics of the impurities in the sand (Freestone *et al.* 2002: 265), i.e., calcium carbonate and feldspar minerals (Freestone 2006: 208).

[22] These groups were introduced in Chapter 2 (pages 33ff).

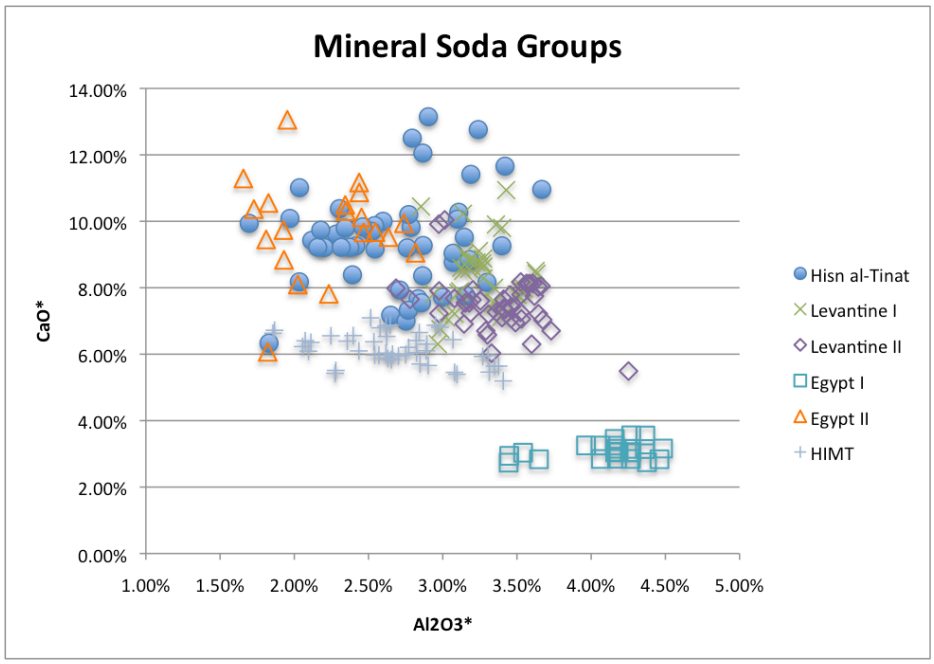

Figure 4.16: Scatter plot of the lime and alumina contents of the Ḥiṣn al-Tīnāt samples and the five mineral soda primary production groups currently known (chart based on Freestone 2006: 208; data from Freestone, personal communication).

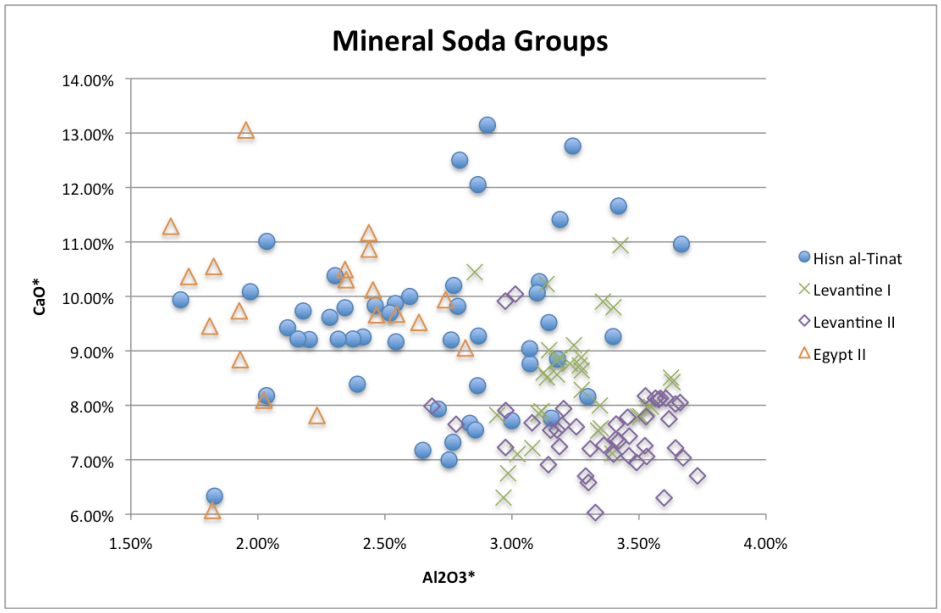

Figure 4.17: Detailed view of the lime and alumina scatter plot shown in Figure 4.16, with the Egyptian I and HIMT groups removed (chart based on Freestone 2006: 208; data from Freestone, personal communication).

As can clearly be seen, none of the Ḥiṣn al-Tīnāt samples fall within the bounds of the Egyptian I (Wadi Natrūn) technological group. One sample (No. 215, a small pushed-in bottle base with a high kick, made of light green glass) is close to points from both the HIMT and Egyptian II groups because of its low alumina and lime contents; however it does not have the high levels of iron, magnesium, manganese, and titanium that defines the HIMT group, which thus makes the affiliation with the Egyptian II group more likely. The Ḥiṣn al-Tīnāt glasses seem largely unrelated to the Egyptian I and HIMT primary production groups, so these groups will not be included in further discussions and presentations of the data (Figure 4.17).

The Ḥiṣn al-Tīnāt mineral soda glasses fall within the known bounds of the Egyptian II, Levantine I, and Levantine II groups but also serve to expand the range of compositions acceptable for these groups. There is some overlap between production groups and the distinction between the two Levantine groups is particularly fuzzy; although trace element data further supports the division of the Ḥiṣn al-Tīnāt glasses between primary production zones in Egypt and the Levant, they do not as easily help to discriminate between the Levantine I and II groups because both relied on the same coastal sand sources and thus have very similar compositional profiles (Freestone *et al.* 2000: 73). However, the Levantine I and II groups can still be differentiated, as the latter has lower lime and soda as well as higher silica, and there are slight differences in the trace element compositions which probably reflect the use of sands from different parts of the Palestinian coast. The Ḥiṣn al-Tīnāt mineral soda glasses can therefore be divided into three groups: Group 1 are those glasses similar to Egyptian II glasses, Group 2 are those similar to Levantine I glasses, and Group 3 are similar to Levantine II glasses.

These groups are shown together in Figures 4.18 and 4.19; in order to clearly summarize the main characteristics and differences of each group, their average major/minor oxide and trace element compositions are given in Tables 4.3 and 4.4.

Group 1 (similar to Egyptian II glasses)

The major, minor, and trace element concentrations of 27 Ḥiṣn al-Tīnāt samples fit within the Egyptian II production group, and are defined here as Group 1. Overall, this group has relatively low silica, potash, and alumina as well as high soda, lime, and iron. The Egyptian II production group is particularly distinctive in terms of its trace elements, having high zirconium (80-300 ppm Zr), high titanium (300-1100 ppm Ti), and low strontium (40-300 ppm Sr); these characteristics are likely a reflection of the presence of limestone in the sand rather than shell, which makes sense because strontium isotope analysis has shown that Egyptian II glasses were made using inland sand rather than beach sand (Freestone *et al.* 2000: 73; Freestone *et al.* 2003; Freestone 2006: 209).[23]

Group 1 includes three of the six outlier samples noted above, specifically those with the highest magnesia and potash levels (**Nos. 170, 222,** and **237**). Nos. 170 and 237 fit well overall within this group in terms of major, minor, and trace elements when the possibility of recycling is taken into consideration (see above discussion). The third

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[23] The different strontium levels can be explained as follows: inland sands "contain calcium carbonate derived from limestone rather than marine shell and therefore have a lower strontium level" while beach sands contain fresh shell; "shell is typically made of the CaCO3 polymorph aragonite, which has a much higher capacity to incorporate strontium than calcite" (Freestone *et al.* 2000: 73). The zirconium levels are also connected to the heavy mineral assemblages of inland versus coastal sands.

It is also telling that the identification of the Egyptian II production group is based on samples analyzed from a primary production facility at Tell el-Ashmunein, which is located in Middle Egypt rather that in the Delta area.

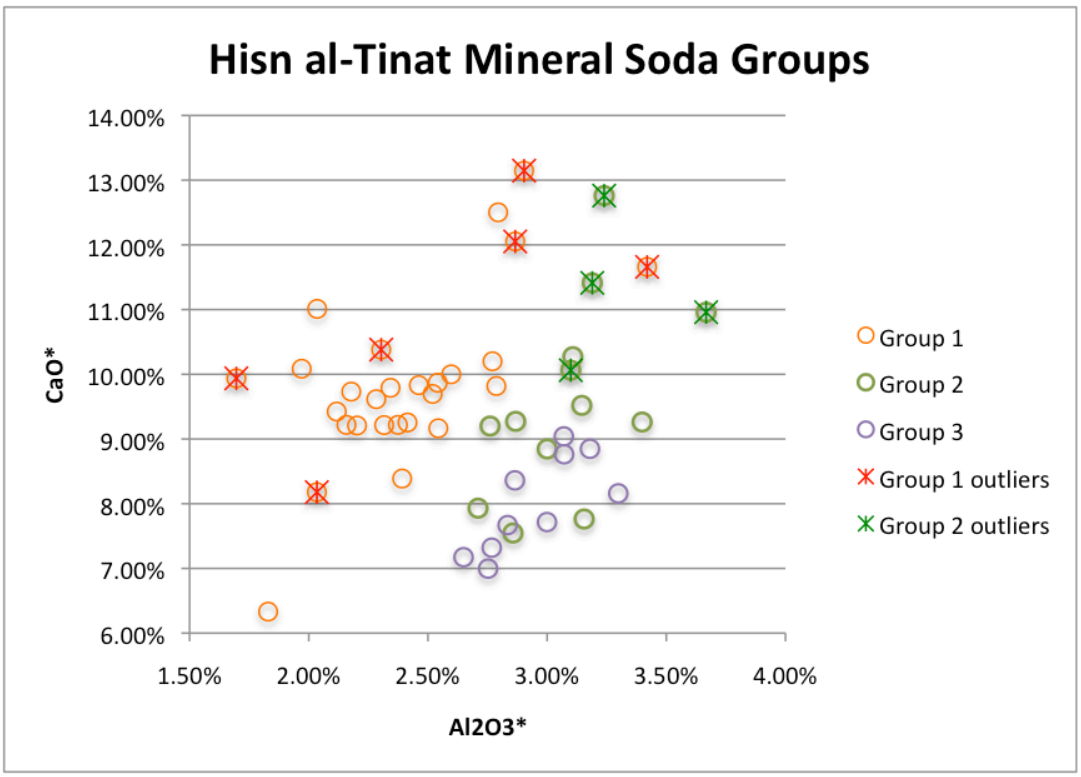


Figure 4.18: Lime and alumina scatter plot of the Ḥiṣn al-Tīnāt mineral soda glasses: Groups 1-3.

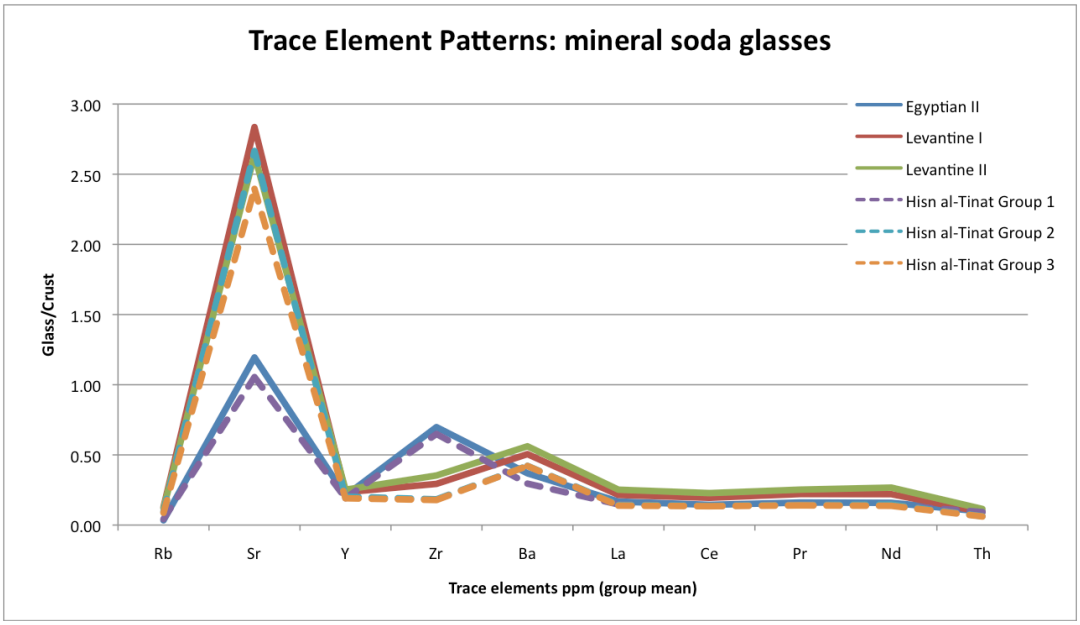


Figure 4.19: Trace elements patterns of the Ḥiṣn al-Tīnāt mineral soda groups, compared to three production groups (Freestone *et al.* 2000: 79; Egyptian II data from Freestone, personal communication), normalized to the mean crustal abundances (Kamber *et al.* 2005). Note that the dotted line of Group 2 lies almost immediately below the dotted line of Group 3.

Oxide (wt%)	SiO2	Na2O	K2O	CaO	MgO	Al2O3	Fe2O3	TiO2	MnO	P2O3	CuO	CoO	PbO2	Sb2O5	SnO2
Group 1 (n=27)	**70.67**	**14.86**	**0.29**	**9.51**	**0.54**	**2.34**	**0.88**	**0.09**	**0.17**	**0.08**	**0.01**	**0.01**	**0.00**	**0.00**	**0.00**
range	68.10-73.16	13.05-16.73	0.18-0.48	6.29-12.40	0.38-0.76	1.82-2.77	0.68-1.52	0.06-0.14	0.02-1.62	0.04-0.12	0.00-0.23	0.00-0.15	0.00-0.02	-	0.00-0.01
σ	1.54	1.02	0.09	1.10	0.10	0.26	0.17	0.02	0.42	0.02	0.05	0.03	0.01	0.00	0.00
Group 2 (n=12)	**71.22**	**14.80**	**0.55**	**8.79**	**0.59**	**2.98**	**0.46**	**0.03**	**0.03**	**0.10**	**0.01**	**0.00**	**0.00**	**0.00**	**0.00**
range	70.56-72.69	13.65-16.86	0.48-0.61	7.50-10.22	0.43-0.74	2.70-3.38	0.35-0.57	0.02-0.04	0.02-0.07	0.07-0.13	0.00-0.07	-	0.00-0.01	-	-
σ	0.77	1.07	0.05	0.97	0.11	0.24	0.09	0.01	0.01	0.02	0.02	0.00	0.00	0.00	0.00
Group 3 (n=10)	**73.85**	**13.13**	**0.51**	**7.96**	**0.55**	**2.93**	**0.45**	**0.03**	**0.03**	**0.09**	**0.00**	**0.00**	**0.01**	**0.00**	**0.00**
range	72.78-74.96	11.97-14.30	0.34-0.67	6.94-9.00	0.46-0.75	2.63-3.28	0.38-0.55	0.02-0.04	0.02-0.06	0.07-0.13	0.00-0.01	-	0.00-0.02	-	-
σ	0.72	0.72	0.09	0.74	0.10	0.21	0.06	0.01	0.01	0.02	0.00	0.00	0.01	0.00	0.00

Table 4.3: Average major/minor oxide composition of the Ḥiṣn al-Tīnāt mineral soda glasses (σ = standard deviation).

Trace elements (ppm)	Li	Be	B	Sc	Ti	V	Cr	Ni	Co	Zn	As	Rb	Sr
Group 1	**4.0**	**0.6**	**89.9**	**3.3**	**542.0**	**18.7**	**26.1**	**7.9**	**6.3**	**31.1**	**4.2**	**4.2**	**147.6**
σ	0.9	0.1	25.9	0.3	110.0	2.9	6.4	3.1	250.1	529.2	4.3	0.9	28.9
Group 2	**3.9**	**0.5**	**63.7**	**2.3**	**198.9**	**9.4**	**60.0**	**9.8**	**2.6**	**13.6**	**3.3**	**9.3**	**373.2**
σ	0.9	0.1	14.6	0.3	50.0	1.9	63.0	5.2	1.0	10.9	1.2	1.6	58.9
Group 3	**3.5**	**0.6**	**70.0**	**2.4**	**163.7**	**9.4**	**60.0**	**9.7**	**2.6**	**10.5**	**3.0**	**8.5**	**335.4**
σ	0.4	0.4	20.8	0.1	35.9	1.3	44.8	3.6	0.9	3.3	2.2	1.6	52.3

Trace elements (ppm)	Zr	Nb	Ag	Sb	Cs	Ba	La	Ce	Pr	Ta	Au	Y	Bi	U
Group 1	**130.5**	**3.9**	**0.3**	**0.5**	**0.1**	**132.6**	**5.5**	**11.1**	**1.4**	**0.2**	**0.3**	**6.3**	**0.0**	**0.9**
σ	33.1	0.4	0.4	20.8	0.1	35.9	1.3	44.8	3.6	0.9	3.3	2.2	1.6	52.3
Group 2	**36.9**	**1.8**	**0.1**	**1.1**	**0.1**	**189.4**	**5.4**	**11.1**	**1.4**	**0.1**	**0.5**	**6.7**	**0.1**	**0.9**
σ	7.5	0.3	0.2	1.2	0.1	25.1	0.6	1.0	0.1	0.0	1.0	0.7	0.1	0.3
Group 3	**35.9**	**1.7**	**0.1**	**2.5**	**0.1**	**189.0**	**5.2**	**10.9**	**1.3**	**0.1**	**0.6**	**6.3**	**0.1**	**0.8**
σ	11.2	0.3	0.1	2.7	0.0	17.4	0.6	1.1	0.2	0.0	0.9	0.6	0.1	0.3

Trace elements (ppm)	W	Mo	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Th
Group 1	**0.1**	**0.2**	**5.2**	**1.1**	**0.2**	**1.0**	**0.1**	**0.9**	**0.2**	**0.5**	**0.1**	**0.6**	**0.1**	**2.9**	**1.2**
σ	11.2	0.2	0.5	0.2	0.1	0.1	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.7	0.3
Group 2	**0.1**	**0.4**	**5.3**	**1.1**	**0.3**	**1.0**	**0.1**	**0.9**	**0.2**	**0.5**	**0.1**	**0.5**	**0.1**	**1.0**	**0.8**
σ	0.0	0.2	0.6	0.1	0.0	0.2	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.3	0.3
Group 3	**0.1**	**0.4**	**5.0**	**1.1**	**0.3**	**1.0**	**0.1**	**0.9**	**0.2**	**0.5**	**0.1**	**0.5**	**0.1**	**0.9**	**0.8**
σ	0.1	0.2	0.6	0.3	0.1	0.3	0.0	0.1	0.0	0.1	0.0	0.2	0.0	0.3	0.3

Tables 4.4: Average trace element composition of the Ḥiṣn al-Tīnāt mineral soda glasses.

outlier, No. 222, is more problematic. Because its lime, iron, and alumina contents are similar to Egyptian II glasses, it is possible that this fragment belongs to this group and is recycled; however, No. 222 is comparatively much lower in titanium and zirconium than the rest of Group 1. In addition, No. 222 has elevated lithium, arsenic, rubidium, strontium, uranium, and molybdenum as well as lower hafnium. Perhaps most significant of all is No. 222's very high level of boron (571.3 ppm compared to the 86.7 ppm average of Group 1); this is a unique characteristic not typically found in 1st millennium CE glasses of the Near East—high boron glasses will be discussed in more detail in

Chapter 5, which discusses the bracelets found at Ḥiṣn al-Tīnāt (all of which were produced using plant ash soda, and many of which have high levels of boron).

In addition to these initially-recognized outliers, three more outlier samples (**Nos. 154, 176,** and **180**) were identified in part by their higher lime and slightly higher alumina levels, but especially because of their distinct trace element characteristics; No. 176 may be recycled, as it too has higher traces of transition metals and somewhat higher levels of potash, magnesia, and manganese but it also has higher traces of rubidium and strontium. Nos. 154 and 180 are quite similar to the other members of Group 1 although they have higher strontium and zirconium levels in addition to their slightly higher lime and alumina. Nos. 120 and 125 also have higher alumina and lime, but their trace elements are more similar to the rest of Group 1.

The samples are predominantly aqua in color due to a high natural iron content. **No. 121** is a darker blue color because it has high iron (1.5 wt%), and it also has small traces of copper, cobalt, lead, tin, zinc, silver, and antimony that are suggestive of recycling. Several of the naturally-aqua fragments have a slightly greenish hue (**Nos. 129, 138, 176,** and **214**). No. 214 has trace amounts of cobalt, while Nos. 138 and 176 have trace amounts of cobalt, silver, and antimony; this is again indicative of glass recycling. More strongly green colors could be achieved by controlling the furnace atmosphere to alter the effects of the iron content in the glass (**Nos. 206, 215,** and **221**) or by having slightly higher iron (1.1 wt% Fe_2O_3) as well as some added manganese (**No. 209**). Fragment **No. 135** is decorated with purple glass blobs colored by manganese (1.6 wt%) but trace levels of zinc were detected as well.

Group 2 (similar to Levantine I glasses)

The major, minor, and trace element concentrations of 12 Ḥiṣn al-Tīnāt samples fit within the Levantine I production group, and are defined here as Group 2. Overall, this group has relatively low silica as well as high soda and lime when compared to the Levantine II production group; in this sense it is somewhat akin to the Egyptian II production group, although Levantine I glass has higher potash and alumina as well as lower iron, titanium, and manganese than the Egyptian II group.

Group 2 includes three of the six outlier samples noted above, specifically those samples with higher (but not the highest) magnesia and potash levels (**Nos. 139, 175,** and **220**). These outliers also have higher lime and iron levels, and in terms of trace elements they have higher titanium and zirconium as well as slightly higher levels of lithium, vanadium, and molybdenum. All three outliers have slightly elevated levels of manganese, copper, cobalt, and zinc. Nos. 139 and 220 also have noticeable amounts of lead, tin, and antimony; these elevated levels of transition metals, combined with elevated manganese levels and the aqua color of the glasses, again point to the possibility that these are the result of recycling. No. 175 may not necessarily be recycled; it has more cobalt and zinc as well as less manganese and copper than the other two outliers, and in addition the silver and antimony are levels are not elevated. Another outlier possibly related to Group 2 is No. 166. Although the major and minor oxides are in close agreement with the other Group 2 samples, No. 166 has lower silica and higher lime and alumina like the other outliers, although it is very different in terms of its trace element composition.

All samples of Group 2 are aqua in color, which is due to the natural iron content. **Nos. 145** has slight traces of copper and lead, probably due to recycling. **No. 186** is the only sample in this group that is a bit greener than the others, which is probably due to the furnace atmosphere rather than the addition of colorants to the glass batch. **No. 236** may be recycled because it has slightly elevated levels of manganese, copper, lead, zinc, silver, and antimony.

Group 3 (similar to Levantine II glasses)

The major, minor, and trace element concentrations of 10 Ḥiṣn al-Tīnāt samples fit within the Levantine II group—however, this association is borderline, and the Group 3 samples could very well be placed within Group 2 instead.[24] Levantine II glasses are characterized as having higher silica, as well as lower lime, soda, and alumina than the Levantine I production group; the 10 samples in this group do meet these guidelines—but only just. For example, Levantine II glasses typically have more than 3 wt% Al_2O_3 and less than 8 wt% CaO, and the Ḥiṣn al-Tīnāt Group 3 averages 2.93 wt% Al_2O_3 and 7.96 wt% CaO.

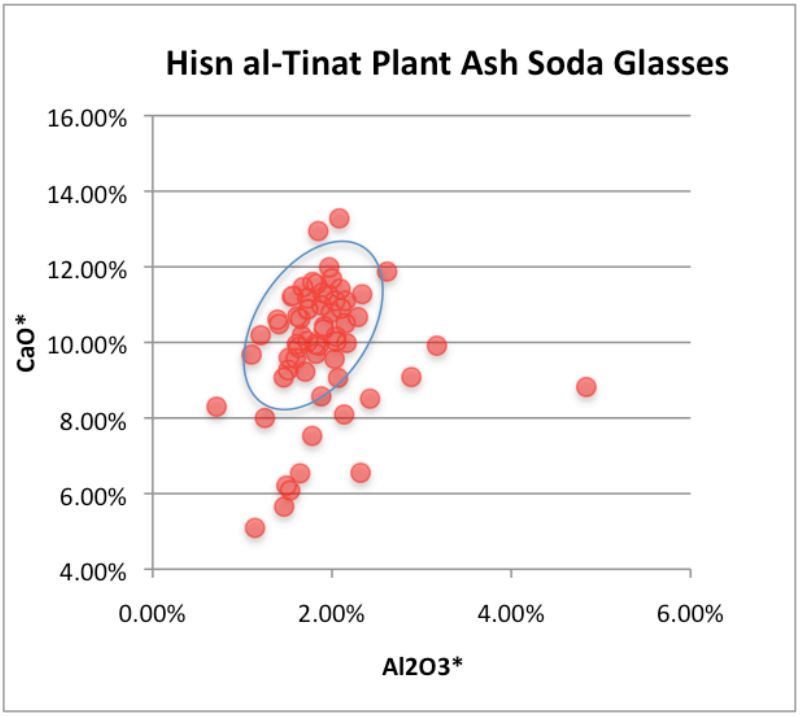
There are no obvious outliers in this group, and none of the samples are obviously recycled. The samples of Group 3 are somewhat more variable in color hue, although they are almost all shades of blue-green. Many are aqua in color, again due to their natural iron content. Green and greenish hues are produced in the same way as for the glasses of Groups 1 and 2; green **No. 128**, yellow-green **No. 193**, and colorless-yellow

[24] The chemical groupings and associations made in this dissertation should be considered *preliminary*, as revisions may be made before the data and interpretations are published. Group 3 is just such a group that will be considered in more depth after this dissertation has been submitted.

No. 194 are probably all due to controlling the furnace atmosphere to affect the natural iron content; aqua-green **Nos. 131** and **132** have slightly elevated copper, lead, and antimony while the aqua-green color of **No. 133** again is most likely due to controlling the furnace atmosphere. **No. 116** has very slightly elevated levels of manganese, lead, silver, and antimony.

Plant ash glasses

The Ḥiṣn al-Tīnāt samples include 64 fragments that were made using plant ash soda and a more pure form of silica (quartz pebbles, chert, and/or low-alumina sand); the plant ash soda glasses are easily identified by their high magnesia and potash contents, which are both over 1.5 wt%, and also by their elevated phosphorus levels. The results for the major/minor elements are presented in Table 4.5 and for trace elements in Table 4.6. Looking at graphical representations of the seven major and minor oxides (for example, Figure 4.20), it is apparent that there is a core cluster of glasses with similar chemical characteristics, as well as a diverse group of outliers that are markedly different from this core cluster (in particular having lower lime, higher or lower magnesia, and various phosphorus levels). Unfortunately, unlike the mineral soda glasses, there are no previously identified primary production groups with which to compare the chemistry of the Ḥiṣn al-Tīnāt plant ash soda glasses. Patterns within the assemblage are therefore first considered here and then compared in Chapter 7 with the patterns of plant ash soda glasses from eight other sites in the Eastern Mediterranean.



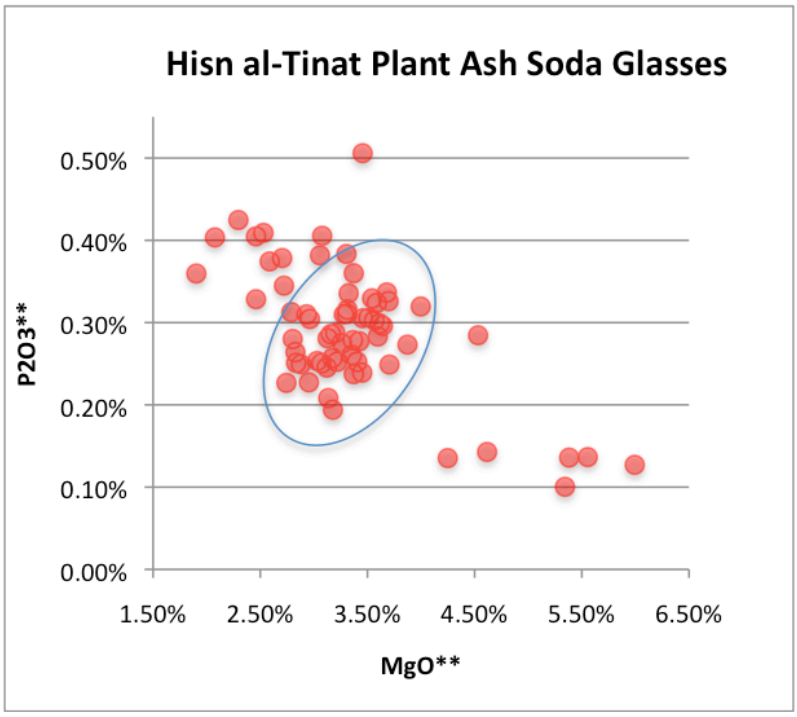


Figure 4.20: Two examples of bivariate scatter plots of the seven major and minor oxides, showing Al_2O_3 and CaO, MgO and P_2O_3, with the core clusters circled in blue.

Table 4.5: <u>HIṢN AL-TĪNĀT PLANT ASH SODA GLASSES</u>: chemical results (major and minor oxides, and colorants/decolorants) given in wt% oxide.

Sample #	Color	SiO2	Na2O	K2O	CaO	MgO	Al2O3	Fe2O3	TiO2	MnO	P2O3	CuO	CoO	PbO2	Sb2O5	SnO2
GROUP 4: plant ash soda glasses with a strong Ti-Zr correlation																
151	Aqua?	68.03	11.09	2.59	11.42	2.04	1.95	0.58	0.05	1.38	0.40	0.00	0.00	0.00	0.00	0.00
155	Purple	69.92	11.75	2.08	9.81	3.14	1.59	0.32	0.04	0.79	0.19	0.00	0.00	0.00	0.00	0.00
158	Aqua	68.43	13.04	2.29	9.54	2.75	1.79	0.53	0.05	0.83	0.31	0.02	0.00	0.03	0.00	0.00
159	Yellow	66.09	12.67	2.54	10.64	2.87	2.05	0.78	0.03	1.62	0.30	0.01	0.00	0.00	0.00	0.00
160	Aqua	66.59	12.24	2.51	11.05	3.26	1.92	0.58	0.03	1.10	0.31	0.01	0.00	0.01	0.00	0.00
161	Colorless?	66.70	12.21	2.44	10.84	2.90	1.99	0.55	0.05	1.63	0.30	0.01	0.00	0.00	0.00	0.00
162	Colorless?	66.38	12.61	2.48	10.51	2.99	1.94	0.57	0.05	1.74	0.37	0.01	0.00	0.00	0.00	0.00
172	Aqua?	71.34	11.72	1.90	9.16	2.85	1.49	0.30	0.03	0.57	0.25	0.00	0.00	0.00	0.00	0.00
173	Aqua?	68.85	13.72	1.83	9.44	2.80	1.58	0.38	0.04	0.73	0.26	0.00	0.00	0.00	0.00	0.00
177	Aqua	67.42	13.00	2.58	9.98	2.76	2.01	0.51	0.04	1.04	0.28	0.01	0.00	0.00	0.00	0.00
187	Colorless-Y?	67.49	10.95	2.68	11.72	2.48	1.93	0.55	0.05	1.32	0.40	0.01	0.00	0.00	0.00	0.00
189	Colorless?	69.54	11.57	2.65	9.66	2.42	1.59	0.48	0.04	1.23	0.40	0.01	0.00	0.00	0.00	0.00
190	Yellow	66.08	12.57	2.60	10.85	2.97	2.11	0.53	0.04	1.73	0.25	0.01	0.00	0.00	0.00	0.00
197	Colorless	67.10	12.32	2.77	10.72	3.67	1.71	0.37	0.03	0.76	0.25	0.00	0.00	0.00	0.00	0.00
203	Colorless-Y	67.07	12.25	2.21	10.52	3.83	2.26	0.46	0.04	0.81	0.27	0.00	0.00	0.00	0.00	0.00
208	Purple	66.28	11.74	2.39	11.03	3.61	2.29	0.47	0.03	1.58	0.33	0.01	0.00	0.00	0.00	0.00
210	Colorless	69.14	11.75	2.26	10.21	3.09	1.88	0.36	0.03	0.71	0.24	0.00	0.00	0.00	0.00	0.00
212	Blue	66.47	12.45	2.78	11.22	3.68	1.88	0.73	0.03	0.07	0.32	0.03	0.01	0.00	0.00	0.00
216	Aqua	66.99	13.18	2.30	10.72	3.18	1.71	0.47	0.04	0.75	0.25	0.01	0.00	0.01	0.00	0.00
218	Blue?	68.74	11.55	2.37	9.27	2.39	1.97	0.65	0.05	1.35	0.32	0.75	0.00	0.08	0.00	0.04
219	Colorless	69.02	12.65	2.03	9.91	3.10	1.71	0.38	0.04	0.53	0.21	0.02	0.00	0.00	0.00	0.00
223	Colorless?	69.37	12.28	2.88	8.86	1.87	2.02	0.53	0.04	1.29	0.35	0.00	0.00	0.00	0.00	0.00
226	Colorless	66.32	13.37	2.31	10.97	3.12	1.70	0.43	0.04	1.10	0.25	0.01	0.00	0.00	0.00	0.00
227	Light green	66.14	15.50	2.39	9.07	3.08	1.67	0.47	0.04	0.86	0.28	0.00	0.00	0.00	0.00	0.00
228	Aqua	67.75	13.85	2.05	10.35	2.73	1.90	0.60	0.03	0.08	0.23	0.01	0.01	0.00	0.00	0.00
231	Colorless/purple?	65.59	12.63	2.36	9.53	2.48	2.06	0.75	0.06	1.24	0.36	2.25	0.00	0.16	0.01	0.05
233	Colorless/purple?	69.38	12.43	2.34	8.37	2.65	1.84	0.64	0.05	1.19	0.37	0.07	0.00	0.20	0.00	0.00
239	Light blue	68.19	13.01	2.45	10.55	2.82	1.64	0.66	0.04	0.03	0.25	0.01	0.01	0.00	0.00	0.00
240	Colorless	68.03	12.37	2.17	10.82	2.92	1.86	0.39	0.03	0.77	0.22	0.01	0.00	0.00	0.00	0.00

Sample #	Color	SiO2	Na2O	K2O	CaO	MgO	Al2O3	Fe2O3	TiO2	MnO	P2O3	CuO	CoO	PbO2	Sb2O5	SnO2
244	Aqua	68.57	12.34	2.25	10.38	2.70	2.12	0.45	0.04	0.47	0.34	0.00	0.00	0.00	0.00	0.00
245	Light aqua	67.08	13.19	2.50	9.84	3.21	2.01	0.49	0.04	0.95	0.27	0.00	0.00	0.00	0.00	0.00
AVERAGE		**67.74**	**12.52**	**2.39**	**10.22**	**2.92**	**1.88**	**0.51**	**0.04**	**0.98**	**0.29**	**0.11**	**0.00**	**0.02**	**0.00**	**0.00**

Sample #	Color	SiO2	Na2O	K2O	CaO	MgO	Al2O3	Fe2O3	TiO2	MnO	P2O3	CuO	CoO	PbO2	Sb2O5	SnO2
GROUP 5: plant ash soda glasses																
148	Aqua	66.41	13.75	2.28	10.53	3.32	1.59	0.63	0.05	0.80	0.28	0.01	0.00	0.02	0.00	0.00
157	Colorless	67.80	13.94	2.29	9.55	3.55	1.09	0.43	0.04	0.58	0.32	0.00	0.00	0.00	0.00	0.00
165	Blue?	68.26	12.72	1.99	9.77	3.02	1.78	0.61	0.05	0.72	0.25	0.11	0.00	0.30	0.00	0.04
168	Aqua	64.94	14.19	2.15	11.27	3.55	1.65	0.58	0.05	0.99	0.28	0.02	0.00	0.02	0.00	0.00
169	Aqua	65.92	13.70	2.19	11.05	3.57	1.53	0.58	0.05	0.74	0.30	0.02	0.00	0.02	0.00	0.00
171	Aqua	68.08	12.82	2.11	10.04	3.39	1.64	0.52	0.04	0.72	0.27	0.01	0.00	0.01	0.00	0.00
199	Aqua	65.00	12.65	2.06	12.70	3.11	1.81	0.73	0.04	1.33	0.28	0.02	0.00	0.02	0.00	0.00
202	Aqua	67.33	14.82	2.23	8.94	3.34	1.44	0.48	0.03	0.67	0.36	0.01	0.00	0.01	0.00	0.00
205	Aqua-blue	66.75	14.27	2.13	9.78	3.29	1.83	0.57	0.04	0.65	0.33	0.03	0.01	0.01	0.00	0.00
207	Aqua	67.52	14.15	2.19	9.46	3.28	1.50	0.47	0.04	0.75	0.31	0.01	0.00	0.01	0.00	0.00
213	Blue	65.88	14.90	2.27	10.02	3.26	1.19	0.82	0.03	0.80	0.38	0.08	0.04	0.02	0.00	0.00
230	Green	64.12	13.22	2.24	11.11	3.09	1.76	0.68	0.05	3.04	0.28	0.02	0.00	0.03	0.00	0.00
232	Aqua	65.14	11.98	2.26	13.08	3.33	2.05	0.63	0.05	0.92	0.23	0.01	0.00	0.02	0.00	0.00
234	Green	66.51	12.27	2.38	11.24	3.36	2.06	0.58	0.05	0.98	0.25	0.01	0.00	0.02	0.00	0.00
241	Light blue	66.06	12.73	2.33	11.41	3.40	1.76	0.66	0.05	1.01	0.24	0.03	0.01	0.03	0.00	0.00
AVERAGE		**66.38**	**13.47**	**2.21**	**10.66**	**3.32**	**1.64**	**0.60**	**0.04**	**0.98**	**0.29**	**0.03**	**0.00**	**0.04**	**0.00**	**0.01**

Sample #	Color	SiO2	Na2O	K2O	CaO	MgO	Al2O3	Fe2O3	TiO2	MnO	P2O3	CuO	CoO	PbO2	Sb2O5	SnO2
OUTLIERS: plant ash soda glasses																
117	Colorless	66.56	13.23	2.46	10.42	3.59	1.37	0.59	0.03	0.92	0.29	0.00	0.00	0.00	0.00	0.00
119	Colorless?	67.08	13.21	2.54	10.31	3.41	1.39	0.43	0.03	0.81	0.30	0.00	0.00	0.00	0.00	0.00
144	Aqua	71.29	13.51	1.80	8.23	3.33	0.71	0.25	0.02	0.02	0.26	0.00	0.00	0.00	0.00	0.00
149	Aqua	67.73	10.92	2.10	11.65	2.26	2.57	0.92	0.08	0.95	0.42	0.00	0.00	0.00	0.00	0.00
156	Blue	68.14	12.11	2.70	7.89	5.27	1.23	1.23	0.03	0.61	0.10	0.17	0.05	0.08	0.00	0.01
164	Aqua?	66.28	16.76	2.70	5.00	5.89	1.12	0.38	0.07	1.22	0.12	0.00	0.00	0.00	0.00	0.00

Sample #	Color	SiO2	Na2O	K2O	CaO	MgO	Al2O3	Fe2O3	TiO2	MnO	P2O3	CuO	CoO	PbO2	Sb2O5	SnO2
178	Blue	63.05	15.05	2.93	8.32	4.45	2.37	1.64	0.08	0.97	0.28	0.18	0.18	0.04	0.00	0.00
179	Green	66.80	15.30	2.52	6.08	5.28	1.46	0.45	0.04	1.57	0.13	0.00	0.00	0.00	0.00	0.00
181	Aqua	66.50	15.02	2.04	7.98	4.19	2.10	0.71	0.06	1.02	0.13	0.01	0.00	0.01	0.00	0.00
183	Colorless?	68.24	14.58	2.35	5.55	5.46	1.44	0.50	0.04	1.38	0.13	0.01	0.00	0.00	0.00	0.00
185	Aqua	67.12	14.95	1.92	7.41	4.55	1.75	0.69	0.06	1.04	0.14	0.01	0.00	0.01	0.00	0.00
195	Aqua	65.13	14.51	2.65	8.94	3.52	2.84	0.88	0.07	0.87	0.30	0.03	0.01	0.03	0.00	0.00
211	Dark blue	69.12	12.07	1.67	6.42	3.45	2.27	3.00	0.06	0.62	0.30	0.59	0.19	0.02	0.00	0.00
224	Y-amber	67.97	15.60	2.75	6.01	3.43	1.52	1.56	0.05	0.10	0.50	0.00	0.00	0.02	0.00	0.00
225	Blue, white	62.34	15.31	1.85	8.73	3.97	4.79	2.02	0.14	0.07	0.32	0.00	0.00	0.02	0.00	0.04
229	Colorless/purple?	65.43	13.81	2.23	11.01	3.22	1.53	0.70	0.05	1.30	0.30	0.01	0.00	0.01	0.00	0.00
238	Brown-Y	66.89	17.31	2.07	6.47	3.06	1.63	1.50	0.08	0.05	0.40	0.00	0.00	0.01	0.00	0.00
242	Green	62.95	14.73	2.77	9.69	3.48	3.10	1.06	0.09	1.45	0.32	0.03	0.00	0.02	0.00	0.01
AVERAGE		**66.59**	**14.33**	**2.34**	**8.12**	**3.99**	**1.95**	**1.03**	**0.06**	**0.83**	**0.26**	**0.06**	**0.02**	**0.02**	**0.00**	**0.00**

Table 4.6: <u>ḤIṢN AL-TĪNĀT PLANT ASH SODA GLASSES</u>: chemical results (trace elements) given in ppm

Sample #	Color	Li	Be	B	Sc	Ti	V	Cr	Ni	Co	Zn	As	Rb	Sr	Zr	Nb	Ag	Sb	Cs	Ba
GROUP 4: plant ash soda glasses with a strong Ti-Zr correlation																				
151	Aqua?	6.5	0.6	55.3	2.4	315.1	15.3	19.3	15.7	5.1	31.9	3.7	13.6	923.0	40.4	2.3	0.2	0.3	0.1	426.7
155	Purple	4.8	0.6	62.5	2.1	213.3	9.3	10.5	7.0	2.0	28.5	1.3	20.6	714.3	39.5	2.0	0.1	0.1	0.2	247.3
158	Aqua	6.1	0.6	88.3	2.3	277.6	12.4	14.6	9.9	5.4	30.3	14.0	13.9	453.7	33.9	1.9	0.2	3.7	0.1	188.1
159	Yellow	54.0	0.9	301.7	2.9	193.6	17.9	22.2	17.4	4.5	27.0	3.0	29.6	615.8	37.0	2.6	0.1	5.1	6.4	241.0
160	Aqua	9.9	0.6	84.2	2.5	180.9	14.3	18.4	11.3	5.7	37.6	2.0	20.5	544.6	41.5	2.2	0.1	1.3	0.5	243.8
161	Colorless?	5.1	0.6	68.8	2.9	293.9	16.4	16.1	10.0	4.1	27.0	3.4	20.3	487.7	38.3	2.2	0.1	0.2	0.2	245.6
162	Colorless?	5.6	0.6	69.8	2.9	293.7	19.1	16.2	14.9	6.1	35.3	3.5	20.9	479.3	35.4	2.2	0.1	0.3	0.2	246.1
172	Aqua?	5.3	0.5	82.7	2.0	182.3	8.0	10.5	5.9	1.9	26.9	7.0	16.4	530.2	27.0	1.4	0.1	0.2	0.2	192.4
173	Aqua?	5.7	0.4	75.1	2.1	227.7	9.5	11.2	6.3	2.5	22.4	7.1	15.5	468.1	29.3	1.6	0.1	0.2	0.2	192.7
177	Aqua	5.3	0.6	61.8	2.3	257.0	14.1	16.9	8.6	3.2	27.0	0.8	21.5	488.7	34.8	2.1	0.1	0.3	0.2	224.8
187	Colorless-Y?	6.1	0.5	70.0	2.7	317.8	14.3	14.4	8.9	4.7	30.4	4.0	14.1	749.3	38.6	2.2	0.1	0.2	0.1	265.2
189	Colorless?	6.3	0.4	77.5	2.3	255.0	13.6	13.0	9.1	4.8	32.1	9.6	14.9	674.7	29.4	1.8	0.1	0.2	0.1	248.0
190	Yellow	5.1	0.9	58.7	3.1	239.6	17.4	15.2	12.4	4.5	25.5	3.9	20.3	479.4	39.4	2.4	0.1	0.2	0.2	255.9
197	Colorless	5.5	0.8	67.8	2.3	195.5	10.4	11.0	6.9	2.1	24.0	4.0	18.3	664.8	34.2	1.9	0.1	0.5	0.1	194.5

Sample #	Color	Li	Be	B	Sc	Ti	V	Cr	Ni	Co	Zn	As	Rb	Sr	Zr	Nb	Ag	Sb	Cs	Ba
203	Colorless-Y	6.5	0.5	93.6	2.5	212.4	12.2	14.5	8.4	2.9	20.2	18.7	14.9	463.4	31.9	1.8	0.1	0.2	0.1	173.2
208	Purple	8.0	0.8	89.8	3.1	209.4	16.2	15.8	12.4	3.8	28.3	15.1	15.4	481.2	32.7	1.9	0.1	0.3	0.2	229.0
210	Colorless	6.4	0.7	80.0	2.3	162.3	10.3	10.2	8.4	2.7	24.9	4.3	18.5	603.6	29.5	1.6	0.1	0.4	0.2	242.6
212	Blue	8.5	0.9	101.7	2.0	162.1	8.4	13.8	27.2	99.9	59.1	5.3	17.4	681.5	28.2	1.5	0.1	0.5	0.2	188.9
216	Aqua	5.8	0.4	68.5	3.0	241.8	10.6	10.8	12.4	10.0	27.8	3.7	16.2	596.3	36.0	1.9	0.8	0.4	0.1	197.6
218	Blue?	6.2	0.3	66.1	3.3	321.9	14.9	13.6	13.0	8.6	51.8	16.1	13.1	564.9	41.8	2.3	3.4	7.0	0.2	267.2
219	Colorless	6.3	0.5	71.7	3.0	213.1	9.8	10.2	7.9	2.2	22.0	0.0	16.6	615.6	28.9	1.7	0.2	0.2	0.1	211.3
223	Colorless?	5.4	0.4	72.4	2.8	268.0	14.7	11.1	11.4	11.8	27.6	2.8	14.4	624.7	31.6	1.9	0.1	0.3	0.2	212.5
226	Colorless	5.1	0.3	72.4	2.7	261.7	11.6	11.4	7.9	3.0	25.0	1.0	17.1	532.4	35.0	1.9	0.0	0.2	0.1	212.2
227	Light green	5.5	0.4	70.5	2.6	266.1	10.7	9.8	7.9	3.7	23.9	1.5	16.7	419.2	33.0	2.0	0.1	0.2	0.2	171.8
228	Aqua	6.5	0.4	69.7	2.4	195.3	8.7	8.8	7.4	43.6	26.8	1.6	18.4	587.4	27.6	1.5	0.0	0.2	0.2	208.3
231	Colorless/P?	11.5	0.5	101.2	2.9	339.5	16.3	35.5	34.5	21.2	488.2	64.9	13.9	525.7	46.4	2.4	9.7	30.3	0.5	268.5
233	Colorless/P?	6.2	0.4	83.0	3.0	285.7	13.8	20.1	12.4	8.7	36.8	4.5	12.7	481.8	33.7	2.1	0.5	1.6	0.1	238.9
239	Light blue	7.5	0.3	84.4	2.2	222.7	8.8	11.0	8.4	64.3	29.5	1.8	17.1	569.7	30.4	1.7	0.1	0.3	0.2	174.4
240	Colorless	7.7	0.5	95.5	2.4	194.3	10.3	9.9	8.7	5.6	25.6	1.8	19.6	602.1	27.7	1.8	0.1	0.2	0.1	250.7
244	Aqua	6.8	0.6	73.7	2.3	217.8	10.3	10.3	7.7	3.1	23.7	0.9	18.8	495.5	30.6	1.7	0.1	0.2	0.2	214.4
245	Light aqua	6.8	0.5	75.4	2.6	233.5	13.2	13.3	10.0	2.8	25.0	2.5	19.1	504.4	30.6	1.9	0.1	0.3	0.3	233.6
AVERAGE		**8.0**	**0.5**	**83.7**	**2.6**	**240.3**	**12.7**	**14.2**	**11.3**	**11.4**	**44.3**	**6.9**	**17.4**	**568.5**	**34.0**	**2.0**	**0.6**	**1.8**	**0.4**	**229.3**

Sample #	Color	La	Ce	Pr	Ta	Au	Y	Bi	U	W	Mo	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Th
GROUP 4: plant ash soda glasses with a strong Ti-Zr correlation – CONTINUED																								
151	Aqua?	5.8	10.8	1.5	0.1	0.0	7.0	0.0	0.5	0.4	4.2	5.6	1.0	0.3	1.0	0.2	1.0	0.2	0.5	0.1	0.5	0.1	1.0	0.8
155	Purple	6.6	11.1	1.6	0.1	0.0	8.5	0.0	0.4	0.4	3.5	6.3	1.2	0.3	1.2	0.2	1.2	0.3	0.7	0.1	0.6	0.1	1.0	0.9
158	Aqua	5.0	9.8	1.3	0.1	0.0	5.6	0.1	0.4	0.3	2.6	5.1	1.0	0.2	0.8	0.1	0.8	0.2	0.4	0.0	0.5	0.1	0.8	0.8
159	Yellow	7.1	13.4	1.8	0.1	8.6	8.6	0.7	1.3	0.7	5.4	7.1	1.4	0.3	1.4	0.2	1.2	0.3	0.7	0.1	1.6	0.1	1.0	7.4
160	Aqua	6.7	12.4	1.6	0.1	1.2	8.0	0.3	1.9	0.4	3.7	6.4	1.4	0.3	1.2	0.2	1.1	0.2	0.6	0.1	0.6	0.1	1.1	2.9
161	Colorless?	6.8	12.1	1.8	0.1	0.0	8.4	0.0	0.4	0.7	6.1	6.7	1.4	0.4	1.2	0.2	1.2	0.2	0.6	0.1	0.6	0.1	0.9	0.8
162	Colorless?	6.9	12.6	1.8	0.1	0.1	7.7	0.0	0.6	0.7	6.7	6.9	1.4	0.3	1.2	0.2	1.1	0.2	0.7	0.1	0.5	0.1	0.8	0.9
172	Aqua?	4.8	8.8	1.2	0.1	0.1	5.7	0.0	0.3	0.3	2.5	4.7	0.9	0.2	0.9	0.1	0.9	0.2	0.5	0.0	0.4	0.1	0.8	0.6
173	Aqua?	4.8	9.4	1.3	0.1	0.0	5.4	0.0	0.3	0.3	2.3	4.6	1.0	0.2	0.8	0.1	0.7	0.2	0.4	0.0	0.4	0.1	0.8	0.7
177	Aqua	6.5	12.2	1.6	0.1	0.1	8.6	0.1	0.4	0.4	3.9	5.8	1.4	0.3	1.1	0.2	1.2	0.3	0.6	0.1	0.6	0.1	0.9	0.8
187	Colorless-Y?	5.6	9.5	1.4	0.1	0.0	6.8	0.0	0.5	0.2	3.6	5.3	1.0	0.2	1.0	0.2	0.9	0.2	0.5	0.1	0.5	0.1	1.0	0.9
189	Colorless?	4.6	9.2	1.2	0.1	0.0	5.2	0.0	0.4	0.2	3.9	4.5	0.9	0.2	0.6	0.1	0.7	0.1	0.4	0.0	0.4	0.1	0.8	0.7
190	Yellow	7.1	13.2	1.9	0.1	0.0	8.6	0.0	0.6	0.7	6.6	7.3	1.5	0.4	1.5	0.2	1.3	0.2	0.6	0.1	0.7	0.1	0.9	1.0
197	Colorless	5.2	9.6	1.3	0.1	0.0	6.5	0.0	0.4	0.3	3.1	4.8	1.1	0.3	0.9	0.1	0.9	0.2	0.6	0.1	0.5	0.1	0.8	0.8
203	Colorless-Y	5.3	9.2	1.3	0.1	0.1	6.2	0.0	0.4	0.3	2.9	5.0	1.1	0.3	1.0	0.1	0.9	0.2	0.5	0.1	0.5	0.1	0.8	0.8
208	Purple	5.5	10.0	1.4	0.1	0.0	7.6	0.0	0.5	0.5	5.0	5.4	1.1	0.3	1.1	0.2	0.9	0.2	0.6	0.1	0.5	0.1	0.7	0.8
210	Colorless	5.9	10.6	1.6	0.1	0.0	6.7	0.0	0.4	0.3	2.8	6.1	1.2	0.3	1.1	0.2	1.0	0.2	0.5	0.1	0.5	0.1	0.8	0.7
212	Blue	5.4	9.6	1.4	0.1	0.0	6.1	0.0	0.3	0.2	2.6	5.1	1.0	0.3	1.0	0.1	0.9	0.2	0.5	0.1	0.4	0.1	0.8	0.8
216	Aqua	5.3	9.1	1.4	0.1	0.1	6.0	0.0	0.4	0.2	2.9	5.0	1.1	0.3	1.3	0.2	0.8	0.3	0.5	0.1	0.4	0.1	0.8	0.7
218	Blue?	5.6	10.6	1.4	0.1	0.2	6.9	0.9	0.4	0.4	3.1	5.2	1.1	0.3	1.0	0.1	1.0	0.2	0.5	0.1	0.5	0.1	1.0	0.8
219	Colorless	4.7	8.7	1.1	0.1	0.0	5.7	0.0	0.3	0.2	2.3	4.4	0.9	0.2	0.7	0.1	0.8	0.2	0.4	0.1	0.4	0.1	0.7	0.6
223	Colorless?	4.8	9.8	1.3	0.1	0.0	6.0	0.0	0.5	0.3	3.8	4.8	1.1	0.3	0.9	0.1	0.8	0.2	0.5	0.1	0.4	0.1	0.8	0.7
226	Colorless	5.4	9.7	1.3	0.1	0.0	6.2	0.0	0.4	0.3	3.4	5.1	1.0	0.3	0.9	0.1	0.8	0.2	0.5	0.1	0.4	0.1	0.9	0.8
227	Light green	5.3	9.7	1.4	0.1	0.6	5.3	0.0	0.4	0.2	2.2	5.1	1.1	0.3	1.1	0.1	0.8	0.2	0.5	0.1	0.4	0.1	0.8	0.8
228	Aqua	5.8	10.1	1.4	0.1	0.0	6.4	0.0	0.3	0.1	1.2	5.6	1.1	0.3	1.0	0.1	1.0	0.2	0.5	0.1	0.4	0.1	0.7	0.6
231	Colorless/P?	5.9	11.3	1.5	0.2	0.5	6.6	1.8	0.7	0.5	2.8	5.6	1.3	0.5	1.2	0.2	1.2	0.2	0.6	0.2	0.8	0.1	1.3	1.1
233	Colorless/P?	5.3	10.6	1.4	0.1	0.0	5.9	0.1	0.4	0.3	2.8	4.9	1.0	0.3	1.0	0.1	1.0	0.2	0.5	0.1	0.4	0.1	0.9	0.8
239	Light blue	4.8	8.5	1.2	0.1	0.0	5.1	0.0	0.3	0.1	1.6	4.5	1.1	0.3	1.1	0.1	0.7	0.2	0.4	0.1	0.4	0.1	0.8	0.7
240	Colorless	5.6	10.7	1.4	0.1	0.3	6.3	0.0	0.4	0.3	2.9	5.5	1.2	0.3	1.0	0.2	0.9	0.2	0.5	0.1	0.5	0.1	0.8	0.9
244	Aqua	5.9	10.2	1.5	0.1	0.4	5.9	0.1	0.5	0.2	2.2	6.3	1.7	0.5	1.5	0.2	1.1	0.2	0.5	0.1	0.5	0.1	0.8	0.9
245	Light aqua	6.3	12.2	1.7	0.2	1.5	7.5	0.1	0.5	1.4	3.6	6.9	1.6	0.4	1.6	0.2	1.6	0.2	0.8	0.2	0.9	0.2	1.3	0.9
Average		**5.7**	**10.5**	**1.4**	**0.1**	**0.5**	**6.7**	**0.1**	**0.5**	**0.4**	**3.4**	**5.5**	**1.2**	**0.3**	**1.1**	**0.2**	**1.0**	**0.2**	**0.5**	**0.1**	**0.5**	**0.1**	**0.9**	**1.1**

Sample #	Color	Li	Be	B	Sc	Ti	V	Cr	Ni	Co	Zn	As	Rb	Sr	Zr	Nb	Ag	Sb	Cs	Ba
GROUP 5: plant ash soda glasses																				
148	Aqua	18.9	0.8	83.8	2.6	290.5	14.7	25.2	16.6	24.0	57.0	4.6	18.0	603.3	61.6	2.7	0.3	1.8	0.2	235.7
157	Colorless	12.5	0.3	119.3	2.4	232.7	11.5	19.0	11.9	2.5	41.7	12.7	8.9	596.1	75.3	1.7	0.1	0.1	0.1	220.2
165	Blue?	9.5	0.5	82.5	2.5	303.4	13.1	23.1	15.4	16.2	68.4	6.7	14.1	490.7	55.0	2.1	1.2	7.5	0.2	196.2
168	Aqua	11.2	0.4	83.8	2.3	295.7	15.0	24.4	18.7	29.6	49.0	5.6	12.3	570.0	69.2	2.1	0.3	2.0	0.2	247.4
169	Aqua	12.9	0.6	95.9	2.4	273.1	13.2	24.3	20.3	36.3	51.6	7.1	13.7	552.4	59.6	2.0	0.3	0.9	0.2	190.0
171	Aqua	9.4	0.4	95.4	2.4	258.3	12.0	18.4	13.4	11.9	37.8	8.3	15.0	573.9	51.1	1.9	0.3	3.1	0.2	217.8
199	Aqua	10.5	0.6	80.7	2.7	256.6	17.2	31.3	25.6	21.6	61.9	9.9	13.2	481.7	65.0	2.2	0.2	3.9	0.2	309.7
202	Aqua	14.2	0.8	127.5	2.4	205.7	13.6	26.8	19.2	20.2	44.1	24.9	10.4	441.2	65.0	1.7	0.4	0.6	0.2	179.4
205	Aqua-blue	9.3	0.7	94.9	2.4	263.0	12.7	17.9	24.0	74.9	58.6	7.6	14.0	486.3	50.8	2.0	0.2	1.6	0.1	175.1
207	Aqua	13.6	0.5	103.4	2.5	210.6	13.7	20.9	14.0	11.9	47.3	7.3	13.0	489.1	53.9	1.8	0.2	0.8	0.2	197.3
213	Blue	15.4	0.5	113.8	2.5	208.3	18.0	30.7	58.4	283.7	108.1	7.5	12.0	544.1	74.5	1.9	0.2	0.7	0.2	220.5
230	Green	12.8	0.6	92.8	2.6	308.7	22.7	27.2	25.5	34.7	72.1	3.1	13.5	512.6	69.3	2.2	0.9	4.6	0.4	598.4
232	Aqua	7.8	0.4	59.2	2.9	295.6	15.6	20.5	15.0	9.1	41.4	2.6	17.4	621.8	50.1	2.2	0.3	2.0	0.2	247.8
234	Green	7.5	0.5	69.4	3.1	282.5	14.0	17.6	12.3	7.2	37.4	1.3	18.2	613.8	47.8	2.3	0.1	1.8	0.2	245.6
241	Light blue	10.7	0.7	71.1	2.6	291.3	14.6	23.0	27.3	51.2	62.3	1.4	15.2	575.4	67.1	2.2	0.3	1.9	0.2	242.8
AVERAGE		**11.7**	**0.5**	**91.6**	**2.6**	**265.1**	**14.8**	**23.3**	**21.2**	**42.3**	**55.9**	**7.4**	**13.9**	**543.5**	**61.0**	**2.1**	**0.4**	**2.2**	**0.2**	**248.3**

Sample #	Color	La	Ce	Pr	Ta	Au	Y	Bi	U	W	Mo	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Th
GROUP 5: plant ash soda glasses – CONTINUED																								
148	Aqua	6.5	13.5	1.6	0.2	0.1	6.8	0.0	0.6	0.5	4.1	5.7	1.1	0.2	1.0	0.2	1.1	0.2	0.6	0.1	0.5	0.1	1.7	1.5
157	Colorless	6.0	12.4	1.5	0.1	0.0	5.4	0.0	0.5	0.2	3.2	5.2	1.0	0.2	0.8	0.1	0.8	0.2	0.5	0.1	0.5	0.1	1.8	1.5
165	Blue?	5.4	10.4	1.4	0.1	0.1	5.7	0.1	0.5	0.3	2.7	5.0	1.0	0.3	0.9	0.1	1.0	0.2	0.5	0.1	0.6	0.1	1.5	1.1
168	Aqua	6.0	11.4	1.5	0.1	0.2	6.1	0.0	0.5	0.6	3.2	5.7	1.1	0.2	0.9	0.2	1.0	0.2	0.5	0.1	0.6	0.1	1.7	1.3
169	Aqua	5.6	11.3	1.4	0.1	0.0	5.4	0.0	0.5	0.3	3.0	5.3	0.9	0.2	0.9	0.1	0.9	0.2	0.4	0.1	0.4	0.1	1.5	1.3
171	Aqua	6.0	11.2	1.5	0.1	0.0	6.1	0.0	0.4	0.3	2.8	5.6	1.1	0.3	0.9	0.1	1.0	0.2	0.5	0.1	0.5	0.1	1.4	1.1
199	Aqua	6.0	11.1	1.5	0.1	0.2	6.1	0.0	0.7	1.2	3.6	5.5	1.2	0.3	1.1	0.2	1.5	0.2	0.6	0.2	1.0	0.1	1.8	1.3
202	Aqua	5.5	11.5	1.4	0.1	0.2	4.9	0.1	0.5	0.2	2.9	5.0	1.0	0.2	0.8	0.1	0.7	0.1	0.4	0.1	0.4	0.0	1.6	1.3
205	Aqua-blue	4.9	9.4	1.3	0.1	0.0	5.2	0.0	0.5	0.2	2.5	4.9	0.9	0.3	0.9	0.1	0.8	0.1	0.4	0.1	0.4	0.1	1.2	0.9
207	Aqua	5.3	11.3	1.4	0.1	0.0	5.2	0.0	0.5	0.2	3.0	5.1	1.0	0.2	0.9	0.1	0.8	0.1	0.5	0.1	0.4	0.1	1.4	1.0
213	Blue	6.3	14.3	1.6	0.1	0.0	4.4	0.0	0.7	0.2	5.5	5.3	1.0	0.2	0.8	0.1	0.7	0.1	0.4	0.1	0.5	0.1	1.9	1.5
230	Green	6.1	10.9	1.5	0.2	1.2	6.7	0.4	0.8	2.4	5.3	6.6	2.4	0.8	2.7	0.4	2.3	0.5	1.1	0.3	1.0	0.2	2.5	1.5
232	Aqua	6.6	11.8	1.6	0.1	0.0	7.8	0.1	0.5	0.5	3.4	6.2	1.4	0.4	2.0	0.2	1.3	0.3	0.7	0.1	0.6	0.2	1.3	1.2
234	Green	6.9	12.0	1.7	0.1	0.0	8.5	0.0	0.4	0.3	3.4	6.5	1.4	0.3	1.3	0.2	1.2	0.2	0.7	0.1	0.6	0.1	1.1	1.0
241	Light blue	6.1	11.6	1.5	0.1	0.1	6.4	0.0	0.6	0.3	3.2	5.5	1.0	0.3	1.0	0.2	0.9	0.2	0.5	0.1	0.5	0.1	1.6	1.3
Average		**6.0**	**11.6**	**1.5**	**0.1**	**0.2**	**6.0**	**0.1**	**0.5**	**0.5**	**3.4**	**5.5**	**1.2**	**0.3**	**1.1**	**0.2**	**1.1**	**0.2**	**0.6**	**0.1**	**0.6**	**0.1**	**1.6**	**1.3**

Sample #	Color	Li	Be	B	Sc	Ti	V	Cr	Ni	Co	Zn	As	Rb	Sr	Zr	Nb	Ag	Sb	Cs	Ba
OUTLIERS: plant ash soda glasses																				
117	Colorless	12.2	1.0	97.1	2.9	206.9	14.6	27.3	28.2	4.8	49.6	11.7	12.5	550.8	107.2	2.5	0.2	0.2	0.3	413.7
119	Colorless?	11.5	0.7	95.2	2.8	204.6	16.1	18.9	12.9	6.5	46.2	0.0	11.9	614.1	112.8	2.4	0.1	0.1	0.2	143.6
144	Aqua	7.9	0.4	88.2	1.9	92.6	7.8	15.4	9.9	1.0	28.5	1.2	8.7	480.3	25.4	1.0	0.0	0.2	0.1	79.5
149	Aqua	7.2	0.5	76.8	3.3	459.2	20.2	23.1	13.6	4.5	31.8	5.0	12.9	666.2	47.9	3.3	0.1	0.3	0.2	292.0
156	Blue	21.4	0.8	53.0	2.2	197.1	11.6	26.9	24.5	401.4	1475.2	9.8	19.2	480.6	54.1	1.7	0.4	6.5	0.2	130.5
164	Aqua?	29.3	0.5	95.9	2.3	397.5	13.0	29.5	11.7	4.3	15.8	1.8	11.4	435.4	312.9	3.0	0.1	0.2	0.1	173.3
178	Blue	19.7	0.6	88.0	3.4	479.2	23.8	88.5	38.3	1424.5	3376.6	3.3	14.5	548.2	124.0	2.9	0.4	1.2	0.2	210.0
179	Green	22.6	0.5	90.4	2.3	256.8	31.4	39.2	14.1	5.6	16.8	7.3	13.5	482.0	97.8	1.9	0.0	0.2	0.2	229.5
181	Aqua	21.3	0.8	116.3	2.9	364.6	22.0	39.7	16.4	28.6	38.0	6.4	12.8	362.2	123.3	3.3	0.8	2.4	0.2	198.7
183	Colorless?	31.2	0.7	108.8	2.1	238.2	29.4	41.1	16.9	29.6	43.8	5.2	14.3	499.1	79.2	1.7	0.1	0.5	0.8	232.5
185	Aqua	19.7	0.4	91.7	2.6	382.1	22.9	39.5	17.2	16.3	28.6	5.1	11.3	403.6	109.8	2.4	0.6	4.8	0.1	230.5

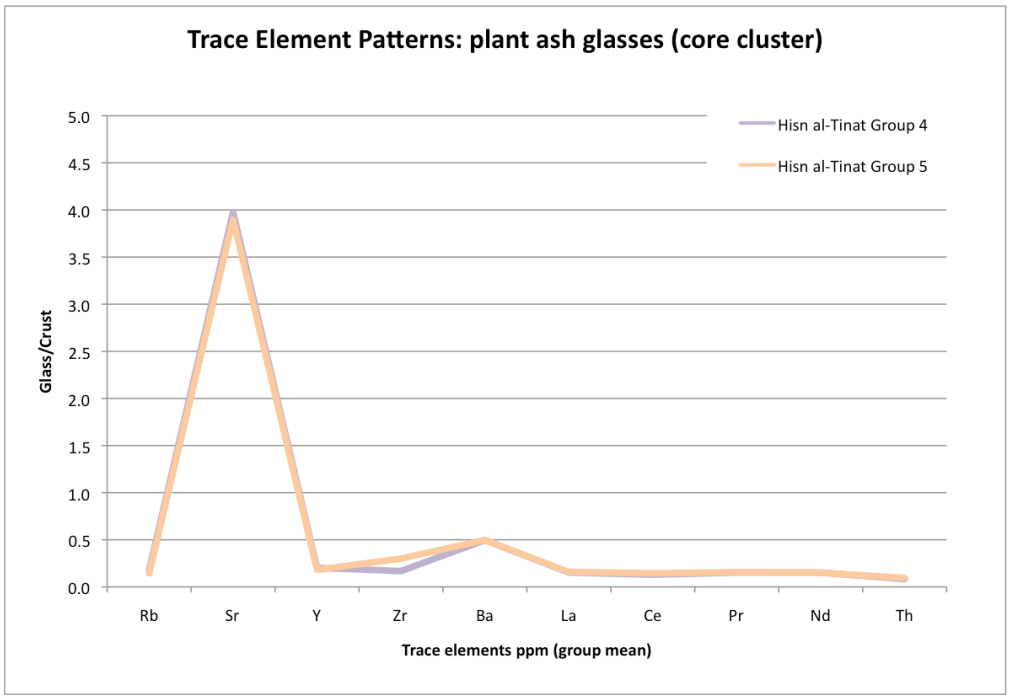
Sample #	Color	Li	Be	B	Sc	Ti	V	Cr	Ni	Co	Zn	As	Rb	Sr	Zr	Nb	Ag	Sb	Cs	Ba
195	Aqua	15.5	1.0	86.1	3.5	396.2	19.9	84.1	25.8	51.1	251.1	9.0	13.5	475.9	103.3	3.2	0.6	2.1	0.2	207.5
211	Dark blue	28.5	0.8	158.2	3.8	370.1	23.5	86.9	406.5	1488.5	631.3	23.3	8.0	394.7	88.7	3.2	0.4	2.9	0.3	160.4
224	Y-amber	14.8	0.2	107.8	3.4	315.7	14.1	49.6	25.6	5.0	34.3	3.5	6.7	348.1	18.7	1.8	0.1	2.3	0.1	52.4
225	Blue, white	10.0	0.5	68.1	6.9	835.6	42.7	119.7	42.8	7.0	40.5	1.3	13.6	409.8	46.9	4.5	0.1	1.5	0.2	102.6
229	Colorless/P?	13.3	0.4	88.8	3.2	326.7	20.8	28.0	22.9	26.4	53.0	1.9	12.4	597.6	99.2	2.6	0.3	0.8	0.2	258.2
238	Brown-Y	11.9	0.4	70.7	3.3	486.9	19.7	51.5	32.9	5.2	36.2	0.0	6.5	322.8	23.5	3.2	0.1	0.6	0.2	62.1
242	Green	14.5	0.5	100.0	4.2	568.3	30.2	93.1	32.7	13.4	51.7	1.6	14.9	504.5	105.5	3.5	2.3	0.8	0.2	223.7
AVERAGE		**17.4**	**0.6**	**93.4**	**3.2**	**365.5**	**21.3**	**50.1**	**44.0**	**195.8**	**347.2**	**5.4**	**12.1**	**476.4**	**93.3**	**2.7**	**0.4**	**1.5**	**0.2**	**188.9**

Sample #	Color	La	Ce	Pr	Ta	Au	Y	Bi	U	W	Mo	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Th
OUTLIERS: plant ash soda glasses – CONTINUED																								
117	Colorless	8.8	15.6	2.0	0.1	0.0	8.3	0.0	0.7	0.2	4.3	7.3	1.5	0.2	1.1	0.2	1.1	0.2	0.6	0.1	0.6	0.1	2.3	1.9
119	Colorless?	8.0	15.8	1.8	0.1	0.0	7.3	0.0	0.5	0.1	3.9	6.7	1.2	0.2	1.2	0.2	1.0	0.2	0.6	0.1	0.5	0.1	2.5	2.1
144	Aqua	4.3	8.8	1.0	0.1	0.0	3.2	0.0	0.4	0.1	1.5	3.5	0.7	0.1	0.6	0.1	0.5	0.1	0.2	0.0	0.3	0.0	0.7	0.7
149	Aqua	7.6	13.3	1.9	0.2	0.0	9.4	0.0	0.7	0.3	2.6	7.3	1.6	0.4	1.3	0.2	1.3	0.3	0.8	0.1	0.7	0.1	1.3	1.3
156	Blue	4.0	8.5	1.0	0.1	0.1	4.3	0.2	0.6	0.3	11.9	3.7	0.7	0.1	0.5	0.1	0.6	0.1	0.4	0.0	0.4	0.1	1.4	1.2
164	Aqua?	7.3	13.9	1.7	0.2	0.0	6.4	0.0	0.7	0.4	2.7	5.8	1.2	0.2	0.9	0.2	1.0	0.2	0.6	0.1	0.8	0.1	7.3	2.5
178	Blue	6.5	13.5	1.6	0.2	0.0	5.9	0.0	0.8	0.6	4.4	5.5	1.1	0.2	0.8	0.1	0.8	0.2	0.5	0.1	0.5	0.1	3.1	1.8
179	Green	5.3	10.4	1.3	0.1	0.0	4.8	0.0	0.5	1.0	3.1	4.6	1.0	0.2	0.8	0.1	0.7	0.2	0.5	0.0	0.5	0.1	2.5	1.3
181	Aqua	6.5	12.6	1.6	0.2	0.0	6.4	0.0	0.7	0.4	3.0	5.6	1.1	0.3	1.0	0.1	0.9	0.2	0.6	0.1	0.6	0.1	3.0	1.8
183	Colorless?	5.0	9.9	1.2	0.1	0.0	4.7	0.0	0.5	0.8	3.0	4.1	0.9	0.1	0.6	0.1	0.6	0.1	0.3	0.0	0.5	0.1	1.8	1.2
185	Aqua	5.8	10.9	1.3	0.1	0.0	5.6	0.0	0.6	0.4	2.3	5.0	1.0	0.2	0.9	0.1	0.8	0.2	0.5	0.1	0.5	0.1	2.7	1.4
195	Aqua	7.2	15.0	1.7	0.2	0.3	6.7	0.1	1.0	0.9	3.2	6.3	1.4	0.3	1.1	11.8	1.0	0.2	0.7	0.1	1.1	0.1	2.6	1.8
211	Dark blue	7.4	15.4	1.7	0.2	0.1	6.3	0.1	0.9	0.2	34.7	6.6	1.4	0.3	1.1	0.2	1.0	0.2	0.5	0.1	0.5	0.1	2.4	2.2
224	Y-amber	2.9	5.9	0.7	0.1	0.0	3.2	0.0	0.3	0.1	1.0	2.7	0.6	0.1	0.5	0.1	0.5	0.1	0.3	0.0	0.3	0.0	0.5	0.7
225	Blue, white	7.1	13.1	1.6	0.3	0.0	8.8	0.1	0.5	0.1	0.5	6.2	1.3	0.3	1.3	0.2	1.3	0.3	0.7	0.1	0.8	0.1	1.1	1.7
229	Colorless/P?	7.7	15.3	1.8	0.1	0.5	6.8	0.4	0.7	0.5	5.4	6.5	1.4	0.3	1.2	0.2	1.1	0.2	0.5	0.1	0.7	0.1	2.4	1.9
238	Brown-Y	4.1	7.8	1.0	0.2	1.0	3.7	0.1	0.3	0.2	1.0	4.0	1.4	0.4	1.7	0.1	0.8	0.2	0.6	0.1	0.5	0.1	0.7	0.9
242	Green	7.8	14.9	1.9	0.2	0.1	7.0	0.0	1.1	0.3	8.1	6.8	1.4	0.3	1.2	0.2	1.1	0.2	0.6	0.1	0.6	0.1	2.5	2.0
AVERAGE		**6.3**	**12.3**	**1.5**	**0.2**	**0.1**	**6.0**	**0.1**	**0.6**	**0.4**	**5.4**	**5.5**	**1.1**	**0.2**	**1.0**	**0.8**	**0.9**	**0.2**	**0.5**	**0.1**	**0.6**	**0.1**	**2.3**	**1.6**

Recent studies discuss how certain trace elements may be able to distinguish different silica sources due to the variability of geochemical environments (Freestone *et al.* 2000; Freestone 2006; Aerts *et al.* 2003; Shortland *et al.* 2007; Silvestri *et al.* 2008; Degryse *et al.* 20010a). Freestone first suggested the potential for using trace elements to discriminate production groups for plant ash soda glasses, illustrating this idea by showing the different distribution patterns for three plant ash soda glass samples from Oman, and suggesting that these correspond to different origins of the glasses (Freestone 2006: 212, Fig. 13). When the same trace element distribution line-graphs are created for the Ḥiṣn al-Tīnāt samples, the core cluster can be broken into two subsets, termed here as Groups 4 and 5.

While these two groups in the core cluster are quite similar (Figure 4.21, top), Group 5 has slightly higher levels of zirconium. The outliers, on the other hand, show much wider variety in terms of their Sr, Zr, and Ba (Figure 4.21, bottom); there appear to be two main patterns, temporarily identified as subgroups G.1 and G.2 (Figure 4.22). At least two samples have singular patterns related to high Sr or Zr, and four samples have similar patterns overall to Group 4 (Nos. 149, 151, and 230) and Group 5 (No. 117) although they have elevated Sr and Ba levels (Figure 4.23).

Although Freestone's distribution graphs are helpful in identifying some degree of difference, it is clear that only Sr, Zr, and Ba are of real use here. Other trace element combinations, however, prove to be even better discriminators; Ti, Zr, La, and Cr have been used successfully to differentiate Late Bronze Age plant ash soda glasses produced



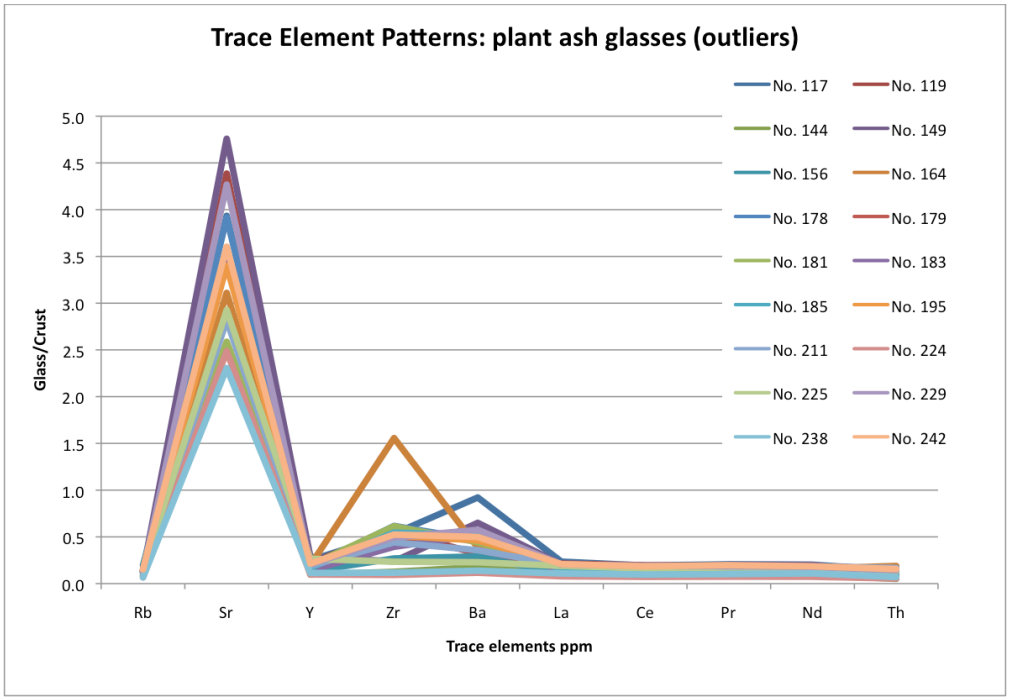
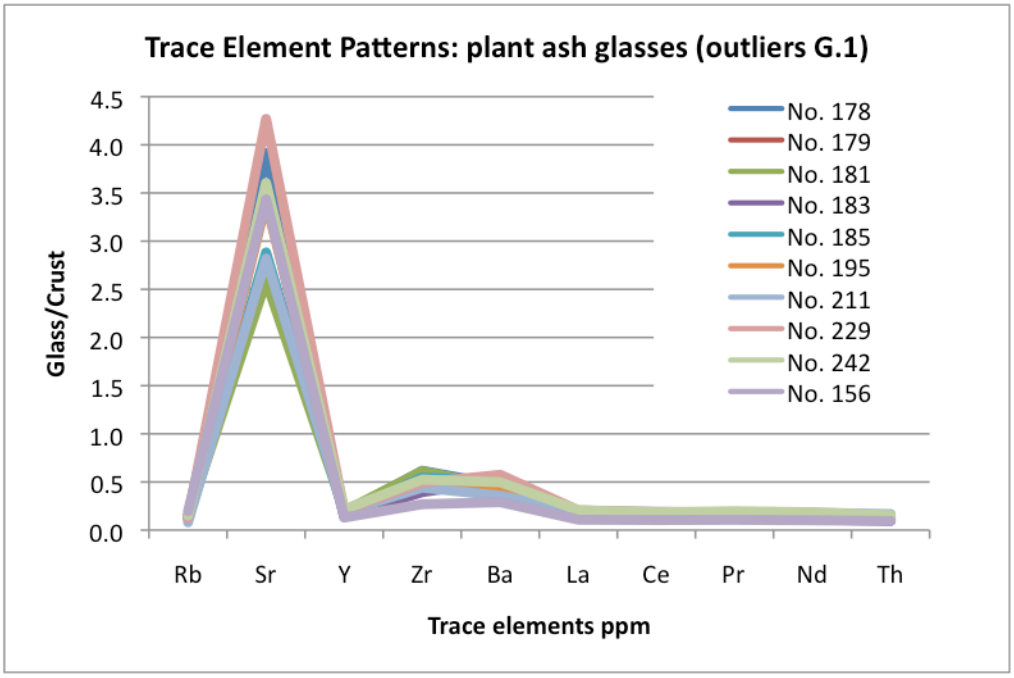


Figure 4.21: Trace element distribution pattern of the core cluster showing the slight differences between Groups 4 and 5 (top), and the various patterns of the outlier samples (bottom).



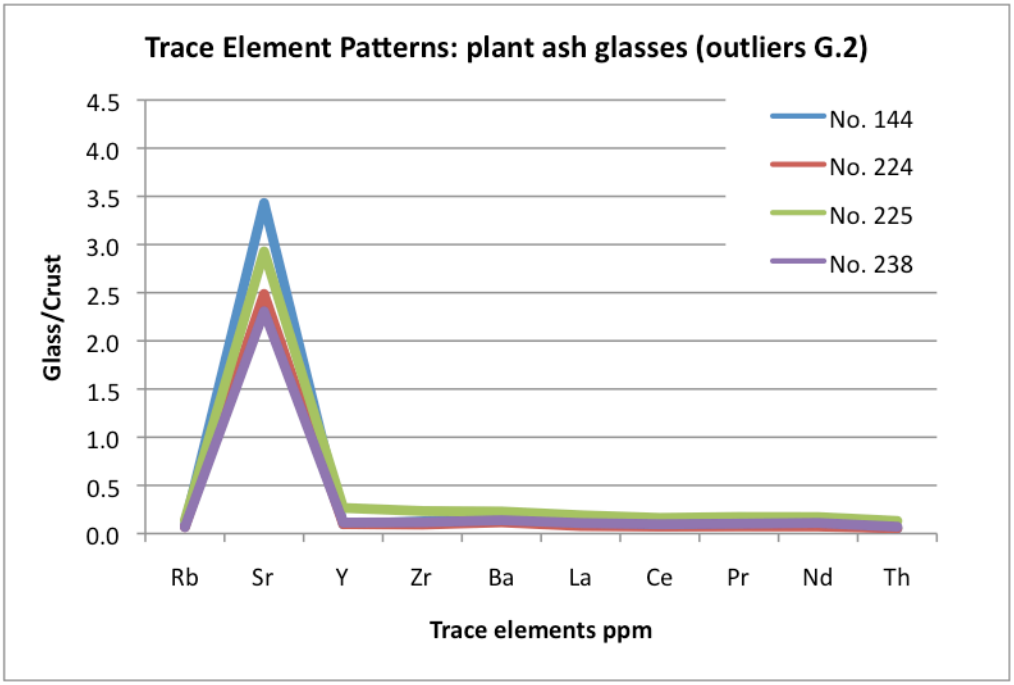
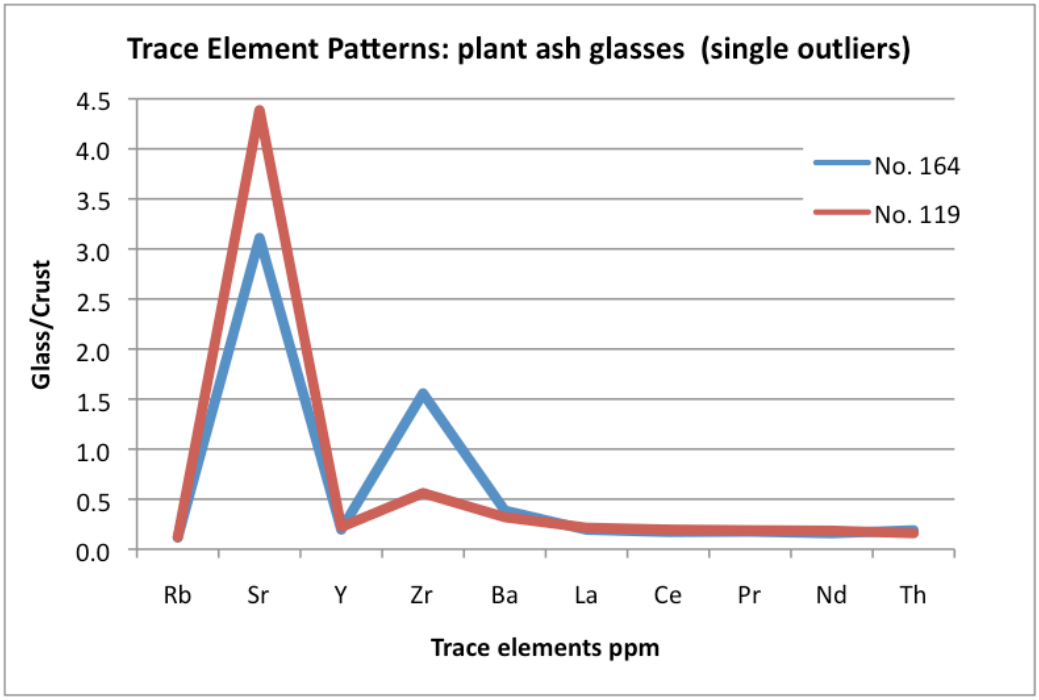


Figure 4.22: Trace element distribution pattern of outliers subgroup G.1 (top) and subgroup G.2 (bottom).



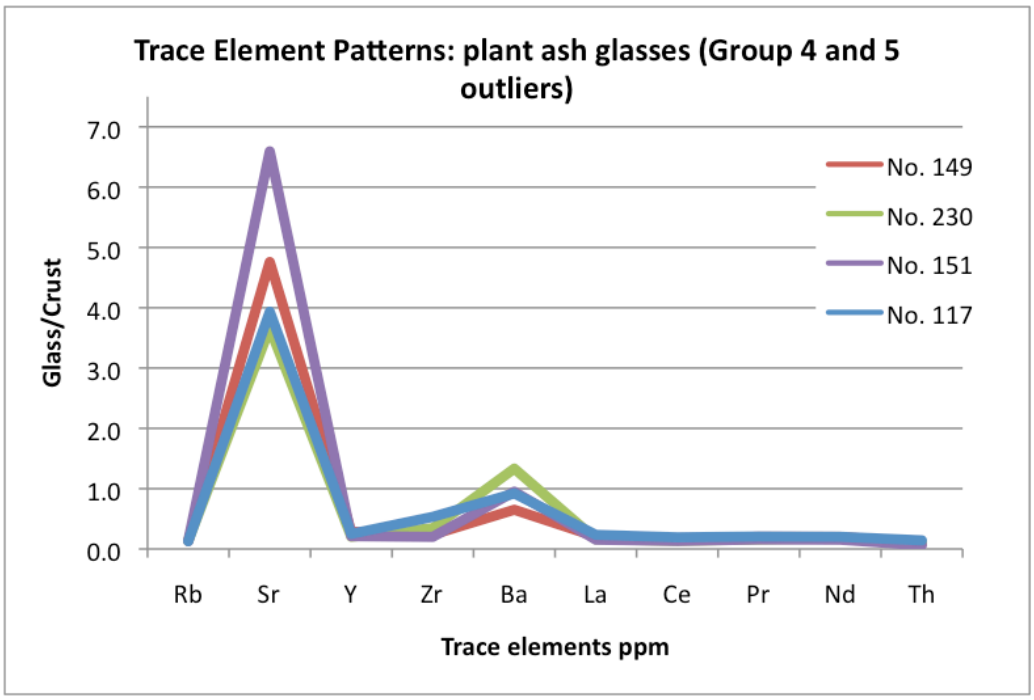


Figure 4.23: Trace element distribution pattern of two solitary samples, Nos. 164 and 119 (top), and of the Group 4 and 5 outliers (bottom).

in Egypt and Mesopotamia (Shortland *et al.* 2007: 787),[25] while Zr-Sr and Zr-Ba are also often diagnostic of silica sources (Silvestri *et al.* 2008).[26] The use of Rare Earth Elements (REE) has been discussed recently in the literature, but these have not yet been proved to be useful discriminators;[27] the analysis of strontium, neodymium, lead, or oxygen isotopes also has the potential to help differentiate plant ash soda glasses (Freestone *et al.* 2003; Freestone 2005; Freestone 2006), but because this technique is time-consuming and expensive it is not yet of widespread use.

The characteristics of the trace element Ti, Zr, La, Cr, Sr, and Ba are indeed useful for bringing the compositional differences of the Ḥiṣn al-Tīnāt plant ash soda glasses into sharper focus, in particular for identifying the outliers with more confidence and further refining the two groups of the core cluster (Figure 4.24); the strong Ti-Zr correlation for some of the samples in the core cluster (Group 4) suggests it can be divided into two groups, which together are distinct from a third group made up of outliers (lumped together for the time being) that represent a wide variety of compositional characteristics, suggesting a wide range of raw material sources, production origins, or both. Although more easily distinguishable by trace elements, these

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[25] These elements are highly correlated, and come from heavy minerals that accompany quartz (Wedepohl *et al.* 2011: 93). They are particularly useful because "all four are refractory and non-volatile and their inter-element ratios are not affected by the high temperatures involved in either manufacturing or subsequent reprocessing. Moreover they are commonly used as compositional discriminants in igneous geochemistry because they are known to be particularly robust to low temperature alteration and weathering" (Shortland *et al.* 2007: 787).

[26] Barium is related to alkali feldspars, so higher levels of Ba indicate a sand that is richer in alkali feldspars (Silvestri 2008: 1498; Silvestri *et al.* 2008: 338).

[27] Although the three major glass types (mineral soda, plant-ash soda, and wood-ash soda glasses) do have specific REE patterns (Wedepohl *et al.* 2011: 91-92), there is little variation *within* these types; for example, REE abundances and patterns are homogenous in mineral soda glasses and do not seem to be correlated with provenance (Degryse and Shortland 2009: 140), because the REE content of glass is "dependent on the clay fraction of the sand, and is identical for most possible provenance areas in the Mediterranean" (Degryse and Shortland 2009: 135); in addition, for plant ash soda glasses "the majority of elements apparently do not deviate much from the bulk REE distribution" (Wedepohl *et al.* 2011: 92).

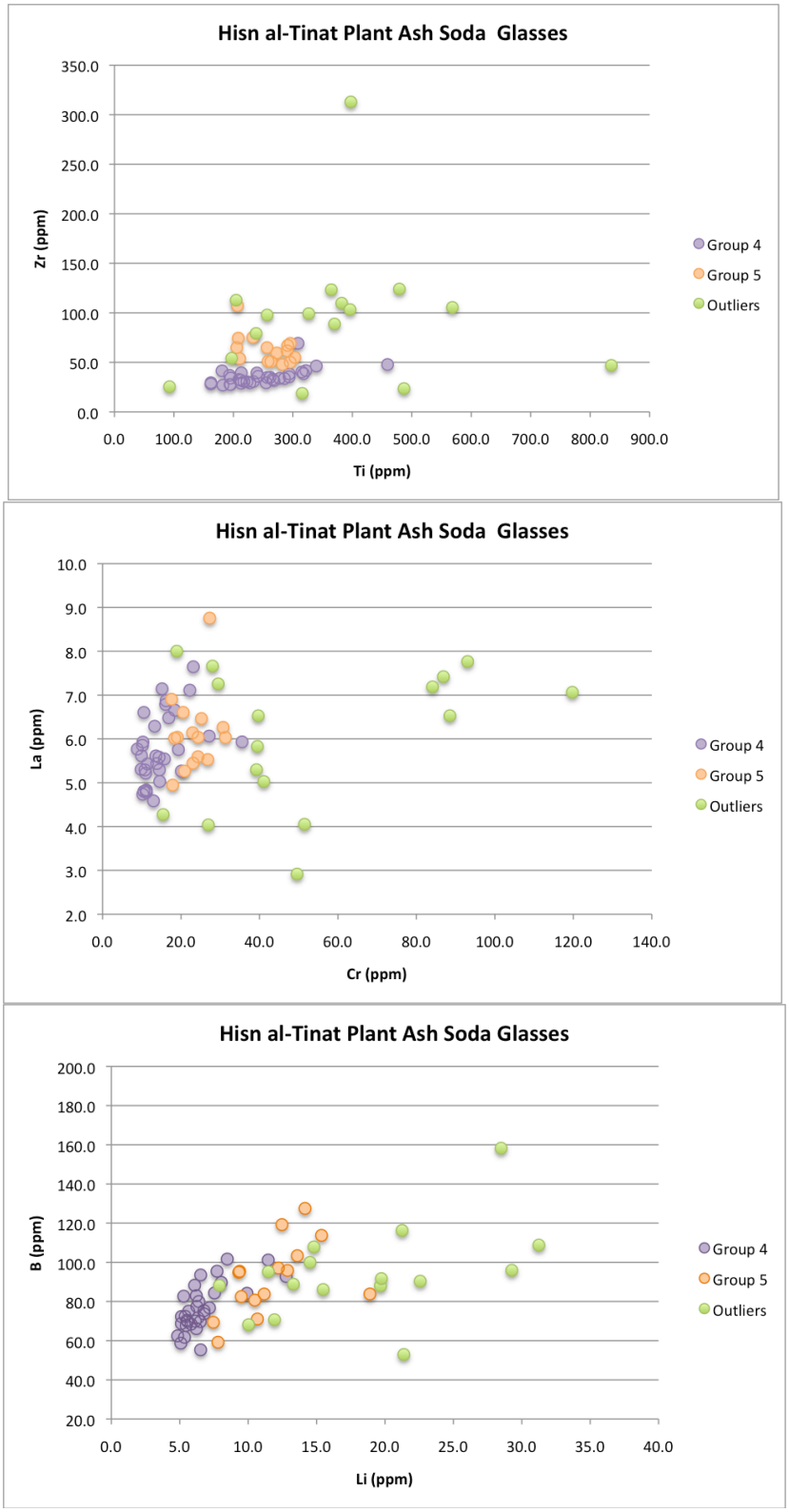


Figure 4.24: Bivariate scatter plots of Zr-Ti, La-Cr, and B-Li, which clearly illustrate the clustering of Groups 4 and 5 and the spread of the outliers. Note that in the Li-B plot No. 159 is not shown, because it has much higher levels of both elements than the rest of the samples.

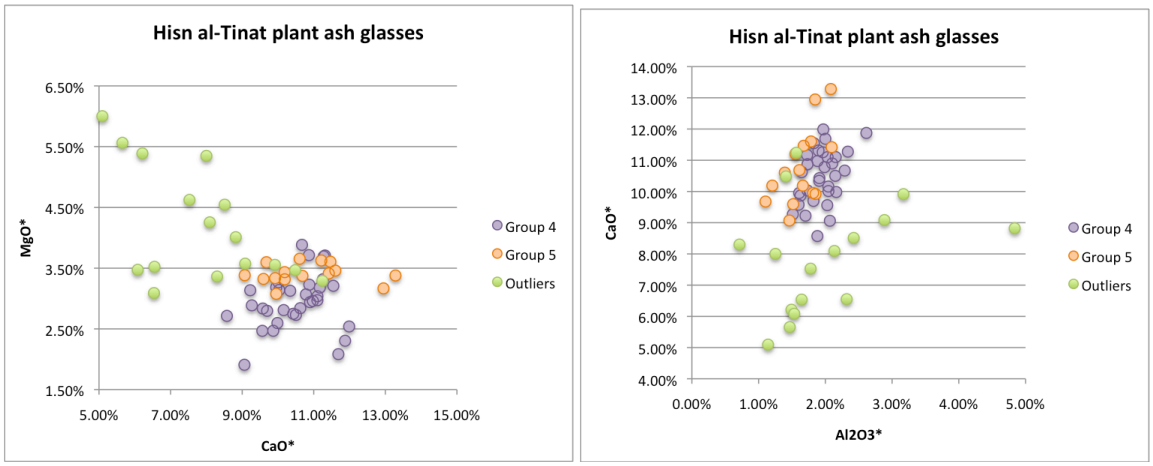


Figure 4.25: Bivariate scatter plots of CaO*, MgO*, and Al_2O_3*, which clearly illustrate the clustering of Groups 4 and 5 and the spread of the outliers.

three broad groups are also often visible in terms of their major/minor oxides (Figure 4.25), although there is more overlap. The characteristics of these groups are described below in more detail.

Groups 4 and 5

The core cluster might be divided into two: Group 4 with 33 members and Group 5 with 15 members. Although these groups are similar in many respects, Group 4 tends to have slightly lower magnesia, soda, and iron, as well as higher alumina, silica, manganese, and copper than Group 5. In terms of trace elements, Group 4 has distinctly lower Zr, Cr, and Li levels than Group 5, and there is a strong correlation between Ti-Zr. These compositional differences can be seen in Tables 4.7 and 4.8, which give the mean value for each group.

In Group 4, three of the samples (**Nos. 149, 151**, and **230**) are slightly different from the rest of the group, being on the high lime, alumina, iron, and phosphorus end of

Oxides (wt%)	SiO2	Na2O	K2O	CaO	MgO	Al2O3	Fe2O3	TiO2	MnO	P2O3	CuO	CoO	PbO2	Sb2O5	SnO2
Group 4 (n=33)	**67.74**	**12.56**	**2.38**	**10.18**	**2.94**	**1.87**	**0.51**	**0.04**	**0.96**	**0.29**	**0.11**	**0.00**	**0.02**	**0.00**	**0.00**
range	65.59-71.34	10.95-13.85	1.83-2.88	8.37-11.72	1.87-3.83	1.49-2.29	0.32-0.78	0.03-0.06	0.03-1.74	0.19-0.40	0.00-2.25	0.00-0.01	0.00-0.16	0.00-0.01	0.00-0.05
σ	1.42	0.86	0.25	0.79	0.42	0.20	0.12	0.01	0.47	0.06	0.43	0.00	0.05	0.00	0.01
Group 5 (n= 14)	**66.54**	**13.49**	**2.20**	**10.63**	**3.34**	**1.64**	**0.59**	**0.04**	**0.83**	**0.29**	**0.03**	**0.00**	**0.04**	**0.00**	**0.01**
range	65.94-68.08	11.98-14.90	1.99-2.38	8.94-13.08	3.02-3.57	1.09-2.06	0.43-0.82	0.03-0.05	0.58-1.33	0.23-0.38	0.00-0.11	0.00-0.04	0.0-0.30	-	0.00-0.04
σ	1.13	0.95%	0.11	1.22	0.16	0.28	0.10	0.01	0.20	0.04	0.03	0.01	0.08	0.00	0.01

Table 4.7: Average major/minor oxide composition of the core cluster of Ḥiṣn al-Tīnāt plant ash soda glasses (σ = standard deviation).

Trace elements (ppm)	Li	Be	B	Sc	Ti	V	Cr	Ni	Co	Zn	As	Rb	Sr	Zr	Nb	Ag	Sb	Cs	Ba	La
Group 4	**8.1**	**0.5**	**84.6**	**2.6**	**237.8**	**12.6**	**14.0**	**11.2**	**11.6**	**44.7**	**7.0**	**17.6**	**556.7**	**33.8**	**1.9**	**0.6**	**1.8**	**0.4**	**222.7**	**5.7**
σ	8.8	0.2	42.5	0.4	47.5	3.1	5.2	6.0	21.3	84.2	12.0	3.4	84.9	4.9	0.3	1.8	5.6	1.1	29.5	0.8
Group 5	**11.7**	**0.5**	**91.5**	**2.5**	**262.0**	**14.2**	**23.1**	**20.9**	**42.9**	**54.8**	**7.7**	**14.0**	**545.7**	**60.4**	**2.1**	**0.3**	**2.0**	**0.2**	**223.3**	**5.9**
σ	3.1	0.1	19.6	0.2	34.8	1.8	4.4	11.9	72.0	18.2	5.9	2.7	57.8	9.2	0.3	0.3	1.9	0.0	35.6	0.5

Trace elements (ppm)	Ce	Pr	Ta	Au	Y	Bi	U	W	Mo	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Th
Group 4	**10.5**	**1.4**	**0.1**	**0.5**	**6.7**	**0.1**	**0.5**	**0.4**	**3.4**	**5.5**	**1.2**	**0.3**	**1.1**	**0.2**	**1.0**	**0.2**	**0.5**	**0.1**	**0.5**	**0.1**	**0.9**	**1.1**
σ	1.4	0.2	0.0	1.6	1.1	0.4	0.3	0.3	1.4	0.9	0.2	0.1	0.2	0.0	0.2	0.0	0.1	0.0	0.2	0.0	0.2	1.2
Group 5	**11.7**	**1.5**	**0.1**	**0.1**	**6.0**	**0.0**	**0.5**	**0.4**	**3.3**	**5.5**	**1.1**	**0.3**	**1.0**	**0.1**	**1.0**	**0.2**	**0.5**	**0.1**	**0.5**	**0.1**	**1.5**	**1.2**
σ	1.2	0.1	0.0	0.1	1.1	0.0	0.1	0.3	0.7	0.5	0.2	0.1	0.3	0.0	0.2	0.0	0.1	0.0	0.1	0.0	0.2	0.2

Table 4.8: Average trace element composition of the core cluster of Ḥiṣn al-Tīnāt plant ash soda glasses (σ = standard deviation).

these ranges while No. 230 also has lower silica; in terms of trace elements, recall that while these three samples have a similar distribution pattern to the rest of the group, they have higher Sr and Ba levels. Two other samples in Group 4 (**Nos. 159** and **231**) also have trace elements that are slightly distinct from the rest of the group; both have somewhat elevated lithium (10-50 ppm Li) and boron (100-300 ppm B), and it should be noted that No. 231 has very high levels of copper, lead, antimony, and tin as well. In Group 5, **No. 117** would appear to be a slight outlier to the rest of the group, with a higher Ba level in particular.

In terms of color, the plant-ash soda glasses as a whole are more variable than the mineral soda glasses, including in particular more glasses that are colorless or yellowish. Naturally aqua glasses are again colored by their natural iron impurities; although there is more iron present in plant-ash soda glasses, they also have more manganese than the mineral soda glasses, which counteracts the bluish hue from the iron. The aqua glasses often have 0.01-0.02 wt% CuO, and the aqua glasses of Group 5 seem to have more noticeable levels of lead. Blue glasses have trace amounts of CoO, which appears to be correlated with Zn, while greener glasses are colored through manipulation of the natural iron by means of the furnace atmosphere. Purple glasses typically have lower iron and higher manganese levels. Yellowish glasses also often have higher manganese levels, while the colorless glasses typically have lower iron (0.4-0.6 wt%) combined with higher manganese (0.5-1.7 wt%) compared to the other glasses. Quite a few of the plant ash soda glasses were initially labeled “unknown” in terms of their color when recorded in the field because they were too corroded to be described clearly; the results of chemical analysis make it possible to suggest a color for many of these samples. For example, the

iron and manganese proportion of No. 151 likely make it a naturally aqua colored glass, while the copper concentrations (0.8-2.3 wt% CuO) of Nos. 218 and 231 suggest they may be bluish glasses; the slightly elevated levels of cobalt, lead, tin, silver, and antimony are indicative of recycling.

Outliers

The very heterogeneous "outlier" group consists of 16 samples; while they are distinct enough from the core cluster to be discussed separately, it is difficult to consider them as a unified group although they do share some similarities. All have noticeably lower levels of lime and most have higher levels of magnesia and lower levels of phosphorus as well, which may suggest that the plant ash used for fluxing was different from that used when making Groups 4 and 5. The outliers also typically have higher levels of soda than Group 4, although some samples have similar levels to Group 5. Although there are naturally-aqua colored examples amongst the outlier glasses, it is noticeable that more of the green-blue and yellow-brown glasses fall into this group. It comes as no surprise that the most distinct object in the entire assemblage, the blue-white marvered flask No. 225, is included amongst the outlier samples; No. 225 has a much higher alumina (4.8 wt% Al_2O_3), titanium (830 ppm Ti), and chromium (120 ppm Cr) levels.

The differences between the core cluster and the outlier clusters are particularly noticeable in terms of their trace elements. The trace-element distribution charts shown above suggest that the outliers might be able to be subdivided further; two divisions are tentatively suggested here, called outlier subgroup G.1 and subgroup G.2, although a

more detailed examination is still needed. Subgroup G.1 displays a sort of plateau in the distribution chart, with similarly elevated levels of Zr and Ba (recall that Groups 4 and 5 consistently have higher Ba than Zr), while subgroup G.2 does not have elevated levels of either Zr or Ba (Figure 4.22). In addition to these subdivisions, two other outlier samples (No. 119 and 164) are quite distinct in terms of their high Zr levels, while No. 164 also has lower Sr (Figures 4.23); the unique outlier status of this latter sample is of particular interest, as it is one of the tong-decorated wall fragments.

Kinet Höyük fragments

All four of the fragments from the later medieval occupation of Kinet Höyük are made using plant ash soda (Figure 4.14), which is not unexpected for glass dating to the 12th-14th centuries CE as by this point in time all glass was made using a vegetal soda sources (e.g., plant ash in the Near East and wood ash in Europe). However there are some slight differences between the Kinet fragments and the Ḥiṣn al-Tīnāt plant ash glasses. The Kinet fragments have lower levels of lime and alumina, as well as higher soda than Groups 4 and 5.

The different colors of these samples—purple, aqua, colorless, and light green—indicate that the same basic variety of colors were in use in this later period, and the chemical composition shows that the color manipulation was the same as well. Purple fragment **No. 246** is colored with 1.6 wt% MnO while naturally-aqua fragment **No. 247** has trace amounts of iron, tin, lead, and copper that indicate recycling. Fragment **No. 248** is colorless due to trace amounts of manganese combined with relatively low iron; light

green **No. 249** has a small trace of copper but was probably subject to a different furnace atmosphere.

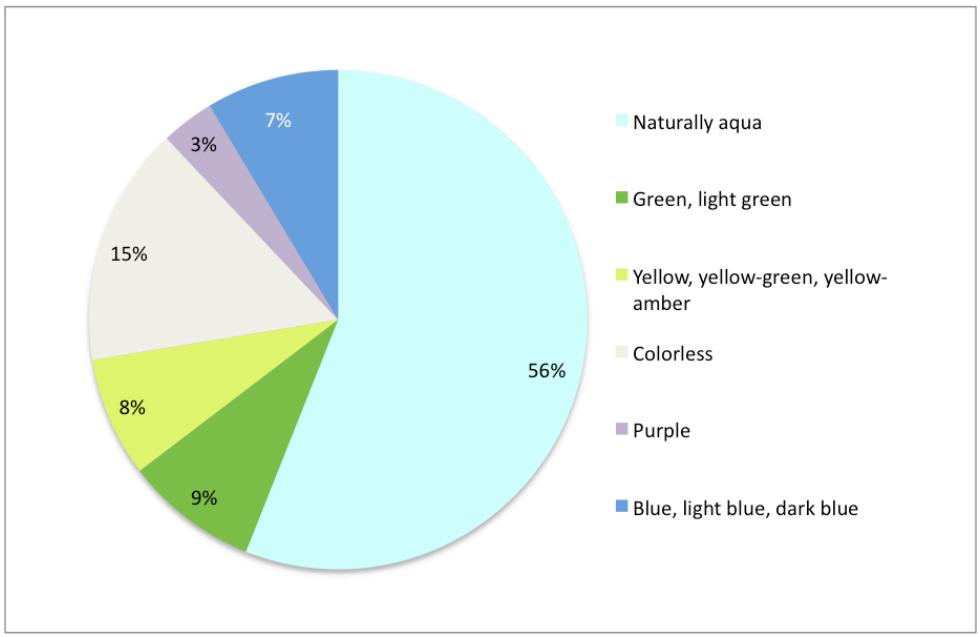
SUMMARY

Typological Summary

All but one of the Ḥiṣn al-Tīnāt vessels are of blown manufacture, with the unsampled molar flask being the only exception. Most of the vessels are plain, but the few that are decorated are done so using simple methods (colored blobs, pinched fins, molding, and impressing); decorative effects like grooves, incisions, facet-cutting, multiple wound-trails, pinched ribbing, appliqué, painting, enamel, silver stain, and luster are notably absent. Most of the fragments come from domestic vessels related to dining or to the *toilette*, including drinking and serving vessels (beakers, bowls, cups, jugs, and bottles) as well as small storage containers (bottles, flasks, and jars), some of which probably contained medicines, perfumes, or cosmetics. The vast majority of the vessels are on the green-blue color spectrum (Figure 4.26) although purplish, colorless, yellowish, brownish-yellow, and one fragment of darker blue glass are present as well; overall, this color scheme is consistent with glass produced in the Eastern Mediterranean during Late Antiquity.[28]

There are surprisingly few published reports of glass from post-7th century excavations in Turkey, Greece, or the other Byzantine territories, which makes it difficult

[28] Strongly colored, *millefiori*, and opaque glasses were fashionable during the Hellenistic and early Roman periods, but after the 1st century CE decolored or naturally colored glass dominated.



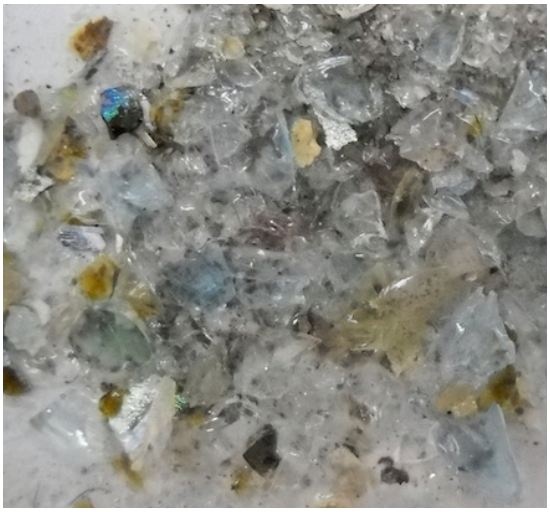


Figure 4.26: (Top) Pie chart of the color proportion of the Ḥiṣn al-Tīnāt samples; (bottom) photo of glass shatter from the assemblage, illustrating the range of colors (it should be noted that light green and purple are not shown although present at the site, and some of the seemingly "colorless" shatter actually comes from aqua glasses, which are too thin to reveal the true tint).

to have a meaningful comparative discussion of these areas[29] and further necessitates the bulk of comparisons be made with contemporary assemblages from the Islamic lands to

[29] This is especially frustrating for the site of Yumuktepe, also located on the southern coast of Cilicia, for which publications of the glass are extremely vague. For example, the glass specialist simply writes "the largest group consists of bottles of different forms, types, sizes, dimensions, colors, and ornamentations"

the south. The site of Amorium (central Turkey) is the exception, being the first and only extensive study of Middle Byzantine glass from a major site in Anatolia;[30] however, it should be emphasized that much of the glass is still only broadly dated to the 8th-12th or 10th-12th centuries CE, although a more narrow chronology might be soon possible in light of recent research and planned future publications (Christopher Lightfoot, personal communication). Interestingly, "some characteristics of the plain, utilitarian glassware of Amorium find their closest parallels among the glass of the Islamic world," as when the finds are compared to sites like Beirut and Qal'at Sem'an; this is also true for Ḥiṣn al-Tīnāt, which should not be surprising considering that "both the Early Islamic and Byzantine glass industries followed a tradition founded in the Late Roman period" (Lightfoot 2005: 175). Moreover, Ḥiṣn al-Tīnāt's location very much puts the site within the Syrian cultural region.

In many ways the vessels from the Ḥiṣn al-Tīnāt assemblage are strikingly similar to the types found at Amorium, especially in terms of rim and base shapes. The most interesting observations, however, are not the similarities of the glass assemblages but rather the elements of difference. There are a few vessel types from Ḥiṣn al-Tīnāt that are not present at Amorium, including large bowls (No. 189), bowls with a horizontal rib (KT025972), jars with an overhanging lip (No. 207), bubble-neck bottles (Nos. 169 and 203), and vessels with colored-blob decorations (Nos. 135 and 194). The opposite is also true, that there are vessel types from Amorium not present at Ḥiṣn al-Tīnāt. The most

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(Köruğlu 2009: 237) and does not provide any further description, nor does she give a catalog or any illustrations, which makes any degree of comparison impossible.

[30] In Anatolia "until now scholars have drawn largely on the material from Sardis or Corinth" (Lightfoot 2005: 179); the former was published in 1980 (with the latest glass dating to the 6th and first half of the 7th centuries) and the latter in 1952 (with the date of the glass a source of contention amongst scholars, but probably dating to the 11th-14th century).

common vessel types in 7th-11th century CE contexts at Amorium are wineglass-shaped lamps and fire-polished "blue-coil" bowls. Lamps of any type are absent from Ḥiṣn al-Tīnāt; on the one hand this is noteworthy because lamps—vessels with a stemmed foot (often described as wineglasses or goblets), vessels with a cylindrical stem (meant to be placed in a candelabrum), or vessels with three or more small loop-handles (for suspension)—are almost ubiquitous in Byzantine assemblages from the 5th century CE onwards, but on the other hand this absence might perhaps be explained by the small size of Ḥiṣn al-Tīnāt and the lack of evidence for a religious building.[31] Trailed decoration (of the same glass or more often of a contrasting color like dark blue) was a common and fairly simple and cheap decorative method used for Byzantine glass from the 4th century onwards, so it is again surprising that this decorative feature is lacking among the finds of Ḥiṣn al-Tīnāt. Amorium's blue-coiled bowls are so similar and so consistent they likely represent a single period and place of manufacture, probably dating to the 11th century (Lightfoot and Ivison 2002: 260).

Several fragments from both Amorium and Ḥiṣn al-Tīnāt have very close parallels with 8th-12th century Islamic vessels, which suggests that there was some amount of importing taking place during this period. The most decorative vessels in the Ḥiṣn al-Tīnāt assemblage (the molar flask **KNH23501** and the marvered bottle **No. 225**) also happen to be the vessels that are most likely to be imports from Islamic lands; however, it should be stressed that these vessels were probably imported because of what they contained (medicines, perfumes, oils, or cosmetics) rather than for their own sake. The purple molded jar, **No. 208**, is another example of a container for an imported

[31] Glass lamps are typically (although not exclusively) associated with synagogues, churches, mosques, and monasteries; important public buildings also sometimes have remains of glass lamps.

commodity, possibly from the southern Islamic territories. At Amorium, Islamic imported glass includes impressed, dichroic, opaque red, and red streak fragments; only one example of Islamic marvered glass was found, a fragment from the rim and neck of a small bottle or flask of deep greenish-blue glass appearing black and decorated with opaque red festoons (Gill 2002: 162, 179, and Fig. 2/22, no. 334); it is similar in size but not shape or color to Ḥiṣn al-Tīnāt fragment No. 225.

Chemical Summary

Both mineral soda and plant ash soda glasses were identified in the Ḥiṣn al-Tīnāt sample set. The mineral soda glasses (49 samples) include three distinguishable groups that can be directly compared with the groups that have been characterized primarily by Freestone: Group 1 (with 27 samples) is chemically similar to the Egyptian II production group, Group 2 (with 12 samples) is chemically similar to the Levantine 1 production group, and Group 3 (with 10 samples) is chemically similar to the Levantine II production group; there are some samples that do not fit neatly into these groups although they share many characteristics, but these outliers are likely the result of the common practice of recycling.

The plant ash soda glasses (64 samples) consist of a core cluster that may be divided into two sub-groups based on their trace element concentrations, Groups 4 (with 33 samples) and Group 5 (with 14 samples); there is also a number of outlier samples that are distinct from this core cluster, two sub-groups might be distinguished based on their trace elements (subgroups A and B) but overall they vary in their compositional profiles. Most of the glasses were naturally colored through the effects of iron impurities in the

raw materials; some were made bluer by the addition of colorants such as copper or cobalt, while the purplish and colorless fragments were colored or decolored by adding manganese to the batch.

CHAPTER FIVE: GLASS JEWELRY FROM ḤISN AL-TĪNĀT, ANALYTICAL RESULTS

INTRODUCTION

This chapter presents the results of the typological and chemical analyses of 16 glass bracelets from the site of Ḥiṣn al-Tīnāt in southern Turkey. These fragments are unique objects in the assemblage and arguably the most interesting as well. Although these objects are clearly a minority component of the assemblage, they are more diagnostic than many vessel fragments and thus possibly have a greater potential to address issues of glass use and circulation. There is no evidence for a fashion of glass bracelets in either Europe or the eastern Mediterranean region until the end of the 3rd century CE, but thereafter bracelets became the most prevalent type of glass jewelry (Spaer 1988: 51; Antonaras 2011: 323); as objects of personal adornment, they thus represent cultural tastes and styles more readily than do everyday household objects.

Maud Spaer initiated the study of glass bracelets in the Near East, focusing on the pre-Islamic (1988) and Islamic bracelets (1992) found in Palestine. Spaer's basic typology has been a fundamental starting point for the analysis of glass bracelets in the Roman and post-Roman world, but the following discussion will make it clear that the Ḥiṣn al-Tīnāt bracelets may have more in common with bracelets found in southeastern Europe and Anatolia than they do with those of Palestine; unfortunately there is no publication from this region that is of similar scale or synthesis. Spaer's basic typology is

frequently referenced below because of the clarity of her classification scheme, but more important comparisons are made with finds from Amorium (Gill 2002), Sagalassos (Lauwers *et al.* 2010), Mersin-Yumuktepe (Köruğlu 1998, 2009, 2010; Derviş 2006), and Sardis (von Saldern 1980) in Turkey as well as with Corinth (Davidson 1952) in Greece and Djadovo (Borisov 1989) in Bulgaria; more general comments made by glass specialists of Byzantine glass (Antonaras 2006) and Late Antique European glass (Haevernick 1960) are also considered.

TYPOLOGICAL ANALYSIS

The Ḥiṣn al-Tīnāt bracelets have an average external diameter of 6 cm, and range from 4 to 8 cm in diameter; the smallest (**No. 243**) may have been intended for a child. Three basic types—oblong, rounded, and peaked—can be distinguished, although these cross-section shapes are sometimes further manipulated for decorative purposes (Table 5.1 and Figure 5.1). Two of the oblong types are plain (**No. 150, 222**), one has a central depression (**No. 235**), two have horizontal ribbing (**Nos. 118** and **146**), and one is painted (**No. 174**). The three peaked, carinated, or slightly pointed types (**Nos. 147, 198,** and **243**) vary in the sharpness of their peaks but are all of plain monochrome glass. Of the seven rounded types (**Nos. 152, 153, 163, 167, 188, 191,** and **217**), six are spirally twisted (**Nos. 152, 153, 163, 167, 188,** and **217**) and one is painted (**Nos. 191**).

There are two possible manufacturing techniques for these bracelets: the first involves bending a glass strap or cane into a circle and joining the two ends, and the second involves piercing a blob of hot glass and rotating it on a rod to expand it into the desired size; only the first method leaves a visible seam, unless the bracelet is reheated to

No.	Color	Cross-section	Manufacture or decoration	Ext. diam.	Unit (locus-lot)	Date (based on ceramics)
118	Colorless and purple	Oblong, flat interior and ridged exterior	Four fused canes	7 cm	TF8 (3-5)	10th-12th c.
146	Aqua (bluish)	Oblong, flat interior and ridged exterior	Three fused canes	6 cm	TF9 (2-4)	11th-12th c.
147	Aqua (greenish)	Slightly peaked	One large strap or cane	6 cm	TF9 (2-4)	11th-12th c.
150	Aqua	Oblong	One large strap or cane	6 cm	TF9 (4-17)	10th-12th c.
152	Aqua	Rounded	Twisted (loose) cane	?	TF9 (4-18)	11th-12th c.
153	Dark blue	Rounded	Twisted (tight) cane	6 cm	TF9 (6-57)	11th-12th c.[1]
163	Dark blue	Rounded	Twisted (tight) cane	5 cm	TF9 (9-13)	11th-12th c.
167	Dark blue	Rounded	Twisted (tight) cane	6 cm	TF9 (13-47)	9th-10th c.
174	Aqua	Oblong	One strap or cane; opaque yellow background with red dots/hashes (silver stain decoration)	5 cm	TF9 (16-33)	9th-10th c. (mixed EI and MB)
188	Dark blue	Rounded	Twisted (loose) cane	8 cm	TF9 (18-40)	~ 10th c.
191	Aqua	Rounded	Single cane; opaque yellow background with brown chains and central red dots (silver stain decoration)	6 cm	TF9 (19-48)	11th-12th c.
198	Dark blue	Peaked	One strap or cane	6 cm	TF9 (23-59)	8th-10th c.
217	Colorless and purple	Rounded	Twisted, internal purple thread	6 cm	TF11 (1-1)	surface
222	Blue	Oblong	One strap or cane	7 cm	TF11 (2-4)	11th-12th c.
235	Aqua (greenish)	Oblong	One strap or cane; slight central depression on exterior	6 cm	TF11 (6-16)	11th-12th c.
243	Light blue	Peaked	One strap or cane	4 cm	TF12 (13-14)	11th-12th c.

Table 5.1: Summary of the glass bracelets from Ḥiṣn al-Tīnāt. Abbreviations are as follows: EI = Early Islamic; MB = Middle Byzantine.

[1] Radiocarbon AMS (accelerator mass spectrometry) dates became available on 20 February 2012; although the results need to be inspected more closely, TF9.6.57 dates to ca. 1020-1150 CE (Asa Eger, personal communication).

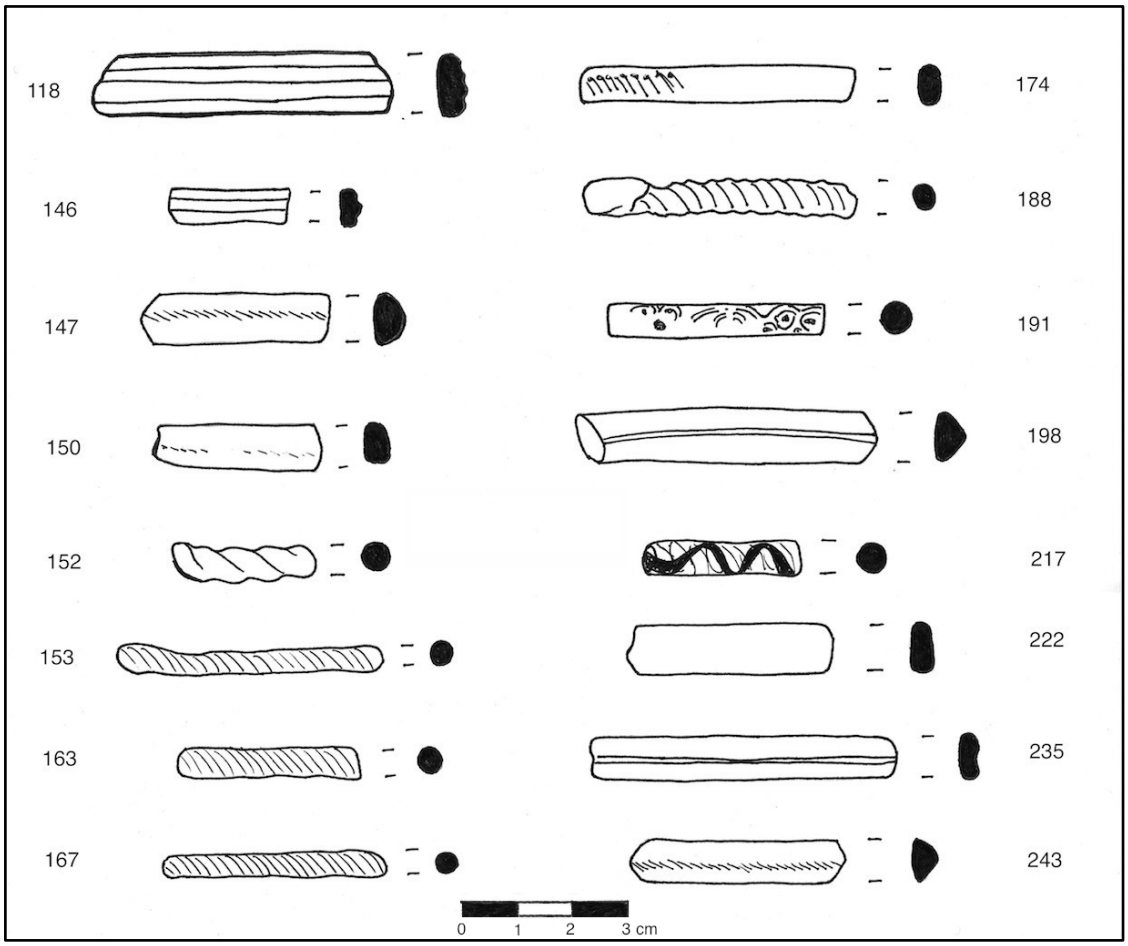

Figure 5.1: Line-drawings of the glass bracelets from Ḥiṣn al-Tīnāt (ordered by sample number), showing both the manufacture/decorative technique and the cross-section shape and size.

disguise the seam. Bangles with rounded or peaked sections were most likely made using the seamed method, whereas those with an oblong or flat section probably used the seamless method (Spaer 1988: 52; Antonaras 2006: 426-427); however, these techniques cannot be directly confirmed for the Ḥiṣn al-Tīnāt samples because of their highly fragmentary nature.

Oblong Cross-Section

Two of the Ḥiṣn al-Tīnāt fragments with an oblong cross-section (**Nos. 150** and **222**) are of undecorated monochrome glass, one naturally aqua and the other blue. These fragments fall into Spaer's Type A "monochrome, undecorated" group but do not fit neatly into her sub-typology; they are somewhat similar to her Subtype 2b "semicircular, flattened" variety, but they also share characteristics with her Subtype 3 "flat" variety (1992: 48 and Table 1). Much closer parallels come from Anatolia, in particular the Type 1 "seamless, plain semi-circular" and the Type 2 "seamless, plain, flat" green and dark blue bracelets from 10th-13th century contexts at Sagalassos (Lauwers *et al.* 2010: 145-146, Fig. 2 nos. 1 and 2), as well as the Type II.1.b "undecorated" with "an oval cross section" bracelets from Amorium (Gill 2002: 79).

Greenish-aqua **No. 235** has an almost flat cross-section with a central depression or groove, a shape that is lacking in the Levantine region but is found in Anatolia. Close parallels come from Amorium, including fragment no. 370 of greenish blue glass (Gill 2002: 83 and 107, fig. 1/22) and nos. 470, 496, and 543 in greenish blue, light blue, and dark blue glass (Gill 2002: 229 and Fig. 2/28). At Mersin-Yumuktepe, undecorated bracelets with "grooved" cross-sections were also found in contexts dating to the 11th-13th centuries (Köruğlu 2010: 37-38)[2] although because these bracelets are not illustrated the exact degree of similarity is unclear. A green bracelet with a similar central depression was also found amongst the 22 bracelets recovered from the 5th-7th century necropolis at Perrhe in south-central Turkey (Höpken 2010: 159 and Abb. 6, no. 89).

[2] My thanks to Müge Durusu-Tanıröver for her assistance in translating this Turkish publication.

Two of the Ḥiṣn al-Tīnāt fragments with an oblong cross-section and horizontal ribs, **Nos. 118** and **146**, fall into Spaer's Type B "tooled or molded, monochrome" Subtype 4 "horizontal ribbing, mainly seamed" variety (1988: 57; 1992: 48, Table 1; 2001: 194). Spaer dates horizontal ribbed bracelets to the Early Byzantine[3] period; she notes the type is not particularly common in Palestine[4] (2001: 196), but was a dominant type in purple glass at Resafa in the 6th-early 7th centuries (1988: 57).[5] Bracelet **No. 118** is notably made from a light purple glass but the similarities end there, as the Resafa bracelets all have multiple horizontal ribs and are much wider and thinner in cross section. The Ḥiṣn al-Tīnāt fragments have three to four ribs and are relatively flat in section, a combination for which it is indeed difficult to find exact parallels in the Near East—most of Spaer's examples have 5-9 horizontal ribs.[6] Many examples from Amorium also have 6-9 horizontal ribs (Gill 2002: 107 and Fig. 1/22, nos. 329 and 392), but several bracelets closely match the Ḥiṣn al-Tīnāt fragments and are described as having a grooved cross-section and molded profile, including nos. 339, 391, and 416 (Gill 2002: 107 and Fig. 1/22; 229 and Fig. 2/28). The closest overall parallel in terms of size and shape is a cobalt-blue fragment with a flat cross-section and three ribs from Sagalassos (Lauwers *et al.* 2010: 147-149, Fig. 2 no. 8). Finds from 11th-12th century contexts at Djadovo in Bulgaria described as "flat bracelets with fluted face sides"

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[3] First appearing in the 6th and early 7th centuries CE—or possibly as early as the 5th century—and then continuing into the Islamic period (Spaer 1988: 60).

[4] The few examples come from the Tyropoeon Valley, Jerusalem, and Kafr Kama (Spaer 1988: 57).

[5] The examples from Resafa are "violettpurpurnen bis dunkelvioletten" (Mackensen 1984: 59, Pl. 18 no. 15, Pl. 19 no. 17, Pl. 23 nos. 35 and 36, Pl. 28 no. 9; Ulbert 1986: Pl. 74 no. 1977/2).

[6] Two fragments from Khirbet el-Minyeh have three ribs but a more rounded and pointed cross-section: one blue bracelet (Spaer 1992: 60-61 and Fig. 25, no. 2) from Mamluk contexts (ca. 13th century) and one "glossy purple(?), appearing black with strong horizontal streaks" fragment from 8th century CE contexts but "possibly intrusive" (1992: 59-60 and Fig. 24, no. 1).

(Borisov 1989: 293-294 and Fig. 349a) match this type, and give good evidence for a later date and wider geographic spread for this style. One fragment of "claret" color from Qal'at Sem'an is from 13th-14th century Mamluk contexts but it is assigned an Early Christian "typological date" of the 6th-7th centuries (Dussart *et al.* 2004: 70-71, no. 13), likely because of Spaer's chronology.

Rounded Cross-Section

Six of the Ḥiṣn al-Tīnāt fragments with a rounded cross-section are of Spaer's Type C "spirally twisted" variety. Spaer identifies several subtypes, including Subtype 1a "monochrome with a dense twist," Subtype 1b "monochrome with a loose twist," and Subtypes 2 through 5 "multicolored with trails." Three of the monochrome dark blue Ḥiṣn al-Tīnāt bracelets have such a dense twist (**Nos. 153, 163**, and **167**); another monochrome dark blue bracelet has a loose twist (**No. 188**), as does one monochrome aqua bracelet (**No. 152**) and one polychrome example of a colorless bangle with an internal purple thread (**No. 217**).

The spirally twisted bangle is a common and long-lasting type in all regions. In Palestine, monochrome twisted bracelets of a variety of sizes and colors are first seen during the 4th-5th centuries CE and became quite frequent during the late Byzantine period (Spaer 1988: 60; Spaer 2001: 195-196); the majority of pre-Islamic monochrome twisted bracelets are of the densely twisted rather than the loosely twisted variety (Spaer 1988: 59). Of the 2000 fragments found at Qasr al-Hayr as-Sharki in Syria, 95% are green, dark blue, or opaque black monochrome twisted bracelets, although "in a few instances, a thread of a different color is twisted with the main body" (Salam-Liebich

1978: 145).[7] In contrast to the horizontal ribbed bracelets, twisted bracelets were not characteristic of the finds from Resafa, where one example in light yellow-green glass was found (Mackensen 1984: 59 and Tf. 32 no. 20). Somewhat later parallels come from Mamluk period contexts at Quseir al-Qadim on the Red Sea in Egypt (Meyer 1992: 92) and 10th-14th century CE 'Abbāsid-Mamluk contexts at Qal'at Sem'an (Dussart *et al.* 2004: 70-71, nos. 14-16), although the latter are assigned a Late Roman to Early Christian "typological date" of the 6th-7th centuries (probably influenced again by Spaer's chronology). Twisted bracelets from southeastern Europe, Greece, and Anatolia confirm that this was a widespread type: monochrome spirally twisted glass bracelets were present in Corinth (Davidson 1952: 263, nos. 2143 and 2147), 11th-12th century contexts at Djadovo (Borisov 1989: 293, 295 and Fig. 351), 11th-13th century contexts at Mersin-Yumuktepe (Köruğlu 1998: 289 and Fig. 7, nos. 1-16; 2010: 37-38), in 10th-13th century contexts at Sagalassos (Lauwers *et al.* 2010: 147-148, Fig. 2 no. 6), and in Late Roman and Byzantine contexts at Amorium (Gill 2002: nos. 423-448).

Twisted bracelets with spiraled trails in contrasting colors appear to date exclusively to the Islamic and later periods in Palestine (Spaer 2001: 196) and Byzantine and later periods elsewhere.[8] A much more uncommon variation of this type is colorless glass with internal colored spirals; colorless **No. 217** with its internal purple thread is thus unique among the Ḥiṣn al-Tīnāt twisted bracelets. Spaer suggests that this variation

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[7] The dating of these bracelets is quite vague: the 6th-9th centuries is suggested by Lamm but the 8th-10th or 12th-14th centuries may be more likely based on the occupation history of the site.

[8] Examples from Jordan include Jerash (Meyer 1988: 214-216, Fig. 13 nos. bb and w). Examples from Turkey and Greece include 10th-13th/14th centuries contexts at Sardis (von Saldern 1962: 12, Pl. 7 no. 20; 1980: 98-101), Amorium (Gill 2002: 88-92 and 203-206, Type 1b and 2: Nos. 449-486, and 592-633), Yumuktepe (Köruğlu 1998: 289 and Fig. 7, nos. 1-16; 2010: 37-38), Gritille (Redford 1986: 122, 131, and Fig. 13, nos. G and H), and Corinth (Davidson 1952: 263-264). Examples also come from 11th-12th century contexts at Djadovo (Borisov 1989: 293, 296 and Fig. 352).

largely dates to after the 14th century and was likely produced in Hebron in the Palestinian Territories (1992: 46-49).[9] However, this type has been observed in Turkey and Greece during the Middle Byzantine period as well (Antonaras 2006: 428);[10] for example, one colorless twisted bracelet with yellow and opaque-white internal threads and another of dark green with two lighter internal threads were found at Amorium (Gill 2002: 91, 108, and Fig. 1/23, nos. 468-469). In light of this, No. 217 is more likely to be a local object from the Middle Byzantine period rather than a late Medieval or early modern contaminant coming from the southern Levant.

Painted Decoration

One bracelet fragment with an oblong cross-section (**No. 174**) and one with a rounded cross-section (**No. 191**) are decorated with painted geometric designs (Figures 5.2 and 5.3); the former has red slanted lines with one rounded end on an opaque yellow background while the latter has a opaque whitish background with a brown net pattern filled with red dots. The geometric designs are clearly painted onto the bracelets' surface, but the substance used to paint them is more problematic; possibilities include enamel, metallic-stain (typically silver, but also gold and copper), or a simple mineral or organic paint. Because the method of decoration is not easily discernable to the naked eye, there

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[9] Crowfoot comments that such a bracelet industry at Hebron had a very long production history: "it is extremely difficult to date glass bracelets in Palestine, for those made at Hebron today seem to reproduce faithfully the old coloring and old designs, ribbed, twisted, or plain" (1957: 419).

[10] "Σπανιότερη παραλλαγή αποτελεί η χρήση χρωματιστής ίνας στο κέντρο μάζας διαφανούς γυαλιού, που επιμηκυνόταν και συστρεφόταν" (my translation: "The most rare variety [of the spirally twisted bracelet] is the use of colored threads in the center of a transparent mass of glass, stretched and twisted").

Figure 5.2: (Above) Photograph of No. 174, a fragment of a bracelet with an oblong cross-section and silver-stained decoration.

Figure 5.3: (Above) Photograph of No. 191, a fragment of a bracelet with a circular cross-section and silver-stained decoration.

is a problem with the descriptive terminology within the published literature.[11] The precise identification of the painted substance is important, however; although all the possible processes involve "painting" a liquid or semi-liquid onto the surface of an object

[11] Descriptions of the material used to decorate "painted" medieval bracelets vary in publications (or are not described at all), and in some cases may be incorrect—the problem is compounded for early publications or those published in English by a non-native speaker. When photographs are actually published, they are almost always in black-and-white and it is thus almost impossible to distinguish paint types.

with a brush, they vary significantly in terms of their material properties and fixing techniques (i.e., degree of specialization and difficulty of production) and therefore in their potential value or status; enameling and silver staining are inherently more specialized than the use of "regular" paint. Enamel is a finely powdered colored glass that is suspended in an oily medium, which vitrifies and adheres to an object's surface when heated; metallic stain is a mix of metallic salts (e.g., copper or silver oxide, chloride, carbonate, or sulphate) with a liquid medium that also "fixes" when heated, the metallic ions diffusing into the very glass matrix to produce a yellow, amber, or orange stain that in effect becomes part of the surface.

Without a microscopic examination of the surface of the fragments[12] it is not possible to say for certain whether the examples from Ḥiṣn al-Tīnāt are decorated with paint, metallic-stain, or enamel—although the latter seems unlikely because of the low relief of the designs.[13] The decorations look as though they are applied with red and brown paint on top of an opaque yellow or whitish base coat, but there is the possibility that these are actually metallic stained designs that have been altered by the weathering process.[14] Indeed it has been suggested that for the two painted Ḥiṣn al-Tīnāt bracelets, the designs were applied with silver-stain directly onto the translucent aqua glass

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[12] A microscopic examination requires a relatively large section of the bracelet's painted surface. However, only very small samples of glass were removed from the artifacts and exported for analysis so as to limit the invasiveness of this study.

[13] The use of enamel would leave a somewhat raised decorative surface: "αντίθετα από ότι συμβαίνει με το σμάλτο, δεν δημιουργείται κάποιο ανάγλυφο στην κοσμούμενη επιφάνεια, αλλά το χρώμα ενσωματώνεται στην επιφάνεια του σώματος" (Antonaras 2006: 428; my translation: "unlike the case of enamel, it does not create any relief in the surface, rather the color is embedded in the surface of the body").

[14] At Amorium "metals, gold and silver" were used to decorate bracelets, which is assumed to means they were stained; "where gold was used in the decoration, this is usually well preserved, with a bright polished appearance; but elsewhere there is only the slightest glint of gold on otherwise pale brownish orange to suggest it may have been applied sparingly or diluted with a base pigment. Silver was used more rarely and has tarnished to a nondescript matte" (Gill 2002: 207-208).

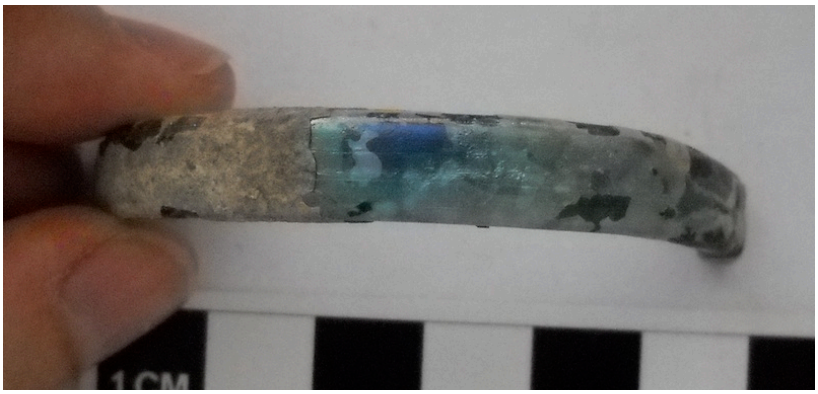

Figure 5.4: Undecorated, aqua-green glass bracelet fragment No. 235, showing similar weathering layers to Nos. 174 and 191?

Figure 5.5: Examples of silver-stained blue bracelet fragments from Amorium (Gill 2002: 182, Pl. 11-12).

(Anastasios Antonaras, personal communication). If this is the case, then the yellowish/whitish layers could merely be the weathering layers of the glass. Some of the weathering layers on the glass bracelets from Amorium are described as being a "hard shiny enamel-like surface with opaque creamy-white" discolorations or yellowish, brown or even brick red with iridescence beneath (Gill 2002: 183); a further comparison might be made with the weathering layers of the non-painted bracelets from Ḥiṣn al-Tīnāt like **No. 235** (Figure 5.4).

However, it is actually far from clear whether silver-stained designs are ever seen on top of such a weathering patina; moreover, the silver-stained bracelets from Amorium

do not look very similar to the Ḥiṣn al-Tīnāt examples (Figure 5.5),[15] as the silver stain of the former appears white and yellow in color rather than red and brown and there appears to be no surface patina at all (Gill 2002: 182, 20, 216-218 and Pl. 11-12, nos. 736, 741, 748, 663, and 744[16]); when there is a patina, it appears that this forms *over* the stained design, thus obscuring it. The most convincing evidence that the painted designs of No. 174 and 191 are not precisely metallic-stained come from the site of Djadovo. At this site, 808 bracelet fragments were recovered from the 11th-12th century CE necropolis, including many examples with silver-stained designs. Three fragments of painted bracelets from Grave no. 13 are of particular interest:

> Unlike the [silver-stained] painted bracelets discussed above, the ornaments on those from grave No. 13 were not lasting and *they lie over a solid irization layer*, which is an indication that they were not baked. Moreover, it is well known that the irization is due not only to soil conditions, but also to the chemical composition of the glass. Therefore, the bracelets from grave No. 13 must have another composition[17] (Borisov 1989: 291-292; my italic emphasis).

In short, these painted bracelets are distinct from the others found at the site because the painting is on top of a weathering ("irization") layer—just like those at Ḥiṣn al-Tīnāt—and is interpreted by the author as indicating a metal oxide paint was applied, but not fixed through subsequent heating (Borisov 1989: 290). It seems quite likely that the Ḥiṣn al-Tīnāt bracelets were produced in a similar way.

At Sardis, one blue bracelet with an oblong cross-section with "two rows of painted circles bounded by two lines and interrupted by at least one pair of lines" was

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[15] It should be noted that these Amorium fragments are the only silver-stained bracelets found that are published in color.

[16] Although the silver details of no. 744 "appear as matt brown and are difficult to discern" (Gill 2002: 217).

[17] That these bracelets are thought to have a different composition in addition to a different method of decoration will be taken up below in the discussion of the chemical results.

found in Middle Byzantine contexts dating to the 10th-early 13th/14th centuries CE (von Saldern 1980: 101, Pl. 18 no. 779);[18] "the color of the painted decoration is unknown" as von Saldern worked from a photograph and did not actually see the object in person. At least 15% of the bracelets found at Amorium—usually those that are blue or green glass with a round or flat cross-section—have "painted"[19] decoration and are grouped together as Type 4 (Gill 2002: 92-98; Figs. 1/25, 1/26, 1/27, 1/28, and 1/29 nos. 489-558). Two Amorium fragments of "green" glass bracelets with rounded sections are strikingly similar to **No. 191**. The painted design of Amorium no. 516 (Figure 5.6) consists of a "white honeycomb pattern of cells containing red circles" that is "obscured by creamy enamel-like weathering" (Gill 2002: 95 and 109, Fig. 1/26), while no. 692 has a "white honeycomb pattern consisting of two scalloped lines with zigzag between linking crests and forming two rows of cells, each containing a red circle" with a "creamy scummy weathering over entire surface, with flaking; pattern only visible in places" (Gill 2002: 212 and 232, Fig. 2/34).

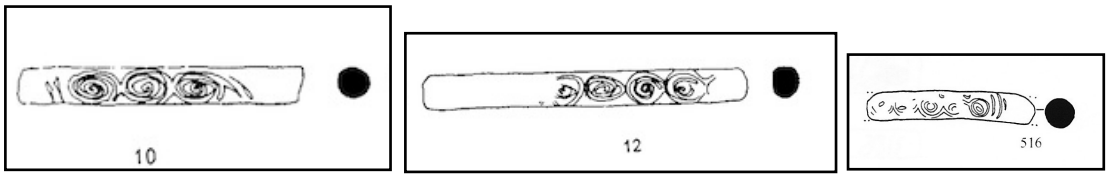

Figure 5.6: Examples of "enameled" glass bracelets from Mersin-Yumuktepe (left and center) and "painted" glass bracelets from Amorium (right) that resemble No. 191 (drawings from Köruğlu 1998: 231 and Fig. 8, nos. 10 and 12; Gill 2002: 109 and Fig. 1/26, no. 516)

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[18] These bracelets are dated generally as Middle Byzantine, because unclear stratigraphy does not allow for any narrower dating (von Saldern 1980: 98).

[19] The exact medium of the painting is not discussed. The most common color is white, and other colors include "pale blue, brick red, primrose yellow, orange, gold and probably silver." The white and pale blue could be paint or enamel although the red, orange, yellow and metallic colors suggest the use of metallic stain.

Several fragments recovered from 11th-13th century CE contexts at Mersin-Yumuktepe (Köruğlu 2009: 243, Fig. 13) are also similar in shape and design appearance to the Ḥiṣn al-Tīnāt examples (Figure 5.6). These are described as being decorated with spirals, stylized branches, hatches, crosses, birds, snakes, triangles, and text designs (Köruğlu 2010: 37-38). The technique that is used to decorate the Mersin-Yumuktepe fragments is not exactly clear, as the bracelets are described as "embroidered" in the text, but the illustration is labeled as "drawings of enameled glass bracelets."[20] Similar bracelets were also found in 10th-13th century contexts at Sagalassos; some of these were flat in section and others were round, and most were made of cobalt blue glass with circles, lines, and spirals painted in white, yellow, or pale blue "enamel" (Lauwers *et al.* 2010: 146-148, Fig. 2 no. 3 and Fig. 3)—only one example of these is included as a photograph, but it is not possibly to verify whether the design is indeed made with enamel.

Several bracelet fragments with "painted designs" were also discovered at medieval Corinth. These are described in the site report as a new type of bracelet that probably first appeared around the beginning of the 11th century CE (Davidson 1952: 262). The 15 examples described in the catalog are of blue-green glass[21] typically having oblong or rounded cross-sections and decorated with "scrolls, zigzags, circles, saltires, running loops" and more rarely with birds or religious inscriptions (Davidson 1952: 262-265, Fig. 63, Pl. 112-113 nos. 2148-2162). These designs are described as "cold-painted"

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[20] The edited volume is published in English, but unfortunately this article is quite poorly translated and edited, and as a result is very difficult to understand. Without good-quality photographs it is not possible to independently determine whether the design is indeed raised from or absorbed into the surface as described by Antonaras (2006: 428).

[21] Specifically described as turquoise blue, blue-green, blue, dark blue, or green glass; the exception was one amethyst-colored fragment, but it probably belongs to the late Byzantine period (Davidson 1952: 263).

and as produced with the same method used to decorate the vessels found in Corinth's "Agora South" glass workshop (Matson 1940); several of these bracelet fragments were also found in the "Agora Northeast" glass workshop, which Davidson suggests indicate they were locally produced at Corinth and thus shared decorative techniques with the nearby vessel glassmakers (Davidson 1952: 83-84, 88, 262).[22]

Peaked or Carinated Cross-Section

The peaked bracelets at Ḥiṣn al-Tīnāt (**Nos. 147, 198,** and **243**) correspond to Spaer's pointed Type A ("undecorated, monochrome") and are a combination of her Subtype 2a ("semicircular rounded") and Subtype 4 ("evenly pointed with a strong point").[23] In Palestine, peaked cross-sections are "exclusively Islamic" in date (Spaer 1988: 52-53) and are suggested to be Mamluk or later (Spaer 1992: 48).[24] However, this type is common in Byzantine Anatolia. Examples of undecorated monochrome bracelets with "triangular" or peaked cross-sections at Amorium vary in color and decorative method (Gill 2002: 107 Type II.1.f and fig. 1/22, nos. 335-336, 356, 476, 523, 524). Two peaked examples from Gritille date to the 11th century or later (Redford 1986: Fig. 13, objects A and M).

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[22] It should be remembered that the medieval Corinth glass factories were originally dated to the 11th-12th centuries CE (Davidson 1952: 264; Weinberg 1940, 1975), but were then redated to the 13th century CE (Whitehouse 1991).

[23] In the illustration in Spaer 1992 (48, Table 1), her Subtype 2a does not seem different enough to her Subtype 4b to be considered as two separate subtypes, and Spaer herself notes that the point need not be sharp and is often slightly rounded (Spaer 1992: 47).

[24] Spaer notes that the more strongly pointed bracelets are particularly characteristic of the Mamluk and later periods, and she suggests that a "slightly emphasized" point probably began in earliest Islamic times (1988: 60; 1992: 51; 2001: 195); perhaps the Ḥiṣn al-Tīnāt peaked examples fall between Spaer's A2a and A4 types because they are indeed earlier in date (i.e., prior to 13th century).

CHEMICAL ANALYSIS

The chemical analysis of glass bracelets is by no means common. Sites that do have chemical data for medieval bracelets from the Byzantine and Islamic regions include Sagalassos (Lauwers *et al.* 2010), Amorium (Wypyski 2005), Mersin-Yumuktepe (Derviş 2006), and Mezraa Höyük in Turkey (Derviş 2006); Drastar Castle/Silistra (Georgieva *et al.* 2010a and 2010b) and Djadovo (Borisov 1989) in Bulgaria; Qasr al-Hayr as-Sharki (Brill 1999a and 1999b) and Raqqa (Henderson *et al.* 2004) in Syria; Fusṭāṭ in Egypt (Brill 1999a and 1999b); as well as Tell Abu Sarbut and Khirbat Faris in Jordan (Boulogne and Henderson 2009). Although data from these sites will be referenced in order to better interpret the chemical results of the Ḥiṣn al-Tīnāt bracelets, these publications all have certain (and sometimes severe) limitations, as will be seen in the discussions below.

The results of chemical analyses for the Ḥiṣn al-Tīnāt bracelets are given in Tables 5.2 and 5.3, which shows that nearly all were made using a soda-rich plant ash as an alkali; sample **No. 222** is the only example that is made using mineral soda as a flux, but, as suggested in the previous chapter, this fragment may very well be a handle from a vessel. The 15 bracelets made from plant ash soda will therefore be the primary focus of the following discussion. These samples are easily divided into three highly distinctive chemical groups (Figure 5.7 and Table 5.4) termed here Groups A, B, and C; the differences between these are most clearly illustrated in terms of their alumina and boron contents, and also correspond somewhat to glass color and often to bracelet shape and/or decorative technique as well.

Table 5.2: <u>HIṢN AL-TĪNĀT BRACELETS</u>: chemical results (major and minor oxides, and colorants/decolorants) given in wt% oxide.

Sample ID #	Color	SiO2	Na2O	K2O	CaO	MgO	Al2O3	Fe2O3	TiO2	MnO	P2O3	CuO	CoO	PbO2	Sb2O5	SnO2	B2O3
Group A: Glasses Similar to Group 4																	
118	Colorless, purple	67.74	11.43	2.56	9.76	2.75	2.09	0.70	0.04	1.93	0.33	0.18	0.00	0.02	0.00	0.00	0.02
146	Aqua (bluish)	70.28	11.79	2.79	7.72	1.95	1.07	0.63	0.02	0.04	0.36	1.66	0.00	0.98	0.01	0.42	0.02
152	Aqua	69.24	11.29	2.31	10.65	2.16	2.00	0.72	0.06	0.75	0.41	0.00	0.00	0.00	0.00	0.00	0.02
217	Colorless, purple	70.49	12.13	2.26	8.10	2.78	1.68	0.54	0.05	1.16	0.32	0.01	0.00	0.00	0.00	0.00	0.02
Group B: High Boron Glasses																	
147	Aqua (greenish)	64.20	13.77	1.75	11.72	2.74	2.62	2.98	0.05	0.04	0.08	0.00	0.00	0.00	0.01	0.00	0.69
150	Aqua	66.44	13.40	1.47	10.75	2.76	2.78	2.08	0.07	0.05	0.09	0.00	0.00	0.00	0.01	0.00	0.81
174	Aqua	64.43	14.39	1.56	12.47	2.55	2.46	1.77	0.06	0.04	0.14	0.00	0.00	0.00	0.01	0.00	0.85
191	Aqua	62.49	15.24	1.67	12.43	2.83	2.93	2.16	0.06	0.05	0.08	0.00	0.00	0.00	0.01	0.00	0.73
235	Aqua (greenish)	62.28	15.71	1.60	12.25	2.80	2.80	2.26	0.07	0.06	0.09	0.00	0.00	0.00	0.01	0.00	0.82
Group C: High Alumina-High Boron Glasses																	
153	Dark blue	54.28	18.87	3.94	5.88	5.06	9.76	1.52	0.07	0.11	0.26	0.09	0.08	0.01	0.00	0.00	0.65
163	Dark blue	54.35	20.80	3.96	5.10	4.10	9.46	1.57	0.08	0.09	0.20	0.09	0.07	0.01	0.00	0.00	0.54
167	Dark blue	52.98	20.28	4.14	6.01	4.46	10.07	1.41	0.07	0.08	0.17	0.06	0.06	0.01	0.00	0.00	0.42
188	Dark blue	59.87	19.83	4.48	1.69	1.25	10.55	1.61	0.04	0.03	0.23	0.15	0.04	0.01	0.00	0.00	0.38
198	Dark blue	54.50	19.14	4.13	5.15	4.47	10.47	1.53	0.06	0.08	0.23	0.10	0.07	0.00	0.00	0.00	0.61
243	Light blue	52.65	20.33	3.79	6.44	5.21	9.29	1.53	0.08	0.14	0.27	0.09	0.04	0.00	0.00	0.00	0.64
Outlier (mineral soda, possible handle?)																	
222	Blue	67.85	16.07	1.22	8.06	1.69	2.01	1.71	0.05	0.50	0.21	0.10	0.07	0.04	0.00	0.00	0.18

Table 5.3: HIṢN AL-TĪNĀT BRACELETS: chemical results (trace elements) given in ppm.

Sample ID #	Color	Li	Be	B	Sc	Ti	V	Cr	Ni	Co	Zn	As	Rb	Sr	Zr	Nb	Ag	Sb	Cs	Ba
Group A: Glasses Similar to Group 4																				
118	Colorless, purple	7.5	0.6	63.5	2.9	235.1	19.3	18.3	15.7	8.1	32.7	0.0	14.8	521.5	45.9	2.7	0.5	1.7	0.2	276.7
146	Aqua (bluish)	15.8	0.7	70.3	2.3	139.2	11.2	38.6	36.0	5.3	44.7	74.9	8.8	247.7	33.8	1.6	8.0	21.4	0.2	36.6
152	Aqua	5.4	0.5	63.5	2.7	377.1	16.3	17.1	10.3	3.7	27.1	3.5	12.5	531.5	37.3	2.5	0.1	0.4	0.1	227.9
217	Colorless, purple	4.7	0.5	66.2	3.1	278.6	14.3	10.7	8.4	3.6	24.9	0.0	14.2	389.1	32.9	2.1	0.0	0.1	0.1	195.0
Group B: High Boron Glasses																				
147	Aqua (greenish)	493.3	2.0	2147.6	4.4	274.8	28.5	79.0	88.8	7.9	29.2	57.6	104.3	2366.1	32.4	4.3	0.1	56.0	62.6	95.7
150	Aqua	441.6	1.7	2508.7	4.2	406.9	24.4	73.2	78.2	8.7	24.5	48.9	78.9	1955.0	30.4	3.7	0.4	39.2	47.4	87.7
174	Aqua	496.1	1.0	2651.8	3.4	386.9	19.4	67.3	56.0	6.0	25.4	40.5	72.7	2439.1	37.0	3.3	0.1	29.1	46.8	76.2
191	Aqua	464.4	1.6	2261.4	4.7	336.7	26.4	73.4	82.6	8.0	23.4	39.1	84.1	2273.9	33.7	4.1	0.3	31.1	52.2	84.0
235	Aqua (greenish)	489.3	1.0	2545.4	4.6	391.4	24.9	68.1	76.0	7.4	23.5	35.5	81.4	2195.4	32.0	3.7	0.3	34.4	48.8	85.7
Group C: High Alumina-High Boron Glasses																				
153	Dark blue	125.1	2.9	2016.4	4.7	395.6	14.4	15.9	26.9	657.5	131.9	11.5	92.7	241.2	101.5	23.4	0.3	1.7	1.8	201.5
163	Dark blue	112.3	2.5	1676.7	4.7	490.3	12.2	9.5	17.9	568.3	134.1	4.9	112.4	246.2	116.3	29.3	0.3	1.3	2.1	241.0
167	Dark blue	110.2	2.6	1318.5	5.1	409.4	12.4	6.8	14.8	482.4	94.0	5.3	114.9	284.8	126.4	31.1	0.2	0.9	2.0	248.8
188	Dark blue	90.7	3.8	1189.9	2.7	213.2	3.8	5.3	12.5	295.8	376.2	4.6	195.7	62.6	96.4	27.9	0.5	3.8	5.9	25.8
198	Dark blue	114.1	3.2	1882.7	4.9	360.7	10.9	5.7	20.7	535.4	111.6	12.2	104.3	215.9	107.6	26.4	0.3	1.8	1.9	215.6
243	Light blue	129.1	2.1	1996.3	4.6	496.5	15.1	15.0	24.5	283.6	94.9	4.8	84.3	271.0	93.4	22.0	1.3	2.1	1.4	207.2
Outlier (mineral soda, possible handle?)																				
222	Blue	45.1	0.6	571.3	3.1	289.8	17.6	20.0	23.6	512.9	130.1	37.3	16.2	389.6	36.3	2.2	0.3	11.0	3.9	148.8

Sample ID #	Color	La	Ce	Pr	Ta	Au	Y	Bi	U	W	Mo	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Th
Group A: Glasses Similar to Group 4 – CONTINUED																								
118	Colorless, purple	6.4	12.3	1.5	0.1	0.0	8.2	0.1	0.3	0.7	4.5	6.2	1.4	0.2	1.4	0.2	1.0	0.2	0.6	0.1	0.5	0.0	0.9	0.9
146	Aqua (bluish)	5.0	9.9	1.2	0.1	0.2	5.5	2.6	1.7	0.1	1.4	4.6	1.0	0.2	0.9	0.1	0.8	0.2	0.4	0.1	0.5	0.1	1.0	1.6
152	Aqua	5.9	11.4	1.5	0.1	0.0	6.6	0.0	0.5	0.2	2.0	5.6	1.1	0.3	1.0	0.1	1.0	0.2	0.6	0.1	0.5	0.1	1.0	0.9
217	Colorless, purple	5.1	10.9	1.4	0.1	0.1	6.0	0.0	0.3	0.3	2.9	5.1	1.0	0.3	0.9	0.2	0.9	0.2	0.5	0.1	0.5	0.1	0.8	0.7
Group B: High Boron Glasses – CONTINUED																								
147	Aqua (greenish)	8.4	18.3	2.1	0.3	0.9	11.1	0.6	2.0	0.7	1.7	7.3	1.6	0.3	1.6	0.2	1.6	0.4	1.2	0.2	1.2	0.2	0.9	2.9
150	Aqua	7.2	14.8	1.8	0.2	0.0	7.8	0.0	1.5	0.6	1.3	6.3	1.3	0.2	1.1	0.2	1.2	0.3	0.7	0.1	0.8	0.1	0.9	2.7
174	Aqua	6.3	12.2	1.5	0.2	0.0	6.9	0.0	1.0	0.7	0.8	5.3	1.1	0.2	0.9	0.2	1.2	0.2	0.6	0.1	0.7	0.1	0.9	2.4
191	Aqua	7.6	14.6	1.7	0.2	0.0	9.0	0.0	1.3	0.6	1.2	6.3	1.4	0.3	1.5	0.2	1.3	0.3	0.8	0.1	0.9	0.1	1.0	2.8
235	Aqua (greenish)	7.2	14.1	1.7	0.2	0.3	8.9	0.0	1.4	0.7	1.2	6.3	1.6	0.3	1.6	0.3	1.9	0.4	1.0	0.2	1.3	0.1	0.9	2.6
Group C: High Alumina-High Boron Glasses – CONTINUED																								
153	Dark blue	23.5	47.4	5.5	1.2	1.1	33.0	0.3	4.4	1.7	4.8	19.5	4.6	0.8	5.3	0.7	5.0	1.1	3.1	0.6	3.2	0.4	3.0	17.2
163	Dark blue	27.2	57.0	6.6	1.4	0.1	38.6	0.2	5.0	1.6	5.9	22.5	5.7	0.8	5.1	0.9	5.8	1.2	3.5	0.5	3.6	0.6	3.5	19.3
167	Dark blue	27.8	57.5	6.9	1.3	0.1	42.5	0.1	5.2	1.6	5.1	24.1	6.2	0.9	5.6	0.9	6.2	1.3	3.8	0.5	4.0	0.5	3.8	21.1
188	Dark blue	18.5	38.0	4.3	1.9	0.1	30.8	0.2	9.0	2.2	4.6	14.4	3.6	0.0	3.6	0.6	4.1	0.9	2.5	0.4	3.0	0.5	3.9	37.2
198	Dark blue	26.0	52.4	6.2	1.3	0.1	37.0	0.2	4.7	1.4	5.0	21.6	5.6	0.8	5.0	0.8	5.6	1.1	3.4	0.5	3.4	0.5	3.4	19.0
243	Light blue	21.6	44.4	5.1	1.0	0.1	28.9	0.1	4.0	1.4	4.0	17.1	4.1	0.7	3.8	0.6	4.3	0.9	2.6	0.4	2.8	0.4	3.0	15.8
Outlier (mineral soda, possible handle?) – CONTINUED																								
222	Blue	4.7	9.4	1.2	0.2	0.1	5.6	0.1	1.9	0.4	3.7	4.4	0.9	0.2	0.8	0.1	0.8	0.2	0.5	0.1	0.5	0.1	0.9	1.1

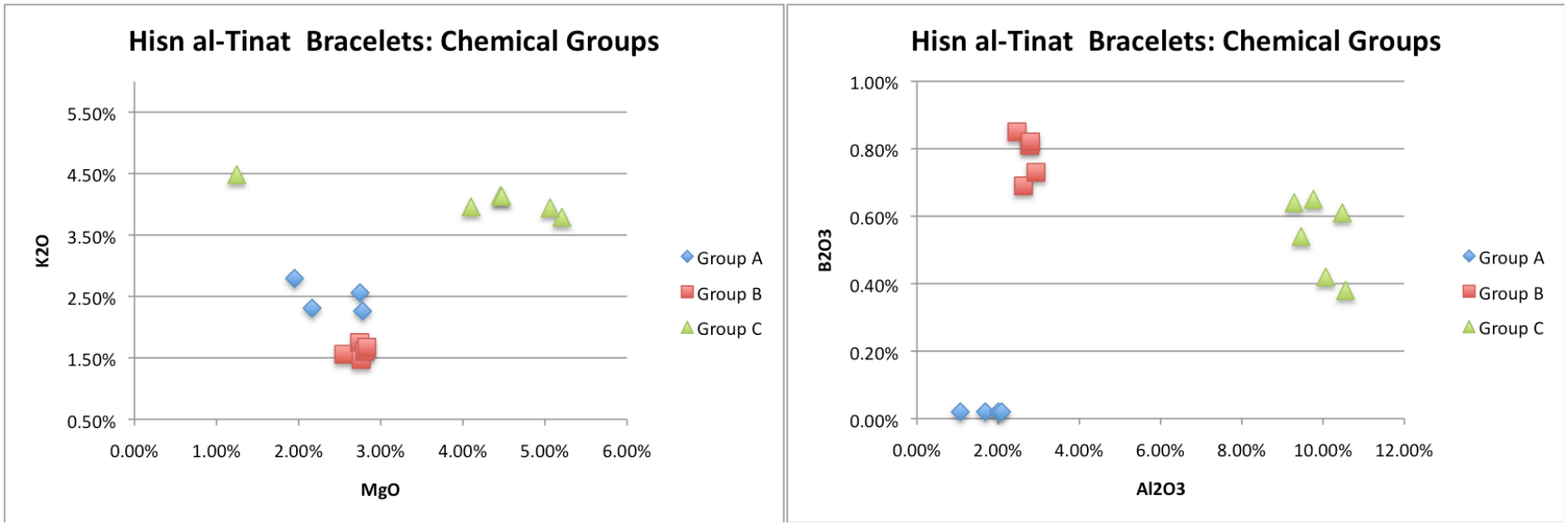

Figure 5.7: Comparison of the three chemical groups of bracelets: scatter plots of (left) magnesia versus potash, and alumina versus boron trioxide (right).

Oxide (wt%)	SiO2	Na2O	K2O	CaO	MgO	Al2O3	Fe2O3	TiO2	MnO	P2O3	CuO	CoO	PbO2	Sb2O5	SnO2	B2O3
Group A	69.44	11.66	2.48	9.06	2.41	1.71	0.65	0.04	0.97	0.35	0.46	0.00	0.25	0.00	0.10	0.02
Group B	63.97	14.50	1.61	11.92	2.74	2.72	2.25	0.06	0.05	0.10	0.00	0.00	0.00	0.01	0.00	0.78
Group C	54.77	19.88	4.07	5.04	4.09	9.93	1.53	0.07	0.09	0.23	0.10	0.06	0.01	0.00	0.00	0.54

Table 5.4: Average chemical composition of the three groups of bracelets, given in wt% oxide.

Group A: Similar to Plant Ash Group 4 (strong Ti-Zr correlation)

Group A includes two fragments made from naturally aqua colored glass (**Nos. 146 and 152**) and the two colorless-purple glass fragments (**Nos. 118 and 217**); these also correspond to the two examples of the horizontally ridged bracelet type (Nos. 118 and 146) and two examples of the spirally twisted type (Nos. 152 and 217). Unlike the majority of the glass bracelets, four samples do not have significant or elevated levels of either alumina or boron. This group has the highest silica content (averaging 69.4 wt%) as well as the lowest soda (averaging 11.7 wt%) and alumina (averaging 1.7 wt%) levels of the three chemical groups.

Fragment **No. 146** has high levels of copper (1.7 wt% CuO), which explains its more bluish hue; the fragment also has lead, antimony, tin, nickel, zinc, and silver levels that are far too elevated to indicate recycling, which are perhaps instead linked to the blue colorant (i.e. copper) itself. In terms of trace elements, Group A has significantly lower levels of lithium, beryllium, boron, and rubidium when compared to Groups B and C. In comparison to the Ḥiṣn al-Tīnāt vessel fragments made using plant ash soda, Group A seems to be quite close to Group 4 in terms of its major, minor, and trace elements patterns (slightly lower magnesia, soda, and iron as well as higher alumina, silica, manganese and copper; lower Zr, Cr, and Li; a strong Ti-Zr correlation) although the magnesia levels of Group A are slightly lower that the majority of samples in Group 4.

Group B: High Boron Glasses

Five samples have very high levels of boron as well as slightly elevated levels of alumina. These bracelets are all made of naturally aqua colored glass, including **Nos. 147,**

150, 174, 191, and 235. In terms of style, this group has oblong, peaked, and rounded bracelet shapes and notably includes the two painted examples. This group has the lowest potash level of the three chemical groups, as well as slightly higher than typical lime levels. The group also has very high iron (averaging 2.3 wt%) and boron levels (ranging 0.7-0.9 wt% B_2O_3); it has relatively high alumina levels when compared to the amount typically found in plant ash-soda glasses, but these levels are not nearly as high as that of the samples in Group C. The high iron might explain the natural aqua color of the glass fragments in this group, combined with relatively low manganese levels. All the samples have ~0.01 wt% antimony, which might suggest recycled glass. In terms of trace elements, Group B has extremely high levels of lithium (440-500 ppm), boron (2140-2650 ppm), and strontium (1960-2440 ppm) in comparison to the other two groups; this group also has higher levels of vanadium, chromium, nickel, arsenic, antimony, and cesium as well as lower levels of barium.

Group C: High Alumina and High Boron Glasses

Six samples had very high levels of alumina and boron, although a lower boron concentration than Group 5. These samples intriguingly include all the dark blue glass fragments (**Nos. 153, 163, 167, 188, and 198**) as well as one light blue fragment (**No. 243**). Four of the samples are of the spirally twisted variety while two are peaked. The group has by far the lowest levels of silica (averaging 54.8 wt%) and lime (averaging 5.0 wt%) as well as the highest levels of soda (averaging 20.0 wt%), potash (averaging 4.1 wt%), and magnesia (averaging 4.1 wt%). The low silica levels are particularly striking,

as the silica component of soda-lime-silica glasses is typically in the 60-80 wt% SiO_2 range.[25]

This group is most distinctive in terms of its extremely high alumina levels (averaging 9.9 wt%). The samples also have high levels of boron (ranging 0.4-0.7 wt% B_2O_3), although not quite as high as that characterizing Group B. The relatively high levels of iron (>1.4 wt%) are probably linked to the deep blue color of the glasses, although the color is primarily due to the presence of cobalt (0.0-0.1 wt% CoO). Unlike the rest of the high-alumina glasses of this group, **No. 188** has low magnesia (1.3 wt%) and very low lime (1.7 wt%), as well as slightly higher silica (59.9 wt%) than the rest of the group; in addition, **No. 188** has only half as much cobalt and other trace elements as the other members of this group. In terms of trace elements, Group C has lower strontium as well as higher rubidium, zirconium, and niobium than Groups A and B; Group C in general has much higher levels of the elements in periods (or rows), five and six of the Periodic Table (Figure 5.8)—notably including the Rare Earth Elements La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb—than do the other two groups (Table 5.3). There also seems to be a strong correlation between the cobalt and zinc content of these glasses, which is likely linked to the cobalt source itself.[26]

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[25] Silica in the 50 wt% range is more suitable for high-lead (a.k.a. "lead-silicate") glasses, but the samples in Group C clearly do not have elevated levels of lead. See the next chapter for more on high-lead glasses.

[26] This point will be taken up and discussed in more detail in the next chapter, when the chemical composition of the deep blue scratch-decorated glass fragments from Ayla is discussed.

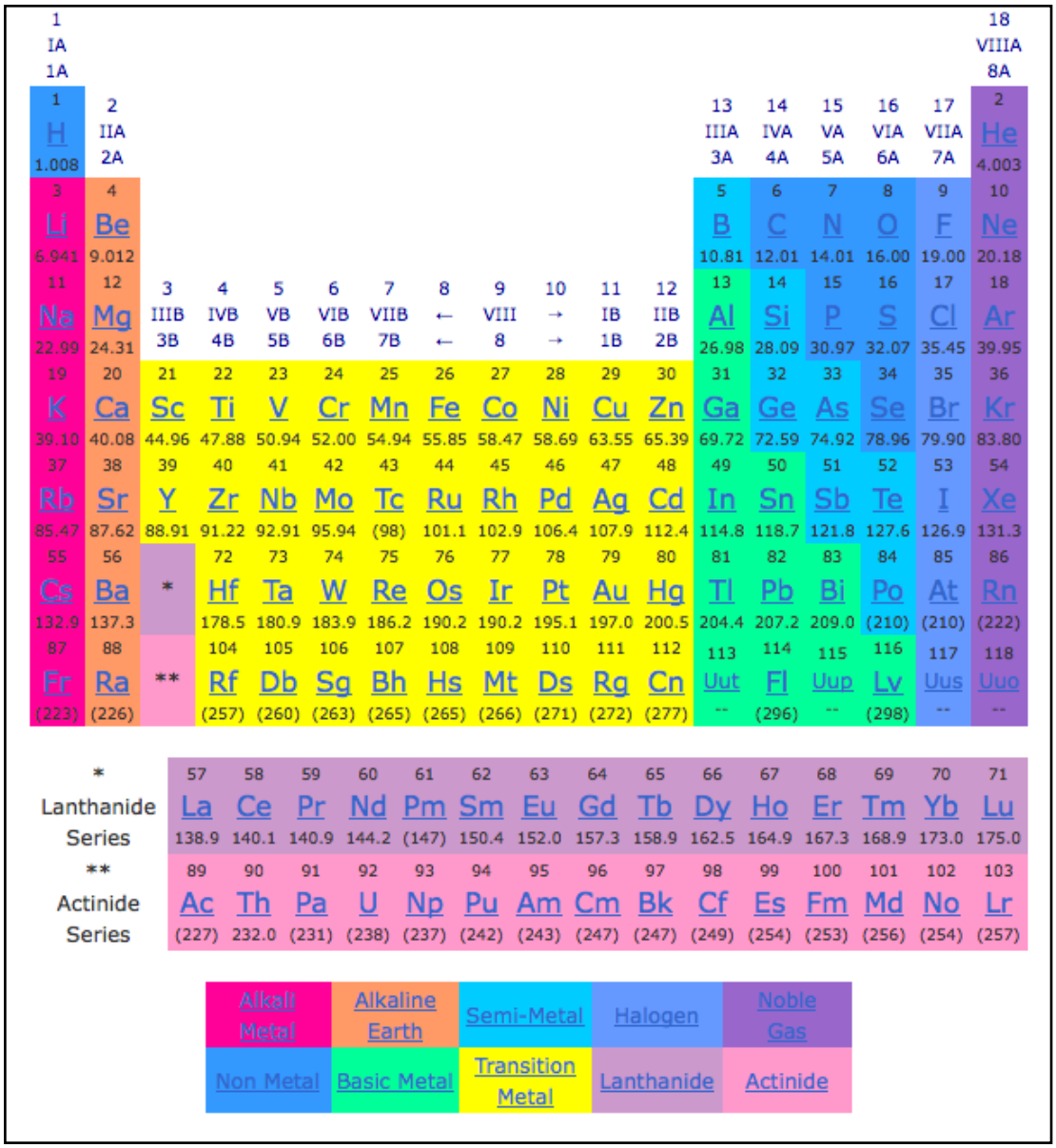

Figure 5.8: Group C is elevated in certain transition metals (yellow) and especially the Rare Earth Elements or Lanthanides (light purple); the relationship of these elements to one another is seen in their placement in the Periodic Table of the Elements.

Comparison With Other Glass Bracelets

Approximately 113 glass bracelets were excavated at Sagalassos in the Middle Byzantine occupation levels that are probably related to small isolated hamlets, "some of them fortified," that occupied the site from the 8th-13th centuries CE (Lauwers *et al.* 2010:

145). Nine different stylistic types of bracelet were identified (including semicircular, circular, and flat cross-sections that were plain, twisted, ribbed, or painted) dating to the 10th-13th centuries, and 11 samples were chemically analyzed in addition to two chunks of plant ash glass and a fragment of vessel glass that were also found at the site.[27] Unfortunately, the authors do not identify the precise type or even the color of the individual samples, which makes a detailed discussion relating typology to chemistry impossible. What the authors do say is: 1) the glasses have "elevated alumina and lowered magnesium and potassium levels compared with other plant ash glasses from the literature," 2) they have elevated antimony levels "possibly remaining from recycling Roman colorless glass," and 3) they have high levels of soda that is perhaps due to "raw plant ash glass was mixed with remaining natron glass" (Lauwers *et al.* 2010: 149). These descriptions of the soda, magnesium, potassium, and antimony levels are strikingly similar to Ḥiṣn al-Tīnāt Group B, but boron was not measured so it is not possible to more directly relate these glasses. An exception to this is one fragment from Sagalassos (SA07VL96) that has extremely high alumina and very low lime compared to the others. With an average composition of 10.2 wt% Al_2O_3, and 4.6 wt% CaO, this sample is much more similar to our Group C, but unfortunately the authors do not indicate the color or style of this fragment; seven spirally twisted cobalt blue and green bracelets were found at the site, so it is tempting to assume SA07VL96 is one of these based on the Ḥiṣn al-Tīnāt results.

At Amorium, of the 1,307 bracelet fragments excavated between 1987-1997, to my knowledge only three have been chemically analyzed (Wypyski 2005); moreover,

[27] Interestingly, "the number of excavated [bracelet] fragments far outnumbered the vessel glass of the period." (Lauwers *et al.* 2010: 145).

these were made of red glass, which is generally a rare color for glass during this period and even more so for bracelets. However, the purpose of Wypyski's study was to characterize glass tesserae from Amorium; some of these were made of opaque red glass, which therefore explains why red glass bracelets were sampled (for purposes of comparison). Interestingly, Wypyski's analysis shows that the red bracelets have a different composition from the glass mosaic tesserae, even from the red tesserae. All the Amorium samples are soda-lime-silica glasses, but the bracelets had greater levels of magnesia (1.9-2.7 wt%) and potash (1.5-1.6 wt%) and two of the bracelets had greater amounts of lime (8.5-10.7 wt%) and strontium (0.1-0.2 wt% SrO) as well. All three bracelets were colored and opacified in the same manner as the red glass tesserae, using copper oxide (1.1-2.1 wt%), but the tesserae had significant levels of lead while the bracelets only contained a small trace; both the red bracelets and red tesserae also had elevated iron oxide levels (3-5.4 wt%). Despite certain differences largely related to color, the Amorium samples are somewhat similar in chemical composition to Ḥiṣn al-Tīnāt Groups A and B; the magnesia and potash levels are more akin to Group B but the lower lime is more in line with Group A.

At the site of Mersin-Yumuktepe, 500 bracelet fragments dating to the 11th-12th centuries CE have been recovered;[28] 58 of these were studied as part of an unpublished Master's thesis (Derviş 2006) and ten were chemically analyzed. In this same thesis, 16 glass bracelets from 13th century CE contexts that were excavated between 2000-2002 at Mezraa Höyük (Birecik-Şanlıurfa, close to ancient Edessa) were also studied, and seven of these were chemically analyzed. However, of the 74 total samples from the two sites

[28] This is the count as of 2002, but since that time more fragments have probably been found, as this is an ongoing excavation.

that were included in the thesis, Derviş actually only presents chemical data for seven objects from Mezraa Höyük; these are all black, brown, and dark green glass bracelets with "plain," "cylindrically ribbed," or spirally twisted cross sections. All the samples are interpreted as made with mineral soda as a flux[29] because of the low magnesia (1.5-2.1 wt%), potash (1-1.6 wt%), and alumina (0.2-0.5 wt%) levels. The soda levels (7.5-13 wt%) are thought by the author to be much too low, probably due to leaching during burial, while the low lime (2-2.6 wt%) and alumina levels are attributed to the use of quartz sand in production; the silica content was found by difference, and is suspiciously high (80-85 wt%). Overall, this study appears to have problems and is probably not a very reliable source for analytical information,[30] which is unfortunate because this is one of the few chemical studies of medieval glass bracelets from the region near Ḥiṣn al-Tīnāt.

At least five glass bracelets dating to the 9th-10th centuries CE from the second Bulgarian capital of Preslav have been chemically analyzed using neutron activation analysis (Kuleff *et al.* 1985a and 1985b; Djingova and Kuleff 1992).[31] The complete chemical results for the individual objects have not been presented in publications, but some compounds and trace elements are available (Kuleff *et al.* 1985b: 233 and Table 2). Glass that was made locally in the workshop at Patleina Monastery in Preslav was

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[29] A relatively local source of trona is noted to be present in Beypazarı near Ankara (Derviş 2006: 61; Suner *et al.* 2003; Örgül 2003).

[30] In addition to the disappointing number of objects analyzed, the choice of samples is not representative of the bracelet shapes and colors that were present at the sites. In addition, the methods and parameters used are not well described, nor is there good evidence for the adequate attention to analytical accuracy and precision.

[31] All the bracelet fragments were recovered in the excavation of ecclesiastical contexts (monasteries and churches); one might wonder whether these are associated with burials, as most archaeologically-recovered Middle Byzantine bracelets come from grave contexts (Amorium, for example).

characterized by taking samples from the walls of five glassmaking pots found within the workshop, the mean value of which is 68.8 wt% SiO_2, 14.9 wt% Na_2O, 7.8 wt% CaO, 1.1 wt% K_2O, 1.7 wt% MgO, 1 wt% Fe_2O_3, and 2.5 wt% Al_2O_3 (Kuleff *et al.* 1985b: 234 and Table 3) which is striking considering this indicates glass was being made at Preslav using mineral soda as a flux; the authors observe that because the chemical profile of these major compounds is very similar to that of Byzantine glasses, trace elements are essential for differentiating local production (Kuleff *et al.* 1985b: 235 and Table 4). Through a comparison with the chemical signature of the Preslav workshop, three of the five bracelet fragments that were analyzed appear to have been produced locally (Kuleff *et al.* 1985a: 187): no. 18 is a twisted bracelet of yellowish glass, no. 21 is a relief bracelet of greenish-bluish glass, and no. 22 is a twisted bracelet of bluish glass. The bracelets made in Preslav were also produced alongside window glass and different kinds of vessels, "demonstrating the variety of the production of the investigated medieval glass workshop" (Kuleff *et al.* 1985a: 187).

A few glass bracelets excavated from 11th-13th century CE contexts in the necropolis at Drastar Castle near the city of Silistra in northern Bulgaria have also been analyzed (Georgieva *et al.* 2010a and b). Examples of four different bracelet colors and types were studied: sample 1.1 is a deep blue spirally twisted fragment, sample 2.1 is a deep brown smooth fragment, sample 3.3 a violet furrowed fabric, and sample 4.1 is a light blue smooth fragment; clearly samples 1.1 and 4.1 are of particular interest because of their similarity in appearance to the Ḥiṣn al-Tīnāt fragments. The Bulgarian bracelets were found to be soda-lime-silica glasses made with plant ash soda, containing: 65 wt% SiO_2, 14.2-16.5 wt% Na_2O, 8.1-9.6 wt% CaO, 3.4-4.3 wt% MgO, 1.6-2.5 wt% Al_2O_3,

1.4-1.9 wt% K_2O, 0.6-2.7 wt% Fe, 0.01-0.3 wt% Cu, and trace amounts of Co, Cr, and Ni (Georgieva *et al.* 2010a 1528); this compositional profile is similar in terms of its silica, soda, and potash to Ḥiṣn al-Tīnāt Group B, although the lime and alumina contents of the Drastar samples are closer to Group A, and their magnesia levels are higher than either of these two groups (but lower than that of Group C). The authors also point out the magnesia level is high compared with other medieval glasses found in Bulgaria, which is thought to indicate the glass was produced from magnesium-containing carbonates (like dolomite), while the alumina level is attributed to clay-kaolin sands (2010a: 1529). Georgieva *et al.* compare their results to glasses from several other sites by looking at the ratio of alkali oxides to alkaline earth oxides.[32] They find that the Drastar samples are similar to samples from Venice, Preslav, and some sites in the Near East in that they all have a ratio of 1.0-1.5 (Figure 5.9); the authors conclude that this range is "produced according to the so-called Near East recipe norm"[33] which indicates "the strong influence of the Near East tradition on the glass making technology in our country" (Georgieva *et al.* 2010b: 74).

An attempt to duplicate this method for the chemical results of the bracelet fragments from Ḥiṣn al-Tīnāt (Figure 5.10) provides some very interesting results, which

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[32] This approach is used by Shtapova (1983) to produce a so-called "recipe norm," but unfortunately this Russian publication could not be accessed by the Brown Interlibrary Loan system, so Shtapova's methods and line of reasoning cannot be directly assessed or discussed here. It appears that the method plots the ratio of the alkaline earth oxides [CaO+MgO] to alkali oxides [Na2O+K2O] versus the wt% of alkaline earth oxides [CaO+MgO].

[33] Georgieva *et al.* report that samples from 1st century CE Aquileia, 6th century CE Philippi, 9th-10th century CE Patras, and 8th-12th century CE Poitiers (Italy, southern Greece, and France) were produced according to "the Roman province recipe norm" with a ratio around 2.0-2.5, while "the Roman capital recipe norm" with a ratio around 3.0 characterizes the glasses from the sites of 9th-10th century CE Pliska and 2nd-4th century CE Oescus in Bulgaria (Georgieva *et al.* 2010b: 74).

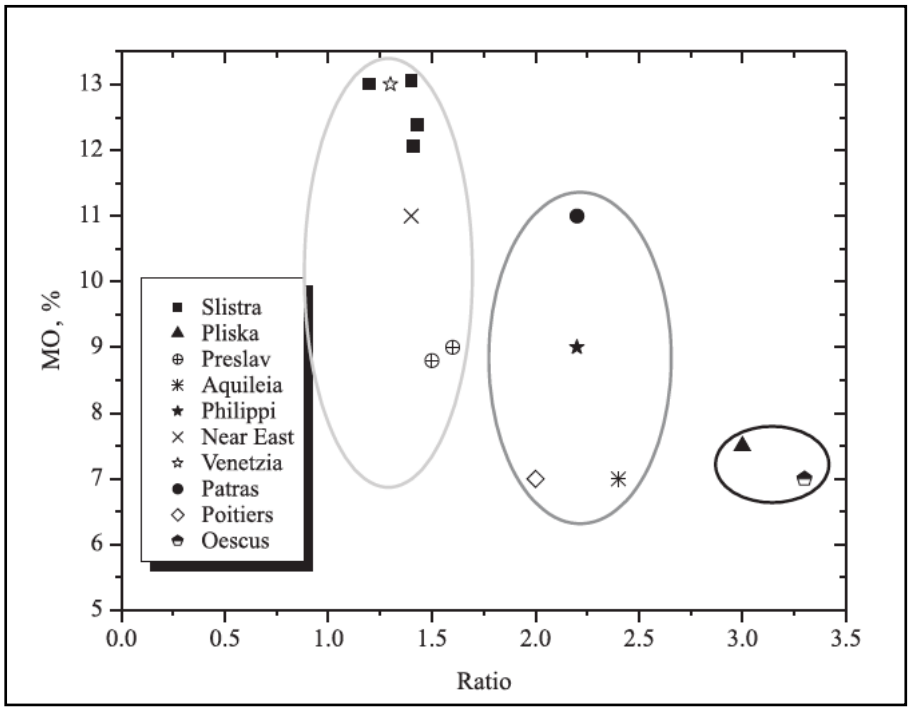

Figure 5.9: Scatter plot showing several so-called "recipe norms" of glassmaking, specifically plotting the ratio of alkali oxides to alkaline earth oxides vs. wt% alkaline earth oxides (Georgieva *et al.* 2010b: 73, Fig.2; method as suggested by Shtapova 1983).

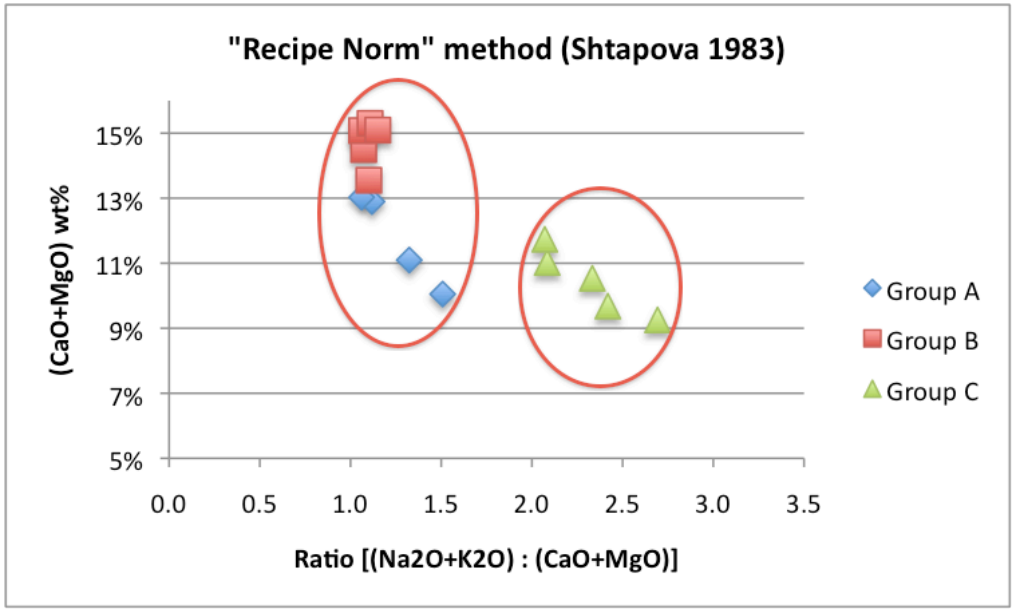

Figure 5.10: Scatter plot comparing the three chemical groups of Ḥiṣn al-Tīnāt bracelets using the "recipe norm" method, specifically plotting the ratio of alkali oxides to alkaline earth oxides vs. wt% alkaline earth oxides (as suggested by Shtapova 1983 and used by Georgieva *et al.* 2010b). Note that sample No. 188 is not shown here, as its ratio of 8.3 makes it a significant outlier.

may relate to the source of the three different chemical groups defined here as Groups A, B, and C. As can be seen, the Ḥiṣn al-Tīnāt samples in Groups A and B are within the same ratio (or recipe norm) as the medieval glasses analyzed from Drastar castle (Silistra) and Preslav in Bulgaria, as well as glasses vaguely described as from the "Near East."[34] It may be that Georgieva *et al.*'s "Near East" recipe norm masks multiple recipes, as the high boron glass of Group B is certainly not a Near Eastern product and is more likely to be of Balkan or Anatolian origin (see discussion below). The Ḥiṣn al-Tīnāt samples in Group C, however, fall largely within the same ratio range as the glasses from Patras, Philippi, Poitiers, and Aquileia. No. 188, however, has a very high ratio of 8.3 that obviously does not plot with the ratios shown in Georgieva *et al.*; this sample was chemically distinct in several ways from the other members of Group C although its very high alumina content, deep cobalt blue color, and spirally twisted style still links it to this group. It may be that the different ratios of the two high boron groups (Groups B and C) are linked to two different production zones, one possibly in Anatolia and one in Bulgaria.[35]

A brief but critical chemical study concerns four more bracelets from Bulgaria. As mentioned previously, Ḥiṣn al-Tīnāt examples Nos. 174 and 191 appear to be distinct from metallic-stained bracelets found in the Byzantine world during this period. Recall

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[34] The precise identification of the "Near East" sites cited by Georgieva *et al.* 2010b is, however, unclear. Caley (1962: 56) is cited in the text as the source of the "Near East" data while Verità and Toninato (1990: 169-175) are cited as the source of the "Near East, XII AD" data point presented in the footnote of Figure 2. Looking directly at these two cited publications does little to clarify the situation. For example, page 56 of Caley does not actually include any chemical data from the Near East; on page 57 there is some data from 8th century BCE Assyrian Nimrud and an undated Egyptian sample, but this can hardly correspond to the 12th century CE date indicated in Figure 2 (2010b: 74). The footnotes in Figure 2 appear to be inaccurate for all sites, so perhaps note 18 should read note 19 instead (although this does nothing to resolve the problem).

[35] This could perhaps indicate that slightly different economies of production characterized the Byzantine Empire and the First Bulgarian Empire (Koropeckyj 1991).

that three fragments of painted bracelets from an 11th-12th century CE grave at Djadovo provided by far the closest visual comparison for the presence of paint on top of weathering layers that was not "fixed" through heating; the Djadovo fragments might additionally provide chemical insight into the production of these bracelets:

> It is well known that the irization is due not only to soil conditions, but also to the chemical composition of the glass. Therefore, the bracelets from grave No. 13 must have another composition (Borisov 1989: 291-292).

Two of the three such bracelets from grave No. 13 were analyzed and compared with the analytical results of a silver-stained bracelet from a medieval settlement near the village of Djadovo, and a painted bracelet found in a glass-making workshop at Stara Zagora (Bulgaria) dating to the 10th-11th centuries CE; the latter two samples were "non-irized" or non-weathered, which suggests their pigments were fixed (i.e., metallic stained).

The chemical results (Table 5.5) show the two irized bracelets from grave No. 13 are similar to each other but are different from the other two fragments, "which indicates the irized and non-irized bracelets originated from different centers" (Borisov 1989: 292). Although the Ḥiṣn al-Tīnāt samples contain lower potash and manganese as well as higher lime and alumina, the two irized painted bracelets from Djadovo contain high levels of silver and boron (unlike the other two samples from Bulgaria). Borisov suggests "in all probability precisely these components [silver and boron] are the reason for the irization of the bracelets;" whether or not this is true is beside the point, as what is important is that the Djadovo samples are similar to the Ḥiṣn al-Tīnāt samples in terms of style, decorative technique, and now the bulk glass chemistry as well. Similar bracelets "with irization and unstable paintings" were also found in excavations near the Bulgarian village of Krăn (also in the Stara Zagora district), while "the absence of such bracelets in

neighboring countries suggests they were produced in the Bulgarian lands" (Borisov 1989: 292).

Sample	Type	SiO2	Na2O	K2O	CaO	MgO	Al2O3	Fe2O3	MnO	CuO	Ag	B2O3
Ḥiṣn No. 174	Paint	64.43	14.39	1.56	12.47	2.55	2.46	1.77	0.04	0.00	0.10	0.85
Ḥiṣn No. 191	Paint	62.49	15.24	1.67	12.43	2.83	2.93	2.16	0.05	0.00	0.30	0.73
Djadovo 1	Paint	65.07	15.36	2.32	9.03	2.93	1.82	2.47	0.74	0.06	0.05	0.13
Djadovo 2	Paint	64.86	15.43	2.31	9.13	3.32	1.71	2.27	0.82	0.06	0.04	0.13
Djadovo 3	Stain	64.85	15.35	2.02	8.59	2.33	2.89	2.90	0.92	-	-	-
Stara Zagora	Stain	72.36	13.01	3.19	6.16	0.93	1.74	1.10	1.14	-	-	-

Table 5.5: Comparison of the chemical results of the painted bracelet fragments from Ḥiṣn al-Tīnāt with fragments from Djadovo and Stara Zagora (data from Borisov 1989: 292, Table 24).

Chemical analysis has shown that painted bracelets were produced in Rus' from the second quarter of the 12th century onwards, but these are notably "different in their dimensions, style of painting, and chemical composition (Russian *potash-lead-silica* as opposed to eastern Mediterranean *soda-lime-silica*) from the Byzantine painted bracelets excavated on the same Rus' sites," for example at Novgorod (Ristovska 2009: 203, my italic emphasis). The visual and chemical similarities of the two Djadovo samples and Nos. 174 and 191 are clear, and Borisov's suggestion for a Bulgarian origin is interesting in light of the similar high boron and relatively low alumina content of his samples and the entire Ḥiṣn al-Tīnāt Group B. Medieval glass workshops in Bulgaria have been identified in Pliska and Preslav (9th-10th centuries CE) as well as in Stara Zagora and Hissar (10th-11th centuries CE).[36]

In addition to the chemical studies of finds from the Anatolian and Bulgarian regions, some bracelet fragments recovered from the Islamic Near East have also been chemically analyzed. In *Chemical Analyses of Early Glasses* (1999a; 1999b), Brill does

[36] Indeed it appears that Bulgaria had a long tradition of glassworking, with an earlier 4th-7th century CE workshop identified in Gabrovo and 14th century CE workshop in Veliko Tarnovo (Georgieva *et al.* 2010a: 1526).

Sample	Color	SiO2*	Al2O3*	Fe2O3*	MgO*	CaO*	Na2O*	K2O*	B2O3
QH 3172	Aqua	63.73	2.07	1.23	4.88	8.48	17.21	2.40	0.03
QH 3173	Green	60.37	1.81	1.12	5.75	7.39	21.12	2.45	0.03
QH 3174	Black	60.21	2.25	1.27	6.59	8.55	18.51	2.62	0.03
QH 317	Black	64.00	2.57	1.65	5.69	9.23	13.69	3.18	0.03
QH 3176	Blue-aqua	71.68	0.71	0.75	2.38	5.04	13.64	5.79	0.05
Fustat 3118	Opalescent	70.96	0.92	0.72	3.69	8.44	10.90	2.77	0.02
Fustat 3119	Blue-aqua	64.45	2.14	1.04	5.76	3.62	19.60	1.75	0.02
Fustat 3120	Olive, white	64.91	2.86	1.26	5.88	3.48	18.80	2.05	0.03
Fustat 3121	Red opaque	48.94	1.27	4.33	0.76	2.80	14.90	0.68	0.03
Fustat 3122	Yellow opaque	60.17	1.27	0.99	5.00	3.01	17.40	1.89	0.02
Fustat 3123	Green opaque	60.76	2.04	1.27	5.46	3.58	17.60	1.79	0.03
Fustat 3124	Bl-aqua, yellow	65.43	1.00	0.60	3.50	12.80	5.70	2.38	0.03
Zujaj 189	Dk. brown	60.77	5.81	1.24	4.75	4.28	20.90	2.26	NA
Fukh. 263	Dk. brown	68.81	1.83	1.06	3.21	5.36	17.59	2.14	NA
Fukh. 264	Dk. brown	67.53	2.02	1.28	3.12	5.13	18.39	2.53	NA
Fukh. 265	Dk. brown	61.13	3.93	1.19	5.59	5.91	20.26	1.99	NA
Fukh. 266	Dk. brown	68.68	1.73	2.55	2.95	6.48	15.41	2.20	NA
Fukh. 267	Green opaque	68.37	2.99	1.94	3.67	8.17	13.02	1.82	NA
Fukh. 268	Dk. green	67.21	1.86	2.20	4.39	6.55	15.37	2.42	NA
Fukh. 269	Dk. green	67.43	1.80	2.08	4.38	6.51	15.33	2.47	NA
Fukh. 270	Blue	62.74	3.87	2.41	4.19	8.19	15.85	2.75	NA
Fukh. 271	Dk. brown	69.23	2.17	1.50	5.17	6.64	13.45	1.84	NA

Table 5.6: Reduced chemical compositions (*) and raw boron content of bracelet fragments from Syria and Egypt: Qasr al-Hayr as-Sharki (QH) and Fusṭāṭ (data from Brill 1999b: 169-170 and 172), and Tell Zujaj and Tell Fukhkhar at Raqqa (data from Henderson *et al.* 2004: Table 1).

include some analyses of glass bracelets: five samples from "Islamic" contexts at Qasr al-Hayr as-Sharki in Syria and seven samples from 9th-13th century CE Fusṭāṭ (Table 5.6). The five bracelets from Qasr al-Hayr are described as being aqua, blue-aqua, green, and black in color, but aspects of their style or decoration are not given (1999a: 88). The same is true for the bracelet fragments from Fusṭāṭ, which are made of blue-aqua, "opalescent," opaque yellow, opaque red, or opaque green glass; two exceptions are an olive colored bracelet that is spirally wound with a thread of opaque white glass, and a blue-aqua colored bracelet with an opaque yellow thread. Neither of these sites seems to have glass especially similar to the Ḥiṣn al-Tīnāt samples in terms of color (e.g. the use of opaque glass) or chemistry. The low alumina and boron levels of Brill's samples clearly differentiate these from Ḥiṣn al-Tīnāt Groups B and C; although Group A is similar in the content of some of the major and minor elements (note that the elevated iron of the Qasr

al-Hayr as-Sharki and Fusṭāṭ samples likely relates to the darker colors), the magnesia and soda levels of Group A are significantly lower.

Among the 280 glass objects chemically analyzed from the site of Raqqa in Syria (Henderson *et al.* 2004) were nine bracelet fragments from 11th-12th century CE contexts at Tell Fukhkar and one from 8th-9th century CE contexts at Tell Zujaj (Table 5.6). Again, the glass color is noted by the authors, but nothing more specific is given about the bracelet typology or the style and decoration of the samples; the objects were largely of dark brown and dark green glass, although one opaque green and one blue fragment were included. The single fragment from Tell Zujaj has significantly more alumina than Henderson's defined groups, but this is not discussed in the publication. Six of the bracelets from Tell Fukhkar belong to Henderson's Type 4 group and three are classified as Type 2; he suggests that these are "not likely to have been produced at Tell Fukhkhar, but are more probably the result of recycling or reuse of earlier glass" because of their compositionally "diffuse" character and similarity to the 9th century glass from nearby Tell Zujaj (Henderson *et al.* 2004: 452). Overall, the Raqqa bracelet fragments are similar to the Ḥiṣn al-Tīnāt Group C in terms of magnesia and lime content, although they contain lower levels of potash and alumina (more similar to Groups A and B); however, without a measurement for the boron content, it is difficult to say just how similar the Raqqa bracelets truly are to the Ḥiṣn al-Tīnāt examples.

Glass bracelets from two sites in Jordan—Tell Abu Sarbut and Khirbat Faris—were studied as part of one of the more thorough chemical investigations of medieval glass bracelets in the Near East (Boulogne and Henderson 2009). Although the samples used in the study date primarily to the Mamluk and Ottoman periods (the late 12th-19th

centuries CE, and thus are much later than the period under consideration here),[37] the data generated and observations made by the authors are still important to at least mention here. Three chemical types were distinguished, including high-alumina glasses, mineral soda glasses,[38] and plant ash soda glasses (Boulogne and Henderson 2009: 55, Table 1); this wide range is explained by the authors as indicating the use of a wide range of primary raw materials and a wide range of geographic origins for the bracelets themselves. Indeed, parallels for Jordanian bangles have been found in Yemen and India, and the authors reference previous chemical analyses that suggest that glass with elevated alumina levels probably derived from India and Southeast Asia (Boulogne and Henderson 2009: 59).

Comparison With Other High Alumina Glasses

It has been shown that the Group C bracelets contain extremely high levels of alumina, averaging 9.9 wt%, which is more than twice the amount that is typically considered high. Indeed, high alumina is so rare for glass that it is can be quite surprising; in their review of the chemical composition of Roman and medieval glasses from Bulgaria, Kuleff and Djingova note that four glasses from the First Bulgarian capital of Pliska have between 7-11.2 wt% Al_2O_3, "which is more typical of ceramic materials than glass; therefore we consider this data to be an analytical error" (2002: 102).

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[37] Several types of bangles were sampled, including monochrome flat or triangular bracelets; those decorated with polychrome prunts, crumbs, or glass strips; as well as monochrome or polychrome spirally twisted bracelets. Most were made of translucent dark green, "black" (actually brown), or less frequently blue glass (Boulogne and Henderson 2009: 54-55).

[38] Only one sample was made using natron, while the rest were made "with an alkali-rich mineral other than natron" (Boulogne and Henderson 2009: 62).

An alumina content of 4 wt% or more seems to be the generally agreed upon level distinguishing high alumina glasses, as soda-lime-silica glasses (including both mineral soda and plant ash soda types) typically have between 1-3 wt% Al_2O_3 (Freestone 2006: 203, Table 2). Schibille, however, includes samples with as little as 2.4 wt% Al_2O in her discussion of high alumina glasses from Pergamon (2011: 3, Table 1), while Lauwers *et al.* report that bracelets from Sagalassos have "elevated" alumina levels of 2-3 wt% (2010: 149). These levels may be high when compared to typical plant ash glass, but they are quite low when compared to the high alumina glasses discussed elsewhere (Dussubieux *et al*. 2010); if these lower limits are indeed acceptable, then the Ḥiṣn al-Tīnāt Group B glasses (averaging 2.7 wt% Al_2O_3) should be considered high alumina glasses too.

Studies of ancient glasses containing high alumina have largely concluded that such objects were likely made in India, Southeast Asia, and East Africa rather than Europe or Western Asia (Brill 1987; Robertshaw *et al.* 2003; Popelka *et al.* 2005; Lankton and Dussubieux 2006; Dussubieux *et al.* 2008; Dussubieux *et al.* 2009; Dussubieux *et al.* 2010). These same studies have shown that high alumina glasses were made with both mineral soda and plant ash soda, and in some cases probably a mixture of the two. The average chemical compositions for some high alumina soda glasses from different sites and periods are given in Table 5.7; the plant ash soda glasses with high alumina shown here have lower silica as well as higher potash and magnesia than typical plant ash soda glasses, while the mineral soda glasses with high alumina have higher potash than regular mineral soda glasses. It may additionally be significant that the lime

Object types and date range	Site or region found	SiO2	Na2O	K2O	CaO	MgO	Al2O3	Fe2O3	TiO2	MnO	P2O3
PLANT ASH SODA, HIGH ALUMINA GLASSES											
Bracelets (8th-12th c. CE)	Ḥiṣn al-Tīnāt, Turkey	54.77	19.88	4.07	5.04	4.09	9.93	1.53	0.07	0.09	0.23
"Ornaments" (2nd c. BCE-2nd c. CE)	Pakistan, N. India, China, and Bangladesh[39]	58.18	15.48	4.16	7.11	3.94	4.97	1.71	NA	0.10	0.31
Beads (9th c. CE and later)	Sub-Saharan Africa,[40] Madagascar	58.36	12.83	3.40	6.14	6.02	7.22	NA	NA	NA	NA
Vessels (9th c. CE and later)	Sumatra[41]	61.30	19.50	2.60	4.50	4.70	5.90	1.50	NA	NA	NA
MIXED ALKALI, HIGH ALUMINA GLASSES											
Bracelet (10th-13th c. CE)	Sagalassos, Turkey[42]	59.59	15.05	4.37	4.61	0.63	10.21	1.90	0.36	0.25	0.13
Bracelets (12th-19th c. CE)	Tell Abu Sarbut and Khirbat Faris, Jordan[43]	52.85	18.08	7.19	4.95	2.00	8.27	4.38	1.05	0.13	0.57
MINERAL SODA, HIGH ALUMINA GLASSES											
Beads and bracelets (4th c. BCE-10th c. CE)	SE Asia and Sri Lanka[44]	62.50	15.50	2.30	3.00	0.70	9.80	1.70	0.59	0.10	NA
Beads (9th-19th c. CE)	Africa and west coast of India[45]	61.50	17.70	2.40	3.80	1.10	7.50	2.60	0.39	0.11	NA
Beads and bracelets (4th-3rd c. BCE)	SE Asia[46]	66.80	14.60	3.30	2.90	1.30	7.10	2.20	0.32	0.09	NA
Beads, bracelets, vessels (14th-19th c. CE)	SE Asia, Kenya[47]	64.30	16.80	2.40	1.40	0.70	6.90	2.80	0.41	0.30	NA
Bracelets, tesserae, window glass, raw glass (12th-14th c. CE)	Sardis, Turkey[48]	61.10	17.40	1.40	4.90	1.50	9.80	2.10	0.52	0.60	NA
Vessels, windows, chunks (10th-14th c. CE)	Pergamon[49]	60.28	16.14	1.64	8.50	1.41	7.34	1.62	0.40	1.33	0.20

Table 5.7: Chemical composition of some high alumina glasses, including plant ash, mixed alkali, and mineral soda types.

[39] Dussubieux *et al.* 2010: 1646, based on data from Bara in Dussubieux and Gratuze 2003: 321, Table 4.
[40] Robertshaw *et al.* 2003: 144, Table 2 (Type B); Robertshaw *et al.* 2006; Popelka *et al.* 2005.
[41] Dussubieux 2009: 391, Table 3 (samples from Kenya may also fall into this group).
[42] Lauwers *et al.* 2010: 150-151.
[43] Boulogne and Henderson 2009: 64.
[44] Dussubieux *et al.* 2010: 1649, Table 3 (m-Na-Al 1).
[45] Dussubieux *et al.* 2010: 1649, Table 3 (m-Na-Al 2); Robertshaw *et al.* 2010.
[46] Dussubieux *et al.* 2010: 1649, Table 3 (m-Na-Al 3).
[47] Dussubieux *et al.* 2010: 1649, Table 3 (m-Na-Al 4).
[48] Dussubieux *et al.* 2010: 1649, Table 3 (m-Na-Al 5); Brill 1999a and 1999b.
[49] Schibille 2011: 3, Table 1.

content for both these types is extremely low compared to regular soda glasses.[50] The vast majority of these glasses appear to be beads, bracelets, or small ornaments; this could be significant, indicating perhaps an independent industry or "sub-industry" for small objects that used specific ingredients (particular raw material sources, or recycled materials) and/or manufacturing processes; another possible interpretation is that the glass chemistry reflects a local regional or cultural preference for the use of glass for decorative objects (ornaments, beads, and bracelets) rather than for vessels.

Dussubieux *et al.* 2010 identify five sub-groups of high alumina glasses made from mineral soda (abbreviated to m-Na-Al), a type that first appears in the 5th century BCE and is relatively common as late at the 19th century; this type "is particularly abundant in South Asia, where raw materials to produce m-Na-Al glass are readily available," although "the number and importance of the manufacturing centers is unknown as archaeological information is extremely scarce" (Dussubieux *et al.* 2010: 1646). Of the three sub-types they identify that were produced in later periods, one group may have been manufactured in western India and traded to the east coast of Africa starting in the 9th century CE (Dussubieux *et al.* 2008; Dussubieux *et al.* 2010: 1654). Another of these sub-types characterizes glass found at Sardis in Turkey; although there is no glassmaking or glassworking evidence on the site, the cobalt used to color this glass is chemically characteristic of the cobalt used in the Middle East while "the fact that this type of glass was only identified at Sardis reinforces the idea of a local production"

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[50] While high alumina and high iron can result in short working times, high alkali glass with low silica and lime could actually make glass easier to work, for longer periods and at lower temperatures (Boulogne and Henderson 2009: 72). Although this could have been an advantage in vessel production, it is not clear how important such properties would have been to jewelry makers, as bracelets and beads can be quickly formed.

(Dussubieux *et al.* 2010: 1654).[51] Another site in Turkey, Pergamon, also appears to have high alumina glasses that were made using mineral soda; although "the magnesia and potash levels of these samples do not unambiguously determine whether a mineral or an organic fluxing agent was employed" (Schibille 2011: 7), "it seems rather likely that a mineral soda-rich efflorescence was used" (Schibille 2011: 9).

Other studies have identified several groups of high alumina glasses that were made using plant ash soda, also found at sites primarily in Asia and Africa. Dussubieux and Gratuze discuss evidence of a 2nd century BCE to the 2nd century CE workshop in Bara, Pakistan, that made high alumina glass using plant ash soda (2003: 319); this same sub-type has also been identified in North India and Xinjiang province (Dussubieux *et al.* 2010: 1646). Robertshaw *et al.* identifies another sub-type of high alumina plant ash soda glass that was produced staring in the 9th century CE and found in Sub-Saharan Africa (Robertshaw *et al.* 2003; Robertshaw *et al.* 2006). A third sub-type has been identified in Kenya and Sumatra (Dussubieux 2009; Dussubieux *et al.* 2010). Overall, although trade of high alumina plant ash glasses with Asia is again assumed, "surprisingly little seems to be known about plant-ash glass in South Asia in the second millennium CE" (Robertshaw *et al.* 2006: 106). These three sub-types of plant ash soda high alumina glasses do compare well with the Ḥiṣn al-Tīnāt Group C samples in many respects (although the latter has significantly more alumina); however, if more studies measured trace element composition, the Turkish samples would perhaps be more clearly distinguished from the African and Asian samples; for example, glass samples from Sumatra contain low levels

[51] "The small number of studies of South Asian glass material found at later periods [9th century CE and onward] jeopardizes any attempt to test the hypothesis of an Indian origin" for the Sardis type and two other sub-groups (Dussubieux *et al.* 2010: 1654).

of boron, strontium, and zirconium (McKinnon and Brill 1987: 9-12, Table I) which clearly differentiate them from Ḥiṣn al-Tīnāt Group B.

Almost all of the high alumina glass artifacts discussed in the literature come from Africa or Asia where "the production of soda glasses with high alumina concentrations is part of a long tradition" (Dussubieux *et al.* 2010: 1646). Soda glass with high alumina is quite rare in the Mediterranean: the few examples include cobalt-blue glass from Iron Age Europe (Gratuze and Picon 2005) and artifacts from Italy with a wide compositional variability "suggesting an accident or a small scale experimental production" (Dussubieux *et al.* 2010: 1646). In addition, only recently have high alumina glasses been identified at medieval sites in the Near East: Boulogne and Henderson claim that the westernmost known occurrence of high alumina glasses are the Mamluk-Ottoman period bracelets from Tell Abu Sarbut and Khirbat Faris in Jordan (2009: 71). However, finds from Sardis, Sagalassos, Pergamon, and now Ḥiṣn al-Tīnāt in Turkey move this known distribution further to the northwest, and perhaps even suggest a different production zone.

Compared with the nine high-alumina samples from Tell Abu Sarbut and Khirbat Faris (Boulogne and Henderson 2009), Group C has similar silica, soda and lime levels; similar but slightly higher alumina levels; significantly lower potash and phosphorus levels, and significantly higher magnesia levels. Boulogne and Henderson believe that the high potassium and phosphorus levels of their samples, combined with elevated magnesia and sulfur, "strongly suggest that these were made not only from a mineral source of soda but also from an organic source" (Boulogne and Henderson 2009: 71), i.e., from a mixed soda. Their samples also contain elevated iron, titanium, and manganese, which could

possibly suggest an Egyptian link. The Anatolian finds are all of a somewhat earlier period than these Jordanian bracelets, dating to the Middle and Late Byzantine periods (ca. 10th-14th centuries CE). However, a comparison of the Ḥiṣn al-Tīnāt Group C bracelets with these other Turkish sites is not particularly conclusive. The Sardis and Pergamon samples are interpreted as made from mineral soda, and they indeed share a similar composition (although the Sardis samples have a lower lime content than do the Pergamon samples). The one high-alumina glass fragment from Sagalassos (SA07VL96) has slightly higher silica and potash levels than Group C, as well as lower lime and soda levels and significantly lower magnesia levels; it should be recalled that Lauwers *et al.* suggest a mixed mineral and plant ash soda for the Sagalassos glasses based on mixing lines in the data when magnesia and potash are plotted together (2010: 149), but this one high alumina fragment does not fall on this mixing line.[52] The Ḥiṣn al-Tīnāt Group C samples, however, seem to be the only samples that were clearly made with plant ash, as they have magnesia and potash levels well over 1.5 wt%.

Comparison With Other High-Boron Glasses

Glass scholarship has only recently recognized the existence of a type of ancient glass that is characterized by high boron; this is largely because boron is a trace element not typically included in chemical analyses, but it may also be possible this was not a widely produced or circulating glass. In 1968 Brill first noticed that boron levels are normally no higher than 0.01-0.03 wt% B_2O_3 (Brill 1968: 51; Brill 2002: 16). Amongst Brill's more than 3000 analyses of ancient glass (1999b), only two-dozen or so of these

[52] Another explanation for seemingly mixed alkali may be that the plant ash was purified in some way (see Robertshaw *et al.* 2003: 144).

contain more than 0.01-0.02 wt% B_2O_3. This small group of samples contains between 0.08-1.0 wt% B_2O_3; all the fragments are vessel or window glass dating from 6th/7th to the 12th century CE contexts and have connections with Turkey, Cyprus, or Greece (Brill 2005b: 217; Brill 1999b: 217-219). Schibille has noted that although boron could be introduced into a glass batch as a contaminant in raw materials (including the silica source), "boron is more generally associated with alkali and alkali earth metals" (2011: 10); this is an especially interesting comment considering the elevated alkali earth metals that were observed for Ḥiṣn al-Tīnāt Group C. The chemical results for the high boron glasses that are discussed here are shown in Table 5.8.

Site	Samples	SiO2*	Na2O*	K2O*	CaO*	MgO*	Al2O3*	Fe2O3*	B2O3*	B2O3
Ḥiṣn al-Tīnāt	Average (n=11)	59.24	17.53	2.97	8.21	3.50	6.69	1.86	-	0.65
Corinth	No. 3281	68.22	14.25	2.27	9.31	2.45	1.80	1.70	-	0.26
Paphos	No. 2309	67.81	14.36	1.86	9.29	2.53	2.03	2.12	-	0.18
Corning Museum of Glass	No. 3320	68.74	13.73	2.05	9.31	2.50	1.67	2.01	-	0.25
Aphrodisias	Average (n=7)	68.90	15.50	1.46	8.00	2.74	1.65	0.52	0.93	-
Zerek Camii	Average (n=10)	67.50	15.40	1.80	9.79	2.39	1.76	1.03	0.31	-
Djadovo	Average (n= 2)	63.50	15.06	2.27	8.90	3.16	4.66	2.32	0.13	-
Pergamon	Average (n=17)	62.70	16.50	1.69	8.83	1.40	7.33	1.57	-	0.36

Table 5.8: Reduced chemical compositions (some with the raw boron content) of high-boron glasses; data from Brill (1999b, 2002, 2005), Borisov (1989), and Schibille (2011)

The fragments of high-boron glasses, ranging from 0.40 wt% to almost 1.00 wt% B_2O_3, that have been analyzed by Brill include:

> Vessel fragments and waste glass from the 14th century "factory" at Corinth, a few fragments from the Roman "industrial" site at the port of Corinth, ten 14th century(?) window glasses of assorted colors from the Zerek Camii in Istanbul, and a group of vessel fragments and large chunks of cullet from Aphrodisias (Brill 2002: 17).

The cullet from Aphrodisias[53] is especially interesting, as it is made from plant ash soda, has quite a high boron content (almost 1.0 wt% B_2O_3), and is aqua green in color (Brill 1968: 51)—similar both chemically and typologically to the aqua colored Ḥiṣn al-Tīnāt Group B glasses. Brill also analyzed a group of deep blue beakers decorated with gilding and enamel from Corinth, Paphos (Cyprus), and unprovenanced fragments from the Corning Museum of Glass; these were shown to be plant ash soda glasses with 0.10-0.25 wt% B_2O_3, and are considered "similar enough that they could have been made in the same place at about the same time" (Brill 2002: 16). Deep blue glasses colored with cobalt often seem to be associated with high boron, as suggested by Brill's samples and the Ḥiṣn al-Tīnāt Group C samples.[54]

The high-boron bracelets that were excavated at Djadovo in Bulgaria have a lower level (0.13 wt% B_2O_3) than our samples, but this is clearly high enough to be considered a high-boron glass; these Bulgarian samples are notable not only because they are glass bracelets and happen to look similar to samples No. 174 and 191, but also because high boron glasses were "heretofore exclusively associated with glasses found in Constantinople, Asia Minor, Cyprus, and Greece" (Ristovska 2009: 203-204, note 21), so our knowledge of the distribution and perhaps production zone of high boron glass is expanding geographically (and, perhaps significantly, in a northward direction).

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[53] The excavator dated the Aphrodisias cullet to the 5th-7th centuries CE (Brill 1968: 51), but it is unclear how this date was determined and whether any stratigraphic or chronological refinements have been made in the last 40 years. Could there have been a later Byzantine glassworks in the vicinity? It was common practice in the post-Roman world for industrial workshops to be established in city centers (Bet She'an and Corinth are good examples).

[54] Brill suggests there may be an actual correlation between the B_2O_3 and CoO contents in some glasses, and he notes that Sayre also analyzed four dark blue glasses containing cobalt and found they contained 0.30-1.00 wt% B_2O_3 (Brill 1968: 52, note).

It currently appears that the production zone of high-boron glass is "likely to be in Turkey,[55] perhaps near colemanite deposits" (Brill 2005b: 217). Colemanite[56] is a boron-containing mineral that is mined in the area between Izmir, Ankara, and Istanbul (Brill 2002: 17). All of the high-boron glasses analyzed by Brill are soda-lime-silica glasses made with plant ash; he suggests that the high boron levels may possibly derive from this source: "it is possible that plants harvested in that area for making soda ash might have contained elevated levels of boron, and that could have found its way into the glasses" (Brill 2002: 17). However, Brill acknowledges another possible source are the boron-rich "natron" deposits in the same region, and more recently it has been shown that high-boron Middle and Late Byzantine glasses from Pergamon were likely made from such an evaporitic mineral soda source (Schibille 2011: 11-12). Schibille argues that it seems doubtful that plant ashes could contain enough boron to reach a nearly 1.00 wt% B_2O_3 concentration in glass, "especially considering the toxicity of boron for plants and the ability of boron-tolerant plants to effectively efflux boron" (Schibille 2011: 12, citing studies by Miwa *et al.* 2007 and Camacho-Cristoball *et al.* 2008). Thus, for the Pergamon samples—which have high-boron and high alumina, but low potash, magnesia, and phosphorus—she is in favor of a mineral soda rich in boron, lithium, and strontium used to flux an alumina-rich silica source.

Possible mineral deposits include Ca-borate (colemanite), Na-borate (borax), Na-Ca-borate (ulexite) Mg-borate, and Sr-borate deposits located at Emet, Bigadiç, Kestelek, and Kırka; this "borate district" in Western Anatolia (Figure 5.11) is one of the largest

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[55] "*For the moment*, Turkey seems somewhat more likely than Greece or Cyprus" (Brill 2002: 17, my italic emphasis).

[56] $2CaO.3B_2O_3.5H_2O$ (Brill 2002: 17).

Figure 5.11: Map pinpointing the location of the evaporitic deposits in "the borate district" of Western Anatolia: Emet, Bigadiç, Kestelek, and Kırka.

borate reserves in the world (Helvaci and Alonso 2000: 3). Both Brill (1968: 51; Brill 2002: 17) and Schibille (2011: 12) have noted that elevated boron levels are found to be associated with sometimes elevated lithium and strontium oxides; geological studies of the borate deposits in western Turkey have shown that these deposits indeed often contain increased lithium and strontium (Helvaci and Alonso 2000; Helvaci *et al.* 2004), although "the exact ratios and absolute concentrations of these elements are highly variable" (Schibille 2011: 12). This is certainly true for Ḥiṣn al-Tīnāt Groups B and C:[57] the former group has a range of 440-500 ppm Li and 1950-2400 ppm Sr while the latter

[57] Although it should be noted that Group C has lower strontium levels than Group A (which has neither high boron nor high lithium).

has a range of 90-130 ppm Li and 210-280 ppm Sr[58] (and the higher lithium and strontium levels in Group B make sense considering this group has higher boron levels that Group C).

The only published study mentioned here that includes measurements of other trace elements is Pergamon (Schibille 2011), and although the glasses are interpreted as being made with mineral soda, they have a notable range of 16-1780 ppm Li and 150-3000 ppm Sr as well as high alumina. Moreover, the Pergamon glasses are chemically distinct in terms of their color chemistry: the colorless or "pinkish" fragments have very high boron (~1.0 wt% B_2O_3), lithium (~0.1 wt% Li_2O), and strontium levels (~0.2-0.4 wt% SrO) while the colored fragments have still high but comparatively lower boron (0.1-1.0 wt% B_2O_3) as well as lower lithium and strontium. These observations are highly significant when compared to Ḥiṣn al-Tīnāt Groups B and C, the former being naturally aqua glass with higher born, lithium, and strontium than the latter group of highly colored glasses. One major point of difference, however, is that Ḥiṣn al-Tīnāt Group C has significantly elevated rare earth elements while all the Pergamon glasses are generally depleted in these elements (Schibille 2011: 9).

SUMMARY

Although bracelets are the clear minority of glass fragments found at Ḥiṣn al-Tīnāt, they are in many ways the most noteworthy of the samples examined in this project. The sixteen bracelet fragments recovered from the site are made from colorless-

[58] This does not include the low 62.6 ppm Sr of sample No. 188 because it is quite different from the average content of the other five samples of Group C; remember that this sample is distinct from the other group members in many ways.

purple, aqua, light blue, and dark blue glass; they include plain bangles with oblong, circular, or triangular cross sections, some of which are further decorated with horizontally ribs, twisting, or even painted designs. These colors, profile shapes, and decorative techniques are associated with three chemical groups that are extremely distinctive—which is often not the case for plant ash soda glasses, as can be seen in Chapter 4—especially in terms of their trace elements.

Group A includes aqua and colorless-purple bracelets that are spirally twisted or ridged, and they are made using plant ash soda as a flux. Group B includes only naturally-aqua colored bracelets and are more varied in their shapes (including peaked, oblong, and circular cross-sections), also notably including two painted fragments; these glasses are also made using plant ash soda as a fluxing agent, but their extremely high and correlated boron/lithium/strontium levels make them very distinctive. Group C includes only deep blue glasses colored with cobalt, of spirally twisted or peaked styles; this group is also characterized by high boron (although it has less lithium and strontium than does Group B) as well as by very high levels of the Rare Earth Elements, but its very high alumina content is by far the most noteworthy feature of this group. These latter two groups are distinctive enough in their chemical composition to suggest an Anatolian and/or Bulgarian glass production zone, which would represent a new addition to the glass production groups that were primarily located in Egypt and the Levant in the Late Roman, Byzantine, and Early Islamic periods.

CHAPTER SIX: GLASS FROM AYLA, ANALYTICAL RESULTS

INTRODUCTION

This chapter presents the results of the typological and chemical analyses of glass vessels from the site of Ayla in southern Jordan. Of the several thousand fragments of glass that were excavated between 1986-1995 and are now stored in the Oriental Institute in Chicago, 551 fragments from nine different excavation areas of the site were initially inspected and 113 of these were then chosen for closer typological and chemical analysis in this project. The choice of samples was based first on those areas described as having promising Early Islamic contexts[1] or areas that had a relatively good chronological sequence for the entire 8th-12th century CE span of the site's occupation. A secondary consideration was the type of object; diagnostic fragments were preferentially chosen because these can more easily be related to specific vessel types, while undiagnostic body shards were selected only when diagnostic fragments were not available from a particular locus. As in the previous chapter, the fragments are organized and discussed by diagnostic type in order to more easily organize and highlight the observations made in this study.

TYPOLOGICAL ANALYSIS

Although there are no complete vessels, as in the Ḥiṣn al-Tīnāt study, the majority

[1] I.e., the excavators believe these include Umayyad and early 'Abbasid layers.

of the 113 samples are diagnostic rims and bases. During the initial assessment of the 551 fragments, the Ayla assemblage was seen to include a great variety of glass colors: naturally aqua, light green, colorless, olive-green, yellow, yellowish-brown, olive-brown, light purple, dark blue, and emerald green. Most of the samples that were selected for further analysis are on the blue-green color spectrum in order to avoid complications in comparison due to the addition of colorants to the raw glass batch. As a result, the range of Ayla samples may appear similar to or even less diverse than the Ḥiṣn al-Tīnāt assemblage; however, this is due to the fact that at the latter site significantly less glass was recovered so almost all of it was included for analysis, regardless of color. However, some fragments of highly colored glass from Ayla were considered when they were deemed particularly diagnostic or noteworthy (e.g., deep blue and emerald green glasses).

Vessel fragments

Of the 113 fragments that were sampled, **No. 62** was removed because it is a modern intrusion.[2] Of the remaining fragments, 46 (approximately 41% of the total) were from vessel rims, 30 (27%) were from the wall of the vessel, and 21 (19%) were from vessel bases. The remaining 13% of the sample population came from other parts of vessels or from objects that were not vessels at all, including five fragments from the shoulder or neck of a vessel, three handle fragments, the tips of two lamp stems, two possible windowpanes, one fragment of a decorative crimped glass trail (that likely wrapped around the body of a bottle), one possible bracelet, one irregularly-broken chunk of glass, and one tubular object that may be a malformed vial.

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[2] See the chemical assessment section below.

Undecorated wall fragments

Of the 30 fragments of vessel walls that were included in this study, 28 are not decorated. Although these fragments could ultimately be from any vessel type, they vary in wall thickness and thus indicate a variety of vessel types and sizes—from thin-walled bottles and cups to thicker and heavier bottles and bowls. The majority of these wall fragments chosen are naturally aqua or light green glass, although a few fragments of light purple (**Nos. 25** and **26**), deep blue (**Nos. 77, 80,** and **106**), and colorless (**No. 44**) glass were also included. Undecorated wall shards are still relatively unhelpful for a detailed typological discussion, but are of more interest in terms of their chemical analytical results.

Decorated fragments

Only two of the 30 wall fragments sampled have decorations, **Nos. 16** and **41**, while the other wall fragments are of plain blown glass. Both of these are deep blue glasses with scratched geometric decorations on their exterior surfaces; this technique, incising or sgraffito, became very popular for Islamic glass in the 8th-9th centuries CE. A fragment of light green glass, **No. 89**, from the rim of a beaker or small bowl/cup with vertical walls has similar decorative patterns (Figure 6.1) and several other examples in deep blue glass were noted but not sampled.

Scratch-decorated glass from Bet She'an has been studied in depth by Hadad (2000), and similar finds from Alexandria/Kom el-Dikka have been examined more recently by Kucharczyk (2009); Whitehouse (2010a) has also discussed this decorative technique in relation to 24 fragments in the collection of the Corning Museum of Glass.

The finds from Bet She'an date from the Umayyad and 'Abbāsid-Fāṭimid periods, including 22 beakers and bowls with straight walls and one bottle;[3] the fragments are made of dark blue, yellowish green, yellowish brown, olive, or dark purple glass. The

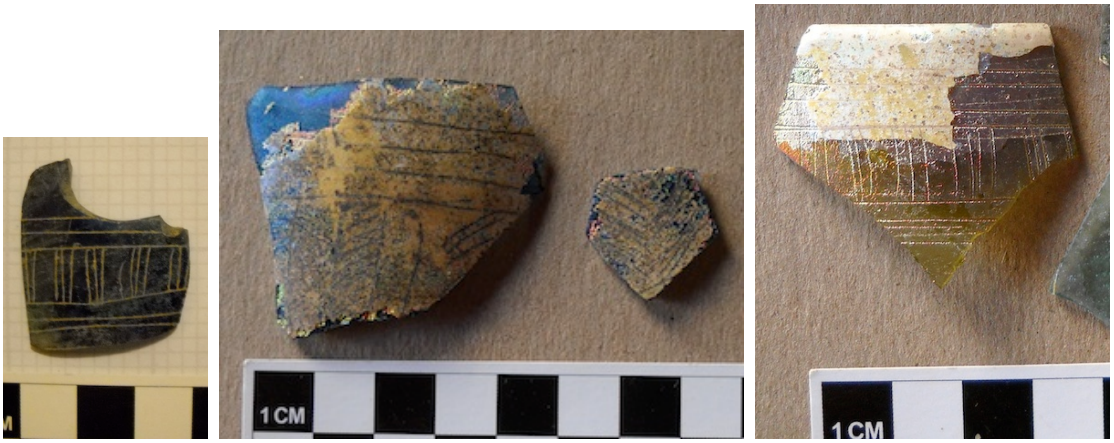

Figure 6.1: Scratch-decorated glass fragments of dark blue and light green glass including (left to right) Nos. 16, 41, and 89.

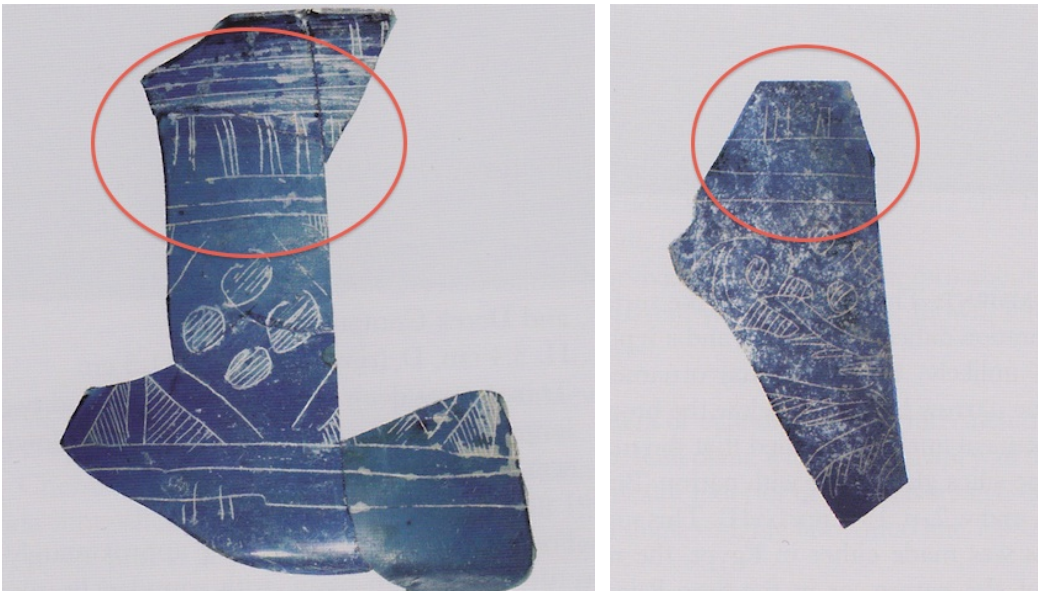

Figure 6.2: Two scratch-decorated fragments from the Corning Museum of Glass (Whitehouse 2010a: 18-19, nos. 7 and 9) with designs similar to Ayla fragment Nos. 16 and 89 are circled in red. The fragment at the left was found during excavations at Fusṭāṭ, and the fragment at the right is no. 6353 in the chemical analysis of Brill 1999, and is included in Table 6.1.

[3] Incised bottles and jugs are generally much more rare than beakers, bowls, and plates (Hadad 2000: 71); other closed shapes such as jars and pitchers have also been observed (Kröger 2005: 142-143).

finds from Alexandria come from funerary contexts dating to the 8th-10th century and include the same forms and glass colors; shades of blue are the most common color and the designs are more varied and complex than those seen at Bet She'an.

Incised or scratched patterns are typically compartmentalized, "the body of the vessel is divided into vertical or horizontal units, creating geometrically defined areas" (Kucharczyk 2009: 42); hatching (repeated and closely spaced slanting lines) is by far the most common feature of these vessels, filling in the space of triangles, circles, and other shapes. Darkly colored glass was typically favored for such vessels, because scratched lines appear white and thus "achieves its best effect against a dark ground" (Kröger 1995: 117). The decoration of Nos. 16 and 89 are simple and quite similar, consisting of horizontal lines forming a register filled by vertical lines; this motif can be seen elsewhere including on fragments from the Corning Museum of Glass (Figure 6.2; also see note 13). No. 41 is somewhat more unusual, and its herringbone or feathered design parallels fragments from Alexandria (Kucharczyk 2009: 44 nos. 9 and 10). Only the shape of No. 89 can be determined, a cylindrical cup or beaker with vertical sides, which is the most widespread shape (Figure 6.3) for scratch-decorated glass vessels (Kröger 2005: 142-143).[4] The deep blue of Nos. 16 and 41 is the most common color scratch-decorated glasses, accounting for some 80% of known examples (Whitehouse 2010a: 13).

As scratch-decorated examples from the Umayyad period are comparatively few in number (a few fragments are known from only two sites, Susa and Bet She'an), Hadad concludes that this decorative type is more widespread in the 'Abbāsid-Fāṭimid periods

[4] Of the 44 specimens at the Corning Museum of Glass, 64% are from cylindrical cups (Whitehouse 2010a: 13).

Figure 6.3: A deep blue cup/beaker with vertical sides (the most common vessel shape for scratch-decorated vessels) from the Corning Museum of Glass and reportedly purchased in Cairo (Whitehouse 2010a: 17-18, no. 6; and no. 6348 in the chemical analysis of Brill 1999, included in Table 6.1).

(late 8th-11th centuries CE).[5] Scratch-decorated Early Islamic vessels might even be given a more precise chronology, because examples having been found in dated Chinese tombs (Jiayao 1991). One tomb in the crypt of the Famen Temple site in the Shaanxi province of China with a *terminus ante quem* of 874 CE has 20 Islamic glass vessels, including six cobalt-blue glass dishes with scratch decorations.

Hadad observes the similarity of incised glass vessels to steatite[6] and black burnished clay bowls with incised geometric designs that were also found at Bet She'an (2000: 66 and Fig. 5);[7] examples of such steatite vessels have been found at Aqaba in

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[5] Hadad cites parallels from al-Mina in Syria; Nessana and Hammat Gader in Israel; Pella and Aqaba in Jordan; Fusṭāṭ and al-Ṭūr in Egypt; Samarra, Tulūl al Uhaiḍir, and Nippur in Iraq; Susa and Nishapur in Iran; Corinth in Greece; Dvin in Armenia; Manda in Kenya; and the Famen Temple in China (2000: 65). Hadad underscores the fact that some of these sites only had one sherd (al-Mina, Hammat Gader, Pella, Corinth, Dvin), which suggests the glass was an import to these places (Hadad 2000: 70). Other find spots as noted by Kucharczyk (2009: 41) include Tebtynis and Rāya in Egypt, Gao in Mali, and Istanbul.

[6] Steatite is variously termed soapstone, talc schist, and talc slate (Klemm and Klemm 2008: 18).

[7] Incised steatite vessels were produced during the 7th-12th centuries but were most popular in the 8th-10th centuries CE. They were used as cooking vessels, oil lamps, or incense burners and were traded widely

‘Abbāsid period contexts as well (Whitcomb 1987). Other scholars liken the motifs of the scratched designs to the decorations on luster glass (Charleston 1989).[8] In short, the evidence largely suggests an 8th-9th century Abbāsid date for the scratch-decorated glass fragments studied here. In terms of production, there have been debates since the late 1920s as to where incised glass vessels were manufactured—whether it was in Egypt, Syria, or Iraq (or in all three regions)—although no workshops where incised objects were produced have yet been discovered. Kröger (1995: 117) and Kucharczyk (2009: 40) believe these vessels were made in various locations due to their wide distribution; the validity of a Syrian center of production has been questioned as no fragments were found at Ḥamā (Lane 1937: 67-68), but this will likely remain an open question until the finds from Raqqa are published.

The other decorated vessel fragments are diagnostic parts such as rims, necks, and bases (Figure 6.4). Relief patterning by means of tonging, pincering, impressing, or stamping a design as well as mold-blowing are the most commonly observed decorative techniques. Among the fragments that were sampled, **No. 27** (see also the line-drawing in Figure 6.5) is the rim fragment of a small hemispherical bowl made of colorless or naturally-aqua glass that has a decorative band of concentric ovals around the walls just below the rim of the vessel; the pattern can be felt on both the exterior and interior surfaces, which suggests it was achieved using tongs. Aqua fragment **No. 12** also has a geometric design in relief on its exterior surface, although weathering layers make it

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throughout the Middle East. In terms of production, there was a large steatite vessel industry in the Arabian Peninsula (Hallett 1990) and a production center has also been discovered in the southern portion of Egypt’s Eastern Desert (Harrell and Brown 2008). Incised black clay bowls, on the other hand, date to the 8th-9th centuries CE (Magness 1994).

[8] “It is tempting to note that two of the objects from the [Famen] temple have traces of gilding in the incised lines” (Carboni and Whitehouse 2001: 156).

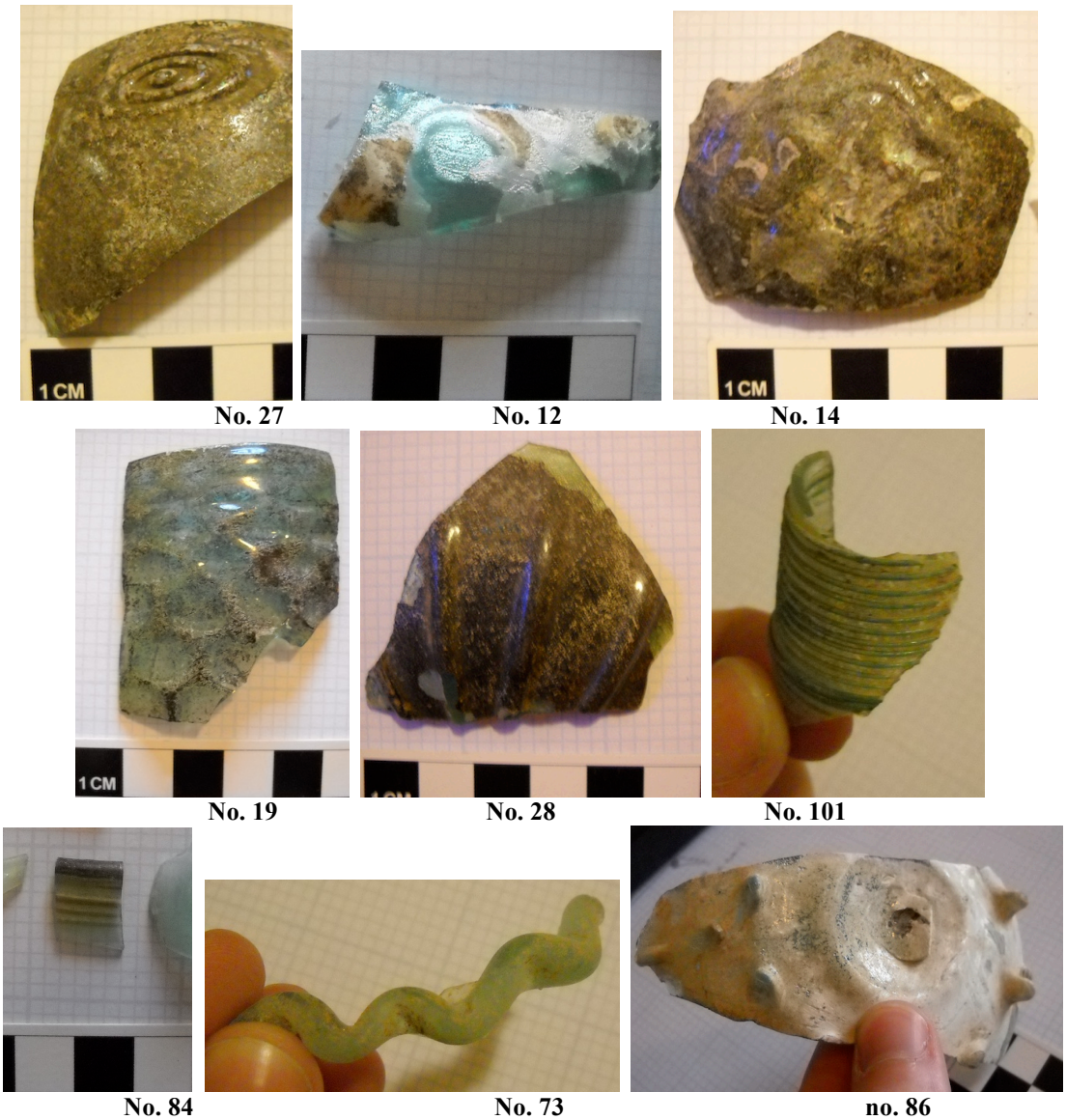

Figure 6.4: Detail of the various decorative methods and effects used for the glass samples from Ayla; <u>tonged or impressed</u> decoration: No. 27 and No. 12; <u>mold-blown patterning</u>: No. 14, No. 19, and No. 28; <u>applied trails</u>: No. 101, No. 84, and No. 73; <u>pulled/tooled feet</u>: No. 86.

much more difficult to determine how the design was produced. Fragment Nos. 14, 19, and 28 are decorated by mold-blowing. **No. 14** is the base of a small bowl or closed vessel like a bottle or jug made of colorless glass; the bottom is thicker and slightly pushed upwards by the pontil rod, but the concentric star-like relief pattern is quite distinctive (see also the line drawing in Figure 6.10) and similar to many of the mold-

blown patterns observed on base fragments among the cargo of glass cullet on the 11th century CE Serçe Limanı ship (Bass *et al.* 2009: 27ff, especially B4b Mold 14). The honeycomb patterning of aqua glass fragment **No. 19** is a very common mold-blown design that can be found on many examples and many different vessel forms (see also the line drawing in Figure 6.6); such "reticulations" are first attested in the Roman era but became especially popular in the Islamic periods (Scanlon and Pinder-Wilson 2001: 73). The thick ribs of **No. 28** are also likely to have been produced with the use of a dip mold: the curving shape of the aqua colored fragment suggests a rounded bowl or bottle, with the ribs tapering towards the bottom of the vessel; a similar effect can be seen on an Umayyad-period cylindrical bowl from Bet She'an (Hadad 2005: 97 and Pl. 4 no. 82).

Trailed decorations were very popular for glass vessels in the Near East during the Byzantine-Umayyad periods. Nos. 101 and 84 (Figure 6.4) have thin threads of colored glass applied near the mouth, although the decorations are finished differently. **No. 101** is a neck fragment from a long-necked bottle of aqua glass that has multiple thin, darker aqua glass threads wound closely together and left standing proud of the surface. This style began in the Early Byzantine period but is also one of the most common decorations of the Umayyad period, at which time the style is notably "more rich and diverse" than it had been previously (Hadad 2005: 25); very close parallels come from Fusṭāṭ (Scanlon and Pinder-Wilson 2001: 62-64 and Fig. 32, no. 32c) and Umayyad contexts at Bet She'an (Hadad 2005: 113 and Pl. 12, nos. 223-231). Although too small to reconstruct the rim diameter and identify vessel function, aqua glass fragment **No. 84** likely comes from a bowl/cup/goblet; it is decorated with a thick olive thread at the lip and thinner threads just below the rim, which were applied and then marvered flush when

the vessel was reheated and the rim was worked (a similar treatment can be seen in line drawing of sample **No. 113** in Figure 6.7). Fragment **No. 73** (Figure 6.4) is itself a large, naturally aqua glass trail; it is thick and rippled, and would have originally wrapped around the circumference of a globular vessel—very small and thin fragments of the vessel wall are actually still visible on the concave side of the fragment; such decorations are more commonly wrapped around the neck of a bottle, but a good parallel example of a "ruffle" from globular vessel with a similar break pattern comes from Jerash (Meyer 1987: 213-214, and Fig. 13, no. K).

No. 86 (Figure 6.4) is a very unique base fragment, probably from a globular vessel like a bottle or jug. It has relatively thick walls, and around the base circumference there are small projections pinched outwards from the body forming a ring of "toes" (see also the line drawing in Figure 6.10) although these are merely decorative because the base already sits flat. This treatment of a vessel base is not very common, but some footed parallels include vessels from late 8th century CE contexts at Fusṭāṭ (Foy *et al.* 2003a: 140 and Fig. 2, no. 22) and 'Abbāsid-Fāṭimid contexts at Bet She'an (Hadad 2005: 147 and Pl. 29 no. 566, 167 and Pl. 39 nos. 812-813); somewhat different finds from 'Abbasid period contexts at Tebytynus/Tebtunus (Fayyum) and Fusṭāṭ include bowl-shaped vessels raised on a stem that have nipped projections around the bottom circumference of the bowl (Foy *et al.* 2003a: 140 and Fig. 2, No. 23; Rousset *et al.* 2001: 487, and Fig. 6, no. 103).

Handle fragments

Three handle fragments were included in this study. **Nos. 60** and **97** are of

naturally aqua glass and **No. 110** is of light green glass. All are straight handles with rounded cross-sections, and were formed by attaching a blob of hot glass to the body and pulling out a straight length before attaching the other end to the neck or shoulder of the vessel. The overall size of the fragments suggests they came from small jugs; other unsampled fragments were often thinner and smaller and some almost certainly come from suspension lamps with loop handles.

Rim fragments

The 46 rim fragments included in this study come primarily from bowls/beakers/cups and bottles (Figures 6.5-6.8). As was true for the Ḥiṣn al-Tīnāt vessels, the Ayla vessels are simple in both their rim form and finishing methods. Although folded or rolled rims are present, plain fire-rounded rims (sometimes resulting in a thickened lip) are much more common. Rim diameters range from 1-20 cm depending, of course, on the size and intended function of the vessel. Vessels with rim diameters over 9 cm are identifiable as bowls while those with rim diameters 6.5-8 cm more likely served as cups, beakers, goblets, and/or lamps. Rim diameters less than 5 cm are assigned to flasks and bottles; however, funnel-mouthed flasks are very common in the Byzantine and Islamic periods so it must be kept in mind that fragments with 6-8 cm rim diameters could theoretically be from such vessels as well.

Nos. 36 and **57** are aqua glass fragments from two of the largest vessels in the sample, each with 20 cm rim diameters; they both have slanting conical walls, although the former has a straight lip while the latter has an externally-folded rim. As was mentioned previously in Chapter 4, large bowls with simple rim treatments are of course

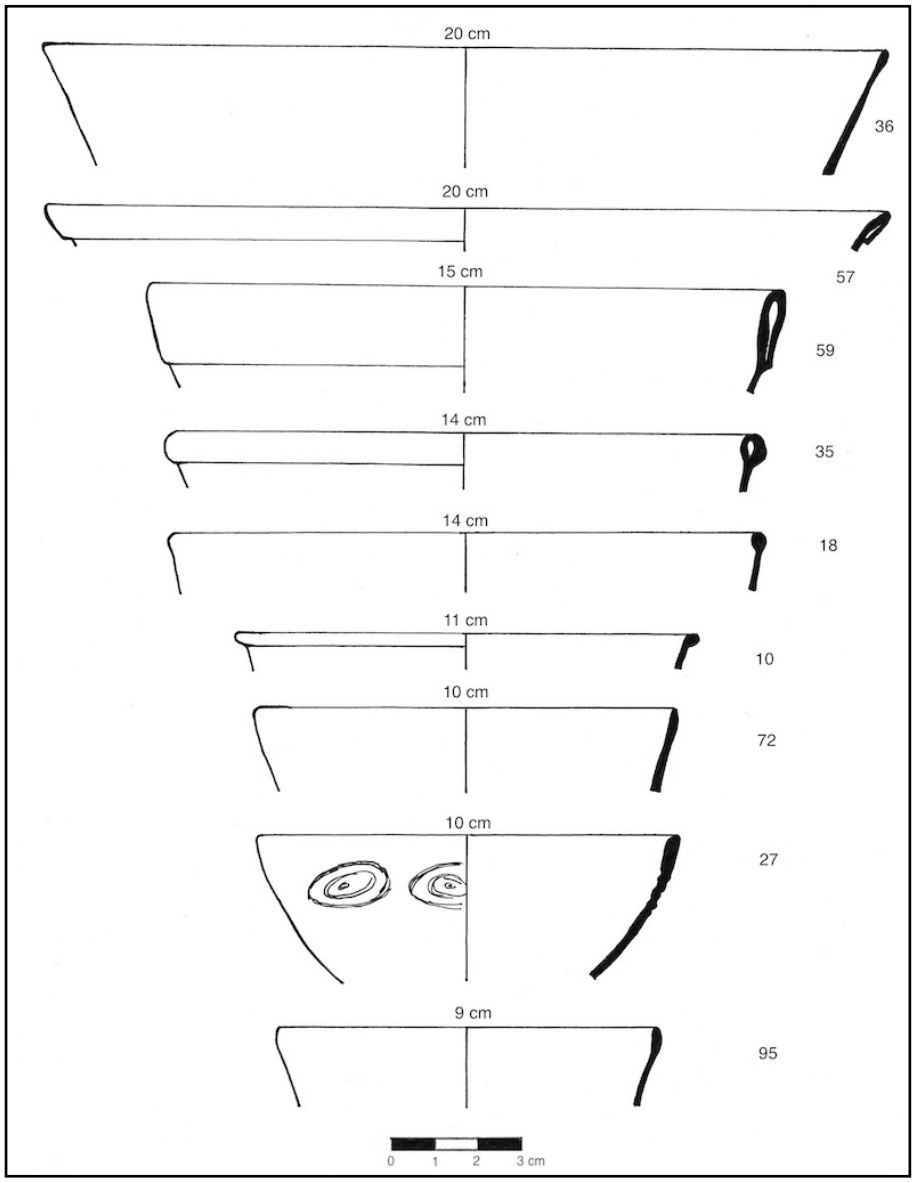

Figure 6.5: Line-drawings of rim fragments of bowls from Ayla; rim diameters are given at the top of each, and object numbers are shown to the right.

a very long-lasting form. However, in the ‘Abbasid period “bowls with outfolded rims continued to be used alongside new forms, such as cylindrical bowls and large bowls with slanting walls and solid bases” (Pollak 2003: 167); No. 36 has such slanted walls, and many of the other examples are indeed cylindrical in shape. **Nos. 18, 35,** and **59** are both large bowls with 14-15 cm rim diameters; No. 18 is of colorless glass and has a

folded lip**,** No. 35 is of yellowish-green glass and has a rolled lip, and **No. 59** is of aqua glass with a fire-rounded lip.

The majority of the vessels examined are less than 12 cm in rim diameter. Everted rims seem to be rare; **No. 10** (aqua glass, 11 cm rim diameter) has a slightly everted lip, while unsampled fragment from area L8b-21 (RN542) has both an everted rim and a hollow tube forming a horizontal band in the wall. **No. 72** (aqua glass, 11 cm rim diameter) and **No. 95** (aqua glass, 9 cm rim diameter) have somewhat vertical rims with gently tapering walls. **No. 27** is a small, shallow hemispherical bowl with tong-impressed circular decorations (also shown in Figure 6.4); similar examples were noted at Early Islamic Ramla (Gorin-Rosen and Katsnelson 2005: 105, 107 and Fig. 2, no. 20) and 9th-10 century contexts at el-Ashmunein (Bailey 1998: 140-150 and Pl. 92, no. Y30). The small size and fused blue-threaded decoration of **No. 113** (aqua glass, 6.5 cm rim diameter) is very similar to that of decorated goblets found at Tell Tanninim and tentatively dated to the 5th-7th centuries (Pollak 2006: 174 and Fig. 137, nos. 107-109). The 6.5 cm diameter and curving profile of **No. 108** could also identify this vessel as a small beaker/goblet (or alternatively a wide-mouthed flask that narrows to a waist where it meets the vessel body); it has a decorative trail of glass wrapped rather haphazardly around the vessel near the rim.

Vessels with 6-12 cm rim diameters are typically one of two basic profile shapes: deep cylindrical vessels with nearly vertical walls (**Nos. 19, 29, 30, 47, 55,** and **61**), or bowls with an incurved and rounded rim (**Nos. 67, 70, 83,** and **104**). Deep cylindrical vessels with vertical rims are very common in the ʻAbbāsid period (Gorin-Rosen and Katsnelson 2005: 101); vessels with incurved, rounded rims and a cylindrical body are

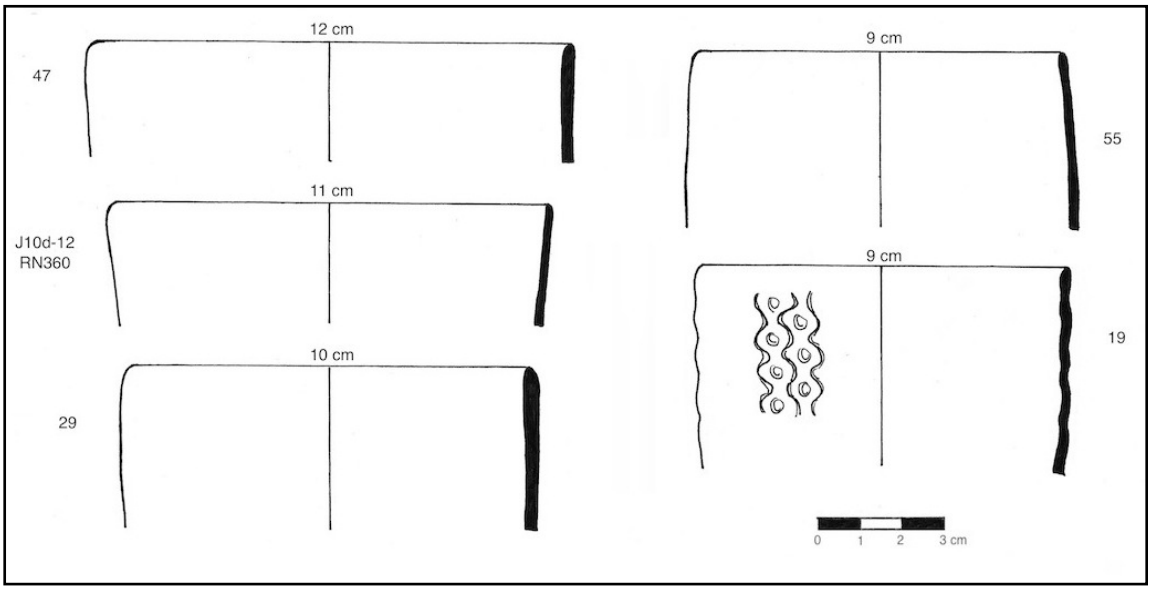

Figure 6.6: Line-drawings of rim fragments of bowls or beakers from Ayla; rim diameters are given at the top of each, and object numbers are shown to the right or left (unless the fragment was not sampled for analysis, in which case the excavation finds number is given).

found in Umayyad assemblages like Bet Sh'ean (Hadad 2005: 91 and Pl. 1, nos. 25-26) but become a dominant type in many 'Abbāsid period assemblages in the Near East (Pollak 2003: 167) for example at Caesarea, Ramla, Hammat Gader, Bet She'an, and Fusṭāṭ. Although most of the fragments are of plain, free-blown manufacture some vessels of this size and shape were also produced by mold-blowing, as is the case for No. 19. Deep bowls with an incurved rounded rims first appear in the Umayyad period but became prominent in later periods; 'Abbāsid examples are typically bigger and more greenish in hue than earlier vessels; although not sampled, one such vessel (Figure 6.7, J10d-48 RN725) is similar to examples from Ramla (Gorin-Rosen and Katsnelson 2005: 104-105 and Fig. 2, no. 12) and to examples from Bet She'an dating to the late 8th-11th centuries CE (Hadad 1998: 75 and Pl. 27, nos. 457-459). Another unsampled vessel from Ayla in the same area/loci (Figure 6.7, J10d-48 RN725) has vertical walls but a slight horizontal bulging rib just beneath the rim, which looks very similar in to vessels

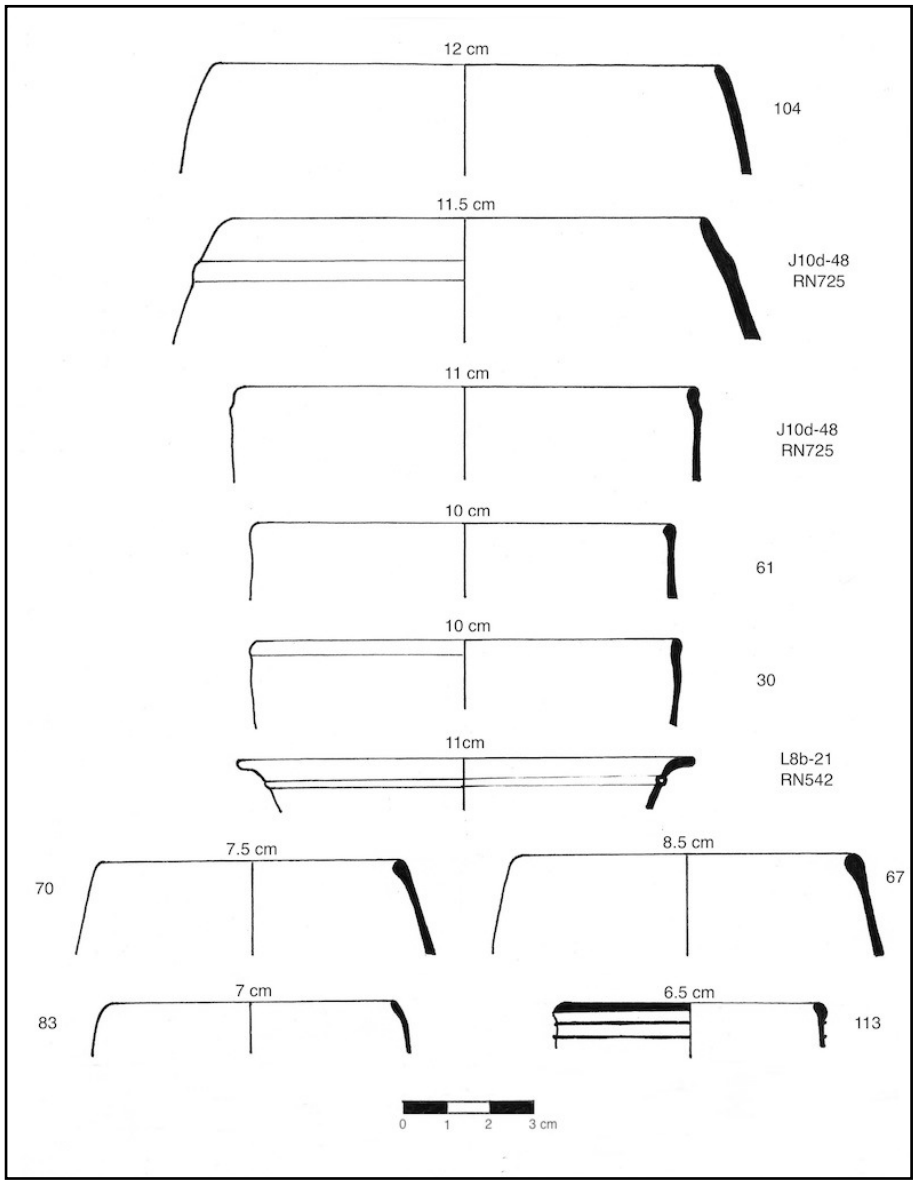

Figure 6.7: Line-drawings of rim fragments of bowls, beakers, cups, lamps, or other open-form vessels from Ayla; rim diameters are given at the top of each, and object numbers are shown to the left or right (unless the fragment was not sampled for analysis, in which case the excavation finds number is given).

recovered from the 9th-mid 10th century CE contexts at Caesarea (Pollak 2003: 167, 169, and Fig. 3, no. 38).

Many of the rims from bottles, flasks, or jugs have a fairly substantial portion of the neck remaining as well (Figure 6.8). These vessels range from large bag-shaped

bottles with very thick walls and a somewhat carelessly irregular shape like **No. 5**, to a variety of small vials made from naturally aqua glass. These small bottles have cracked-off rims (**No. 9**), rounded rims with slightly thickened lips (**Nos. 68** and **92**), flattened lips (**No. 3**), or have a trail of glass wrapped around the rim to form a thicker lip (**No. 31**).

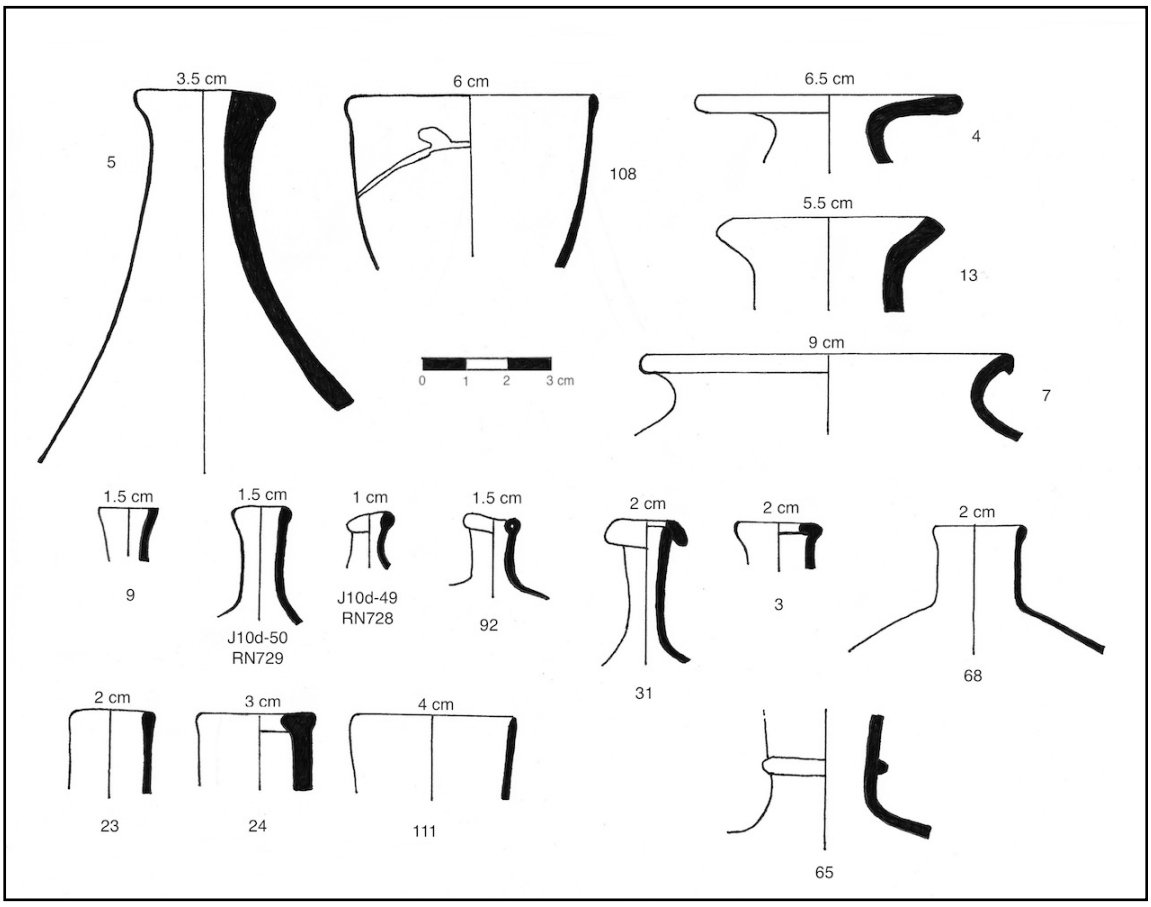

Figure 6.8: Line-drawings of rim and neck fragments of bottles, jars, and flasks from Ayla; rim diameters are given at the top of each, and object numbers are shown below or to the left, right, or below (unless the fragment was not sampled for analysis, in which case the excavation finds number is given).

Several rims (**Nos. 23, 24,** and **111**) belong to small bottles with a wide cylindrical neck, a simple upright rim, and a wide horizontal shoulder; these had a cylindrical or globular body and could be plain or decorated. This type is thought to be a

new in the Early Islamic period at Caesarea (Pollak 2003: 167) and close parallels also come from the Serçe Limanı ship (Bass *et al.* 2009: chapter 20).

Two large bottle neck fragments include Nos. 4 and 13. **No. 4** is from a rather thick-walled "shelf-rim" or "disk-rim" bottle with a flat, flaring rim and a tall neck that tapers from the body to the rim; such vessels could either be plain or were decorated with wheel-cut decorations on the body, and numerous parallels come from Ramla (Gorin-Rosen and Katsnelson 2005: 112-113 and Fig. 4, no. 42), 9th-10th century contexts at Caesarea (Pollak 2003: 167 and Fig. 3, nos. 44, 50-51), 10th-11th century contexts at Tiberias (Lester 2003: 160 and Fig. 2, nos. 16-17), 8th-10th century contexts at el-Ashmunein (Bailey 1998: 152 and Pl. 93, no. 58), "pre-12th century" contexts at Quseir al-Qadim (Meyer 1992: 77 no. 387-388), Fustat (Scanlon and Pinder-Wilson 2001: 87, 90, and Fig. 41j-l, 41m-o), Nishapur (Kröger 1995: 81-82, nos. 108-109; 126-127, no. 171), and from the 11th century Serçe Limanı ship (Bass *et al.* 2009: chapter 16).

No. 13 is the rim of a thick-walled bottle that is not quite as distinctive; however, the sharply everted rim and squared lip was frequently observed among the Ayla drawings of Carol Meyer, and similar vessels were published from 8th-9th century CE contexts at el-Ashmunein (Bailey 1998: 152 and Pl. 93, no. Y56) and Quseir al-Qadim (Meyer 1992: 77: no. 386). At least one rim fragment with an everted lip (**No. 7**) comes from a large jar (yellowish-colorless glass, 9 cm rim diameter); this particular profile was noted as strikingly similar to No. 207 in Chapter 4, and although parallels are generally difficult to find it seems to be quite common at Ayla.[9]

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[9] As mentioned in Chapter 4 (page 121, note 9), several colorless or nearly colorless glass jar fragments are among the objects drawn by Carol Myer in the late 1980s; these fragments were recovered from areas/loci G11c-7 RN497 and G10b-4 RN531 of the "Fāṭimid house" (Whitcomb 1988b), and seem to be largely

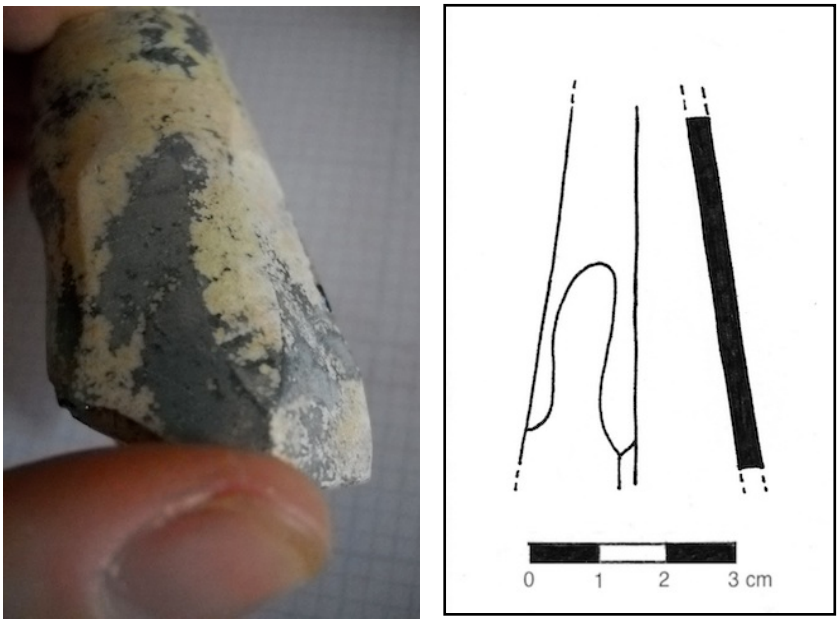

Figure 6.9: Ayla sample No. 8, emerald green bottle neck: (left) photograph using raking light to show the facet cut decoration and (right) line-drawing making these cut decorations more clear.

Neck and shoulder fragments

Three fragments come from the neck or shoulder of larger storage vessels that served as bottles or flasks, or possibly jugs. One of these, **No. 65**, comes from a bottle of deep blue glass and has a rather thick decorative trail wrapped the neck (Figure 6.8). Another of these, **No. 8**, is the heavily weathered neck of a bottle with thick walls that flare toward the body of the vessel (Figure 6.9). This fragment is a rare example of emerald green glass; the color description "emerald green" or sometimes "bright green" refers to a "sparkling green that is different from the ordinary iron green" and is usually associated with high-lead glass containing copper (Brill 1999a: 16). The lower portion of the neck is cut in such a way so as to highlight with long vertical facets with alternating rounded and pointed ends. The shape of the neck—narrow at the top and widening to the

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from 10th-11th century CE contexts. As No. 7 comes from "tip-fill" contexts, such comparisons may be useful for dating.

body of the bottle—is similar to "disk-rim bottles" with relief-cut decorations found on the Serçe Limanı wreck (Bass *et al.* 2009: Fig. 16.4 nos. DR 143, 145-147), at Nishapur (Kröger 1995: 126-128, 172-173), and at Fustat (Scanlon and Pinder-Wilson 2001: 86-91), as well as to the Ayla fragment No. 4. Many of these date to the 9th-10th centuries CE and are attributed to Iran, but all seem to be of colorless glass rather than such a distinctive and highly colored glass.

Base fragments

Some 21 vessel bases were sampled in this study, and examples of the most common or unique forms is give in Figure 6.10. One thin and delicate stem-footed goblet of aqua glass was included as sample **No. 1**, although it was not illustrated or photographed. A unique globular base of aqua glass with pinched-out toes (**No. 86)** and a mold-blown vessel with concentric star design (**No. 14**) were discussed previously. Fragment **No. 6** is a slightly thickened pad base of a bottle or jug in yellowish-colorless glass; the bottom is slightly pushed up, and there are relief-carved lines forming a square in the center of the bottom surface. **No. 87** (green glass, 6 cm base ring diameter) is a base with a hollow rolled tubular foot; although this is a very long-lasting style of base, one that is similar to fragments found at Ḥiṣn al-Tīnāt and many other sites in the Near East, the green color of the fragment dates it to after the Byzantine period. **No. 15** (aqua or nearly colorless glass, ~8 cm base diameter) is the base of a large, thick-walled bottle with a rounded bottom that is pushed in; a large punty scar is still visible. There are many small bottles with cylindrical bodies and rounded bases that are slightly pushed up in the

assemblage overall. One very small and poorly preserved bottle base (**No. 82**) has a thickened pad base and was likely a small bottle.

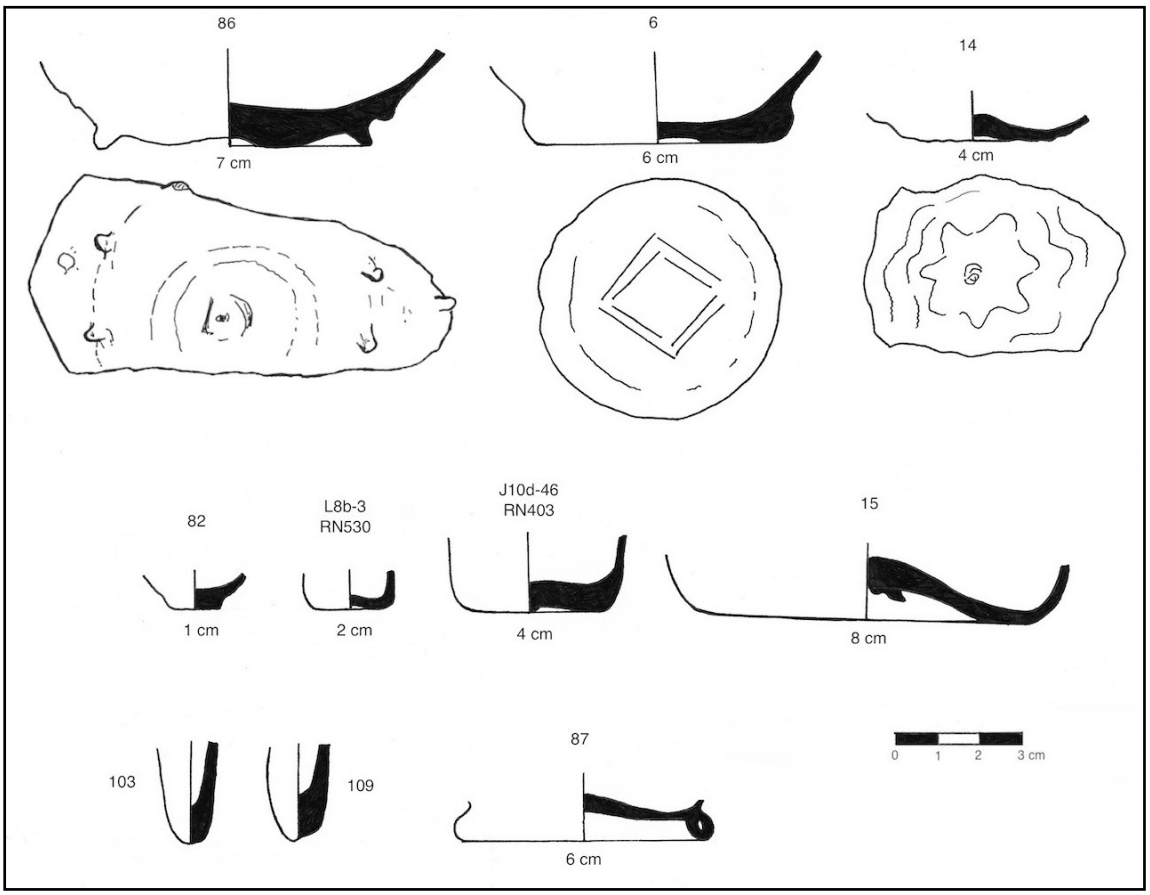

Figure 6.10: Line-drawings of base fragments from bowls, bottles, jugs, lamps, and other vessels from Ayla; base diameters are given at the bottom of each, and object numbers are shown above (unless the fragment was not sampled for analysis, in which case the excavation finds number is given).

Lamp stem fragments

The tips of two stemmed lamps made from naturally aqua and light green glass (**Nos. 103** and **109**, respectively) were easily identifiable (Figures 6.10 and 6.11). Both come from lamps that would have featured a cup-shape and a hollow stem that was meant to be placed in a flat, circular hanging lamp holder called a polycandelon typically made of copper alloy and suspended by a chain (Figure 6.12); such lamps were very popular in

the Late Antique Near East, especially during the 4th-7th centuries, but possibly after this time as well. The Ayla examples resemble Byzantine-Umayyad period hollow-stemmed

Figure 6.11: Examples of stemmed-lamp tips found at Ayla: (left) unsampled fragment from J13d-8 F477, (center) sample No. 103, and (right) No. 109.

Figure 6.12: (Left) Byzantine polycandelon in copper alloy, ca. 6th-7th century CE (Metropolitan Museum of Art object PG.7.2000); (right) examples of solid-stemmed lamps from Anatolia (from Olcay 2001: 81).

examples from all over the Near East, including Beirut (Jennings 2006: 142-143, Type 4a), Bet She'an (Hadad 2005: 133 and Pl. 22, nos. 436-440), Jerash (Bauer 1938: 520 and Fig. 17 no. 237, 522 and Fig. 18 no. 375, 523 and Fig. 19 no. 29; Meyer 1987: 203, 205, and 208 and Fig. 11, nos. H and J), Late Byzantine to Early Islamic contexts at Tell Tanninim (Pollak 2006: 192 and Fig. 151, no. 69), and Petra (O'Hea: 2001: 372, 374, and Fig. 6, no. 4). It may be of interest that this style of stemmed lamp appears to have gone out of use at the end of the Umayyad era at Bet She'an (Hadad 2005: 29).

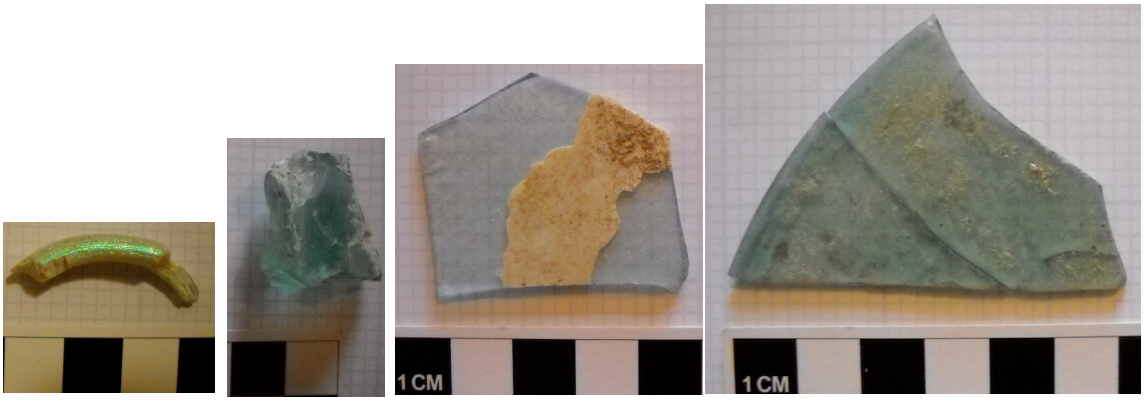

Figure 6.13: Other (non-vessel) fragments of glass from Ayla: (from left to right) possible bracelet No. 32, chunk No. 81, windowpane No. 75, and windowpane No. 76.

Other (non-vessel) Objects

Although most of the objects sampled in this study are recognizable vessel fragments, a few samples do come from other types of glass objects (Figure 6.13). One such object, **No. 32**, is a small semi-circular fragment (~4-5 cm in diameter) with an oblong cross-section that looks like it may possibly be part of a small bangle bracelet; however, it is far too weathered to determine the color of the glass or to discern any other details. Although no glassmaking evidence has yet been noted for Ayla, the aqua-colored glass chunk **No. 81** does not come from any recognizable part of a vessel; it may well be a chunk of raw or recycled glass that came from elsewhere and was remelting during the

glassworking process. Finally, two very flat and rather thick fragments are almost certainly from glass windowpanes. **No. 75** is a flat fragment of naturally aqua glass; **No. 76** is also naturally aqua but is more greenish in hue, and it appears to be from a very large circular pane as it has a curved edge that is 20 cm in diameter and a very slight lip along the edge. Windowpanes of "crown glass" from the early 11th century CE Serçe Limanı shipwreck (Bass *et al.* 2009: 385-389) and 9th-12th century CE Soba in the Sudan (Harden 1955: 68 and Fig. 37, no. 34) are very similar to No. 76 in terms of color, diameter, and thickness of the rim; "crown glass" is formed by blowing a glass bubble and opening this using centrifugal force as would be done when forming a bowl or plate, except that the glass is rotated with more speed so to completely flatten it.

CHEMICAL ANALYSIS

The vessel fragments from Ayla are almost all soda-lime-silica glasses; as was the case for the Ḥiṣn al-Tīnāt fragments in Chapter 4, the type of flux that was used—mineral soda or plant ash soda—helps to distinguish two main technological traditions (Figure 6.14). Of the 111 soda-lime-silica glasses in the Ayla assemblage, 78 (70%) were made using mineral soda as a flux and 33 (30%) were made using plant ash soda. Two other samples, however, were chemically distinct from these two major soda-lime-silica groups: **No. 8** is a unique example of a lead-silicate glass[10] and **No. 62** is likely a fragment of modern glass;[11] the former is considered in the discussions below while the latter was removed from further consideration. In the following sections, the mineral

[10] In this case, lead oxide is the dominant flux rather than soda.

[11] Please refer to Chapter 4, note 15 for more about chemically distinguishing modern and ancient glass. In short, No. 62 has very low iron and potash as well as very high arsenic; its typological form is also unique, being a whitish-colorless bottle stopper.

soda, plant ash soda, and lead-silicate glasses will be discussed separately in order to highlight technological details and possible primary production group affiliations.

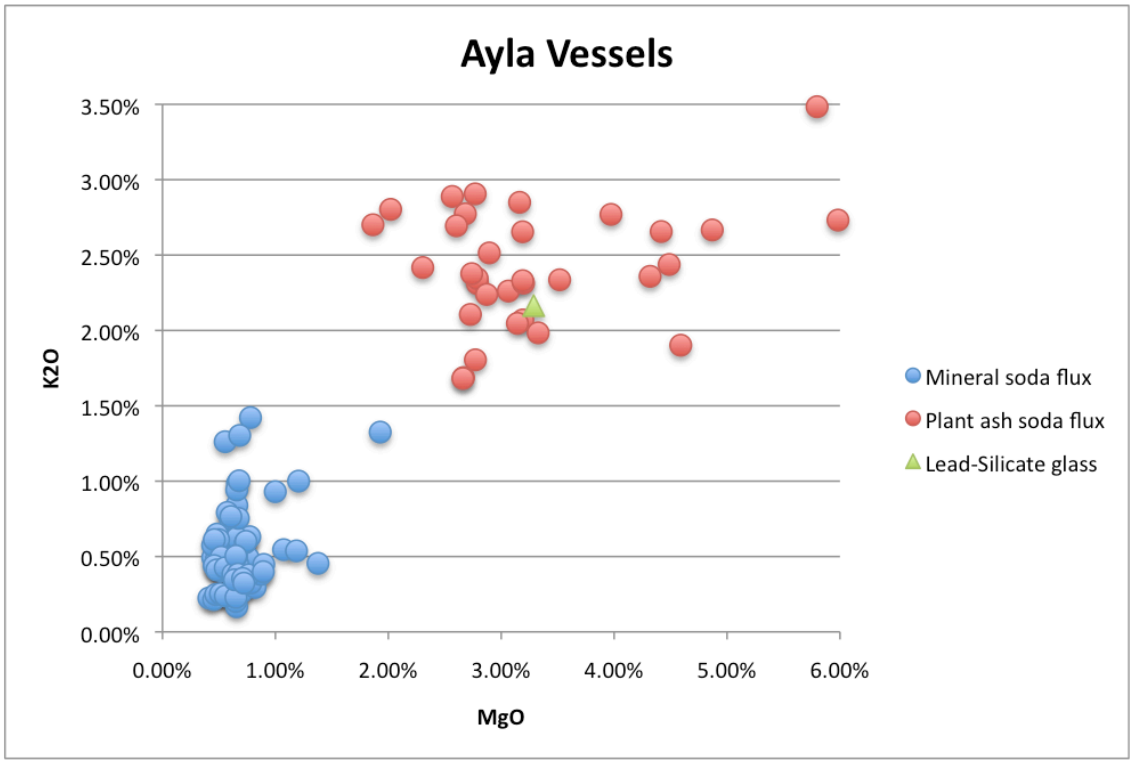

Figure 6.14: Bivariate scatter plot of magnesia and potash (two of the best discriminators) showing the two main technological groups of vessel glass from Ayla, i.e., soda-lime-silica glasses made using mineral or plant ash soda flux. The single fragment of lead-silicate glass is also indicated.

Mineral soda glasses

The great majority of the Ayla glass samples were made using mineral soda and sand as the primary raw ingredients; the results of the major/minor elements are presented in Table 6.1, while the results for the trace elements are given in Table 6.2. These glasses are all below 1.5 wt% for both magnesia and potash (ranging 0.4-1.4 wt% MgO and 0.7-1.4 wt% K_2O) and the great majority are below 1 wt%.

Table 6.1: <u>AYLA MINERAL SODA GLASSES</u>: chemical results for the MAJOR AND MINOR OXIDES and colorants/decolorants, given in wt%.

Sample ID #	Color	SiO2	Na2O	K2O	CaO	MgO	Al2O3	Fe2O3	TiO2	MnO	P2O3	CuO	CoO	PbO2	Sb2O5	SnO2
GROUP 1: mineral soda glasses similar to the Egyptian I group																
54	Aqua	70.65	17.90	0.45	3.80	0.90	4.02	1.56	0.31	0.05	0.09	0.00	0.00	0.00	0.00	0.00
69	Aqua	70.29	18.47	0.40	3.52	0.89	4.04	1.62	0.33	0.05	0.07	0.00	0.00	0.00	0.00	0.00
74	Aqua	70.10	17.30	0.93	3.65	1.00	4.31	1.77	0.33	0.05	0.25	0.00	0.00	0.00	0.00	0.00
76	Aqua	70.04	20.02	0.50	3.81	0.65	3.15	1.04	0.16	0.04	0.12	0.03	0.00	0.01	0.00	0.00
91	Green	71.36	15.87	0.54	3.18	1.19	4.56	2.40	0.37	0.06	0.10	0.00	0.00	0.00	0.00	0.00
AVERAGE		**70.49**	**17.91**	**0.56**	**3.59**	**0.93**	**4.02**	**1.68**	**0.30**	**0.05**	**0.13**	**0.01**	**0.00**	**0.00**	**0.00**	**0.00**

Sample ID #	Color	SiO2	Na2O	K2O	CaO	MgO	Al2O3	Fe2O3	TiO2	MnO	P2O3	CuO	CoO	PbO2	Sb2O5	SnO2
GROUP 2: mineral soda glasses similar to the Egyptian II group																
12	Aqua	69.11	15.18	0.36	9.80	0.63	2.54	1.01	0.09	0.26	0.07	0.01	0.00	0.06	0.00	0.00
16	Blue	70.40	13.82	0.38	9.32	0.68	2.49	1.48	0.09	0.27	0.08	0.13	0.09	0.01	0.00	0.00
29	Aqua?	75.10	12.14	0.17	7.69	0.66	2.47	0.79	0.08	0.02	0.14	0.00	0.00	0.00	0.00	0.00
31	Aqua	69.92	14.99	0.21	10.21	0.45	2.23	0.81	0.08	0.02	0.02	0.00	0.00	0.00	0.00	0.00
36	Aqua	72.68	14.05	0.20	8.57	0.65	2.72	1.02	0.09	0.02	0.06	0.00	0.00	0.00	0.00	0.00
37	Aqua	70.06	13.50	0.55	10.27	1.07	3.13	1.15	0.10	0.12	0.12	0.00	0.00	0.00	0.00	0.00
38	Aqua	71.63	13.92	0.27	9.52	0.70	2.77	1.08	0.11	0.02	0.08	0.00	0.00	0.00	0.00	0.00
40	Aqua	71.31	13.33	0.33	9.95	0.76	3.07	1.13	0.11	0.02	0.08	0.00	0.00	0.00	0.00	0.00
41	Blue	71.10	13.72	0.38	8.99	0.76	2.69	1.63	0.10	0.36	0.16	0.14	0.04	0.01	0.00	0.00
43	Aqua	69.37	15.45	0.43	10.08	0.56	2.56	0.87	0.13	0.03	0.08	0.00	0.00	0.00	0.00	0.00
45	Aqua	69.10	15.85	0.28	10.10	0.65	2.47	0.83	0.13	0.04	0.07	0.00	0.00	0.00	0.00	0.00
47	Aqua	69.19	14.36	0.32	11.12	0.78	2.60	0.86	0.14	0.05	0.09	0.00	0.00	0.00	0.00	0.00
48	Purple	67.45	15.31	0.38	10.37	0.62	2.49	1.00	0.14	1.67	0.11	0.01	0.00	0.01	0.00	0.00
49	Aqua	70.11	14.28	0.35	9.93	0.71	2.83	1.10	0.20	0.03	0.10	0.00	0.00	0.00	0.00	0.00
50	Aqua	69.96	13.85	0.32	10.41	0.72	2.96	1.08	0.21	0.03	0.10	0.00	0.00	0.00	0.00	0.00
51	Aqua	69.27	14.79	0.35	10.70	0.64	2.56	0.94	0.18	0.03	0.09	0.00	0.00	0.00	0.00	0.00
52	Aqua	69.88	13.81	0.38	10.64	0.76	2.59	0.96	0.18	0.31	0.10	0.01	0.00	0.01	0.00	0.00
53	Aqua	70.22	14.50	0.23	10.30	0.65	2.51	0.87	0.17	0.02	0.07	0.00	0.00	0.00	0.00	0.00
55	Aqua	70.23	14.85	0.24	10.03	0.56	2.53	0.85	0.16	0.02	0.07	0.00	0.00	0.00	0.00	0.00
67	Aqua	71.19	15.50	0.25	8.85	0.51	2.67	0.93	0.09	0.02	0.05	0.00	0.00	0.00	0.00	0.00

Sample ID #	Color	SiO2	Na2O	K2O	CaO	MgO	Al2O3	Fe2O3	TiO2	MnO	P2O3	CuO	CoO	PbO2	Sb2O5	SnO2
70	Aqua	69.77	15.31	0.38	9.61	0.67	2.33	0.96	0.16	0.15	0.16	0.02	0.00	0.06	0.00	0.00
71	Aqua	69.99	13.39	0.60	9.99	0.74	3.49	1.03	0.12	0.06	0.16	0.02	0.00	0.16	0.00	0.02
79	Aqua	69.01	18.17	0.25	8.65	0.47	1.77	0.70	0.08	0.03	0.06	0.01	0.00	0.00	0.00	0.00
83	Lt. green	69.12	15.72	0.22	11.27	0.41	1.78	0.61	0.07	0.01	0.06	0.00	0.00	0.00	0.00	0.00
86	Aqua	69.43	16.31	0.44	9.77	0.46	1.77	0.74	0.10	0.02	0.23	0.00	0.00	0.00	0.00	0.00
89	Lt. green	68.01	16.24	0.30	9.99	0.82	2.58	1.07	0.13	0.03	0.08	0.00	0.00	0.00	0.00	0.00
90	Aqua	71.42	11.91	0.59	9.83	0.73	3.77	1.08	0.08	0.05	0.10	0.03	0.00	0.18	0.00	0.01
93	Aqua	67.77	16.99	0.41	10.49	0.48	2.00	0.77	0.11	0.02	0.20	0.00	0.00	0.00	0.00	0.00
AVERAGE		**70.06**	**14.69**	**0.34**	**9.87**	**0.65**	**2.59**	**0.98**	**0.12**	**0.13**	**0.10**	**0.01**	**0.00**	**0.02**	**0.00**	**0.00**
Group 2 outliers																
88	Aqua	67.08	17.17	1.00	8.35	1.21	2.71	1.17	0.08	0.59	0.17	0.01	0.00	0.01	0.00	0.00
102	Aqua	68.91	13.05	1.33	10.15	1.93	2.58	0.85	0.11	0.52	0.18	0.02	0.00	0.02	0.00	0.00

Sample ID #	Color	SiO2	Na2O	K2O	CaO	MgO	Al2O3	Fe2O3	TiO2	MnO	P2O3	CuO	CoO	PbO2	Sb2O5	SnO2
GROUP 3: mineral soda glasses similar to the Levantine I group																
1	Aqua	66.30	16.74	0.99	10.49	0.66	4.03	0.73	0.04	0.03	0.00	0.00	0.00	0.00	0.00	0.00
33	Aqua	70.19	13.17	1.42	9.73	0.78	3.09	0.66	0.04	0.09	0.18	0.00	0.00	0.01	0.00	0.00
34	Aqua	69.64	16.50	0.84	8.14	0.66	2.85	0.38	0.02	0.02	0.03	0.00	0.00	0.00	0.00	0.00
59	Aqua	70.59	14.05	0.54	8.54	0.70	3.69	0.90	0.10	0.08	0.12	0.05	0.00	0.30	0.00	0.04
84	Aqua, Y-Br	70.63	11.68	0.63	10.93	0.77	3.72	1.03	0.08	0.04	0.11	0.03	0.00	0.12	0.00	0.01
87	Green	70.45	11.70	0.45	9.24	0.57	3.43	0.58	0.04	0.02	0.08	0.01	0.00	3.05	0.00	0.03
96	Lt. green	67.46	17.42	0.55	9.06	0.54	2.85	0.36	0.03	1.01	0.07	0.00	0.00	0.00	0.00	0.00
97	Aqua	69.26	16.60	0.94	8.53	0.66	2.48	0.48	0.03	0.02	0.17	0.05	0.01	0.11	0.00	0.00
98	Aqua	68.44	15.80	1.00	9.66	0.68	2.89	0.63	0.05	0.05	0.19	0.00	0.00	0.00	0.00	0.00
99	Lt. green	64.50	17.61	1.26	10.41	0.56	2.86	0.50	0.04	1.68	0.16	0.01	0.00	0.00	0.00	0.00
100	Aqua	67.37	17.34	0.59	9.80	0.58	3.03	0.50	0.03	0.03	0.06	0.00	0.00	0.00	0.00	0.00
101	Aqua	70.22	16.07	0.42	8.66	0.56	2.73	0.44	0.03	0.03	0.05	0.00	0.00	0.00	0.00	0.00
107	Aqua	70.14	16.18	0.74	8.05	0.60	3.20	0.38	0.04	0.02	0.10	0.00	0.00	0.00	0.00	0.00
110	Lt. green	68.99	16.52	0.61	9.04	0.60	3.17	0.41	0.03	0.02	0.13	0.00	0.00	0.00	0.00	0.00
111	Aqua	69.48	15.01	0.40	9.88	0.65	3.41	0.46	0.04	0.02	0.06	0.00	0.00	0.00	0.00	0.00
112	Aqua	66.92	15.82	1.30	9.63	0.68	3.36	0.66	0.05	0.96	0.19	0.03	0.00	0.01	0.00	0.00
113	Aqua, Bl	69.85	13.88	0.60	10.57	0.71	3.22	0.49	0.04	0.03	0.10	0.00	0.00	0.01	0.00	0.00
AVERAGE		**68.85**	**15.42**	**0.78**	**9.43**	**0.65**	**3.18**	**0.56**	**0.04**	**0.24**	**0.11**	**0.01**	**0.00**	**0.21**	**0.00**	**0.00**

Sample ID #	Color	SiO2	Na2O	K2O	CaO	MgO	Al2O3	Fe2O3	TiO2	MnO	P2O3	CuO	CoO	PbO2	Sb2O5	SnO2
GROUP 4: mineral soda glasses similar to the Levantine II group																
3	Aqua	74.05	14.16	0.49	6.76	0.48	3.50	0.53	0.03	0.02	0.00	0.00	0.00	0.00	0.00	0.00
18	Colorless?	74.66	13.50	0.52	6.22	0.60	3.32	0.51	0.03	0.02	0.04	0.00	0.00	0.00	0.00	0.00
39	Aqua	72.98	14.96	0.62	7.09	0.52	3.24	0.47	0.03	0.03	0.05	0.01	0.00	0.00	0.00	0.00
56	Aqua	74.70	14.32	0.57	6.09	0.44	2.88	0.42	0.05	0.02	0.06	0.00	0.00	0.00	0.00	0.00
58	Lt. green	73.59	14.69	0.41	6.76	0.52	2.98	0.44	0.05	0.02	0.07	0.00	0.00	0.00	0.00	0.00
61	Aqua	75.49	12.95	0.43	6.40	0.54	3.12	0.49	0.05	0.03	0.06	0.00	0.00	0.00	0.00	0.00
63	Aqua	75.90	12.22	0.46	6.19	0.53	3.44	0.76	0.08	0.03	0.06	0.00	0.00	0.00	0.00	0.00
66	Aqua	75.01	11.97	0.62	7.64	0.66	3.35	0.64	0.04	0.03	0.06	0.00	0.00	0.00	0.00	0.00
68	Lt. green	74.27	13.17	0.75	6.38	0.67	3.63	0.57	0.06	0.03	0.08	0.00	0.00	0.00	0.00	0.00
72	Aqua	74.79	13.19	0.65	6.54	0.48	3.31	0.60	0.07	0.03	0.06	0.00	0.00	0.00	0.00	0.00
73	Aqua	74.81	13.12	0.61	6.66	0.50	3.27	0.60	0.07	0.02	0.06	0.00	0.00	0.00	0.00	0.00
78	Aqua	75.24	12.29	0.45	7.25	0.67	3.00	0.45	0.03	0.02	0.05	0.00	0.00	0.00	0.00	0.00
81	Aqua	73.73	14.81	0.61	6.36	0.46	2.87	0.44	0.03	0.02	0.05	0.00	0.00	0.00	0.00	0.00
82	Aqua	74.05	14.92	0.43	6.24	0.47	2.75	0.42	0.03	0.02	0.05	0.00	0.00	0.00	0.00	0.00
85	Aqua	73.66	13.65	0.50	7.38	0.66	2.97	0.46	0.03	0.02	0.05	0.00	0.00	0.00	0.00	0.00
92	Lt. green	74.34	12.96	0.47	7.13	0.56	3.39	0.53	0.04	0.02	0.05	0.00	0.00	0.00	0.00	0.00
94	Lt. green	73.66	14.53	0.50	6.71	0.52	2.84	0.54	0.04	0.02	0.07	0.00	0.00	0.01	0.00	0.00
108	Lt. green	73.07	13.80	0.77	7.55	0.61	3.28	0.41	0.04	0.02	0.06	0.00	0.00	0.00	0.00	0.00
AVERAGE		**74.33**	**13.62**	**0.55**	**6.74**	**0.55**	**3.17**	**0.52**	**0.04**	**0.02**	**0.05**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Group 4 outliers (mixed Levantine I and II?)																
32	?	71.84	14.20	0.52	8.45	0.64	2.89	0.42	0.02	0.03	0.03	0.00	0.00	0.00	0.00	0.00
57	Aqua	72.15	13.93	0.49	8.13	0.76	3.41	0.51	0.05	0.03	0.06	0.00	0.00	0.00	0.00	0.00
75	Aqua	70.85	17.29	0.60	6.81	0.48	2.94	0.42	0.05	0.02	0.06	0.00	0.00	0.00	0.00	0.00
95	Aqua	71.76	16.50	0.49	6.91	0.45	2.71	0.38	0.03	0.02	0.05	0.00	0.00	0.00	0.00	0.00
103	Aqua	70.62	17.26	0.60	7.03	0.49	2.90	0.35	0.04	0.04	0.08	0.00	0.00	0.00	0.00	0.00
109	Lt. green	71.76	15.43	0.79	7.60	0.57	2.74	0.39	0.04	0.02	0.14	0.00	0.00	0.00	0.00	0.00
AVERAGE		**71.50**	**15.77**	**0.58**	**7.49**	**0.56**	**2.93**	**0.41**	**0.04**	**0.03**	**0.07**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Sample ID #	Color	SiO2	Na2O	K2O	CaO	MgO	Al2O3	Fe2O3	TiO2	MnO	P2O3	CuO	CoO	PbO2	Sb2O5	SnO2
GROUP 5: mineral soda glasses similar to the HIMT group																
35	Y-green	68.04	16.69	0.38	5.48	0.87	2.77	2.87	0.16	1.97	0.06	0.01	0.00	0.00	0.00	0.00
114	Lt. green	66.32	16.83	0.45	5.59	1.38	3.64	3.50	0.30	1.55	0.14	0.01	0.00	0.00	0.00	0.00
AVERAGE		**67.18**	**16.76**	**0.42**	**5.54**	**1.12**	**3.20**	**3.18**	**0.23**	**1.76**	**0.10**	**0.01**	**0.00**	**0.00**	**0.00**	**0.00**

Tables 6.2 AYLA MINERAL SODA GLASSES: chemical results for the TRACE ELEMENTS given in ppm.

Sample ID #	Color	Li	Be	B	Sc	Ti	V	Cr	Ni	Co	Zn	As	Rb	Sr	Zr	Nb	Ag	Sb	Cs	Ba
GROUP 1: mineral soda glasses similar to the Egyptian I group																				
54	Aqua	3.5	0.6	85.9	6.5	1845.7	41.2	74.5	11.3	5.2	21.6	5.7	8.5	173.0	167.1	6.2	0.0	0.1	0.1	158.4
69	Aqua	3.8	0.6	125.6	6.2	1955.4	44.2	76.4	11.0	5.1	23.6	7.7	8.2	182.2	162.5	6.2	0.1	0.2	0.1	166.1
74	Aqua	5.7	0.6	87.3	6.4	1980.4	48.5	78.2	12.6	6.0	31.8	17.1	13.2	208.2	186.9	6.8	0.1	0.3	0.2	187.4
76	Aqua	4.0	0.4	69.7	4.1	932.6	23.9	39.8	8.4	3.7	41.3	7.0	9.0	200.9	73.6	3.7	0.2	13.2	0.1	164.1
91	Green	4.9	0.6	106.6	8.5	2243.8	67.8	122.9	14.2	6.9	34.7	2.7	11.2	174.1	358.6	10.0	0.1	0.1	0.1	209.4
AVERAGE		**4.4**	**0.6**	**95.0**	**6.3**	**1791.6**	**45.1**	**78.4**	**11.5**	**5.4**	**30.6**	**8.0**	**10.0**	**187.7**	**189.7**	**6.6**	**0.1**	**2.8**	**0.1**	**177.1**

Sample ID #	Color	La	Ce	Pr	Ta	Au	Y	Bi	U	W	Mo	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Th
GROUP 1: mineral soda glasses similar to the Egyptian I group – CONTINUED																								
54	Aqua	7.4	15.8	1.9	0.2	0.0	9.7	0.0	0.9	0.1	0.1	7.5	1.6	0.4	1.5	0.2	1.4	0.3	0.8	0.1	0.8	0.1	3.5	1.5
69	Aqua	7.5	15.9	2.0	0.3	0.0	9.8	0.0	0.9	0.1	0.1	7.4	1.6	0.4	1.3	0.2	1.3	0.3	0.8	0.1	0.8	0.1	3.5	1.5
74	Aqua	8.8	18.6	2.3	0.3	0.1	10.7	0.0	1.0	0.1	0.2	8.4	1.7	0.5	1.7	0.2	1.5	0.3	0.9	0.1	0.9	0.1	4.1	1.8
76	Aqua	5.9	13.3	1.6	0.1	0.0	6.8	0.0	1.1	0.1	0.2	5.9	1.3	0.4	1.1	0.2	1.0	0.2	0.6	0.1	0.6	0.1	1.8	1.0
91	Green	11.6	24.3	3.2	0.5	0.0	14.6	0.0	1.3	0.2	0.3	11.6	2.6	0.6	2.4	0.4	2.3	0.4	1.3	0.2	1.3	0.2	8.2	3.0
AVERAGE		**8.2**	**17.6**	**2.2**	**0.3**	**0.0**	**10.3**	**0.0**	**1.0**	**0.1**	**0.2**	**8.2**	**1.8**	**0.4**	**1.6**	**0.2**	**1.5**	**0.3**	**0.9**	**0.1**	**0.9**	**0.1**	**4.2**	**1.8**

Sample ID #	Color	Li	Be	B	Sc	Ti	V	Cr	Ni	Co	Zn	As	Rb	Sr	Zr	Nb	Ag	Sb	Cs	Ba
GROUP 2: mineral soda glasses similar to the Egyptian II group																				
12	Aqua	3.4	0.7	79.4	3.0	543.7	20.6	28.0	8.7	13.8	63.7	17.6	4.8	195.7	165.2	4.5	0.7	2.7	0.1	168.4
16	Blue	4.7	0.7	91.1	3.1	530.5	21.6	26.3	13.2	743.3	404.9	13.6	4.8	166.8	157.6	4.3	0.3	1.2	0.1	155.9
29	Aqua?	3.3	0.7	133.2	2.7	489.1	17.4	45.4	6.5	2.6	10.8	47.0	2.4	129.2	139.9	3.5	0.1	0.1	0.0	108.1
31	Aqua	4.0	0.9	65.0	2.8	478.9	18.0	20.6	5.6	2.7	12.7	5.4	3.4	150.9	133.7	3.8	0.1	0.2	0.1	119.7
36	Aqua	3.5	1.9	88.1	3.6	537.3	22.7	27.6	8.3	3.1	15.4	7.7	4.4	138.1	114.2	4.1	0.1	0.2	0.1	144.8
37	Aqua	6.0	1.1	94.7	4.0	629.3	24.7	29.9	9.1	4.6	16.6	3.7	5.9	207.3	160.3	4.5	0.1	0.2	0.0	153.4
38	Aqua	4.3	1.3	107.6	3.6	668.6	23.7	32.1	7.6	3.5	14.7	11.1	4.5	142.6	184.5	4.8	0.2	0.2	0.1	142.0
40	Aqua	5.0	1.1	115.9	3.9	674.2	25.0	32.6	8.0	3.0	12.9	5.4	5.3	155.6	192.8	5.1	0.1	0.1	0.1	151.8
41	Blue	4.4	1.5	90.2	3.5	580.5	22.8	30.1	11.7	319.8	358.5	9.0	4.8	149.1	149.7	4.4	0.4	1.8	0.1	156.0
43	Aqua	3.9	0.4	95.0	3.3	809.2	20.4	25.7	6.7	3.4	15.7	6.0	5.3	171.7	167.0	4.9	0.5	0.2	0.1	131.3
45	Aqua	3.7	0.6	45.3	3.3	767.2	20.5	28.9	7.2	3.1	14.4	6.1	4.4	175.9	170.1	4.5	0.1	0.2	0.1	134.5
47	Aqua	4.2	0.5	88.4	3.4	838.8	22.9	29.0	6.5	3.0	15.4	5.8	4.9	210.9	208.9	5.1	0.1	0.2	0.1	157.0
48	Purple	4.4	1.0	81.8	3.4	810.9	26.7	30.5	11.4	10.9	102.3	8.4	5.9	199.8	171.0	4.6	0.3	5.6	0.1	262.1
49	Aqua	4.5	0.5	95.8	3.8	1195.1	26.0	33.3	7.8	3.3	19.9	6.0	6.3	188.6	186.6	5.4	0.1	0.6	0.1	171.6
50	Aqua	4.1	0.4	95.2	4.0	1249.9	26.1	33.2	7.7	3.3	15.0	6.4	5.7	195.7	220.1	5.7	0.0	0.2	0.1	177.4
51	Aqua	3.9	0.5	106.2	3.4	1053.0	22.4	29.5	7.3	2.8	15.4	8.3	5.8	174.9	183.0	4.9	0.1	0.2	0.1	164.8
52	Aqua	4.6	0.6	84.6	3.7	1057.1	22.3	29.2	7.9	12.8	42.1	8.8	4.9	169.3	181.8	4.7	0.2	0.7	0.1	153.8
53	Aqua	4.2	0.5	86.5	3.6	995.5	21.4	28.3	6.3	2.7	13.1	6.0	4.0	152.7	169.3	4.5	0.0	0.1	0.1	132.4
55	Aqua	3.6	0.5	90.5	3.6	986.0	20.2	28.4	6.2	2.5	11.4	6.2	3.9	150.6	156.4	4.3	0.0	0.1	0.0	124.0
67	Aqua	3.4	1.7	90.1	3.3	545.3	20.3	28.6	7.4	2.5	12.2	10.8	4.8	125.9	127.5	4.0	0.1	0.2	0.0	132.6
70	Aqua	4.2	0.5	87.4	3.5	963.1	21.3	27.6	7.6	16.7	132.9	8.5	5.0	153.9	140.3	4.2	1.9	2.6	0.1	128.0
71	Aqua	7.9	0.9	67.6	3.4	696.4	20.4	24.8	11.1	4.7	27.2	10.3	9.1	277.4	79.1	4.2	0.4	3.1	0.2	218.7
79	Aqua	3.4	0.4	100.9	3.1	501.5	14.4	17.9	8.6	2.4	11.8	1.0	3.5	116.9	96.9	3.3	0.1	0.4	0.0	84.9
83	Lt. green	3.7	0.4	111.5	2.8	429.0	12.9	15.7	7.4	2.2	8.9	1.0	3.3	120.9	87.5	2.9	0.0	0.1	0.0	90.7
86	Aqua	3.8	0.5	126.4	3.0	611.0	16.0	18.7	4.7	2.3	19.9	2.2	5.8	119.6	129.0	3.9	0.1	0.1	0.1	101.8
89	Lt. green	5.2	0.3	104.1	3.7	754.5	23.5	28.4	7.4	3.2	14.4	2.2	5.8	181.0	189.3	5.3	0.1	0.1	0.1	168.5
90	Aqua	8.5	0.8	44.9	3.6	484.3	20.3	24.6	9.6	4.2	23.4	3.7	12.2	328.2	81.7	4.4	0.3	3.4	0.2	215.8
93	Aqua	4.0	0.4	122.1	3.1	644.3	16.6	22.3	5.3	2.4	17.2	2.2	6.1	140.4	149.3	4.4	0.0	0.2	0.1	125.7
AVERAGE		**4.4**	**0.8**	**92.5**	**3.4**	**733.0**	**21.1**	**27.8**	**8.0**	**42.3**	**51.5**	**8.2**	**5.2**	**171.1**	**153.3**	**4.4**	**0.2**	**0.9**	**0.1**	**149.1**
Group 2 outliers																				
88	Aqua	6.5	0.4	150.7	3.3	469.5	26.0	18.7	15.3	12.6	32.1	4.2	9.5	600.6	97.0	3.9	0.0	8.9	0.1	213.5
102	Aqua	7.4	0.6	86.8	3.5	662.4	20.4	26.5	17.2	32.2	53.3	6.8	10.6	405.6	136.1	4.0	0.3	9.8	0.1	179.5

Sample ID #	Color	La	Ce	Pr	Ta	Au	Y	Bi	U	W	Mo	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Th
GROUP 2: mineral soda glasses similar to the Egyptian II group – CONTINUED																								
12	Aqua	7.0	13.5	1.7	0.3	0.0	7.5	0.1	1.2	0.2	0.3	6.7	1.2	0.4	1.3	0.2	1.2	0.2	0.8	0.1	0.7	0.1	4.2	1.5
16	Blue	6.0	12.0	1.6	0.2	0.4	6.4	0.0	0.9	0.1	1.2	5.7	1.2	0.3	1.0	0.2	1.0	0.2	0.9	0.1	0.6	0.2	3.8	1.4
29	Aqua?	5.0	9.8	1.3	0.2	0.1	5.2	0.1	0.7	0.1	0.1	5.1	1.0	0.2	0.9	0.1	0.9	0.2	0.5	0.1	0.5	0.1	3.3	1.1
31	Aqua	5.5	11.2	1.4	0.2	0.1	6.1	0.1	1.0	0.2	0.2	5.3	0.9	0.3	1.0	0.2	0.9	0.2	0.5	0.1	0.5	0.1	3.0	1.2
36	Aqua	5.8	12.9	1.4	0.4	0.5	5.8	0.1	1.5	0.6	0.5	5.5	1.2	0.4	1.4	0.2	1.2	0.2	0.6	0.1	0.7	0.1	3.0	1.7
37	Aqua	6.7	12.5	1.7	0.2	0.0	7.6	0.0	0.9	0.2	0.6	6.4	1.3	0.3	1.2	0.2	1.2	0.2	0.8	0.1	0.7	0.1	4.1	1.6
38	Aqua	6.4	13.2	1.7	0.3	0.0	7.0	0.1	0.8	0.2	0.4	6.0	1.3	0.3	1.1	0.2	1.1	0.2	0.7	0.1	0.8	0.1	5.0	1.6
40	Aqua	7.3	13.7	1.8	0.3	0.0	7.6	0.0	0.8	0.2	0.4	6.6	1.3	0.4	1.2	0.2	1.2	0.2	0.8	0.1	0.8	0.1	4.8	1.8
41	Blue	6.0	12.9	1.6	0.2	0.0	6.5	0.1	0.9	0.3	1.5	5.8	1.2	0.3	1.0	0.1	1.0	0.2	0.7	0.1	0.6	0.1	3.9	1.6
43	Aqua	6.5	13.1	1.8	0.3	0.1	7.1	0.0	1.2	0.1	0.2	5.9	1.4	0.3	1.1	0.2	1.2	0.3	0.7	0.1	1.1	0.2	4.1	1.4
45	Aqua	6.4	13.1	1.7	0.2	0.0	6.8	0.0	1.2	0.1	0.1	6.3	1.3	0.3	1.1	0.2	1.1	0.2	0.6	0.1	0.7	0.1	4.0	1.5
47	Aqua	7.3	14.9	1.9	0.3	0.4	7.6	0.1	1.1	0.4	0.3	6.7	1.7	0.4	1.5	0.2	1.2	0.3	0.8	0.1	1.1	0.1	5.0	1.8
48	Purple	6.6	14.2	1.8	0.3	0.0	7.5	0.0	1.5	0.2	0.5	6.2	1.3	0.3	1.2	0.2	1.1	0.2	0.7	0.1	0.6	0.1	4.1	1.5
49	Aqua	7.5	15.5	2.0	0.3	0.0	8.0	0.0	1.1	0.1	0.3	7.2	1.4	0.4	1.3	0.2	1.2	0.3	0.7	0.1	0.8	0.1	4.4	1.7
50	Aqua	8.2	15.9	2.1	0.3	0.2	9.3	0.0	1.1	0.1	0.2	7.6	1.7	0.4	1.4	0.2	1.4	0.3	0.8	0.1	0.9	0.1	5.4	1.8
51	Aqua	7.2	14.5	1.9	0.2	0.0	7.8	0.0	1.0	0.1	0.3	6.7	1.4	0.3	1.3	0.2	1.2	0.3	0.6	0.1	0.7	0.1	4.5	1.6
52	Aqua	6.2	11.9	1.6	0.2	0.0	7.7	0.0	0.8	0.1	0.3	5.7	1.2	0.3	1.1	0.2	0.9	0.2	0.6	0.1	0.7	0.1	3.7	1.4
53	Aqua	5.9	11.7	1.5	0.2	0.0	6.9	0.0	0.7	0.0	0.1	5.3	1.0	0.2	0.9	0.1	0.9	0.2	0.6	0.1	0.5	0.1	3.5	1.2
55	Aqua	6.0	11.1	1.5	0.2	0.0	7.2	0.0	0.8	0.1	0.1	5.4	1.0	0.3	1.0	0.2	0.9	0.2	0.6	0.1	0.6	0.1	3.4	1.3
67	Aqua	5.7	11.4	1.4	0.2	0.1	5.9	0.0	1.0	0.2	0.2	5.2	1.1	0.3	1.0	0.1	0.8	0.2	0.6	0.1	0.7	0.1	3.4	1.2
70	Aqua	5.9	12.1	1.5	0.2	0.0	6.6	0.0	0.9	0.1	0.3	5.3	1.1	0.3	1.0	0.1	0.8	0.2	0.5	0.1	0.6	0.1	3.1	1.2
71	Aqua	7.8	15.3	2.0	0.2	0.1	8.9	0.2	0.8	0.2	0.5	7.2	1.5	0.3	1.3	0.2	1.1	0.3	0.7	0.1	0.7	0.1	1.9	1.3
79	Aqua	4.3	8.7	1.1	0.2	0.1	5.3	0.0	0.6	0.1	0.5	3.9	0.8	0.2	0.9	0.1	0.7	0.1	0.4	0.1	0.4	0.1	2.0	0.8
83	Lt. green	4.7	9.1	1.1	0.2	0.0	5.7	0.0	0.8	0.1	0.2	4.4	0.9	0.2	0.8	0.1	0.8	0.2	0.5	0.1	0.5	0.1	1.9	0.8
86	Aqua	4.9	10.3	1.3	0.2	0.1	5.8	0.0	0.7	0.1	1.0	4.5	1.1	0.2	0.8	0.1	0.8	0.2	0.5	0.1	0.5	0.1	2.7	1.0
89	Lt. green	7.4	14.8	1.9	0.3	0.1	7.8	0.0	0.9	0.1	0.5	7.0	1.5	0.4	1.3	0.2	1.2	0.2	0.7	0.1	0.8	0.1	4.6	1.6
90	Aqua	9.1	18.2	2.4	0.3	0.1	10.1	0.2	0.9	0.1	0.6	9.1	1.9	0.5	1.7	0.2	1.5	0.3	0.9	0.1	0.8	0.1	2.1	1.6
93	Aqua	6.2	12.1	1.6	0.2	0.0	6.9	0.0	0.8	0.1	0.8	6.1	1.2	0.3	1.0	0.2	1.1	0.2	0.6	0.1	0.7	0.1	3.5	1.3
AVERAGE		**6.4**	**12.8**	**1.7**	**0.2**	**0.1**	**7.1**	**0.0**	**1.0**	**0.2**	**0.4**	**6.0**	**1.3**	**0.3**	**1.1**	**0.2**	**1.1**	**0.2**	**0.7**	**0.1**	**0.7**	**0.1**	**3.7**	**1.4**
Group 2 outliers																								
88	Aqua	8.4	15.4	2.1	0.2	0.0	9.0	0.0	1.1	0.2	2.3	8.2	1.7	0.4	1.6	0.2	1.4	0.3	0.8	0.1	0.8	0.1	2.6	1.5
102	Aqua	6.5	12.2	1.6	0.2	0.0	7.8	0.0	0.8	0.2	1.2	5.9	1.2	0.3	1.2	0.2	1.0	0.2	0.6	0.1	0.6	0.1	2.8	1.3

Sample ID #	Color	Li	Be	B	Sc	Ti	V	Cr	Ni	Co	Zn	As	Rb	Sr	Zr	Nb	Ag	Sb	Cs	Ba
GROUP 3: mineral soda glasses similar to the Levantine I group																				
1	Aqua	8.3	5.3	51.5	4.4	241.4	13.6	26.3	14.5	2.8	12.6	0.0	13.1	403.6	60.4	2.5	0.5	0.7	0.2	255.9
33	Aqua	4.3	0.9	76.5	2.3	233.4	13.4	13.9	7.2	4.9	12.2	2.0	13.4	442.1	58.6	2.6	0.1	5.2	0.1	232.4
34	Aqua	3.1	0.9	103.2	1.7	128.1	7.5	10.2	3.4	1.3	6.6	0.0	11.4	461.2	30.2	1.7	0.1	0.4	0.4	218.3
59	Aqua	7.9	0.7	52.9	3.3	588.4	17.6	21.0	9.2	5.4	38.7	9.4	9.3	302.8	65.9	3.5	0.9	5.8	0.2	192.2
84	Aqua, Y-Br	7.2	1.0	47.0	3.6	461.4	19.9	23.2	9.0	3.9	25.1	1.4	10.4	284.4	73.1	4.0	0.2	2.2	0.1	169.6
87	Green	4.8	0.5	40.6	2.6	250.9	12.4	18.3	6.2	1.6	8.1	2.0	7.0	308.5	41.7	2.2	4.0	17.6	0.1	213.8
96	Lt. green	2.9	0.5	73.4	2.2	158.2	10.8	11.2	6.9	3.0	13.0	3.3	10.8	408.5	35.4	1.7	0.1	3.4	0.1	270.3
97	Aqua	3.6	0.3	87.6	2.3	200.0	8.3	22.8	17.0	57.0	8.4	7.4	12.0	335.3	45.1	1.8	0.1	1.8	0.1	182.5
98	Aqua	4.0	0.4	77.7	2.8	319.7	12.7	17.8	6.2	4.1	9.0	2.8	13.0	376.9	67.2	2.7	0.1	2.0	0.1	208.8
99	Lt. green	3.7	0.5	43.3	2.2	229.2	28.6	12.4	12.3	6.2	22.8	5.3	20.5	495.7	40.4	1.7	0.2	3.6	0.2	378.8
100	Aqua	4.6	0.5	47.2	2.3	205.3	11.0	11.6	4.9	1.8	7.0	4.5	12.0	472.0	37.1	2.2	0.0	0.3	0.1	239.2
101	Aqua	4.1	0.4	47.7	2.5	180.9	8.1	12.4	4.9	1.4	7.0	1.5	8.6	420.2	32.4	1.8	0.2	0.2	0.1	215.4
107	Aqua	3.9	0.6	102.5	2.2	213.1	8.4	12.8	4.4	2.3	7.6	5.1	10.5	415.7	39.7	1.9	0.0	0.6	0.1	191.7
110	Lt. green	3.6	0.3	67.9	2.1	206.2	10.4	16.1	5.2	1.6	10.8	5.1	9.1	454.7	35.4	1.8	0.0	0.2	0.1	208.2
111	Aqua	4.1	0.6	45.0	2.2	237.9	8.8	13.7	4.8	1.7	7.9	5.0	8.0	557.3	43.4	2.1	0.0	0.1	0.1	209.8
112	Aqua	3.8	0.6	83.2	2.4	320.4	21.6	17.8	10.2	11.8	37.3	9.9	16.6	538.3	60.2	2.4	0.1	8.6	0.1	475.9
113	Aqua, Bl	4.0	0.4	82.5	2.3	236.2	10.6	14.8	7.4	3.8	10.4	5.9	9.2	526.5	38.4	2.0	0.1	0.6	0.1	288.9
AVERAGE		**4.6**	**0.8**	**66.5**	**2.6**	**259.5**	**13.2**	**16.2**	**7.9**	**6.7**	**14.4**	**4.2**	**11.5**	**423.8**	**47.3**	**2.3**	**0.4**	**3.1**	**0.1**	**244.2**

Sample ID #	Color	La	Ce	Pr	Ta	Au	Y	Bi	U	W	Mo	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Th
GROUP 3: mineral soda glasses similar to the Levantine I group – CONTINUED																								
1	Aqua	8.2	15.4	1.9	0.2	0.0	10.5	2.5	0.9	0.6	0.9	7.4	1.4	0.6	1.5	0.3	1.5	0.4	1.0	0.2	1.0	0.6	1.6	1.2
33	Aqua	6.9	14.0	1.8	0.5	3.6	8.0	1.4	1.3	1.9	1.0	6.7	1.4	0.4	1.2	0.2	1.4	0.4	0.7	0.1	1.1	0.2	1.9	3.2
34	Aqua	5.8	12.5	1.6	0.5	1.5	6.7	0.3	0.8	4.1	0.6	6.0	1.1	0.5	1.3	0.2	1.1	0.2	0.5	0.3	2.0	0.1	1.3	1.1
59	Aqua	7.6	15.1	1.9	0.2	0.2	8.5	0.6	0.9	0.2	0.6	7.6	1.6	0.4	1.4	0.2	1.3	0.3	0.7	0.1	0.7	0.1	1.7	1.3
84	Aqua, Y-Br	7.6	14.8	1.8	0.2	0.1	9.1	0.2	0.8	0.1	0.6	7.4	1.4	0.4	1.5	0.2	1.2	0.2	0.8	0.1	0.7	0.1	1.7	1.3
87	Green	7.1	13.3	1.8	0.2	0.1	7.2	3.5	0.9	0.1	0.4	7.4	1.7	0.5	1.6	0.2	1.4	0.3	0.8	0.1	0.8	0.1	1.5	1.3
96	Lt. green	6.4	12.2	1.6	0.1	0.3	7.9	0.0	0.9	0.1	2.9	6.1	1.3	0.4	1.3	0.2	1.1	0.2	0.7	0.1	0.7	0.1	0.9	0.8
97	Aqua	5.8	11.4	1.5	0.1	0.0	6.8	0.0	0.5	0.1	0.7	5.9	1.3	0.3	1.1	0.2	1.0	0.2	0.6	0.1	0.6	0.1	1.2	0.8

Sample ID #	Color	La	Ce	Pr	Ta	Au	Y	Bi	U	W	Mo	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Th
98	Aqua	6.9	14.0	1.9	0.2	0.0	8.3	0.0	0.6	0.1	0.9	7.0	1.4	0.4	1.3	0.2	1.2	0.3	0.7	0.1	0.7	0.1	1.8	1.1
99	Lt. green	7.1	13.2	1.8	0.1	0.1	8.8	1.6	0.7	0.4	4.3	6.8	1.4	0.4	1.5	0.2	1.3	0.3	0.8	0.1	0.7	0.1	1.1	0.8
100	Aqua	6.7	14.1	1.8	0.1	0.3	7.7	0.1	1.2	0.1	0.7	6.6	1.3	0.4	1.2	0.2	1.0	0.2	0.7	0.1	0.5	0.1	1.0	0.8
101	Aqua	5.6	13.2	1.5	0.1	0.2	6.7	0.0	0.7	0.1	0.3	5.6	1.3	0.4	1.2	0.2	1.0	0.2	0.6	0.1	0.6	0.1	0.9	0.7
107	Aqua	5.7	11.7	1.5	0.1	0.1	6.9	0.1	0.5	0.1	0.6	5.5	1.3	0.4	1.2	0.2	1.0	0.2	0.6	0.1	0.5	0.1	1.0	0.7
110	Lt. green	6.0	12.3	1.6	0.1	0.0	7.3	0.0	1.0	0.1	0.5	5.8	1.2	0.4	1.1	0.2	1.1	0.2	0.6	0.1	0.5	0.1	1.0	0.8
111	Aqua	6.7	14.0	1.8	0.1	0.2	8.5	0.1	0.6	0.2	0.2	6.7	1.5	0.4	1.3	0.2	1.2	0.3	0.7	0.1	0.6	0.1	1.1	0.9
112	Aqua	7.6	13.6	2.0	0.1	0.0	9.4	0.0	0.8	0.2	2.3	7.3	1.6	0.4	1.4	0.2	1.4	0.3	0.8	0.1	0.7	0.1	1.6	1.0
113	Aqua, Bl	6.6	13.6	1.8	0.1	0.0	7.8	0.0	0.7	0.1	0.9	6.5	1.4	0.4	1.3	0.2	1.1	0.2	0.7	0.1	0.6	0.1	1.1	0.8
AVERAGE		**6.7**	**13.4**	**1.7**	**0.2**	**0.4**	**8.0**	**0.6**	**0.8**	**0.5**	**1.1**	**6.6**	**1.4**	**0.4**	**1.3**	**0.2**	**1.2**	**0.3**	**0.7**	**0.1**	**0.8**	**0.1**	**1.3**	**1.1**

Sample ID #	Color	Li	Be	B	Sc	Ti	V	Cr	Ni	Co	Zn	As	Rb	Sr	Zr	Nb	Ag	Sb	Cs	Ba
GROUP 4: mineral soda glasses similar to the Levantine II group																				
3	Aqua	3.8	2.3	30.0	2.8	198.2	9.9	14.9	5.6	1.4	5.9	0.0	10.0	335.5	45.2	2.2	0.1	0.2	0.1	224.0
18	Colorless?	4.0	0.7	44.7	1.9	174.1	10.1	11.3	4.9	1.7	7.5	19.8	9.6	379.5	36.6	2.2	0.3	0.3	0.1	231.2
39	Aqua	4.4	1.3	54.3	2.4	162.9	8.2	15.3	5.6	14.9	20.5	8.6	10.9	317.6	35.8	1.9	0.1	0.3	0.1	195.8
56	Aqua	4.1	0.4	44.9	2.5	295.5	8.4	15.5	4.3	1.2	4.9	5.6	11.8	307.4	41.5	2.1	0.0	0.2	0.1	176.8
58	Lt. green	5.1	0.6	52.5	2.4	311.5	9.1	15.2	4.6	1.2	5.3	13.2	8.4	316.5	39.2	2.1	0.0	0.2	0.1	183.1
61	Aqua	6.2	0.5	41.3	2.6	310.6	9.5	12.9	5.3	1.8	6.8	6.4	8.4	323.7	36.7	2.1	0.1	0.2	0.1	185.1
63	Aqua	7.1	0.5	37.6	3.1	493.0	14.8	17.7	6.8	2.2	7.9	7.0	9.6	294.7	52.4	3.3	0.0	0.2	0.2	190.4
66	Aqua	6.3	0.9	35.5	2.5	228.7	11.8	17.7	6.7	2.2	10.5	9.7	11.3	317.6	41.5	2.3	0.1	0.4	0.1	193.2
68	Lt. green	6.2	0.5	58.4	2.6	349.2	11.2	15.1	5.8	2.3	7.8	7.1	10.0	319.3	40.5	2.3	5.6	0.2	0.1	178.9
72	Aqua	5.2	0.4	37.9	2.7	408.6	12.2	18.6	5.6	1.9	6.9	5.0	13.0	316.4	49.4	2.6	0.2	0.1	0.2	186.6
73	Aqua	5.7	0.4	36.7	2.7	419.6	12.1	17.8	6.0	1.8	7.2	5.9	12.8	325.9	47.9	2.7	0.0	0.1	0.2	193.4
78	Aqua	5.3	0.5	61.3	2.8	187.3	9.0	9.9	4.7	1.5	5.2	1.5	8.2	348.0	31.7	1.8	0.0	0.1	0.1	165.4
81	Aqua	4.8	0.4	56.2	2.8	209.7	9.3	14.3	5.3	2.0	5.1	1.3	11.0	268.3	35.9	1.8	0.0	0.1	0.1	153.4
82	Aqua	5.5	0.5	71.4	2.7	187.7	9.1	11.6	4.5	1.4	4.3	1.2	8.4	283.1	33.9	1.8	0.0	0.1	0.1	150.1
85	Aqua	5.2	0.3	70.1	2.6	191.3	9.8	11.2	5.2	1.5	5.6	2.3	10.2	354.7	32.9	1.8	0.0	0.1	0.1	182.2
92	Lt. green	4.7	0.4	56.2	2.7	224.9	10.0	12.3	5.2	1.6	5.5	2.1	10.5	357.3	42.4	2.3	0.0	0.1	0.1	223.8
94	Lt. green	4.8	0.3	40.9	2.7	241.5	10.3	17.1	5.8	1.6	5.8	1.9	10.4	320.0	43.7	2.3	0.1	0.2	0.1	197.4
108	Lt. green	5.6	0.4	46.9	2.4	220.4	9.8	16.0	4.9	1.6	6.0	5.1	15.8	390.8	35.5	1.9	0.0	0.2	0.2	208.3
AVERAGE		**5.2**	**0.6**	**48.7**	**2.6**	**267.5**	**10.3**	**14.7**	**5.4**	**2.4**	**7.2**	**5.8**	**10.6**	**326.5**	**40.1**	**2.2**	**0.4**	**0.2**	**0.1**	**189.9**

Sample ID #	Color	Li	Be	B	Sc	Ti	V	Cr	Ni	Co	Zn	As	Rb	Sr	Zr	Nb	Ag	Sb	Cs	Ba
Group 4 outliers (mixed Levantine I and II?)																				
32	?	3.6	0.7	75.2	2.0	137.4	8.7	14.7	4.8	2.5	6.6	2.5	7.0	452.9	34.3	1.7	0.3	0.8	0.1	226.8
57	Aqua	5.5	0.4	68.4	2.6	321.0	11.0	13.0	5.2	1.6	5.6	6.6	9.7	431.9	37.6	2.2	0.0	0.1	0.1	212.9
75	Aqua	5.6	0.5	48.6	2.3	271.9	9.2	12.4	4.7	1.3	5.3	5.3	11.4	331.2	33.9	1.8	0.1	0.2	0.1	192.8
95	Aqua	3.4	0.4	37.6	2.2	156.1	6.9	11.9	6.6	1.2	8.0	2.9	10.3	330.7	32.3	1.5	0.1	0.4	0.1	206.0
103	Aqua	3.4	0.4	86.7	2.3	216.2	8.4	13.5	4.1	2.2	6.5	5.0	9.4	393.6	41.5	1.8	0.0	1.4	0.1	167.1
109	Lt. green	3.7	0.5	81.1	2.2	217.2	8.8	17.4	5.3	3.6	8.8	6.5	11.0	378.6	40.0	2.0	0.0	0.8	0.1	178.9
AVERAGE		**4.2**	**0.5**	**66.2**	**2.3**	**220.0**	**8.8**	**13.8**	**5.1**	**2.1**	**6.8**	**4.8**	**9.8**	**386.5**	**36.6**	**1.8**	**0.1**	**0.6**	**0.1**	**197.4**

Sample ID #	Color	La	Ce	Pr	Ta	Au	Y	Bi	U	W	Mo	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Th
GROUP 4: mineral soda glasses similar to the Levantine II group – CONTINUED																								
3	Aqua	6.7	12.7	1.8	0.1	0.1	7.6	0.1	0.6	0.3	0.4	6.5	1.1	0.4	1.3	0.2	1.2	0.2	0.7	0.1	0.6	0.1	1.1	0.9
18	Colorless?	5.8	12.5	1.6	0.1	0.1	6.3	0.0	0.8	0.2	0.6	5.9	1.1	0.4	1.3	0.2	1.1	0.2	0.6	0.1	0.5	0.1	0.9	0.8
39	Aqua	5.4	11.5	1.3	0.1	0.1	6.1	0.1	0.7	0.2	0.5	5.2	1.1	0.3	1.0	0.1	1.0	0.2	0.4	0.1	0.6	0.1	0.9	0.7
56	Aqua	5.4	10.9	1.4	0.1	0.0	6.9	0.0	0.5	0.1	0.2	5.1	1.0	0.3	1.0	0.2	0.8	0.2	0.5	0.1	0.5	0.1	1.0	0.7
58	Lt. green	5.5	11.3	1.4	0.1	0.0	6.7	0.0	0.6	0.1	0.3	5.3	1.1	0.3	0.9	0.1	0.9	0.2	0.5	0.1	0.5	0.1	1.0	0.7
61	Aqua	5.4	11.5	1.4	0.1	0.1	6.5	0.1	0.5	0.1	0.3	5.1	1.1	0.3	0.9	0.2	0.8	0.2	0.5	0.1	0.5	0.1	0.9	0.7
63	Aqua	6.8	14.2	1.8	0.1	0.0	7.7	0.0	0.6	0.1	0.3	6.4	1.3	0.4	1.1	0.2	1.1	0.2	0.6	0.1	0.5	0.1	1.2	1.0
66	Aqua	6.1	13.0	1.6	0.1	0.0	7.0	0.1	0.6	0.1	0.3	6.0	1.3	0.4	1.0	0.2	1.1	0.2	0.6	0.1	0.6	0.1	1.2	0.9
68	Lt. green	5.4	12.0	1.4	0.1	0.3	6.5	0.0	0.6	0.1	0.4	4.8	1.0	0.3	0.8	0.1	0.8	0.2	0.5	0.1	0.5	0.0	1.0	0.8
72	Aqua	6.1	12.2	1.5	0.1	0.1	7.7	0.0	0.5	0.1	0.3	5.7	1.2	0.3	1.2	0.2	1.0	0.2	0.6	0.1	0.5	0.1	1.1	0.9
73	Aqua	6.2	12.7	1.6	0.1	0.0	7.5	0.0	0.6	0.1	0.3	5.7	1.1	0.3	1.1	0.2	1.1	0.2	0.6	0.1	0.5	0.1	1.2	0.9
78	Aqua	4.7	9.9	1.2	0.1	0.0	6.2	0.0	0.4	0.1	0.6	4.3	0.9	0.3	0.9	0.1	0.8	0.1	0.4	0.1	0.4	0.1	0.7	0.6
81	Aqua	4.5	9.2	1.1	0.1	0.0	5.8	0.0	0.4	0.1	0.4	4.1	0.8	0.3	0.8	0.1	0.7	0.1	0.4	0.1	0.4	0.1	0.7	0.6
82	Aqua	4.6	9.2	1.1	0.1	0.0	6.1	0.0	0.4	0.1	0.8	4.3	0.9	0.3	0.8	0.1	0.8	0.2	0.4	0.1	0.4	0.1	0.7	0.6
85	Aqua	4.9	10.6	1.3	0.1	0.0	6.5	0.0	0.5	0.1	0.7	4.7	1.0	0.3	1.0	0.1	0.8	0.2	0.5	0.1	0.4	0.1	0.7	0.6
92	Lt. green	6.5	13.0	1.7	0.1	0.0	7.9	0.0	0.6	0.1	0.6	6.3	1.4	0.4	1.2	0.2	1.2	0.2	0.6	0.1	0.6	0.1	1.1	0.9
94	Lt. green	6.1	12.6	1.6	0.1	0.1	7.0	0.0	0.6	0.1	0.5	5.8	1.2	0.4	1.1	0.2	1.0	0.2	0.6	0.1	0.5	0.1	1.1	0.8
108	Lt. green	5.7	12.9	1.5	0.1	0.2	6.4	0.0	0.6	0.1	0.4	5.5	1.1	0.3	1.1	0.2	1.0	0.2	0.5	0.1	0.5	0.1	0.9	0.7
AVERAGE		**5.6**	**11.8**	**1.5**	**0.1**	**0.1**	**6.8**	**0.0**	**0.6**	**0.1**	**0.4**	**5.4**	**1.1**	**0.3**	**1.0**	**0.2**	**1.0**	**0.2**	**0.5**	**0.1**	**0.5**	**0.1**	**1.0**	**0.8**

Sample ID #	Color	La	Ce	Pr	Ta	Au	Y	Bi	U	W	Mo	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Th
Group 4 outliers (mixed Levantine I and II?)																								
32	?	5.4	11.2	1.4	0.1	0.1	7.0	0.0	0.5	0.2	0.8	5.5	0.9	0.3	1.1	0.2	1.1	0.2	0.6	0.1	0.6	0.1	0.8	0.8
57	Aqua	6.3	13.1	1.6	0.1	0.0	7.7	0.0	0.6	0.1	0.5	6.1	1.3	0.4	1.2	0.2	1.1	0.2	0.6	0.1	0.5	0.1	0.9	0.8
75	Aqua	5.3	11.3	1.4	0.1	0.1	6.3	0.0	0.9	0.1	0.4	5.0	1.1	0.3	0.9	0.1	0.9	0.2	0.5	0.1	0.4	0.1	0.8	0.7
95	Aqua	5.1	11.3	1.4	0.1	0.2	6.1	0.1	0.7	0.1	0.4	5.1	1.1	0.3	0.9	0.1	0.9	0.2	0.5	0.1	0.5	0.1	0.9	0.6
103	Aqua	5.0	10.2	1.3	0.1	0.0	6.5	0.0	0.5	0.1	0.5	4.7	1.0	0.3	0.9	0.1	0.8	0.2	0.5	0.1	0.4	0.1	0.9	0.6
109	Lt. green	5.3	11.6	1.4	0.1	0.1	6.1	0.0	0.6	0.2	0.7	5.3	1.1	0.3	1.0	0.1	0.9	0.2	0.5	0.1	0.5	0.1	1.0	0.7
AVERAGE		**5.4**	**11.5**	**1.4**	**0.1**	**0.1**	**6.6**	**0.0**	**0.6**	**0.1**	**0.6**	**5.3**	**1.1**	**0.3**	**1.0**	**0.1**	**0.9**	**0.2**	**0.5**	**0.1**	**0.5**	**0.1**	**0.9**	**0.7**

Sample ID #	Color	Li	Be	B	Sc	Ti	V	Cr	Ni	Co	Zn	As	Rb	Sr	Zr	Nb	Ag	Sb	Cs	Ba
GROUP 5: mineral soda glasses similar to the HIMT group																				
35	Y-green	3.9	0.8	152.4	5.1	944.2	84.1	57.9	32.4	14.8	34.9	6.3	6.1	451.8	245.7	6.3	0.1	1.3	0.1	316.2
114	Lt. green	5.1	0.7	188.3	6.7	1824.9	100.9	78.3	44.6	11.8	58.0	19.1	7.3	458.3	272.9	8.6	0.1	0.5	0.1	210.0
AVERAGE		**4.5**	**0.7**	**170.4**	**5.9**	**1384.6**	**92.5**	**68.1**	**38.5**	**13.3**	**46.4**	**12.7**	**6.7**	**455.0**	**259.3**	**7.4**	**0.1**	**0.9**	**0.1**	**263.1**

Sample ID #	Color	La	Ce	Pr	Ta	Au	Y	Bi	U	W	Mo	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Th
GROUP 5: mineral soda glasses similar to the HIMT group – CONTINUED																								
35	Y-green	14.4	18.4	3.5	0.4	0.1	14.7	0.1	1.7	0.7	7.3	13.3	3.0	0.8	2.9	0.4	2.7	0.5	1.5	0.2	1.6	0.3	6.5	2.3
114	Lt. green	16.1	21.5	4.2	0.6	0.1	17.4	0.1	1.1	0.6	4.3	15.7	3.5	0.9	3.4	0.5	3.0	0.6	1.7	0.2	1.6	0.3	6.7	2.4
AVERAGE		**15.3**	**20.0**	**3.8**	**0.5**	**0.1**	**16.0**	**0.1**	**1.4**	**0.6**	**5.8**	**14.5**	**3.2**	**0.8**	**3.1**	**0.4**	**2.8**	**0.6**	**1.6**	**0.2**	**1.6**	**0.3**	**6.6**	**2.4**

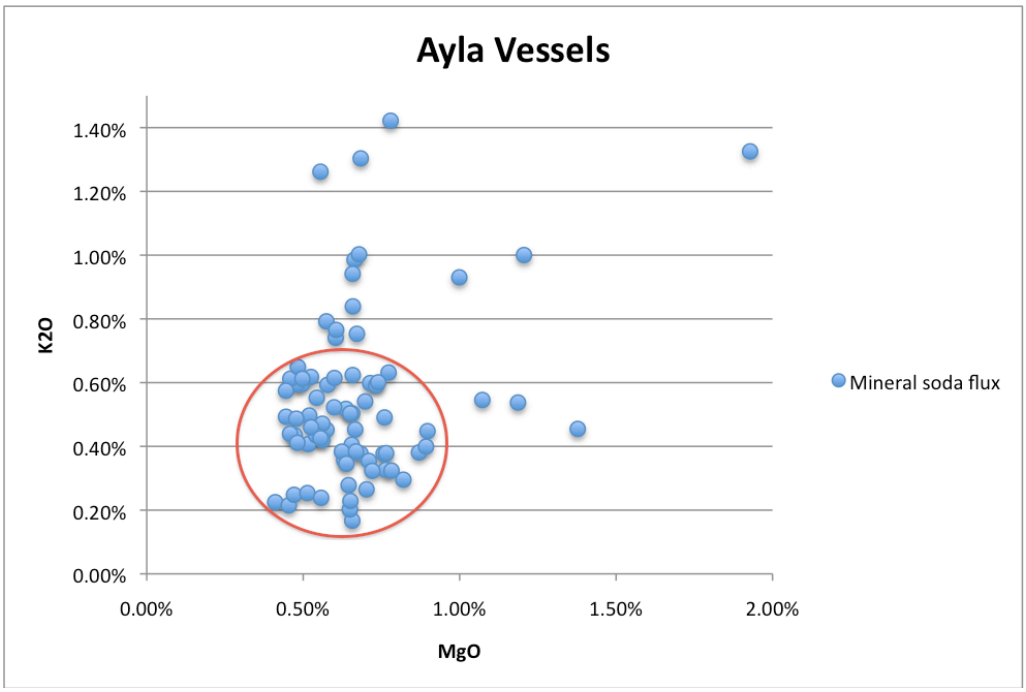

Figure 6.15: Bivariate scatter plot of magnesia and potash (two of the best chemical discriminators) showing the mineral soda technological group, highlighting the main cluster (circled in red) and outliers.

(Figure 6.15). An exception is **No. 102**, a vessel wall fragment of naturally aqua glass that has 1.9 wt% MgO; this sample and three others—**Nos. 33, 99,** and **112**—have markedly higher levels of potash (1.3-1.4 wt%) but are still below the 1.5 wt% mark. Five other samples (**Nos. 37, 74, 88, 91**, and **114**) have slightly over 1 wt% MgO, while eight other samples (**Nos. 1, 34, 68, 97, 98, 107, 108,** and **109**) have less than 1 wt% Mgo but higher potash at 0.7-1.0 wt% K_2O.

The mineral soda glasses from Ayla can be divided into five chemical groups that largely correspond to the production groups characterized by Freestone and colleagues, as shown in Figure 6.16 and 6.17, and are more clearly differentiated in Figure 6.18 and Tables 6.3 and 6.4: Group 1 are those glasses similar to Egyptian I glasses, Group 2 are those similar to the Egyptian II glasses, Group 3 are those similar to Levantine I glasses,

Group 4 are those similar to Levantine II glasses, and Group 5 are those similar to HIMT ("high iron, magnesium, manganese, and titanium") glasses. Of the outlier fragments, the samples with the higher magnesia levels are more chemically similar to glasses from the Egyptian I and II and HIMT production groups, while those outliers with higher potash levels seem to be more similar to glasses made in the Levant.

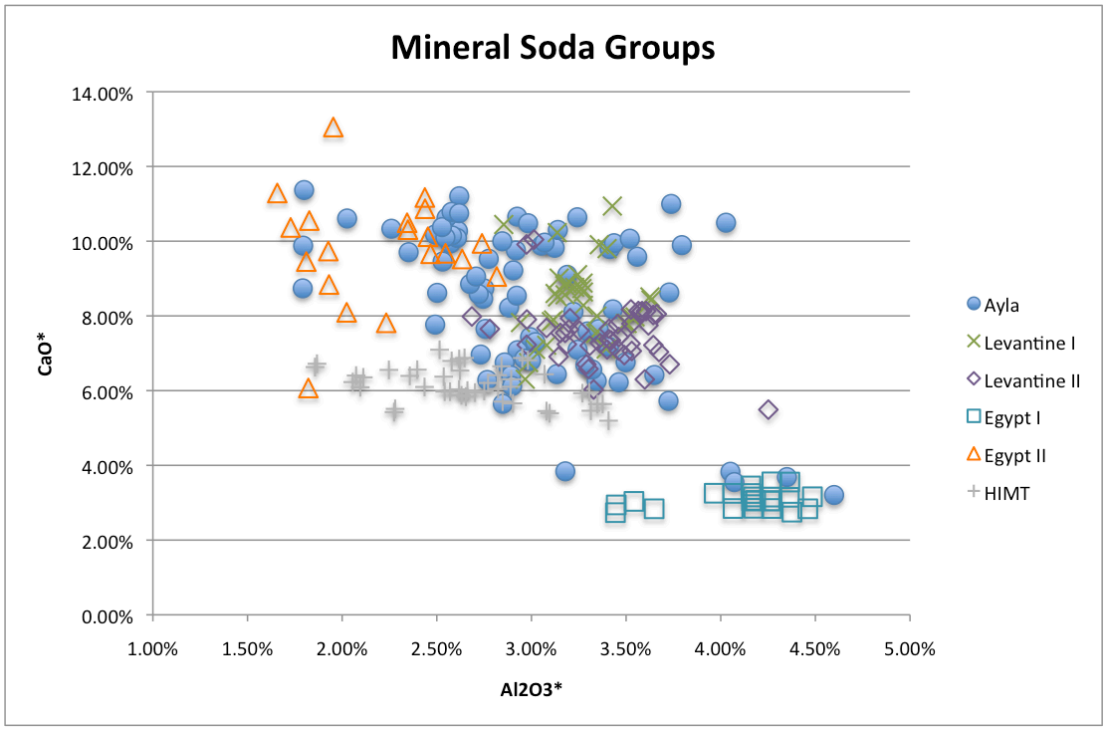

Figure 6.16: Scatter plot of the lime and alumina contents of the Ayla samples and the five mineral soda primary production groups currently known (chart based on Freestone 2006: 208; data from Freestone, personal communication).

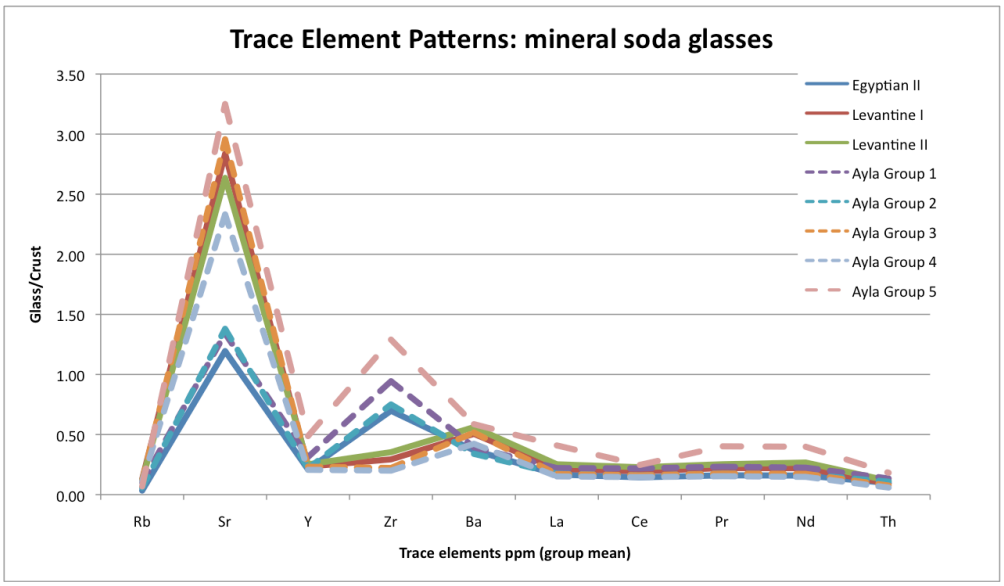

Figure 6.17: Trace elements patterns of the Ayla mineral soda groups, compared to three production groups (Freestone *et al.* 2000: 79; Egyptian II data from Freestone, personal communication), normalized to the mean crustal abundances (Kamber *et al.* 2005). N.B. there is no similar data for the Egyptian I or HIMT groups.

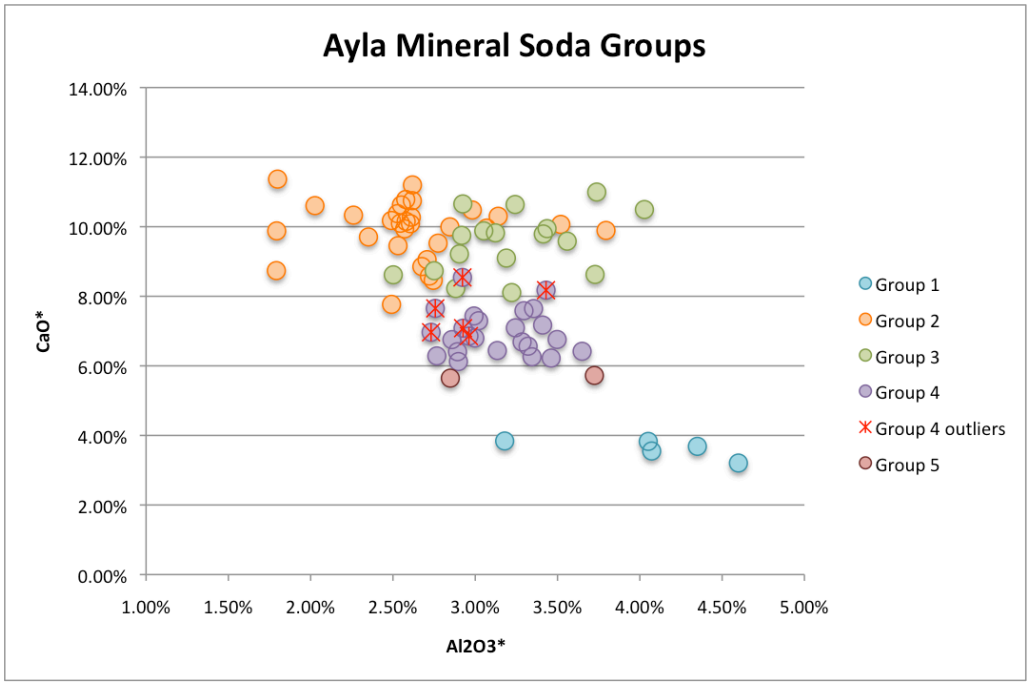

Figure 6.18: Lime and alumina scatter plot of the Ayla mineral soda glasses: Groups 1, 2, 3, 4, and 5 (and the possible outlier sub-group of Group 4 overlain).

Oxides (wt%)	SiO2	Na2O	K2O	CaO	MgO	Al2O3	Fe2O3	TiO2	MnO	P2O3	CuO	CoO	PbO2	Sb2O5	SnO2
Group 1 (n=5)	**70.49**	**17.91**	**0.56**	**3.59**	**0.93**	**4.02**	**1.68**	**0.30**	**0.05**	**0.13**	**0.01**	**0.00**	**0.00**	**0.00**	**0.00**
range	70.04-71.36	15.87-20.02	0.40-0.93	3.18-3.81	0.65-1.19	3.15-4.56	1.04-2.40	0.16-0.37	0.04-0.06	0.07-0.25	0.00-0.03	-	-	-	-
σ	0.54	1.52	0.21	0.26	0.19	0.53	0.49	0.08	0.01	0.07	0.01	0.00	0.00	0.00	0.00
Group 2 (n=30)	**70.06**	**14.69**	**0.34**	**9.87**	**0.65**	**2.59**	**0.98**	**0.12**	**0.13**	**0.10**	**0.01**	**0.00**	**0.02**	**0.00**	**0.00**
range	67.45-75.10	11.91-18.17	0.17-0.60	7.69-11.27	0.41-1.07	1.77-3.77	0.61-1.63	0.07-0.21	0.02-0.36	0.02-0.23	0.00-0.14	-	0.00-0.18	-	-
σ	1.53	1.37	0.11	0.78	0.14	0.45	0.21	0.04	0.32	0.05	0.04	0.02	0.05	0.00	0.00
Group 3 (n=17)	**68.85**	**15.42**	**0.78**	**9.43**	**0.65**	**3.18**	**0.56**	**0.04**	**0.24**	**0.11**	**0.01**	**0.00**	**0.21**	**0.00**	**0.00**
range	64.50-70.59	11.70-17.61	0.40-1.42	8.05-10.93	0.54-0.78	2.48-4.03	0.36-1.03	0.02-0.10	0.02-1.68	0.00-0.19	0.00-0.05	-	0.00-3.05	-	-
σ	1.76	1.88	0.32	0.87	0.07	0.40	0.19	0.02	0.49	0.06	0.02	0.00	0.74	0.00	0.01
Group 4 (n=18)	**74.33**	**13.62**	**0.55**	**6.74**	**0.55**	**3.17**	**0.52**	**0.04**	**0.02**	**0.05**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
range	72.98-75.90	11.97-14.95	0.41-0.77	6.09-7.64	0.44-0.67	2.75-3.63	0.41-0.76	0.03-0.08	0.02-0.03	0.00-0.08	-	-	-	-	-
σ	0.81	0.96	0.11	0.49	0.08	0.26	0.09	0.02	0.00	0.02	0.00	0.00	0.00	0.00	0.00
Group 5 (n=2)	**67.18**	**16.76**	**0.42**	**5.54**	**1.12**	**3.20**	**3.18**	**0.23**	**1.76**	**0.10**	**0.01**	**0.00**	**0.00**	**0.00**	**0.00**
range	66.32-68.04	16.69-16.83	0.38-0.45	5.48-5.59	0.87-1.38	2.77-3.64	2.87-3.50	0.16-0.30	1.55-1.97	0.06-0.14	-	-	-	-	-
σ	1.22	0.10	0.05	0.08	0.36	0.62	0.45	0.10	0.30	0.06	0.00	0.00	0.00	0.00	0.00

Table 6.3: Average major/minor oxide composition of the Ayla mineral soda glasses (σ = standard deviation).

Trace elements (ppm)	Li	Be	B	Sc	Ti	V	Cr	Ni	Co	Zn	As	Rb	Sr	Zr
Group 1	**4.4**	**0.6**	**95.0**	**6.3**	**1791.6**	**45.1**	**78.4**	**11.5**	**5.4**	**30.6**	**8.0**	**10.0**	**187.7**	**189.7**
σ	0.9	0.1	21.5	1.6	501.9	15.8	29.6	2.2	1.2	8.1	5.4	2.1	16.0	104.0
Group 2	**4.4**	**0.8**	**92.5**	**3.4**	**733.0**	**21.1**	**27.8**	**8.0**	**42.3**	**51.5**	**8.2**	**5.2**	**171.1**	**153.3**
σ	1.2	0.4	20.7	0.4	231.5	3.4	5.7	2.0	149.8	97.7	8.5	1.9	46.5	37.1
Group 3	**4.6**	**0.8**	**66.5**	**2.6**	**259.5**	**13.2**	**16.2**	**7.9**	**6.7**	**14.4**	**4.2**	**11.5**	**423.8**	**47.3**
σ	1.6	1.2	21.0	0.7	113.0	5.7	4.8	3.8	13.2	10.3	2.9	3.3	82.8	13.7
Group 4	**5.2**	**0.6**	**48.7**	**2.6**	**267.5**	**10.3**	**14.7**	**5.4**	**2.4**	**7.2**	**5.8**	**10.6**	**326.5**	**40.1**
σ	0.9	0.5	12.0	0.2	96.3	1.6	2.6	0.7	3.1	3.6	4.9	1.9	31.0	5.9
Group 5	**4.5**	**0.7**	**170.4**	**5.9**	**1384.6**	**92.5**	**68.1**	**38.5**	**13.3**	**46.4**	**12.7**	**6.7**	**455.0**	**259.3**
σ	0.8	0.1	25.4	1.1	622.7	11.9	14.4	8.6	2.1	16.3	9.0	0.8	4.6	19.2

Trace elements (ppm)	Nb	Ag	Sb	Cs	Ba	La	Ce	Pr	Ta	Au	Y	Bi	U	W
Group 1	**6.6**	**0.1**	**2.8**	**0.1**	**177.1**	**8.2**	**17.6**	**2.2**	**0.3**	**0.0**	**10.3**	**0.0**	**1.0**	**0.1**
σ	2.2	0.1	5.8	0.1	21.1	2.1	4.2	0.6	0.1	0.0	2.8	0.0	0.1	0.0
Group 2	**4.4**	**0.2**	**0.9**	**0.1**	**149.1**	**6.4**	**12.8**	**1.7**	**0.2**	**0.1**	**7.1**	**0.0**	**1.0**	**0.2**
σ	0.6	0.4	1.4	0.0	38.3	1.1	2.1	0.3	0.0	0.1	1.2	0.0	0.2	0.1
Group 3	**2.3**	**0.4**	**3.1**	**0.1**	**244.2**	**6.7**	**13.4**	**1.7**	**0.2**	**0.4**	**8.0**	**0.6**	**0.8**	**0.5**
σ	0.7	0.9	4.4	0.1	77.4	0.8	1.2	0.2	0.1	0.9	1.1	1.0	0.2	1.0
Group 4	**2.2**	**0.4**	**0.2**	**0.1**	**189.9**	**5.6**	**11.8**	**1.5**	**0.1**	**0.1**	**6.8**	**0.0**	**0.6**	**0.1**
σ	0.4	1.3	0.1	0.0	22.2	0.7	1.4	0.2	0.0	0.1	0.7	0.0	0.1	0.1
Group 5	**7.4**	**0.1**	**0.9**	**0.1**	**263.1**	**15.3**	**20.0**	**3.8**	**0.5**	**0.1**	**16.0**	**0.1**	**1.4**	**0.6**
σ	1.6	0.0	0.5	0.0	75.1	1.2	2.2	0.5	0.1	0.1	1.9	0.0	0.4	0.1

Trace elements (ppm)	Mo	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Th
Group 1	**0.2**	**8.2**	**1.8**	**0.4**	**1.6**	**0.2**	**1.5**	**0.3**	**0.9**	**0.1**	**0.9**	**0.1**	**4.2**	**1.8**
σ	0.1	2.1	0.5	0.1	0.5	0.1	0.5	0.1	0.3	0.0	0.3	0.1	2.4	0.8
Group 2	**0.4**	**6.0**	**1.3**	**0.3**	**1.1**	**0.2**	**1.1**	**0.2**	**0.7**	**0.1**	**0.7**	**0.1**	**3.7**	**1.4**
σ	0.3	1.1	0.2	0.1	0.2	0.0	0.2	0.1	0.1	0.0	0.2	0.0	1.0	0.3
Group 3	**1.1**	**6.6**	**1.4**	**0.4**	**1.3**	**0.2**	**1.2**	**0.3**	**0.7**	**0.1**	**0.8**	**0.1**	**1.3**	**1.1**
σ	1.1	0.7	0.1	0.1	0.1	0.0	0.2	0.1	0.1	0.1	0.4	0.1	0.3	0.6
Group 4	**0.4**	**5.4**	**1.1**	**0.3**	**1.0**	**0.2**	**1.0**	**0.2**	**0.5**	**0.1**	**0.5**	**0.1**	**1.0**	**0.8**
σ	0.2	0.7	0.1	0.0	0.1	0.0	0.2	0.0	0.1	0.0	0.1	0.0	0.2	0.1
Group 5	**5.8**	**14.5**	**3.2**	**0.8**	**3.1**	**0.4**	**2.8**	**0.6**	**1.6**	**0.2**	**1.6**	**0.3**	**6.6**	**2.4**
σ	2.1	1.7	0.3	0.1	0.3	0.0	0.2	0.0	0.1	0.0	0.0	0.0	0.1	0.1

Table 6.4: Average trace element composition of the Ayla mineral soda glasses.

Group 1 (similar to Egyptian I glasses)

Five of the Ayla samples make up Group 1, which is characterized by a chemical composition similar to the Egyptian I production group. The distinguishing features of these glasses are their high iron (averaging 1.7 wt% Fe_2O_3), alumina (>3 wt% Al_2O_3), and magnesia (often >0.9 wt% MgO) and extremely low lime levels (<4 wt% CaO). Four of the five samples in this group have by far the highest titanium of the entire Ayla sample population (even higher than the Egyptian II and HIMT groups, which are both noted for their high titanium), which lends weight to the suggestion of an Egyptian origin for this glass type.

Two of the samples (**Nos. 74** and **91**) have the overall chemical characteristics of Group 1, but were observed above as outliers to the main cluster of mineral soda samples because their magnesia levels are somewhat higher than the majority of the samples. However, these levels are still well below 1.5 wt% MgO and are also not too far off from the concentration of the other group members; as such they cannot truly be considered outliers, and are thus included in the overall averaging of the chemical results in the relevant tables. It should still be noted that sample No. 74 (a plain wall fragment of naturally aqua glass) is chemically the most different of the five samples in this group, having the highest potash and phosphorus levels.

Almost all of the Group 1 samples are aqua in hue because of the very high natural iron content in the glassmaking raw materials. No. 91 has the highest iron level, 2.4 wt%, which accounts for the green color of the glass, although this elevated iron does not appear to be associated with elevated levels of any other metals that might suggest the intentional addition of a colorant or recycled material to the batch. **No. 76** is naturally-

aqua in color, and has high soda (20 wt% Na_2O), very low titanium (0.16 TiO_2), and slightly elevated copper, lead, and antimony—elements associated with colorants, which is therefore suggestive of recycling.

Group 2 (similar to Egyptian II glasses)

The major, minor, and trace element concentrations of 30 Ayla samples are most similar to the Egyptian II production group, and are here defined as Group 2. This group is characterized by relatively low silica, potash, and alumina as well as high soda, lime, and iron. The trace elements are particularly distinctive, with high zirconium (80-220 ppm Zr) and high titanium (470-1250 ppm Ti) as well as low strontium (120-330 ppm Sr); as discussed in Chapter 4, such strontium levels likely reflect limestone rather than shell in the silica source (i.e., an inland rather than coastal source of sand).

Group 2 also includes three of the outlier samples that were noted to have higher magnesia levels: **Nos. 37, 88,** and **102**. All of these are naturally aqua colored glasses. Two of these, Nos. 88 and 102, have higher strontium levels (400-600 ppm) than do the rest of the group. As mentioned above, No. 102 has by far the highest magnesia level of any of the mineral soda glasses sampled from Ayla (1.9 wt% MgO)—and interestingly it is chemically quite similar to the three outliers of the Egyptian II production group identified in the Ḥiṣn al-Tīnāt assemblage. The potash content of No. 102 is 1.3 wt%, however, which is still below the 1.5 wt% rule-of-thumb for both the potash and magnesia of mineral soda glasses. Some authors have suggested that glasses straddling the zone between mineral soda and plant ash soda glasses in terms of their potash and magnesia content might indicate they are a mixed soda glass (i.e., mineral soda and plant

ash soda mixed together) or that more alkali was added to a mineral soda glass during the recycling process; perhaps a better interpretation is that elevated alkali levels reflect fuel ash contamination during the melting process (Paynter 2008; Rehren *et al.* 2010).

No. 102 also has high manganese, but it does not have high iron or titanium (ruling out the possibility this fragment is HIMT glass); its slightly elevated levels of copper, lead, zinc, and antimony are suggestive of recycling. Aqua No. 88 has 1 wt% K_2O and 1.2 wt% MgO, and elevated levels of MnO, CuO, PbO_2, and Sb that also suggest recycling. Fragment No. 37, on the other hand, does not appear to be overly different from the rest of the Group 2 members; its slightly higher than average magnesia level (1.1 wt% MgO) is the only feature that is rather different from the majority of the glasses, and as this is still below the 1.5 wt% mark it is included in the overall average of the results shown in the relevant tables. Several other samples also have slightly elevated levels of manganese, copper, and lead (**Nos. 12, 37, 48, 52,** and **70**), that could suggest some limited recycling as well, although these levels are not as high as those of Nos. 88 and 102.

The fragments of Group 2 are overwhelmingly aqua in color due to the natural iron content of the glass, although there are other glass colors in this group as well. **No. 83** has a light green hue due to the effect of the furnace atmosphere on the iron oxidation state, and **No. 48** has a light purplish hue thanks to the addition of manganese (1.7 wt% MnO). The deep blue and light green scratch-decorated fragments included in this study (**Nos. 16, 41, and 89**) all fit into Group 2; the blue fragments are chemically very similar to each other, while the light green fragment has more soda, titanium, and less manganese.

The unique color and design of the scratch-decorated fragments require a closer examination. Brill's analysis of 24 fragments in the Corning Museum of Glass has demonstrated that Islamic scratch-decorated vessels were made from both mineral soda and plant ash soda glasses[12] (Brill 1995: 211-233; 1999a: 95-97; 1995b: 194-196; 2001: 30-31 and 44, Table 3). This chemical variation has supported the notion that scratched glasses were made in more than one center. Brill is "inclined to believe that the natron-based glasses with scratch decoration were made in Egypt" while the plant ash soda glass examples may have been produced "at the same inland location where numerous other surface finds of glass from the environs of Nishapur were made" (2001: 31).[13]

Scratch-decorated glass fragments from other sites in Egypt such as Rāya/al-Ṭūr and Istabl 'Antar/Fusṭāṭ (Foy *et al.* 2001a) are largely mineral-soda glasses. In addition, the fact that the Ayla scratched samples correspond to the Egyptian II production group—a group that was likely made using inland sands and is defined by samples from Tell el-Ashmunein (a site in Upper Egypt, a.k.a. Hermopolis Magna)—further supports Brill's suggestion of an Egyptian origin for at least some mineral soda scratch-decorated glasses. In may therefore be no coincidence that the steatite vessels industry, mentioned in the previous section, used a similar incising technique and was located in the southern region of Egypt. A map showing the locations of el-Ashmunein and the six Islamic

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[12] The Corning Museum of Glass examples shown as stylistic parallels in Figure 6.2 are also all made using mineral soda as a fluxing agent (Whitehouse 2010a: 17-19).

[13] This line of reasoning would follow the idea that Egypt was the last region to change from mineral soda to plant ash soda technology; if the scratch glasses were indeed all produced at the same time during the 8th-9th centuries CE, then the plant ash examples may well have been made in regions where the new technology of plant ash flux was being exploited (Iran, Mesopotamia, and Syria) while the mineral soda glasses could have been made in regions where mineral soda was still being employed (i.e., Egypt).

steatite stone quarries discussed by Harrell and Brown (2008) is given in Figure 6.19.[14]

Figure 6.19: Google Map of Egypt showing the locations of the site of el-Ashmunein and the location of the Eastern Desert steatite quarries exploited during the Islamic period (Harrell and Brown 2008: 44 and Fig. 3.1); also shown are the location of cobaltiferous alums from the Dakhla and Kharga oases.

A comparison of the chemical results of the deep blue Ayla samples with other dark blue mineral soda glasses with incised decorations is given in Tables 6.5 and 6.6.

[14] It should certainly be kept in mind that an association of the Ayla glasses with the Egyptian II production group does *not* necessarily indicate they were produced at el-Ashmunein; rather it indicates that these glasses were made with inland sands rather than coastal sands, which could *suggest* a more southern Egyptian origin for this production group.

The deep blue color of Nos. 16 and 41 is particularly interesting, as the cobalt colorant may give some indication of raw material provenance because "only a few exploitable [cobalt] deposits exist… thus, there is a better probability of differentiating these ores" (Soulier *et al.* 1996: 133). Scholars have defined four cobalt ores used to color glasses found in France and dating from the Bronze Age to the 18th century CE (Gratuze *et al.* 1992; Soulier *et al.* 1996), but none of these groups correspond well with the analytical results of glass recovered from Ayla.[15]

Sample	Type	SiO2	Na2O	K2O	CaO	MgO	Al2O3	Fe2O3	MnO	CuO	CoO	PbO2
No. 16	Wall	70.40	13.82	0.38	9.32	0.68	2.49	1.48	0.27	0.13	0.09	0.01
No. 41	Wall	71.10	13.72	0.38	8.99	0.76	2.69	1.63	0.36	0.14	0.04	0.01

Table 6.5: Chemical results (given in wt% oxides) of the two deep blue, scratch-decorated glasses from Ayla.

Sample	Type	SiO2	Na2O	K2O	CaO	MgO	Al2O3	Fe2O3	MnO	CuO	CoO	PbO2
6348	Cup	68.79	14.50	0.52	9.82	0.77	2.37	1.69	0.33	0.14	N/A	N/A
6351	Cup	67.85	15.60	0.59	10.20	0.67	2.61	1.34	0.13	0.14	0.08	0.05
6352	Wall	69.09	14.50	0.45	9.56	0.73	2.42	1.41	0.21	0.14	0.08	N/A
6353	Rim	69.18	14.90	0.57	9.84	0.73	2.46	1.26	0.21	0.18	0.08	0.02
6354	Wall	68.82	15.40	0.59	9.71	0.73	2.47	1.30	0.16	0.16	0.08	0.02
6355	Rim	67.87	15.70	0.57	9.61	0.57	2.28	1.83	0.12	0.21	0.10	0.15
6356	Rim	68.09	14.90	0.50	10.20	0.50	2.13	1.96	0.12	0.31	0.15	0.15
6357	Rim	69.09	15.70	0.47	9.72	0.46	2.31	1.27	0.15	0.11	0.03	0.02
6358	Wall	69.01	15.80	0.50	9.25	0.55	2.21	1.45	0.07	0.35	0.08	0.04
6359	Wall	69.23	15.50	0.33	9.75	0.58	2.26	1.37	0.16	0.12	0.03	0.03
6360	Rim	68.29	16.00	0.49	9.67	0.52	2.12	1.59	0.09	0.28	0.08	0.10

Table 6.6: Chemical results (given in wt% oxides) of deep blue, scratch-decorated glasses made of mineral-soda from the Corning Museum of Glass collection (data from Brill 1999b: 194-195).

[15] The cobalt ores used in France include cobalt with the following trace element associations or correlations: Group 1 (Zn-Pb-In), Group 2 (As-Ni), Group 3 (Ni), and Group 4 (cobalt alone, but sometimes Sb and Pb). The two cobalt blue Ayla glasses do have elevated levels of zinc and nickel but not of lead, arsenic, or antimony; indium was not measured, so it cannot be said how the Ayla glasses compare with Group 1 (although samples in the latter largely date to the 13th-15th centuries CE and the cobalt may have been mined in Germany).

Closer to the Near East, two of the best-known cobalt sources are the cobalt-bearing alums[16] of the Great Western Oases (specifically Dakhla and Kharga) in Egypt and the cobalt-rich ores of Iran.[17] The Egyptian source has cobalt levels of 0.05 wt% CoO and above, which is principally correlated with elevated levels of nickel and zinc but also with elevated aluminum, magnesium, manganese, and iron (Kaczmarczyk 1986: 369; Henderson 1985: 280; Gratuze and Picon 2005: 269) although the precise composition is variable (Shortland *et al.* 2006b: 166); the Iranian source is a manganese-free arseno-sulphide ore (Kaczmarczyk 1986: 373). The chemical results of Nos. 16 and 41 appear to have the same suite of trace elements (10 ppm Ni and 350-400 ppm Zn) as the cobalt bearing alums from Egypt.[18] Although the samples do not have higher magnesia and alumina, they do have slightly higher iron levels than the other members of the group. The samples do have faintly elevated levels of arsenic (10 ppm As),[19] but they also have significant levels of manganese that would exclude the possibility of the manganese-free Iranian ores. These observations are of great interest considering the chemical compositional similarity of the fragments in Group 2 to the Egyptian II production group and the location of the Egyptian cobalt sources (Figure 6.19).

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[16] "Strictly speaking, 'alum' is the hydrated double sulphate of potassium and aluminium, but it is more often used as a general term for a hydrated double sulphate that contains aluminium with or without another alkali, alkaline earth or transition metal" (Shortland *et al.* 2006b: 153-154), e.g., 'cobalt-bearing alums.'

[17] Cobalt ores may also have been mined in Oman and the northern Hijaz (al-Hassan website 2011), but there appear to be no studies on these possible sources.

[18] It was first believed that these Egyptian alums were only exploited during the Bronze Age, specifically in the 18th-20th Dynasties or the 16th-10th centuries BCE (Kaczmarczyk 1986). However, a more recent study has suggested that there was continued use of the Egyptian cobalt sources in the 11th-7th centuries BCE although these were more purified and concentrated alums (Gratuze and Picon 2003). To my knowledge, the exploitation of these sources after this Bronze-Iron Age period has not been studied.

[19] Among the four types of cobalt ores identified by Gratuze *et al.*, the group with a high cobalt-arsenic correlation has levels 800-4000 ppm As (1992: 104).

Group 3 (similar to Levantine I glasses)

The chemical results of 41 of the Ayla mineral soda samples correspond to Levantine glasses; of these, the major, minor, and trace elements of 17 samples are similar to the Levantine I production group and are defined here as Group 3. This group has relatively low silica as well as high soda and lime when compared to the Levantine II production group. The outliers initially identified among the mineral soda glasses because of comparatively higher levels of potash (**Nos. 33, 98, 99**, and **112**) all fall into Group 3; although they have more potash than the rest of the group, they have less than 1.50 wt% K_2O and acceptably low magnesia levels, so they are still considered alongside the other members.

Nos. 59 and **84** have traces of iron, copper, lead, and tin that are indicative of recycling. **No. 87** is a fragment of a green bowl with a rolled tubular base ring; it has very high concentration of lead (3.1 wt% PbO_2), some tin (0.03 wt% SnO), and one of the lowest soda contents of this group. **No. 97** has elevated levels of copper, cobalt, and lead, again suggesting recycling. **Nos. 96** and **99** are both light green glass fragments that have elevated manganese levels (>1 wt% MnO); aqua fragment **No. 112** also has high manganese in addition to traces of copper.

Group 4 (similar to Levantine II glasses)

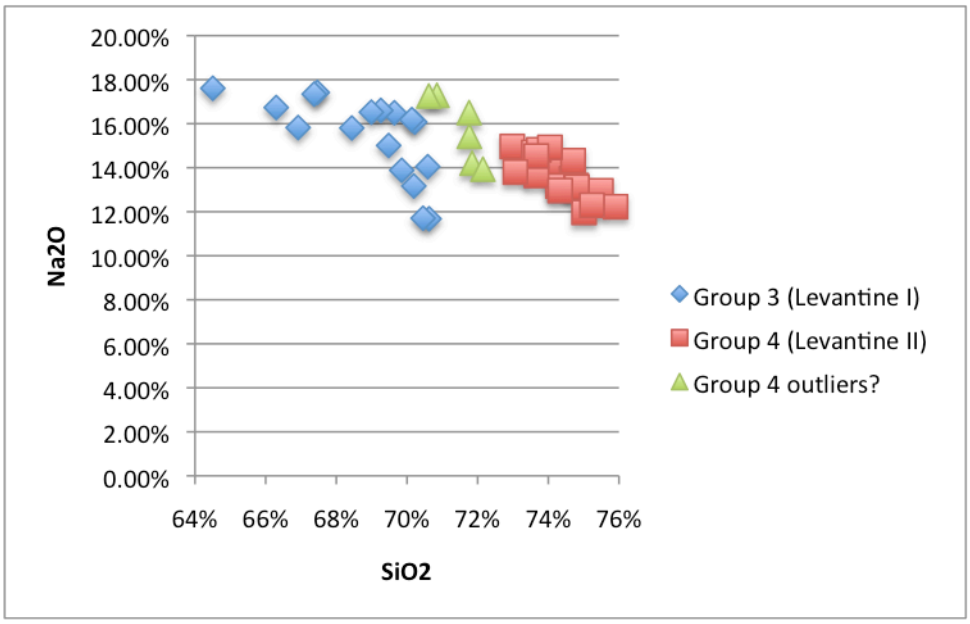
Of the 41 Levantine glasses in the Ayla assemblage, 18 samples are similar to the Levantine II production group, and are defined here as Group 4. These samples have higher silica as well as lower lime, soda, and alumina than the Levantine I production

group. Interestingly, it does not appear that any of the Group 4 members are made of recycled glass, as there is little increase in the transition metals in any of the samples.

It was particularly difficult to assign six of the Levantine glasses (**Nos. 32, 57, 75, 95, 103,** and **109**) to either Group 3 or Group 4, as they seem to have a mix of Levantine characteristics. These samples tend to plot between Groups 3 and 4 in terms of the silica, soda, and lime, the elements that usually help to distinguish Levantine I from Levantine II glasses; this is clearly visible in Figure 6.20. Nos. 32 and 57 have higher lime (>8 wt%) than the majority of the Levantine II glasses but they also have the lower soda levels that are characteristic of Levantine II glasses; Nos. 75, 95, 103 and 109 have the lower lime levels characteristic of Levantine II glasses, but they also have the higher soda levels that is more characteristic of Levantine I glasses. The silica content of these samples does little to resolve this question, as it falls between the two groups. As such, it might be suggested that these six samples are mixtures of Levantine I and II glasses; however, they do not have the elevated levels of the transition metals that could indicate recycling, so if they are indeed mixtures, then this likely occurred during the first melting of raw glass cakes during secondary production.

Taking a close look at the silica-lime scatter plot in Figure 6.20, a faint gap is visible between the blue points of Group 3 and the green points of the questionable samples; this may be enough to associate these samples with Group 4, which are therefore treated here as a sub-type of Group 4 (i.e., "Group 4 outliers"). In addition, this sub-group has less alumina and iron than either Group 3 or 4 but seems to have more potash and magnesia levels more in line with Group 4. It should also be noted that four of

the six samples of this sub-type of Group 4 are somewhat more unusual samples: No. 32 may be a bracelet, No. 75 is a windowpane, and Nos. 103 and 109 are both lamp stems.



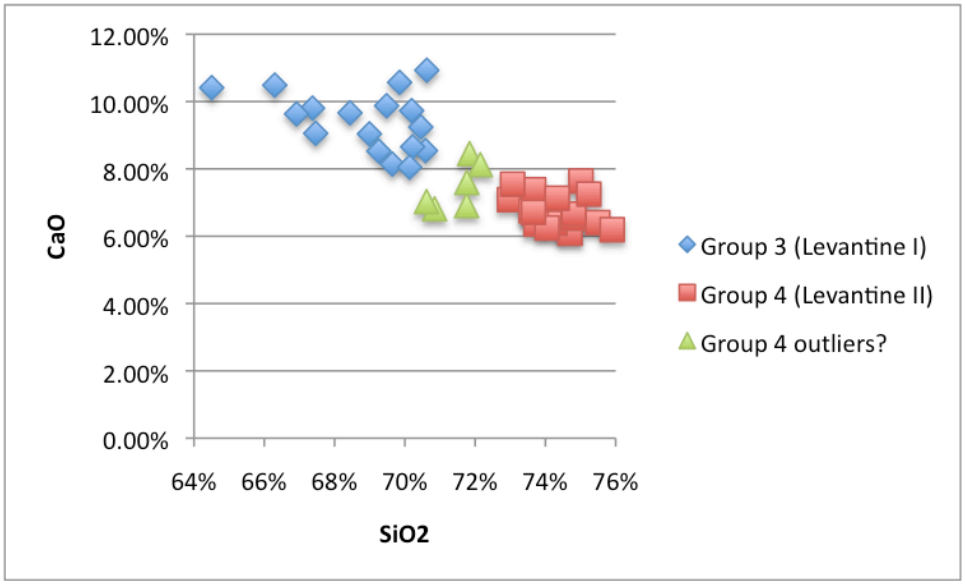


Figure 6.20: Bivariate scatter plots of the silica-soda content (top) and the silica-lime content (bottom) of Group 3, Group 4, and the six outlier Levantine glasses that are possibly a sub-type of Group 4.

Group 5 (similar to HIMT glasses)

Two samples, **Nos. 35** and **114**, easily stand out from the others because of their notably high levels of soda, iron, titania, manganese, phosphorus, and strontium; their magnesia levels are also relatively high (0.9-1.4 wt% MgO), as are their zirconium and barium levels (250-270 ppm Zr and 210-320 ppm Ba). These samples are considered here as Group 5, and their characteristics fit extremely well with the HIMT glass production group. This group is currently thought to originate in northern Egypt (Freestone *et al.* 2005: 155-156), which could account for the high soda and manganese due to the proximity of regions where these ingredients were mined (the Wadi Natrun and the north Sinai respectively). There are two theories to account for the particular chemical signature of HIMT glass: 1) it was made from a mixture of "geochemically distinctive but geographically proximal sand" (e.g., a beach sand and an inland sand), which could naturally occur "for example in an estuarine environment, where fluvially transported sediment can mix with marine sediment" (Freestone *et al.* 2005: 154); or 2) it was made from a mixture of two different primary glass types.

No. 35 is yellowish-green in color while No. 114 is light green. HIMT glasses are typically yellowish, greenish, and/or amber-brown in color, making them visually as well as chemically distinct from the naturally aqua colored glasses of the other primary production groups. It has been pointed out that there is an apparent paradox of a colorful glass that has elevated levels of manganese (typically a decolorant); the addition of pyrolusite (MnO_2) to a glass batch might be explained as linked to the process of oxidizing sulphur, as under reducing conditions S^{2-} combines with Fe^{2+} "to precipitate droplets of iron sulphide, making black glass," so if HIMT glass processing involved

reducing conditions the purpose of adding manganese "may have been to prevent the glass from turning black rather than to make it colorless" (Freestone *et al.* 2005: 156).

Plant ash soda glasses

While mineral soda was used to produce the majority of the samples analyzed from Ayla, 30% (33 fragments) of the soda-lime-silica glasses were made using plant ash soda as the fluxing agent. The plant ash glasses are easily identifiable due to their high magnesia and potash contents, both of which are over 1.5 wt%, and also by their elevated phosphorus levels. The results for the major/minor elements are presented in Table 6.7 and for trace elements in Table 6.8; patterns within the Ayla assemblage are considered here and then compared in Chapter 7 with the patterns of plant ash soda glasses from eight other sites in the Eastern Mediterranean.

The major and minor oxides on their own do little to help sort the Ayla plant ash soda glasses into clear chemical groupings (Figure 6.20), while trace elements prove to be effective discriminators (Figure 6.22). In particular, lithium, boron, and chromium immediately define a core group of 23 samples (identified here as Group 6). The remaining 10 samples can then be investigated for group characteristics; six of these are somewhat similar (Group 7), two are very similar (Group 8), and sample Nos. 10 and 116 are distinct enough not to be placed in any of these groupings and are thus considered outliers.

Table 6.7: <u>AYLA PLANT ASH SODA GLASSES</u>: chemical results of MAJOR AND MINOR OXIDES and colorants/decolorants, given in wt% oxide.

Sample ID #	Color	SiO2	Na2O	K2O	CaO	MgO	Al2O3	Fe2O3	TiO2	MnO	P2O3	CuO	CoO	PbO2	Sb2O5	SnO2
GROUP 6: plant ash soda glasses																
2	Colorless?	66.69	13.57	2.89	9.01	2.57	2.52	0.83	0.05	1.53	0.35	0.01	0.00	0.00	0.00	0.00
4	Colorless?	66.92	13.04	2.91	10.11	2.77	2.16	0.56	0.04	1.16	0.33	0.01	0.00	0.00	0.00	0.00
5	Colorless?	66.74	13.39	2.85	9.62	3.16	2.10	0.62	0.04	1.21	0.25	0.01	0.00	0.00	0.00	0.00
7	Y-colorless?	65.55	12.77	2.69	11.03	2.60	2.27	0.77	0.05	1.86	0.41	0.01	0.00	0.00	0.00	0.00
11	Aqua	69.66	13.04	2.26	8.13	3.06	2.25	0.81	0.05	0.34	0.41	0.00	0.00	0.00	0.00	0.00
13	Colorless	70.39	13.65	2.51	7.31	2.89	1.63	0.47	0.03	0.82	0.29	0.00	0.00	0.00	0.00	0.00
14	Colorless?	69.57	12.33	2.77	8.60	2.68	1.61	0.44	0.03	0.93	0.26	0.00	0.00	0.00	0.00	0.00
15	Colorless?	67.19	13.30	2.36	8.99	4.32	1.69	0.45	0.03	0.93	0.21	0.00	0.00	0.00	0.00	0.00
17	Colorless?	69.10	12.39	2.31	8.57	2.79	1.94	0.63	0.04	1.10	0.31	0.00	0.00	0.00	0.00	0.00
19	Aqua	70.31	11.71	2.34	7.94	2.79	2.58	0.83	0.06	0.89	0.44	0.02	0.00	0.12	0.00	0.00
20	Colorless?	70.53	13.49	2.80	6.66	2.02	2.13	0.63	0.04	1.32	0.39	0.00	0.00	0.00	0.00	0.00
21	Aqua	68.93	13.42	2.07	8.45	3.19	1.95	0.49	0.03	1.21	0.27	0.01	0.00	0.00	0.00	0.00
22	Colorless?	68.56	13.64	2.11	8.56	2.73	2.32	0.80	0.05	0.80	0.33	0.03	0.00	0.08	0.01	0.01
24	Aqua?	71.99	12.80	2.34	7.89	3.52	0.78	0.31	0.02	0.05	0.32	0.00	0.00	0.00	0.00	0.00
25	Purple	71.06	12.96	2.33	7.05	3.19	1.16	0.37	0.03	1.48	0.36	0.01	0.00	0.01	0.00	0.00
26	Purple	70.67	13.05	2.31	7.18	3.20	1.22	0.38	0.03	1.59	0.36	0.01	0.00	0.01	0.00	0.00
27	Aqua?	66.94	13.64	2.38	8.55	2.74	2.07	0.79	0.04	1.12	0.55	0.04	0.00	0.42	0.00	0.01
28	Aqua	68.69	12.81	2.24	8.43	2.87	2.12	0.68	0.04	0.87	0.45	0.02	0.00	0.14	0.00	0.01
30	Colorless?	68.24	12.70	2.65	9.02	3.19	1.86	0.45	0.03	0.93	0.25	0.01	0.00	0.00	0.01	0.00
42	Aqua	67.46	13.73	1.69	9.98	2.67	2.23	0.81	0.08	0.67	0.24	0.03	0.01	0.03	0.00	0.00
46	Colorless	67.51	13.16	1.98	10.39	3.33	1.90	0.32	0.03	0.72	0.21	0.00	0.00	0.00	0.00	0.00
104	Aqua	67.54	13.52	2.05	9.80	3.14	1.91	0.59	0.05	0.71	0.27	0.03	0.01	0.01	0.00	0.00
105	Lt. green	71.56	11.46	2.42	7.92	2.31	2.04	0.47	0.05	0.92	0.37	0.00	0.00	0.00	0.00	0.00
AVERAGE		**68.77**	**13.02**	**2.40**	**8.66**	**2.94**	**1.93**	**0.59**	**0.04**	**1.01**	**0.33**	**0.01**	**0.00**	**0.04**	**0.00**	**0.00**

Sample ID #	Color	SiO2	Na2O	K2O	CaO	MgO	Al2O3	Fe2O3	TiO2	MnO	P2O3	CuO	CoO	PbO2	Sb2O5	SnO2
GROUP 7: plant ash soda glasses																
9	Lt. green	62.82	14.93	2.77	9.30	3.97	3.77	1.15	0.07	0.73	0.53	0.00	0.00	0.00	0.00	0.00
60	Aqua	64.14	15.19	2.66	8.75	4.42	2.26	0.91	0.09	0.84	0.34	0.01	0.01	0.01	0.00	0.00
65	Blue	63.74	15.72	2.67	6.93	4.87	2.46	1.63	0.05	0.94	0.24	0.20	0.09	0.04	0.00	0.03
80	Blue	64.82	15.80	2.44	7.61	4.49	1.89	1.83	0.05	0.34	0.21	0.07	0.03	0.01	0.00	0.01
AVERAGE		**63.88**	**15.41**	**2.63**	**8.15**	**4.44**	**2.59**	**1.38**	**0.07**	**0.71**	**0.33**	**0.07**	**0.03**	**0.02**	**0.00**	**0.01**
Group 7 outliers																
44	Colorless	58.74	18.01	3.48	8.92	5.80	2.74	0.71	0.06	0.87	0.33	0.00	0.00	0.00	0.00	0.00
77	Blue	71.21	11.20	1.68	5.67	2.66	2.16	3.11	0.06	0.77	0.16	0.72	0.10	0.02	0.00	0.00

Sample ID #	Color	SiO2	Na2O	K2O	CaO	MgO	Al2O3	Fe2O3	TiO2	MnO	P2O3	CuO	CoO	PbO2	Sb2O5	SnO2
GROUP 8: plant ash soda glasses																
6	Y-colorless?	68.05	14.10	2.73	6.99	5.98	1.29	0.36	0.02	0.47	0.00	0.00	0.00	0.00	0.00	0.00
23	Colorless	74.96	11.20	1.90	5.40	4.59	1.09	0.38	0.01	0.39	0.07	0.00	0.00	0.00	0.00	0.00
AVERAGE		**71.51**	**12.65**	**2.32**	**6.20**	**5.29**	**1.19**	**0.37**	**0.02**	**0.43**	**0.04**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Sample ID #	Color	SiO2	Na2O	K2O	CaO	MgO	Al2O3	Fe2O3	TiO2	MnO	P2O3	CuO	CoO	PbO2	Sb2O5	SnO2
OUTLIERS: plant ash soda glasses																
10	Aqua	67.54	15.34	2.70	3.97	1.86	5.91	1.93	0.22	0.38	0.27	0.01	0.00	0.03	0.00	0.00
106	Blue	66.45	14.56	1.81	7.98	2.77	1.58	2.02	0.04	1.69	0.22	0.37	0.18	0.01	0.00	0.00

Tables 6.8: AYLA PLANT ASH SODA GLASSES: chemical results TRACE ELEMENTS given in ppm.

Sample ID #	Color	Li	Be	B	Sc	Ti	V	Cr	Ni	Co	Zn	As	Rb	Sr	Zr	Nb	Ag	Sb	Cs	Ba
GROUP 6: plant ash soda glasses																				
2	Colorless?	6.5	2.5	62.8	3.8	299.8	20.7	21.4	13.3	4.2	28.1	0.0	15.6	556.3	50.2	3.3	0.2	0.3	0.1	236.7
4	Colorless?	5.7	2.1	58.2	2.7	227.2	13.1	12.2	8.4	3.9	23.8	0.0	15.2	569.6	41.7	2.6	0.2	0.3	0.1	277.1
5	Colorless?	5.4	2.8	60.9	3.1	241.3	15.1	15.9	10.4	4.1	29.7	0.0	18.5	474.9	43.0	2.5	0.2	1.5	0.1	262.6
7	Y-colorless?	5.4	1.3	61.9	3.1	273.5	21.3	19.8	12.3	4.2	28.9	0.0	14.2	555.1	42.1	2.9	0.1	0.3	0.1	247.9
11	Aqua	5.4	2.5	57.6	3.5	289.2	18.2	15.4	10.1	2.8	26.9	0.0	13.3	390.4	39.1	3.1	0.1	0.3	0.1	182.3
13	Colorless	5.5	1.0	84.7	2.2	174.6	11.0	10.7	7.6	3.2	24.4	3.4	16.4	368.8	28.2	1.7	0.1	0.5	0.2	199.7
14	Colorless?	4.0	0.8	62.2	1.9	155.7	11.6	15.3	7.5	3.3	23.3	18.4	14.9	623.6	32.6	1.8	0.1	0.3	0.1	224.7
15	Colorless?	5.9	0.6	87.9	2.0	164.0	11.3	10.4	8.3	3.0	25.7	9.9	15.2	489.5	31.4	1.8	0.1	0.2	0.2	195.3
17	Colorless?	5.4	0.7	58.7	2.4	224.5	16.3	13.6	9.8	4.3	24.6	13.4	11.6	535.6	36.8	2.5	0.0	0.4	0.1	229.9
19	Aqua	6.4	0.8	76.7	3.1	338.4	18.0	17.7	10.2	6.6	39.7	17.2	12.6	439.4	60.9	3.1	1.0	3.9	0.1	195.7
20	Colorless?	4.9	1.0	60.4	2.8	221.6	16.1	12.3	9.7	4.6	22.5	5.4	11.2	559.9	35.0	2.2	0.1	0.3	0.1	184.9
21	Aqua	5.2	1.3	85.3	2.8	181.3	13.0	13.4	8.7	2.6	18.6	5.5	16.5	341.9	31.0	2.1	0.1	0.2	0.1	191.2
22	Colorless?	6.4	1.3	86.7	2.9	302.5	17.0	19.4	12.1	12.9	52.0	3.8	14.0	414.4	61.5	2.8	0.8	44.7	0.1	218.1
24	Aqua?	6.4	1.0	116.5	2.0	118.7	8.3	14.8	11.2	1.2	27.3	22.9	8.9	378.3	28.0	1.2	0.1	0.2	0.1	47.0
25	Purple	6.4	0.9	92.3	2.4	177.5	12.2	13.9	7.2	3.3	33.4	15.6	14.1	310.4	43.6	1.8	0.1	0.3	0.1	186.8
26	Purple	6.3	0.9	90.5	2.7	186.9	12.7	14.0	7.8	3.6	35.7	16.5	15.0	321.1	46.0	1.8	0.1	0.3	0.2	192.8
27	Aqua?	6.7	6.9	90.7	2.7	268.2	18.4	17.4	13.1	11.1	71.3	6.0	13.4	494.7	46.6	2.5	0.6	22.8	0.2	211.9
28	Aqua	7.4	1.0	101.5	2.3	246.8	15.8	15.7	9.2	6.7	43.9	24.6	11.2	459.7	43.2	2.4	0.4	10.5	0.1	180.5
30	Colorless?	6.5	1.1	80.3	2.0	163.9	11.9	11.4	7.9	3.1	28.4	7.5	15.0	521.3	33.6	1.7	0.1	30.9	0.1	214.2
42	Aqua	7.8	0.5	88.3	2.9	493.5	19.6	24.7	23.4	53.1	72.9	8.8	13.9	508.0	90.0	3.1	0.2	3.7	0.2	210.4
46	Colorless	6.8	0.5	72.5	2.1	186.7	9.5	9.6	5.8	2.6	22.9	8.2	16.4	678.4	32.5	1.7	0.1	0.3	0.2	232.9
104	Aqua	8.4	0.5	89.4	2.5	314.2	13.2	18.0	25.4	90.2	60.4	7.6	15.3	562.5	57.0	2.2	0.2	1.7	0.2	179.3
105	Lt. green	5.2	0.4	73.2	2.6	290.5	12.3	10.2	8.3	4.5	26.4	6.1	11.6	621.8	38.6	2.3	0.1	0.2	0.1	213.2
AVERAGE		**6.1**	**1.4**	**78.2**	**2.6**	**240.9**	**14.6**	**15.1**	**10.8**	**10.4**	**34.4**	**8.7**	**14.1**	**485.9**	**43.2**	**2.3**	**0.2**	**5.4**	**0.1**	**205.0**

Sample ID #	Color	La	Ce	Pr	Ta	Au	Y	Bi	U	W	Mo	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Th
GROUP 6: plant ash soda glasses – CONTINUED																								
2	Colorless?	7.3	13.5	1.8	0.2	0.1	9.0	0.1	0.7	0.7	4.9	7.9	1.6	0.4	1.3	0.2	1.4	0.3	0.8	0.1	0.6	0.1	1.4	1.0
4	Colorless?	6.4	11.2	1.6	0.2	0.1	6.7	0.1	0.4	9.0	3.3	6.3	1.4	0.3	1.1	0.2	0.9	0.2	0.6	0.1	0.6	0.1	1.2	1.0
5	Colorless?	6.6	12.2	1.6	0.2	0.1	7.7	0.1	0.5	0.4	3.7	6.3	1.1	0.3	1.2	0.2	1.3	0.2	0.7	0.1	0.8	0.1	1.3	1.0
7	Y-colorless?	7.2	13.8	1.9	0.2	3.4	8.6	0.1	0.7	0.6	5.0	7.0	1.4	0.4	1.3	0.2	1.4	0.2	0.6	0.1	0.6	0.1	1.1	1.1
11	Aqua	6.6	13.9	1.7	0.1	0.2	6.5	0.1	0.5	0.4	1.8	6.0	1.3	0.3	1.1	0.2	1.2	0.2	0.6	0.1	0.5	0.1	1.1	1.0
13	Colorless	4.9	9.4	1.3	0.1	0.6	5.8	0.0	0.3	0.2	1.9	4.9	0.9	0.3	0.9	0.1	0.9	0.2	0.5	0.1	0.4	0.1	0.7	0.7
14	Colorless?	5.5	11.4	1.5	0.1	0.0	6.0	0.1	0.5	0.4	2.6	5.8	1.2	0.3	1.1	0.2	1.1	0.2	0.5	0.1	0.5	0.1	0.9	0.8
15	Colorless?	5.5	11.1	1.5	0.1	0.1	6.3	0.1	0.9	0.3	2.9	5.6	1.3	0.3	1.1	0.2	1.0	0.2	0.5	0.1	0.5	0.1	0.8	1.6
17	Colorless?	5.9	12.1	1.7	0.1	0.1	6.3	0.0	0.4	0.3	3.0	6.3	1.3	0.4	1.1	0.2	1.1	0.2	0.6	0.1	1.1	0.1	0.9	0.9
19	Aqua	6.7	12.5	1.7	0.2	0.0	7.3	0.1	0.5	0.4	2.6	6.7	1.5	0.4	1.4	0.2	1.2	0.2	0.7	0.1	0.6	0.1	1.6	1.1
20	Colorless?	5.5	10.5	1.4	0.1	0.6	5.7	0.0	0.5	0.2	3.3	5.6	1.1	0.3	1.0	0.1	1.0	0.2	0.5	0.1	0.5	0.1	1.0	0.9
21	Aqua	5.4	10.0	1.4	0.1	0.8	6.4	0.1	0.4	0.5	4.5	5.6	1.0	0.3	0.9	0.1	0.9	0.2	0.5	0.1	0.5	0.1	0.8	0.7
22	Colorless?	6.3	11.4	1.6	0.2	0.1	6.8	0.1	0.6	0.3	3.1	5.8	1.2	0.3	1.1	0.2	1.2	0.2	0.6	0.1	0.6	0.1	1.6	1.0
24	Aqua?	4.2	7.9	1.0	0.1	0.1	3.5	0.1	0.4	0.2	1.3	3.7	0.8	0.2	0.7	0.1	0.6	0.1	0.3	0.0	0.3	0.0	0.8	0.8
25	Purple	3.5	7.8	0.9	0.1	0.1	3.3	0.0	0.4	0.5	4.9	3.4	0.7	0.2	0.5	0.1	0.6	0.1	0.3	0.1	0.3	0.0	1.0	0.7
26	Purple	3.8	8.1	1.0	0.1	0.0	3.5	0.0	0.5	0.5	5.3	3.9	0.7	0.2	0.7	0.1	0.5	0.1	0.3	0.0	0.4	0.0	1.1	0.7
27	Aqua?	6.0	12.0	1.6	0.1	0.1	6.6	0.1	0.5	0.4	3.1	5.9	1.3	0.3	1.1	0.2	1.0	0.2	0.6	0.1	0.5	0.1	1.1	1.1
28	Aqua	5.2	10.0	1.3	0.1	0.1	5.6	0.1	0.5	0.3	3.0	5.1	1.0	0.3	0.8	0.2	1.0	0.2	0.5	0.1	0.5	0.1	1.1	0.8
30	Colorless?	5.5	9.7	1.4	0.1	0.0	6.3	0.0	0.5	0.2	2.7	5.4	1.1	0.3	1.0	0.2	1.0	0.2	0.5	0.1	0.4	0.1	1.0	0.8
42	Aqua	6.5	12.7	1.7	0.2	0.1	6.9	0.0	0.8	0.2	2.5	6.4	1.6	0.4	1.3	0.2	1.1	0.2	0.7	0.1	0.6	0.1	2.3	1.2
46	Colorless	5.5	10.3	1.5	0.1	0.2	6.0	0.0	0.6	0.4	3.2	5.5	1.2	0.3	0.9	0.1	1.0	0.2	0.5	0.1	0.5	0.1	0.9	0.7
104	Aqua	5.3	9.8	1.3	0.1	0.2	5.8	0.1	0.5	0.3	2.7	5.0	1.1	0.3	1.1	0.2	0.9	0.2	0.5	0.1	0.5	0.1	1.4	0.9
105	Lt. green	5.1	9.5	1.3	0.1	0.0	6.2	0.0	0.5	0.1	1.9	4.9	1.0	0.3	1.0	0.2	0.9	0.2	0.5	0.1	0.4	0.1	0.9	0.8
Average		**5.7**	**10.9**	**1.5**	**0.1**	**0.3**	**6.2**	**0.1**	**0.5**	**0.7**	**3.2**	**5.6**	**1.2**	**0.3**	**1.0**	**0.2**	**1.0**	**0.2**	**0.5**	**0.1**	**0.5**	**0.1**	**1.1**	**0.9**

Sample ID #	Color	Li	Be	B	Sc	Ti	V	Cr	Ni	Co	Zn	As	Rb	Sr	Zr	Nb	Ag	Sb	Cs	Ba
GROUP 7: plant ash soda glasses																				
9	Lt. green	15.4	1.2	142.5	4.3	412.0	25.1	116.3	35.2	7.1	42.3	5.6	14.6	487.7	86.7	3.5	0.1	0.3	0.2	158.1
60	Aqua	15.9	0.5	116.3	3.4	512.2	20.1	53.9	32.2	42.6	126.8	11.3	12.7	423.8	73.5	2.9	0.7	0.5	0.2	145.2
65	Blue	20.9	1.6	111.9	3.3	290.6	18.3	75.4	31.7	689.9	3949.8	16.7	11.9	405.1	97.5	2.6	1.8	2.3	0.1	167.1
80	Blue	18.9	0.4	114.8	3.2	312.4	17.6	59.2	23.3	235.0	64.5	2.2	11.2	433.9	120.4	2.5	0.2	0.5	0.2	92.3
AVERAGE		**17.8**	**0.9**	**121.4**	**3.6**	**381.8**	**20.3**	**76.2**	**30.6**	**243.7**	**1045.9**	**9.0**	**12.6**	**437.6**	**94.5**	**2.9**	**0.7**	**0.9**	**0.2**	**140.7**
Group 7 outliers																				
44	Colorless	17.0	0.5	137.1	2.8	344.8	15.3	71.8	24.5	3.5	30.0	9.1	15.6	689.0	55.3	2.4	0.1	0.3	0.2	164.0
77	Blue	28.1	0.3	126.1	4.3	385.8	22.6	75.5	170.2	777.0	710.8	19.1	10.0	229.0	101.8	3.5	0.7	2.6	0.4	145.2

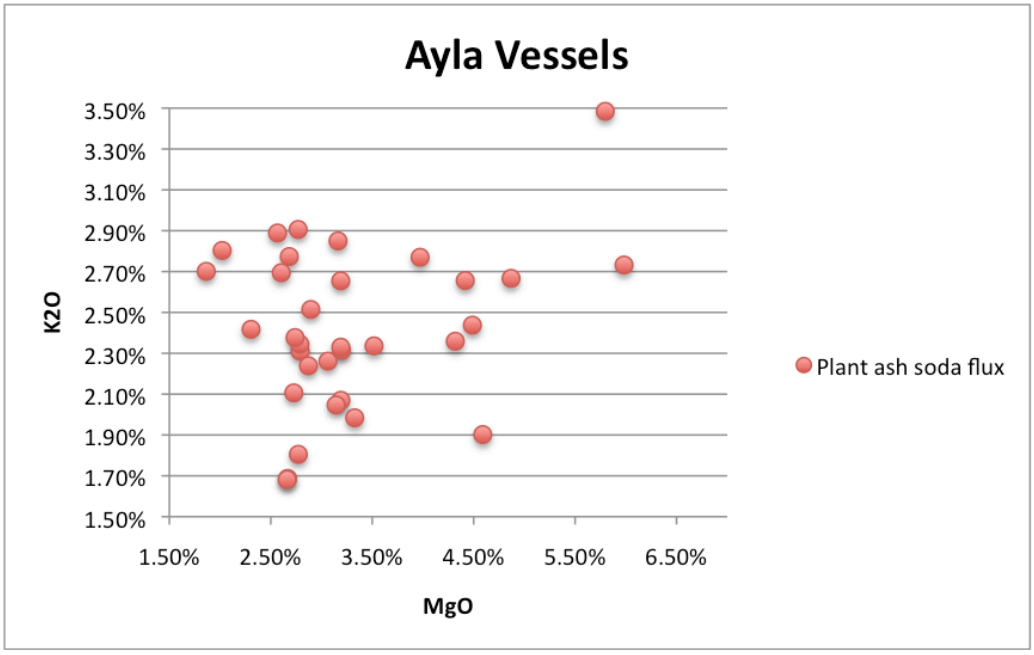
Sample ID #	Color	La	Ce	Pr	Ta	Au	Y	Bi	U	W	Mo	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Th
Group 7: plant ash soda glasses – CONTINUED																								
9	Lt. green	7.6	15.4	1.9	0.2	0.0	6.7	0.0	1.0	0.3	3.7	6.8	1.5	0.3	1.0	0.2	1.1	0.2	0.7	0.1	0.7	0.1	2.2	2.0
60	Aqua	6.9	14.4	1.6	0.1	0.1	5.4	0.0	0.8	0.3	2.8	5.6	1.1	0.2	1.1	0.1	0.8	0.2	0.5	0.1	0.6	0.1	1.8	1.5
65	Blue	6.3	12.2	1.5	0.1	0.1	5.4	0.1	0.7	0.4	4.0	5.3	1.0	0.3	1.0	0.1	0.7	0.2	0.5	0.1	0.5	0.0	2.5	1.5
80	Blue	5.3	10.0	1.2	0.1	0.0	5.5	0.0	0.5	0.1	3.7	4.3	0.8	0.2	0.8	0.1	0.7	0.1	0.4	0.1	0.4	0.1	2.5	1.4
AVERAGE		**6.5**	**13.0**	**1.6**	**0.1**	**0.0**	**5.8**	**0.1**	**0.7**	**0.3**	**3.6**	**5.5**	**1.1**	**0.2**	**1.0**	**0.1**	**0.9**	**0.2**	**0.5**	**0.1**	**0.5**	**0.1**	**2.2**	**1.6**
44	Colorless	5.5	11.0	1.3	0.1	0.0	5.2	0.0	0.6	0.1	2.2	5.0	0.9	0.2	0.8	0.1	0.9	0.2	0.5	0.1	0.5	0.1	1.5	1.4
77	Blue	7.6	15.1	1.8	0.2	0.0	6.7	0.2	0.7	0.2	7.0	6.7	1.3	0.2	1.1	0.2	0.9	0.2	0.5	0.1	0.5	0.1	2.3	1.9

Sample ID #	Color	Li	Be	B	Sc	Ti	V	Cr	Ni	Co	Zn	As	Rb	Sr	Zr	Nb	Ag	Sb	Cs	Ba
GROUP 8: plant ash soda glasses																				
6	Y-colorless?	22.7	3.0	51.1	2.5	94.6	8.0	21.7	14.4	2.7	19.0	0.0	18.6	370.4	27.7	1.4	0.2	0.3	0.2	150.8
23	Colorless	21.3	0.8	60.1	2.0	88.4	6.2	22.9	10.8	1.7	12.1	15.7	13.0	241.2	29.2	1.1	0.1	0.1	0.1	82.4
AVERAGE		**22.0**	**1.9**	**55.6**	**2.2**	**91.5**	**7.1**	**22.3**	**12.6**	**2.2**	**15.6**	**7.9**	**15.8**	**305.8**	**28.4**	**1.2**	**0.1**	**0.2**	**0.2**	**116.6**

Sample ID #	Color	La	Ce	Pr	Ta	Au	Y	Bi	U	W	Mo	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Th
Group 8: plant ash soda glasses – CONTINUED																								
6	Y-colorless?	3.3	6.4	0.8	0.2	0.1	3.6	0.2	0.5	0.6	2.1	2.8	0.8	0.2	0.7	0.1	0.7	0.2	0.4	0.1	0.5	0.1	0.8	1.0
23	Colorless	2.5	5.1	0.6	0.1	0.0	2.6	0.0	0.5	0.3	1.0	2.4	0.3	0.2	0.4	0.1	0.4	0.1	0.2	0.0	0.2	0.0	0.9	0.7
AVERAGE		**2.9**	**5.7**	**0.7**	**0.1**	**0.1**	**3.1**	**0.1**	**0.5**	**0.4**	**1.5**	**2.6**	**0.6**	**0.2**	**0.6**	**0.1**	**0.6**	**0.1**	**0.3**	**0.1**	**0.4**	**0.1**	**0.8**	**0.9**

Sample ID #	Color	Li	Be	B	Sc	Ti	V	Cr	Ni	Co	Zn	As	Rb	Sr	Zr	Nb	Ag	Sb	Cs	Ba
Outliers: plant ash soda glasses																				
6	Y-colorless?	11.6	1.9	73.6	5.5	1339.2	37.3	36.1	15.2	6.3	52.3	0.0	17.1	327.8	346.9	11.2	0.2	1.1	0.1	336.0
23	Colorless	22.4	0.4	161.6	3.0	245.5	28.5	98.9	183.6	1431.4	302.2	18.0	10.0	262.7	17.9	1.7	0.3	1.8	0.2	125.6

Sample ID #	Color	La	Ce	Pr	Ta	Au	Y	Bi	U	W	Mo	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Th
Outliers: plant ash soda glasses – CONTINUED																								
6	Y-colorless?	14.6	34.5	4.0	0.5	0.1	13.3	0.1	1.1	0.3	0.8	14.4	2.6	0.6	2.3	0.4	2.3	0.4	1.4	0.2	1.6	0.2	8.6	4.0
23	Colorless	3.6	6.8	0.9	0.1	0.0	4.2	0.0	1.0	0.2	7.8	3.1	0.7	0.2	0.8	0.1	0.6	0.1	0.3	0.0	0.3	0.1	0.4	0.8



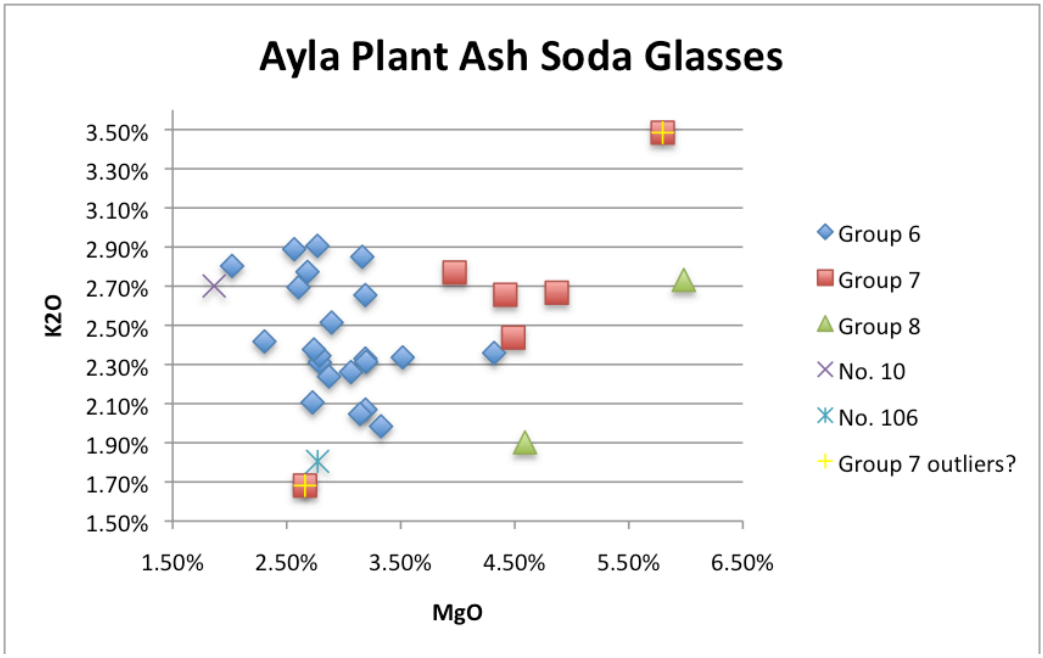
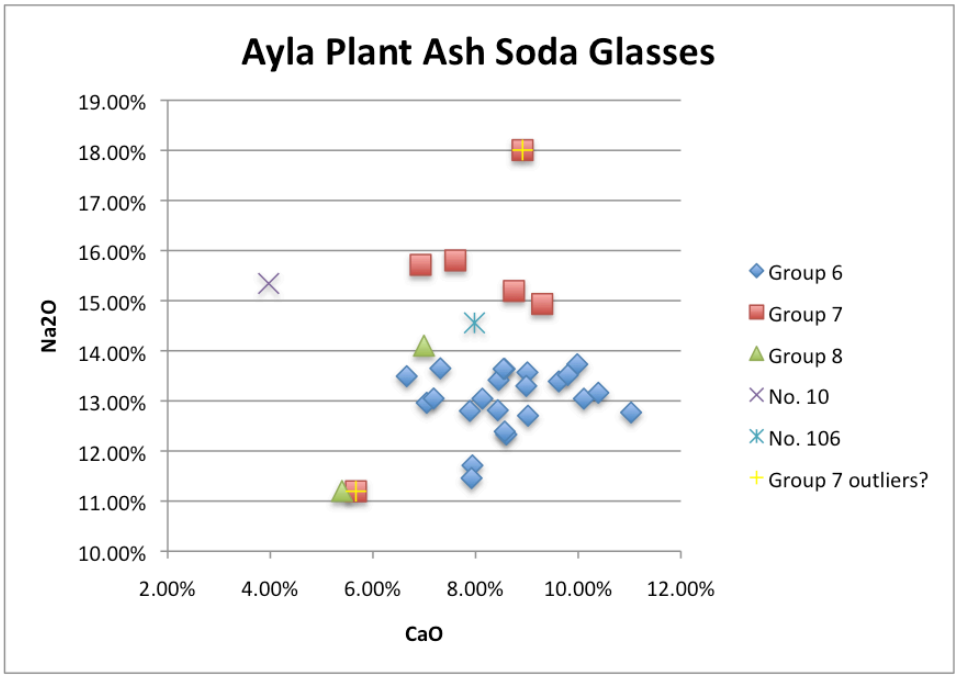


Figure 6.21: Bivariate scatter plot of MgO-K_2O for the Ayla plant ash soda glasses (top: undifferentiated; bottom: divided into groups according to trace element patterns—see Figure 6.23).

Oxides (wt%)	SiO2	Na2O	K2O	CaO	MgO	Al2O3	Fe2O3	TiO2	MnO	P2O3	CuO	CoO	PbO2	Sb2O5	SnO2
Group 6 (n=23)	**68.77**	**13.02**	**2.40**	**8.66**	**2.94**	**1.93**	**0.59**	**0.04**	**1.01**	**0.33**	**0.01**	**0.00**	**0.04**	**0.00**	**0.00**
range	65.55-71.99	11.46-13.73	1.69-2.91	7.05-11.03	2.02-4.32	0.78-2.58	0.31-0.83	0.03-0.08	0.34-1.86	0.21-0.55	0.00-0.04	-	0.00-0.42	-	-
σ	1.78	0.61	0.32	1.12	0.45	0.43	0.18	0.01	0.40	0.09	0.01	0.00	0.09	0.00	0.00
Group 7 (n=6)	**63.88**	**15.41**	**2.63**	**8.15**	**4.44**	**2.59**	**1.38**	**0.07**	**0.71**	**0.33**	**0.07**	**0.03**	**0.02**	**0.00**	**0.01**
range	62.82-64.82	14.93-15.80	2.44-2.77	7.61-9.30	3.97-4.87	1.89-3.77	0.91-1.83	0.05-0.09	0.34-0.94	0.21-0.53	0.00-0.20	0.00-0.09	0.00-0.04	-	0.00-0.03
σ	4.04	2.22	0.58	1.39	1.04	0.66	0.87	0.02	0.21	0.13	0.28	0.05	0.01	0.00	0.01
Group 8 (n=2)	**71.51**	**12.65**	**2.32**	**6.20**	**5.29**	**1.19**	**0.37**	**0.02**	**0.43**	**0.04**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
range	68.05-74.96	11.20-14.10	1.90-2.73	5.40-6.99	4.59-5.98	1.09-1.29	0.36-0.38	0.01-0.02	0.39-0.47	0.00-0.07	-	-	-	-	-
σ	4.89	2.05	0.59	1.13	0.98	0.14	0.02	0.01	0.06	0.05	0.00	0.00	0.00	0.00	0.00

Table 6.9: Average major/minor oxide composition of the core cluster of Ayla plant ash soda glasses (σ = standard deviation); note that the outlier samples from Group 7 are not included.



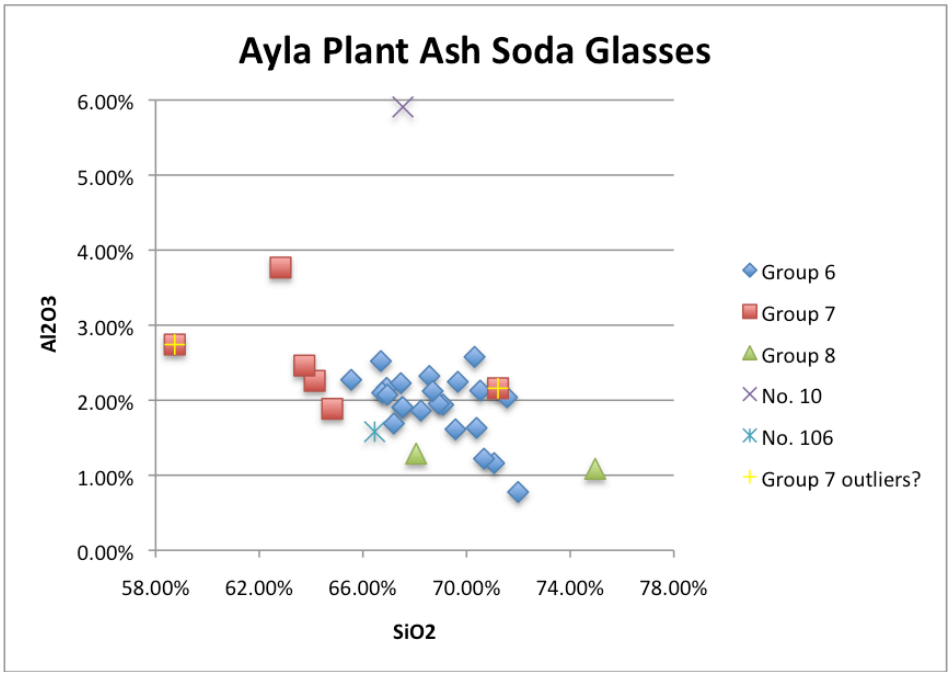


Figure 6.22: Bivariate scatter plot of CaO-Na_2O (top) and SiO_2-Al_2O_3 (bottom) for the Ayla plant ash soda glasses.

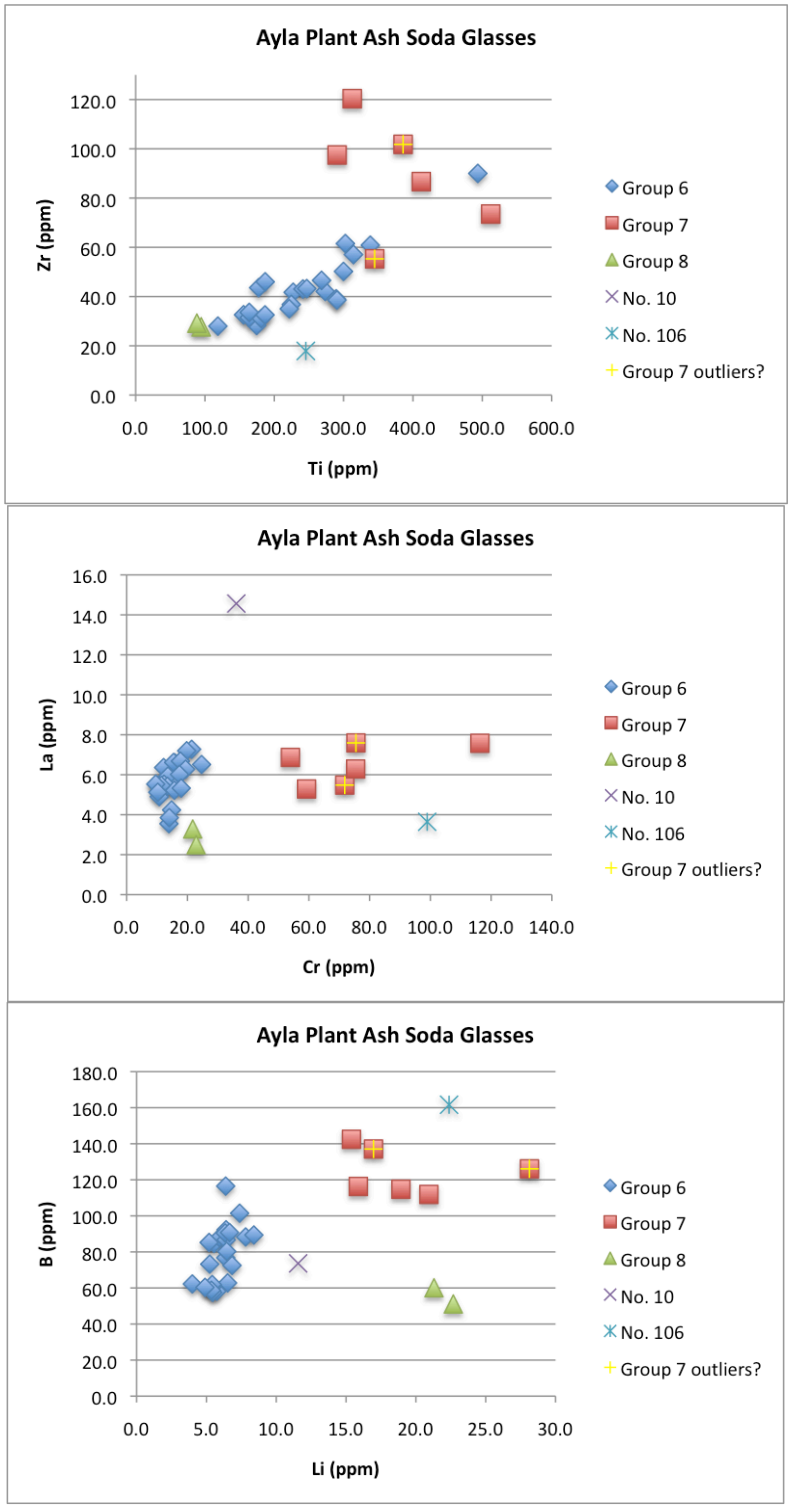


Figure 6.23: Bivariate scatter plots of Zr-Ti, La-Cr, and B-Li, which clearly illustrate the close clustering of Groups 6 and 8. Note that in the Ti-Zr plot No. 10 is not shown, because it has much higher levels of both elements than the rest of the samples.

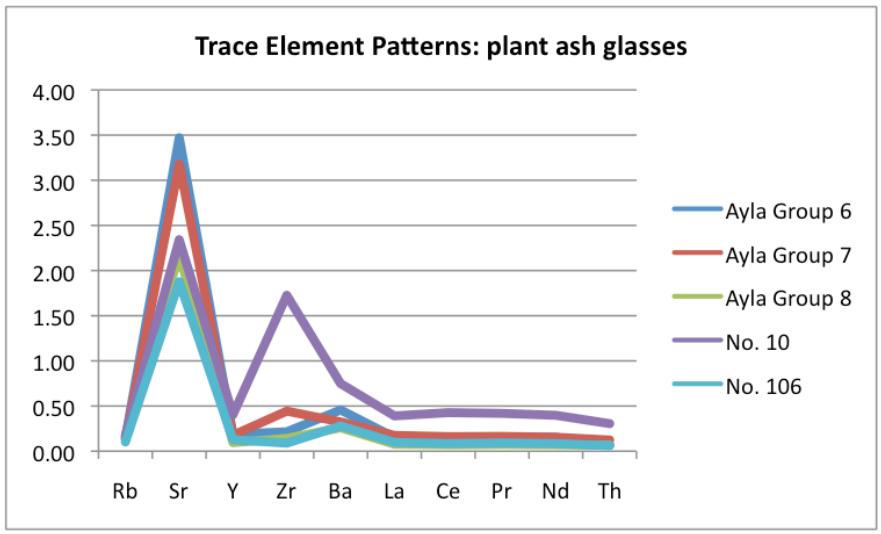


Figure 6.24: The average trace element distribution pattern of Groups 6, 7, and 8 and the two outlier samples; note that the green line for Group 8 is obscured by the aqua line of outlier sample No. 106.

Trace elements (ppm)	Li	Be	B	Sc	Ti	V	Cr	Ni	Co	Zn	As	Rb	Sr	Zr
Group 6	**5.2**	**0.4**	**73.2**	**2.6**	**290.5**	**12.3**	**10.2**	**8.3**	**4.5**	**26.4**	**6.1**	**11.6**	**621.8**	**38.6**
σ	1.0	1.4	16.0	0.5	81.3	3.6	3.9	4.7	20.3	15.5	7.5	2.2	101.8	14.0
Group 7	**17.8**	**0.9**	**121.4**	**3.6**	**381.8**	**20.3**	**76.2**	**30.6**	**243.7**	**1045.9**	**9.0**	**12.6**	**437.6**	**94.5**
σ	4.8	0.5	12.7	0.6	80.3	3.6	21.9	57.7	353.1	1554.8	6.4	2.1	148.5	22.8
Group 8	**22.0**	**1.9**	**55.6**	**2.2**	**91.5**	**7.1**	**22.3**	**12.6**	**2.2**	**15.6**	**7.9**	**15.8**	**305.8**	**28.4**
σ	1.0	1.6	6.4	0.3	4.4	1.3	0.8	2.5	0.7	4.9	11.1	3.9	91.4	1.1

Trace elements (ppm)	Nb	Ag	Sb	Cs	Ba	La	Ce	Pr	Ta	Au	Y	Bi	U	W
Group 6	**2.3**	**0.2**	**5.4**	**0.1**	**205.0**	**5.7**	**10.9**	**1.5**	**0.1**	**0.3**	**6.2**	**0.1**	**0.5**	**0.7**
σ	0.6	0.2	11.6	0.0	43.5	1.0	1.8	0.3	0.0	0.7	1.4	0.0	0.1	1.8
Group 7	**2.9**	**0.7**	**0.9**	**0.2**	**140.7**	**6.5**	**13.0**	**1.6**	**0.1**	**0.0**	**5.8**	**0.1**	**0.7**	**0.3**
σ	0.5	0.6	1.1	0.1	27.6	1.0	2.3	0.3	0.0	0.0	0.7	0.1	0.2	0.1
Group 8	**1.2**	**0.1**	**0.2**	**0.2**	**116.6**	**2.9**	**5.7**	**0.7**	**0.1**	**0.1**	**3.1**	**0.1**	**0.5**	**0.4**
σ	0.2	0.1	0.1	0.1	48.3	0.6	0.9	0.1	0.1	0.1	0.7	0.1	0.0	0.2

Trace elements (ppm)	Mo	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Th
Group 6	**3.2**	**5.6**	**1.2**	**0.3**	**1.0**	**0.2**	**1.0**	**0.2**	**0.5**	**0.1**	**0.5**	**0.1**	**1.1**	**0.9**
σ	1.1	1.0	0.3	0.1	0.2	0.0	0.2	0.0	0.1	0.0	0.2	0.0	0.3	0.2
Group 7	**3.6**	**5.5**	**1.1**	**0.2**	**1.0**	**0.1**	**0.9**	**0.2**	**0.5**	**0.1**	**0.5**	**0.1**	**2.2**	**1.6**
σ	1.7	1.0	0.2	0.0	0.2	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.4	0.3
Group 8	**1.5**	**2.6**	**0.6**	**0.2**	**0.6**	**0.1**	**0.6**	**0.1**	**0.3**	**0.1**	**0.4**	**0.1**	**0.8**	**0.9**
σ	0.7	0.3	0.3	0.0	0.2	0.0	0.2	0.1	0.1	0.0	0.2	0.0	0.1	0.2

Tables 6.10: Average trace element composition of the Ayla plant ash soda glasses (σ = standard deviation); note that outlier samples are not included.

Group 6

With 23 samples, the majority of the plant ash soda glasses from Ayla form a core group that is characterized by relatively low lithium, chromium, and zirconium. This group has slightly higher barium and strontium than the other samples, and there is also a positive correlation between Ti-Zr (Figure 6.22) that may reflect the source of silica used in production. In general, this group has the lowest magnesia of the three plant ash soda groups from Ayla as well as the most manganese; this latter characteristic is explained by the frequency of colorless and purple glass fragments in this group (e.g., manganese serves as both a purple colorant and a decolorizer, depending on whether the furnace atmosphere was oxidizing or reducing). Two samples, **Nos. 24** and **42**, are slightly varied in some of their trace elements, but overall correspond well to the chemical characteristics of Group 6: No. 24 has lower Ba and Rb as well as higher B, while No. 42 has higher Ti, Zr, and Hf. One sample, colorless fragment No. 15, has quite a high level of magnesia (4.3 wt% MgO) that is more in keeping with the magnesia levels of Group 7, but it is otherwise well within the compositional range of this group.

Many of the Ayla samples are small and highly weathered, which made it difficult to determine their precise color by means of visual inspection even when part of the patina was mechanically removed. The chemical results help to suggest a color for many of the unknown samples, as ≥0.5 wt% MnO is an effective decolorizer for glasses with ≤0.5 wt% Fe_2O_3 (Jackson 2005: 771); however, in some cases the color still remains uncertain.[20] Despite this limitation it appears that quite a large number of the Group 6

[20] For example, sample No. 22 has the same level of manganese that created colorless glass No. 13, but the former has almost twice as much iron as the latter, so it is difficult to decide whether No. 22 actually has enough manganese to counter the relatively high iron content.

samples are colorless, or nearly colorless with a yellowish or aqua tinge; **Nos. 2, 4, 5, 7, 13,** and **46** contain ~1 wt% manganese and typically have low iron as well. Other fragments are more purplish in hue due to higher manganese and a relatively low amount of iron; these include **Nos. 25** and **26**, with an average of 1.5 wt% MnO and 0.4 wt% Fe_2O_3.

Some aqua fragments, colored naturally by the iron content of the glass, are also present in Group 6 including **Nos. 11, 19, 21, 24, 27, 28, 42,** and **104**. These aqua fragments tend to have minimal manganese rather than elevated levels of iron. Nos. 19 has trace levels of copper, lead, and antimony that may indicate recycling; No. 27 and 28 also have trace copper, lead, and tin; and Nos. 42 and 104 have traces of cobalt. One fragment, **No. 105**, is light green in color probably produced by controlling the furnace atmosphere and temperature in order to manipulate the coloring effect of the natural iron content of the glass.

Group 7

Six samples appear to be similar enough to be described as a group, although this group is somewhat more diverse than either Group 6 or 8; further subdivision may prove to be necessary, for example removing the proposed Group 7 outliers entirely and considering these as outliers of the entire sample set. However, the Group 7 samples are quite similar in terms of their trace elements, in particular having higher Cr, B, Zr, and Ti than fragments in Groups 6 and 8; the Li content is also higher than Group 6 and more similar to Group 8. In terms of major and minor elements, Group 7 has higher magnesia,

soda, and alumina as well as lower silica than Group 6.[21] The two outlier samples in this group are notably dissimilar to the other fragments in Group 7 in terms of their major and minor element composition: sample **No. 77** has very low magnesia, potash, soda, and lime as well as high silica compared to the other samples, while **No. 44** has very high magnesia, potash, and soda as well as very low silica. These differences may be deemed severe enough to necessitate separating these outliers from Group 7; however, Nos. 44 and 77 are exceedingly similar to the rest of the group in terms of many characteristic trace elements (Figure 6.22). In addition, it is worth pointing out that the two samples in Group 8 are also often widely spaced in terms of their major and minor element compositions (Figure 6.20 and 6.21).

The Group 7 samples include highly colored, naturally colored, as well as decolorized glasses. **No. 9** has a light green hue due to the manipulation of the furnace atmosphere to affect the natural iron content. Naturally-aqua glass fragment **No. 60** has slight traces of copper, cobalt, and lead, indicative of recycling. Three of the samples in Group 7 are deep blue in color due to the presence of trace amounts cobalt; these include **Nos. 65** and **80** and outlier **No. 77**, although the latter also has almost three times as much iron as the other two cobalt-blue glasses as well as very high copper and elevated levels of nickel. The other outlier of this group is **No. 44**; it is a colorless fragment, but does not have significantly more manganese than the other samples.

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[21] With an average of 2.55 wt% Al_2O_3, Schibille 2011 would likely consider these fragments to be High Alumina glasses; however, as discussed in the previous chapter, it seems more appropriate to regard High Alumina glasses as having 4.00 wt% Al_2O_3 or more.

Group 8

Although consisting only of two samples, **Nos. 6** and **23**, the glass chemistry of Group 8 is quite distinctive. Although they differ somewhat in terms of their major and minor elements, these two samples are almost identical in terms of their trace element composition. Like Group 7 and outlier sample Nos. 10 and 116, Group 8 has high levels of lithium when compared to Group 6; however, Group 8 also has very low La, Cr, B, Sr, Zr, and Ti compared to the other samples. Group 8 does have a similar range of potash and soda as the other plant ash glasses, but it also tends to have higher magnesia and silica, lower lime, iron, and alumina as well as much lower phosphorus—0.00 wt% P_2O_3 in the case of sample No. 6!

The two Group 8 samples are both colorless glasses; **No. 6** may be somewhat more yellowish in hue, although the corrosion process has made this difficult to determine precisely. The low levels of iron present in the glass (0.4 wt% Fe_2O_3), together with the manganese, may be responsible for the colorlessness of these glasses.

Outliers

Two fragments did not fit with any of the chemical groups identified for this sample population: Nos. 10 and 106. In particular, the chemical composition of sample **No. 10** is vastly different from all the other plant ash soda glasses from Ayla. Visually, the naturally aqua color of the fabric is not out of the ordinary; however, the shape of the rim is noticeably different from that of the majority of the bowls that were sampled from this site, being slightly everted rather than vertical or slightly inverted (Figure 6.5). In terms of chemical composition, No. 10 has by far the highest concentration of zirconium,

titanium, and lithium—double to triple the amounts that are present in the other samples—as well as higher levels of all the Rare Earth Elements.[22] No. 10 also has the lowest lime and magnesia of the samples, as well as the highest alumina (almost twice as much). The fragment should certainly be considered a High Alumina plant ash soda glass, having 5.9 wt% Al_2O_3.[23] This elevated level of alumina helps to account for the very high concentrations of Li, Zi, and Ti; the alumina-bearing ingredient likely had elevated levels of these particular elements as well as the Rare Earth Elements, reflecting a specific geological origin. In this regard, No. 10 is similar to Ḥiṣn al-Tīnāt bracelet Group C, although the former does not have the very high alumina and boron levels of the latter.[24] In short, outlier sample No. 10 was made using a significantly different silica source than the other plant ash soda glasses sampled from Ayla, and this quality combined with the different typological style of the vessel is highly suggestive of an import, possibly from Egypt.

A cobalt blue fragment from the wall of a vessel, **No. 106**, is a second outlier to the rest of the plant ash soda glasses from Ayla. The blue color was produced by means of elevated iron, copper, and cobalt and also associated with trace amounts of lead; the high copper (0.4 wt% CuO) and cobalt (0.2 wt% CoO) is reminiscent of the high copper

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[22] I.e., Sc, Y, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, and Lu (see Figure 5.8).

[23] It may be of interest that the magnesia and potash content of No. 10 is not as high as the High Alumina glasses that have been published, as discussed in Chapter 5 and summarized in Table 5.7; potash and magnesia both typically appear to be on the order of 3-4 wt% in High Alumina glasses, while No. 10 has 2.70 wt% K_2O and 1.86 wt% MgO. In addition the silica level tends to be low for High Alumina glasses, while No. 10 has an average silica level.

[24] This could possibly indicate a similar silica source was used in the production of Ayla No. 10 and Ḥiṣn al-Tīnāt bracelet Group C, but that different plant ash soda sources were employed for the two glass types (recall in Chapter 5 that the high boron of Group C could be related to the boron deposits in western Anatolia; however, also recall that Schibille questions the ability of plants to absorb boron *contra* Brill 2002: 17).

and cobalt of blue fragment No. 77 (an outlier of Group 7), and both samples have somewhat similar levels of potash and magnesia as well. However, No. 106 does not fit well within the plant ash soda Groups 6, 7, or 8. In some ways the composition of No. 106 resembles that of Groups 7 and 8, but a closer examination refutes either categorization. For example, No. 106 is similar to Group 7 in that both have lower silica and higher soda in comparison to Group 6 (Figure 6.21), but No. 106 has much lower strontium, zirconium, and titanium, which could indicate the use of a different source of silica. The trace element pattern of No. 106 might suggest placing this fragment within Group 8 (Figure 6.23); the overlapping distribution lines seem definitive until the other trace element characteristics of Group 8 are highlighted and shown to be quite unique—recall that although Freestone's select trace element distribution graphs are helpful in identifying some degree of difference, other trace element combinations are probably better overall group discriminators.

Lead-silicate glass

Chemical analysis shows that one of the glass samples from Ayla is not a member of the soda-lime-silica glass family. Sample **No. 8** was chosen specifically because of its distinctive emerald green color, which is a unique hue that is often indicative of highly leaded glass; these glasses are a relatively rare chemical type of medieval Islamic glass (Brill 2001: 28; 2009: 463) that was largely used for vessels with cut decorations (facet cutting, cameo cutting, etc.), because the lead content makes the glass soft and therefore easier to cut and grind. No. 8 has clear facet cuts around the neck, and another example of

such treatment is an emerald green molar flask from the Serçe Limanı wreck (sample no. 3577).

No. 8 was made using lead oxide as a fluxing agent, which therefore places it in a different technological group altogether (i.e., distinct from the soda-lime-silica group). Lead silicate glasses are particularly distinct in terms of their high lead and low silica content; thus, No. 8 has 17.4 wt% PbO_2 and 55.1 wt% SiO_2 (Table 6.11), which is markedly different from the 0.0-0.02 wt% PbO_2 and 65-75 wt% SiO_2 that is characteristic of uncolored soda-lime-silica glasses. An additional distinction of No. 8 is its low[25] soda level, containing only 8.6 wt% Na_2O compared to the 11-18 wt% Na_2O of the soda-lime-silica glasses analyzed from Ayla; No. 8 also has somewhat high alumina and very low manganese. In terms of trace elements, lead-silicate glass fragment No. 8 is also distinct from the soda-lime-silica samples; it has noticeably higher levels of Ni, Cr, As, Ag, Sb, Bi, U, and Th as well as lower Mo. A high copper content (1.3 wt% CuO) in association with elevated tin and zinc (Tables 6.11 and 6.12), strongly suggests the use of bronze scrap metal as a colorant.

Another emerald green glass fragment from Ayla was chemically analyzed in an earlier stage of this project: a rim from a beaker/bowl/cup with relatively vertical walls from area/locus J10d-12, registration number 360-FN3 (Figure 6.24). This analysis was done at Brown University in the fall of 2009 using the electron microprobe facilities of the Geological Sciences Department. Analysis confirms that this fragment is also made from a lead-silicate glass, and it compares very closely with the data from No. 8, having 18.2 wt% PbO_2 and 52.6 wt% SiO_2 (Table 6.11). It should be emphasized that although

[25] However, this amount of soda is actually very *high* for lead-silicate glasses.

these fragments were analyzed using different methods, EPMA and LA-ICPMS, their results are remarkably similar.[26]

Figure 6.25: Emerald green vessel rim (J10d-12, RN360-FN3) analyzed by EMPA in 2009.

Sample	SiO2	Na2O	K2O	CaO	MgO	Al2O3	F2O3	TiO2	MnO	CuO	PbO2	SnO2
No. 8	55.07	8.58	2.16	6.92	3.29	3.61	1.01	0.05	0.07	1.31	17.42	0.10
RN360-FN3	52.61	8.51	2.27	6.84	3.03	3.14	1.08	0.14	0.06	1.35	18.21	N/A

Table 6.11: Chemical results (given in wt% oxides) of the two emerald green lead-silicate glasses from Ayla.

Sample	Li	Be	B	Sc	Ti	V	Cr	Ni	Co	Zn	As	Rb	Sr	Zr	Nb
8	11.6	1.3	52.8	3.0	323.4	21.7	55.0	55.5	5.7	1869.6	215.8	16.8	368.9	65.1	3.2

Sample	Ag	Sb	Cs	Ba	La	Ce	Pr	Ta	Au	Y	Bi	U	W	Mo	Nd	Sm	Eu
8	26.2	21.6	0.4	170.2	7.6	14.1	1.9	0.3	0.2	5.8	2.5	1.5	0.3	0.6	7.3	1.5	0.4

Sample	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Th
8	1.5	0.2	1.4	0.3	0.8	0.1	0.7	0.1	2.9	2.6

Table 6.12: Chemical results of the trace elements of Ayla sample No. 8, determined by LA-ICP-MS

[26] This allows a somewhat more reliable characterization of the lead-silicate glass present at Ayla (only one sample makes it difficult to generalize), and also demonstrates the possibility of comparing chemical data derived using different methods and/or at different laboratories (Knapp and Cherry 1994).

Sample	SiO2	Na2O	K2O	CaO	MgO	Al2O3	F2O3	TiO2	MnO	CuO	PbO2	SnO2
Raqqa (window)	28.48	0.39	0.52	0.35	0.15	1.67	0.34	0.15	-	0.82	66.07	0.23
Serçe Limanı (base)	32.71	0.30	0.49	0.24	0.40	1.76	0.31	0.20	0.01	0.82	65.40	0.01
Serçe Limanı (molar flask)	31.76	0.26	0.38	0.24	0.06	1.36	0.35	0.20	0.10	0.75	62.70	N/A
Serçe Limanı (molded)	34.66	0.33	0.49	0.24	0.06	1.58	0.27	0.20	0.01	0.87	64.20	0.05
Serçe Limanı (molded)	23.36	0.43	0.26	0.70	0.24	0.34	0.18	0.01	0.00	0.82	61.20	0.01
CMG (bowl)	29.49	0.25	0.59	0.65	0.08	1.55	0.24	0.20	0.01	0.44	73.90	0.02
CMG Heshbon (molar flask)	29.96	0.36	0.48	0.31	0.08	1.45	0.77	0.15	0.00	0.59	66.30	0.01

Table 6.13: Chemical results (given in wt% oxides) of 9th-11th century emerald green lead-silicate glasses from Raqqa (Henderson 2004: 444), the Serçe Limanı wreck (Brill 2009: 493, Table A-3), and the Corning Museum of Glass (CMG; Brill 1999b: 204, Table VII.U) which includes one sample from the site of Heshbon in Jordan.

Four emerald green lead-silicate glass fragments were found in the Serçe Limanı wreck (Brill 2009) and are very heavily leaded (with 61-65 wt% PbO_2 and only 30-35 wt% SiO_2), and all have extremely low levels of soda and lime, as well as low potash and magnesia contents that is more akin to mineral soda glasses (e.g., 0.4-0.5 wt% K_2O and 0.1-0.4 wt% MgO); alumina and iron levels are also lower than the Ayla samples. Three of these Serçe Limanı fragments (a vessel base and two mold-blown fragments, one of which is a rim fragment) have lead isotope ratios that are virtually identical to the composition of two green glazed ceramics from the wreck, while the fourth (a molar flask) has lead isotope ratios that are similar to bronze artifacts from the wreck; previous isotope studies suggest the lead from all these objects may derive from mining regions in Turkey or Iran (Barnes *et al.* 1986: 1-12; Brill 2009: 464). One emerald green glass fragment of a window was recovered from the 11th-12th century contexts of Tel Fukhkhar

at Raqqa (Henderson 2004: 444); this fragment is chemically very similar to the Serçe Limanı samples in terms of its very high lead and low silica, soda, lime, potash, and magnesia contents; the emerald green color likely comes from the addition of copper in the form of scrap bronze, as the high level of copper (0.82 wt% CuO) is associated with elevated zinc (0.2 wt% ZnO) and tin (0.2 wt% SnO). Two emerald green lead-silicate glass fragments from the collection of the Corning Museum of Glass have also been analyzed (one of these is from 9th-11th century CE Heshbon in Jordan), and again are similar to the Serçe Limanı and Raqqa glasses. The chemical results of these emerald green glasses, analyzed by Henderson and Brill, are given in Table 6.13.

Other examples of heavily leaded glasses include jewelry and small objects from medieval Russia and Eastern Europe, ca. 9th-13th century (Bezborodov 1975: 310-315); highly leaded glasses from China can be traced back to the Tang and Song dynasties, ca. 7th-13th centuries CE (Meiguang *et al.* 1991), and possibly to the Han dynasty as well (Brill 2009: 464); however, it should be noted that No. 8 does not have high levels of barium or potash that might link it to the many lead-barium-silica or the potash-lead-silica glasses of early China. Brill has suggested the 9th-13th century Islamic lead-silicate glasses might be "connected somehow with the emergence of a relatively uncommon, but readily recognizable, type of dark green glass occasionally found in stained glass windows in Germany and Austria that date from the 12th to early 13th centuries" (2009: 463). The chemistry of these medieval European windows is of interest in regards to the Ayla glasses, because the former have only 25-35% PbO_2 (much lower than the emerald-green samples in Table 6.13, but closer to the levels of the Ayla samples), "which appears to have been added to the ordinary potash:high-lime:silica glasses of the times" (Brill

2009: 464). It may be possible that the emerald green glasses from Ayla are a mixture of "regular" emerald green glass (of the type analyzed by Brill) with plant ash soda glass; possible reasons for this mixing could have been to extend the supply of the emerald green glass, or it could instead merely represent an different recipe of emerald green glass.

SUMMARY

Typological Summary

The majority of the diagnostic fragments sampled from Ayla come from vessels used for dining and drinking or for the *toilette* (Figure 6.26); these include bowls, beakers, and cups as well as bottles of both large and small sizes. The vessels are all of blown manufacture (except for one vessel that was likely cast and then cold-worked), produced by means of free blowing or alternatively through a combination of mold blowing and free blowing in order to produce a textured and decorative surface. The majority of the fragments are glasses on the blue-green color spectrum (Figure 6.27), most of these being aqua glasses resulting from the natural iron impurities of the raw materials or greenish yellow glasses resulting from close control of the furnace environment in order to manipulate the coloring effect of the natural iron content. The addition of metal oxides of manganese, copper, and cobalt were also used to produce colorless, purple, and deep blue glasses.

Most of the Ayla glass vessels are plain, although a variety of techniques were used to decorate the open vessels in particular. In addition to mold-blowing a honeycomb

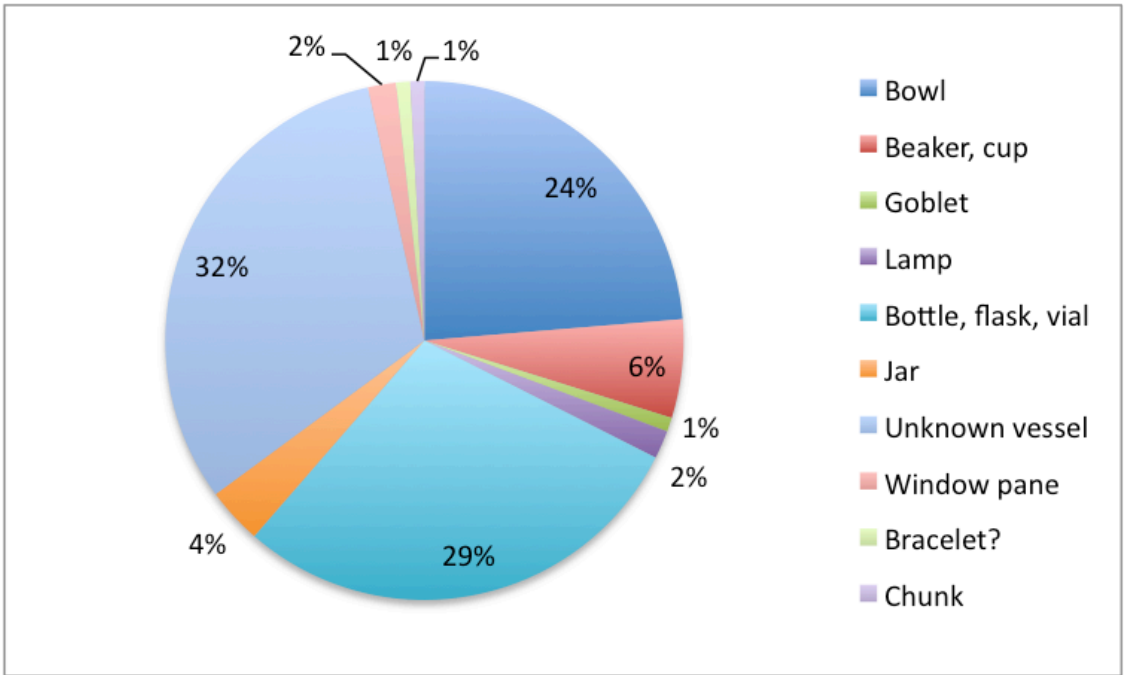

Figure 6.26: Pie charts showing the proportion of glass vessel types of the Ayla samples.

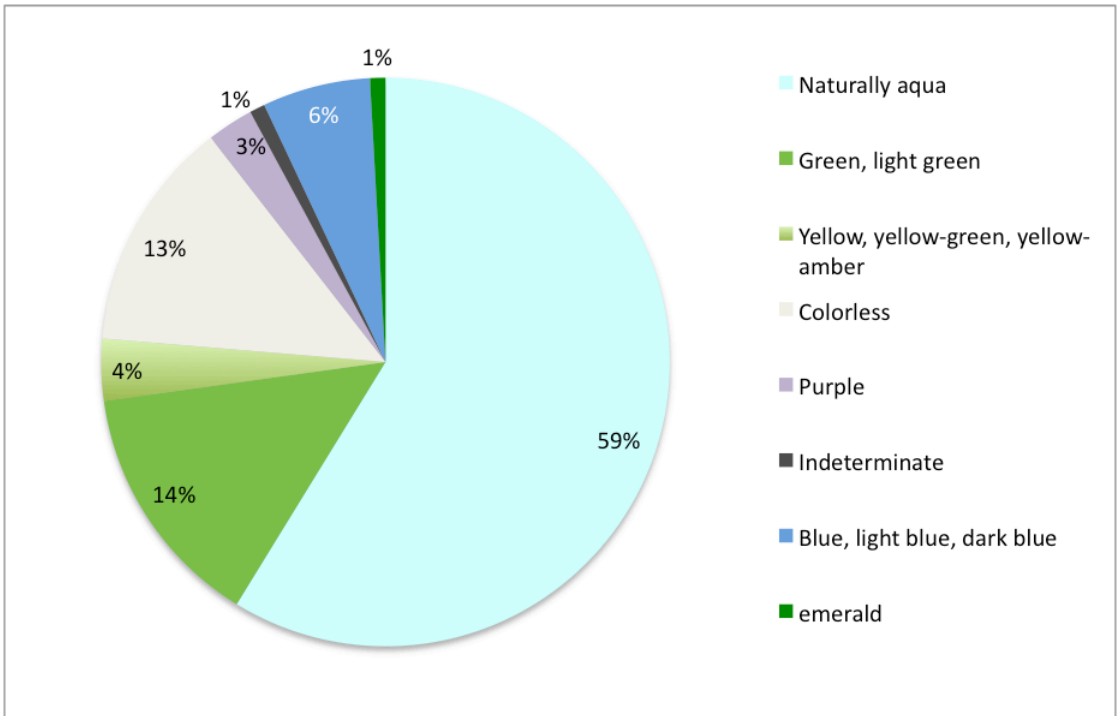

Figure 6.27: Pie charts showing the proportion of glass colors of the Ayla samples.

or ribbed pattern into the surface of the glass, impressing or tonging was employed to create a decorative and textured pattern for some of the beakers, bowls, and cups. The bottles, on the other hand, are typically plain and sometimes rather poorly shaped, often asymmetrical near the rim or shoulder of the vessel or have poorly finished lips; two exceptions to this include a bottle fragment with multiple thin aqua trails spiraled around the circumference of the neck and a bottle fragment of emerald green lead-silicate glass with facet cut decorations around the circumference of the neck. Marvered trailing was also used to decorate the rim of some of the bowls and cups, typically using a contrasting glass color like amber or deep blue on a naturally aqua-colored vessel. Perhaps the most intricate decorative technique was achieved through coldworking, by incising a geometric motif onto the body of a cylindrical beaker of cobalt blue or light green glass.

Chemical Summary

Both mineral soda and plant ash soda glasses are present in the Ayla sample set, and lead-silicate glasses are identifiable as well. The mineral soda glasses (78 samples) include five distinguishable groups that can be directly linked to the groups that have been characterized primarily by Freestone and his colleagues: Group 1 (with 5 samples, chemically-similar to the Egyptian I production group), Group 2 (30 samples, Egyptian II), Group 3 (17 samples, Levantine I), Group 4 (18 samples, Levantine II), and Group 5 (2 samples, HIMT). The plant ash soda glasses (33 samples) include three distinct groups: Group 6 (with 23 samples), Group 7 (6 samples including two outliers), and Group 8 (two samples); in addition to these three groups are two distinctive outliers, Nos. 10 and 116, which have quite different major, minor, and trace element characteristics.

Many of the glasses were naturally colored through the effects of iron impurities in the raw materials and manipulations of the furnace atmosphere; some fragments were turned a deep blue color by the addition of copper and cobalt, while purplish and colorless glasses were colored by adding certain amounts of manganese to the batch.

CHAPTER SEVEN: MIDDLE BYZANTINE AND EARLY ISLAMIC GLASS—A COMPARATIVE AND CONTEXTUAL DISCUSSION

INTRODUCTION

This chapter includes a comparative and contextual discussion of the Ḥiṣn al-Tīnāt and Ayla glass samples. In the first section, the current state of the field is highlighted, calling attention to the inherent importance of the data produced here. The typological and chemical observations that were outlined in Chapters 4, 5, and 6 are next summarized, with the different types of glass compared in terms of both chemical composition and object forms and styles. The two assemblages are then discussed in relation with published data from other sites within the larger Byzantine-Islamic Eastern Mediterranean region in order to make more specific observations about glass technology, production groups, and distribution patterns in this particular time and place. These observations are finally placed into a larger context by considering patterns of artistry, technology, and economy in the 8th-12th centuries CE and the specific histories of the respective archaeological sites.

GLASS FROM THE 8TH-12TH CENTURIES CE: STATE OF THE FIELD

The 8th-12th century CE is a period that is poorly characterized and understood in terms of its material culture, regardless of geographic region (e.g., Europe, Byzantium, or the Islamic world). Glass scholars have only recently attempted to address this issue, or at

least recognized the problems of Late Antique-Early Medieval glass scholarship. There is a very real need for archaeologically-derived data that is inclusive of all the glass that was being made and used in this period, rather than relying exclusively on interpretations that are based on the style of luxury glasses in museum collections (Keller 2010: 3).

The "great enigma" of Byzantine glass became especially apparent during the first half of the 20th century: "whole chapters have been written in glass histories on the subject, yet literally nothing is known" (Smith 1957: 190). Byzantine glass has been described as lacking "an established identity"[1] in that much of the glass from the Early Byzantine period (4th-7th centuries CE) is virtually identical to both Late Roman and Early Islamic glass, while medieval Byzantine glass (8th-12th centuries CE) has barely been studied at all (Henderson and Mango 1995: 333). These problems stem from a paucity of data, so "only the publication of stratigraphic excavations will flesh out the history of glass in the Byzantine world" (Lightfoot and Ivison 2002: 259). This is especially true for the Middle Byzantine period in Anatolia; in his summary of the state of research of Byzantine glass, included as the introduction to the recent volume *Glaz in Byzanz*, Daniel Keller notes that what little scholarship there is emphasizes the Early Byzantine period.[2] The publication of the finds from a major Byzantine site such as Amorium is an invaluable step towards resolving this issue; it is truly no exaggeration for

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[1] In 1908 German art historian Anton Kisa went so far as to say that this is because the Byzantines did not actually have a glass industry of their own (Keller 2010: 1).

[2] "The chronology of glass presented in this volume ranges from the beginning of the Byzantine period in the 4th century almost to the end of the Byzantine Empire. However, the focus is on glass from the Early Byzantine period from the 4th to the 7th/8th centuries. This reflects the state of research on Byzantine glass in the past and at present, but it is hoped that this volume with initiate further studies on the subject" (Keller 2010: 13).

the excavators of this site to write that "of this material the post-7th century glass is, without doubt, the most significant for scholarship" (Lightfoot and Ivison 2002: 259).

Early Islamic glass has also had had problems of scholarship. Because the glass industry continued to operate relatively uninterrupted after the Arab conquest of the Levant, a specifically "Umayyad" glass is particularly difficult to identify—being in effect a continuation of the glass that was already being made and used in the region. As a result, dividing glass that dates to the 7th-8th centuries by the labels "Early Byzantine" and "Umayyad" is somewhat artificial; it is becoming increasingly common to discuss the two together as "Byzanto-Umayyad" glass. Glass of the later 'Abbāsid and Fāṭimid periods (the 9th-12th centuries CE) is more distinctive in characteristics of style and methods of decoration. However, while this is true for some glasses, changes in utilitarian wares continue to be nearly impossible to distinguish simply because basic shapes and forming techniques remained the same over long periods of time.

A great difficulty for traditional art historical analysis of 8th-12th century CE glass is that in this moment of history, glass products could look very similar across different regions—part of this is a result of the sheer scale of the glass trade, but the properties of glass as a material and a history of shared techniques, tastes, and aesthetics come into play as well. For example, regarding Early Byzantine glass, "a kind of *koiné* seems to have enveloped the whole Mediterranean area with forms of glass […] being present in all areas, even if displaying a number of regional particularities" (Saguí 2007: 221). Similarly for Early Islamic glass, "80% or more of vessel shapes and decorative patterns are identical in Egypt, Syria, Iraq, and Iran, and only rarely are local peculiarities noticeable" (von Saldern 1995: 225). Moreover, for Islamic glass there is no "convincing

chronological sequence of various series of decorated glass from the 8th to the 12th century […] likewise the places of manufacture of these groups are still mostly left in the dark" (von Saldern 1995: 233).

It is within this scholarly context that the findings of this project make their mark. Finds from secure archaeological contexts, including fragments of "mundane" utilitarian vessels as well as the more diagnostic decorated vessels and jewelry, can fill in the gaps of our knowledge about the glass that was made and used during the 8th-12th centuries CE in the Eastern Mediterranean. Moreover, the typological and chemical analysis of these fragments can help address larger technological issues such as the experimentation and stabilization of glass production, artistic issues such as the changing aesthetics and taste of glass objects, economic issues such as the movement of finished goods and raw materials, and issues of cultural interactions between neighboring political entities.

GLASS FROM ḤIṢN AL-TĪNĀT AND AYLA: A COMPARISON OF THE DATA

In the previous three chapters, the results of both typological and a chemical analyses of glass artifacts from Ḥiṣn al-Tīnāt and Ayla were discussed at length in order to provide a much needed, detailed case study of 8th-12th century CE glass in the Eastern Mediterranean region. The majority of the fragments examined derive from vessels, which were discussed as individual chapters for each site; a small group of glass bracelets excavated at Ḥiṣn al-Tīnāt proved to be significant enough to merit a separate chapter.

While the results of these analyses are interesting in their own right, combining the typological and chemical results within the sites and then comparing the two assemblages makes the data more meaningful for the larger questions of Late Antique-Early Medieval glass production. This is especially important for the plant ash soda

glasses because there are no previously identified and chemically distinct primary production zones for these, as there are for mineral soda glasses (e.g., the Egyptian I, Egyptian II, Levantine I, Levantine II, and HIMT groups). In addition, comparing contemporary glass from sites with significantly different histories of political affiliation (i.e., Byzantine or Islamic) provides insight into the "nature and culture" of glass during this period of history.

A Summary of the Findings

A close typological comparison of the glass vessels from Ḥiṣn al-Tīnāt and Ayla is somewhat less straightforward than might be desirable, simply because the two samples sets were chosen under very different circumstances and using different parameters: every fragment from Ḥiṣn al-Tīnāt was examined and some 67% of the total assemblage was sampled for this project; in contrast, only a small fraction of glass from Ayla was even seen, and a comparatively very small selection of samples was made.[3] Because of this, it is not realistic to make absolute statements about the differences between the two assemblages, although it is still reasonable to highlight and contrast the characteristics of the vessels present at each site and to hypothesize about the broader implications.

The vast majority of the glass sampled from the two sites is on the blue-green color spectrum, with more than 50% of the vessels of naturally aqua-colored glass. Although a large part of this is due to intentional sample selection (as uncolored samples

[3] As outlined in Chapter 3, the glass samples from Ayla were chosen based upon the suggestions of Donald Whitcomb and Carol Meyer, who helped isolate the most promising loci for study. The 114 fragments that were sampled for this study are certainly not representative of the total assemblage.

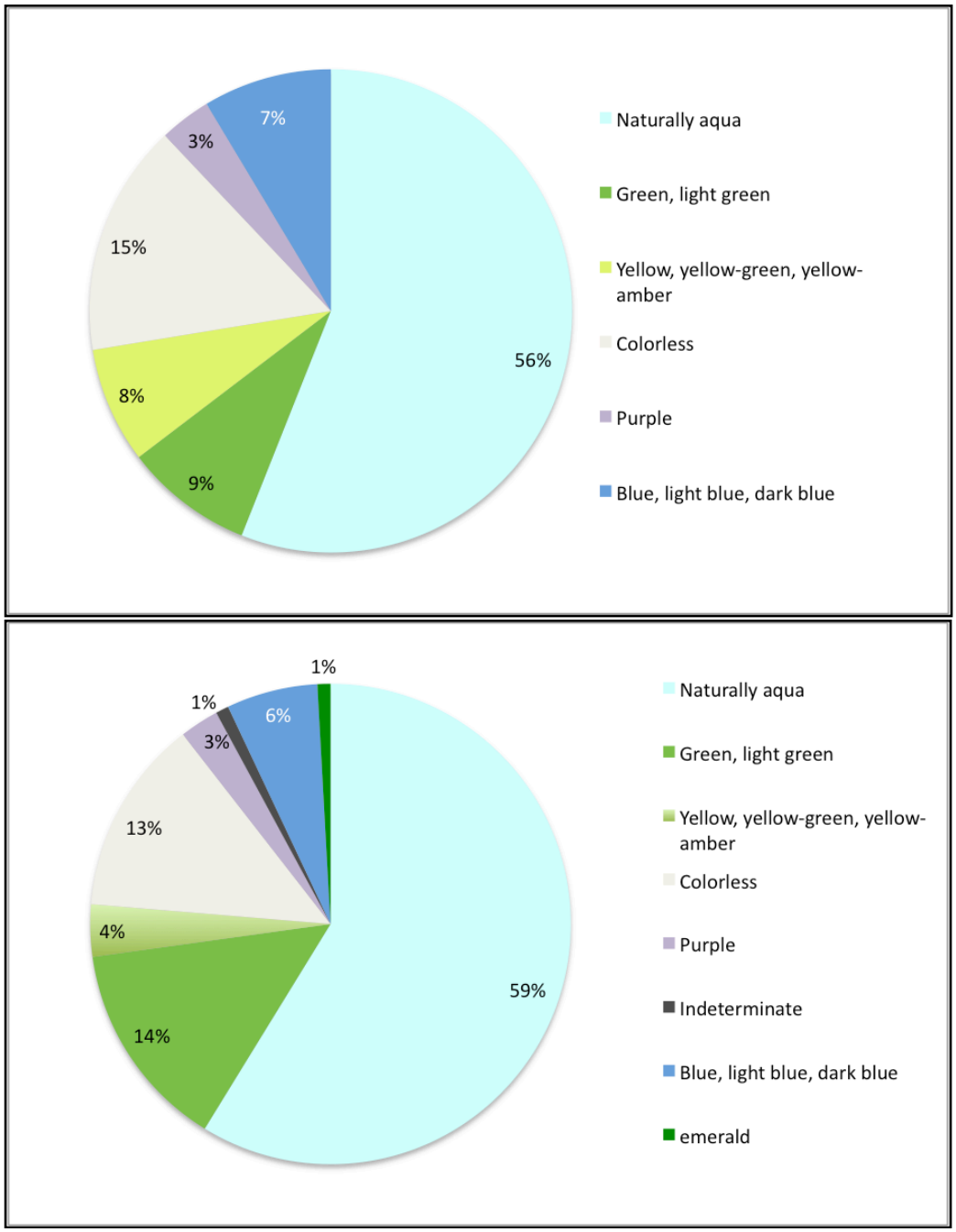

Figure 7.1: Comparison of the relative abundance of various glass colors present in the samples taken from Ḥiṣn al-Tīnāt (top) and Ayla (bottom).

were preferentially chosen in order to avoid potential problems of comparing bulk chemical data with highly colored glasses), it is no coincidence that the color proportions of the glass from the two sites looks very similar (Figure 7.1)—this reflects the most

common color of glass at these two sites as well as the most common color in general for glass made after the 4th century CE. More greenish hues (green, light green, yellow-green) and decolorized (colorless, colorless-yellow, nearly colorless) glasses are also common; blues and purples are less frequent but characteristic of both sample sets. Although the potential for misleading contrasts was cautioned above, it should still be noted that the entire glass assemblage from Ayla does appear to have a larger amount of strongly-colored glasses (including deep amber-brown and green vessels as well as the emerald green fragments) than Ḥiṣn al-Tīnāt, as well as more abundant colorless/nearly colorless glasses.

The principal manufacturing technique for both sites is free-blowing, but there are examples of mold-blowing in each assemblage as well. Most of the fragments in the sample sets come from relatively plain vessels, although some decorated fragments were intentionally included, as these are often more diagnostic and thus helpful for understanding chronology. The glass from Ḥiṣn al-Tīnāt included vessels decorated with colored blobs, nipped fins, tonged/pincered designs, mold-blown patterns, and mold-blown "faux-faceted" shapes; luxury bottles included dark blue glass decorated with opaque white festoons (spear flask No. 225) and colorless facet-cut glass (molar bottle KNH23501). The glass from Ayla included vessels with applied threads, mold-blown patterns, tonging/pincering, and pulled toes; there were few luxury vessels sampled, except for a facet-cut emerald green bottle (No. 8). The form and function of the objects from both sites include a variety of bowls, cups, and beakers in addition to various bottles; some lamps and windowpanes from Ayla were also sampled for any variation in glass chemistry between different classes of objects.

The distinction between imports and local products is a difficult question to address adequately. To some extent, all the glass objects at both Ḥiṣn al-Tīnāt and Ayla were probably imports in the sense that no primary or secondary glass production evidence has yet been found at either site or in the near vicinity (no furnaces, raw glass,[4] moils, wasters, or other debris); combine with this the fact that both sites were trading centers and ports, and the importation of glass vessels is a sensible conclusion. However, this does not mean that glass objects necessarily traveled very long distances; large urban centers in Syria like Antioch, Aleppo, and Raqqa were not far from Ḥiṣn al-Tīnāt, the latter of which was indeed producing glass in the 8th-12th centuries CE. Ayla, too, was not extraordinarily far from known glass-producing centers such as Fusṭāṭ; Ayla herself had a thriving ceramics production industry during the Byzantine and Islamic periods, so it may be that glass was also being locally produced, but has not yet been identified archaeologically.[5]

The question of imports can be addressed by the typology and/or chemistry of particular fragments; by far the clearest example of this is sample No. 225 from Ḥiṣn al-Tīnāt. This sample is a dark blue and white marvered "spear flask" that would have been used as a container for cosmetics, based on parallel examples that have been found together with their metal applicator rods. Typological and chronological analysis places the production of these items firmly in the Islamic regions (Jerusalem, Damascus, and

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[4] I described one fragment from Ayla (sample No. 81) as a "chunk" because of its irregularity and thickness; without a more thorough look at the entire assemblage it is difficult to say whether this has any production significance. No. 81 is part of Ayla Group 4 (similar to Levantine II glass). The excavation locus is an undated dump context.

[5] Janet Duncan Jones has recently analyzed the Roman and Early Byzantine glass from Aila, and suggested to me the possibility of local glass production based on the number of finds and the contemporary local ceramics industry.

Fusṭāṭ being the most likely origin for production) during the 10th-12th centuries CE, while chemical analysis repeatedly found this fragment to be the extreme outlier among the rest of the data. The dating and outlier status of sample No. 225 is significant when it is remembered that the region around Ḥiṣn al-Tīnāt was under Byzantine control at the time, so this is clear evidence that trade across political borders was at times taking place.

The glass bracelets from Ḥiṣn al-Tīnāt were an unexpected surprise among the glass finds from this site, and were included in the study because of their potential to contrast "decorative glass" (i.e., objects of personal adornment) with strictly utilitarian vessel glass. These bracelets proved to be some of the most interesting artifacts as well, because they demonstrate that such objects were often *not* made with the same glass used for producing vessels in the region; moreover, two unique and highly distinctive glass chemical types that are rarely found in the published literature were identified by analyzing the bracelets (see below).

The chemical results are in many ways the most significant contribution of this project. As mentioned previously, because the samples that were selected from Ayla cannot be considered representative of the entire assemblage, it is somewhat precarious to make statements about the presence/absence of various vessel types and decorative techniques—however, there is much more room to make broad statements about the glass as a material. The chemical data illustrates some fascinating similarities and differences in terms of both the glass chemical types and number of different types present at the two sites (Tables 7.1 and 7.2). The evidence from Ḥiṣn al-Tīnāt shows that three types of glass made with mineral soda were in use (Ḥiṣn Groups 1-3), which correspond to three of the five different Near Eastern production groups identified by Freestone and

colleagues: Egyptian II, Levantine I, and Levantine II. Ayla, on the other hand, has evidence for *all five* of Freestone *et al.*'s observed groups (Ayla Groups 1-5): Egyptian I and II, Levantine I and II, as well as HIMT. Since a representative sample of all of the Ḥiṣn al-Tīnāt glass fragments that were recovered from the site were subject to chemical analysis, this pattern of absence is probably not a random effect of sample selection and is definitely worth highlighting and discussing.[6]

Group	Count	Correlation	Flux
Ḥiṣn 1	27	Egyptian II	Mineral soda
Ḥiṣn 2	12	Levantine I	Mineral soda
Ḥiṣn 3	10	Levantine II	Mineral soda
Ayla 1	5	Egyptian I	Mineral soda
Ayla 2	30	Egyptian II	Mineral soda
Ayla 3	16	Levantine I	Mineral soda
Ayla 4	24	Levantine II	Mineral soda
Ayla 5	2	HIMT	Mineral soda
Ḥiṣn 4	33	Ḥiṣn A, Ayla 6	Plant ash soda
Ḥiṣn 5	15	-	Plant ash soda
Ḥiṣn outliers	16	-	Plant ash soda
Ḥiṣn A	4	Ḥiṣn 4, Ayla 6	Plant ash soda
Ḥiṣn B	5	High boron glasses	Plant ash soda
Ḥiṣn C	6	High boron, high alumina glasses	Plant ash soda
Ayla 6	23	Ḥiṣn 4, Ḥiṣn A	Plant ash soda
Ayla 7	6	-	Plant ash soda
Ayla 8	2	-	Plant ash soda
Ayla outliers	2	-	Plant ash soda
Ayla No. 8	1	Lead-silicate glasses	Lead-oxide

Table 7.1: Summary of the technological groups defined by means of chemical analysis.

[6] If the reverse situation were true and the Ayla glasses had comparatively fewer of the known mineral soda groups, then it could possibly be put down to the random sample selection process.

Table 7.2: Summary of the average major/minor chemical composition (in wt% oxide) and standard deviation (σ) of the <u>mineral soda glasses</u> (above) and <u>plant ash soda glasses</u> (below) from Ḥiṣn al-Tīnāt and Ayla.

Oxides	SiO2	Na2O	K2O	CaO	MgO	Al2O3	Fe2O3	TiO2	MnO	P2O3	CuO	CoO	PbO2	Sb2O5	SnO2
Egyptian I type mineral soda glass															
Ayla 1	**70.49**	**17.91**	**0.56**	**3.59**	**0.93**	**4.02**	**1.68**	**0.30**	**0.05**	**0.13**	**0.01**	**0.00**	**0.00**	**0.00**	**0.00**
σ	0.54	1.52	0.21	0.26	0.19	0.53	0.49	0.08	0.01	0.07	0.01	0.00	0.00	0.00	0.00
Egyptian II type mineral soda glasses															
Ḥiṣn 1	**70.67**	**14.86**	**0.29**	**9.51**	**0.54**	**2.34**	**0.88**	**0.09**	**0.17**	**0.08**	**0.01**	**0.01**	**0.00**	**0.00**	**0.00**
σ	1.54	1.02	0.09	1.10	0.10	0.26	0.17	0.02	0.42	0.02	0.05	0.03	0.01	0.00	0.00
Ayla 2	**70.06**	**14.69**	**0.34**	**9.87**	**0.65**	**2.59**	**0.98**	**0.12**	**0.13**	**0.10**	**0.01**	**0.00**	**0.02**	**0.00**	**0.00**
σ	1.53	1.37	0.11	0.78	0.14	0.45	0.21	0.04	0.32	0.05	0.04	0.02	0.05	0.00	0.00
Levantine I type mineral soda glasses															
Ḥiṣn 2	**71.22**	**14.80**	**0.55**	**8.79**	**0.59**	**2.98**	**0.46**	**0.03**	**0.03**	**0.10**	**0.01**	**0.00**	**0.00**	**0.00**	**0.00**
σ	0.77	1.07	0.05	0.97	0.11	0.24	0.09	0.01	0.01	0.02	0.02	0.00	0.00	0.00	0.00
Ayla 3	**68.85**	**15.42**	**0.78**	**9.43**	**0.65**	**3.18**	**0.56**	**0.04**	**0.24**	**0.11**	**0.01**	**0.00**	**0.21**	**0.00**	**0.00**
	1.76	1.88	0.32	0.87	0.07	0.40	0.19	0.02	0.49	0.06	0.02	0.00	0.74	0.00	0.01
Levantine II type mineral soda glasses															
Ḥiṣn 3	**73.85**	**13.13**	**0.51**	**7.96**	**0.55**	**2.93**	**0.45**	**0.03**	**0.03**	**0.09**	**0.00**	**0.00**	**0.01**	**0.00**	**0.00**
σ	0.72	0.72	0.09	0.74	0.10	0.21	0.06	0.01	0.01	0.02	0.00	0.00	0.01	0.00	0.00
Ayla 4	**74.33**	**13.62**	**0.55**	**6.74**	**0.55**	**3.17**	**0.52**	**0.04**	**0.02**	**0.05**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
σ	0.81	0.96	0.11	0.49	0.08	0.26	0.09	0.02	0.00	0.02	0.00	0.00	0.00	0.00	0.00
HIMT type mineral soda glasses															
Ayla 5	**67.18**	**16.76**	**0.42**	**5.54**	**1.12**	**3.20**	**3.18**	**0.23**	**1.76**	**0.10**	**0.01**	**0.00**	**0.00**	**0.00**	**0.00**
σ	1.22	0.10	0.05	0.08	0.36	0.62	0.45	0.10	0.30	0.06	0.00	0.00	0.00	0.00	0.00

Oxides	SiO2	Na2O	K2O	CaO	MgO	Al2O3	Fe2O3	TiO2	MnO	P2O3	CuO	CoO	PbO2	Sb2O5	SnO2	B2O3
Ḥiṣn 4	**67.74**	**12.56**	**2.38**	**10.18**	**2.94**	**1.87**	**0.51**	**0.04**	**0.96**	**0.29**	**0.11**	**0.00**	**0.02**	**0.00**	**0.00**	**-**
σ	1.42	0.86	0.25	0.79	0.42	0.20	0.12	0.01	0.47	0.06	0.43	0.00	0.05	0.00	0.01	-
Ḥiṣn 5	**66.54**	**13.49**	**2.20**	**10.63**	**3.34**	**1.64**	**0.59**	**0.04**	**0.83**	**0.29**	**0.03**	**0.00**	**0.04**	**0.00**	**0.01**	**-**
σ	1.13	0.95%	0.11	1.22	0.16	0.28	0.10	0.01	0.20	0.04	0.03	0.01	0.08	0.00	0.01	-
Ayla 6	**68.77**	**13.02**	**2.40**	**8.66**	**2.94**	**1.93**	**0.59**	**0.04**	**1.01**	**0.33**	**0.01**	**0.00**	**0.04**	**0.00**	**0.00**	**-**
σ	1.78	0.61	0.32	1.12	0.45	0.43	0.18	0.01	0.40	0.09	0.01	0.00	0.09	0.00	0.00	-
Ayla 7	**63.88**	**15.41**	**2.63**	**8.15**	**4.44**	**2.59**	**1.38**	**0.07**	**0.71**	**0.33**	**0.07**	**0.03**	**0.02**	**0.00**	**0.01**	**-**
σ	4.04	2.22	0.58	1.39	1.04	0.66	0.87	0.02	0.21	0.13	0.28	0.05	0.01	0.00	0.01	-
Ayla 8	**71.51**	**12.65**	**2.32**	**6.20**	**5.29**	**1.19**	**0.37**	**0.02**	**0.43**	**0.04**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**-**
σ	4.89	2.05	0.59	1.13	0.98	0.14	0.02	0.01	0.06	0.05	0.00	0.00	0.00	0.00	0.00	-
Ḥiṣn A	**69.44**	**11.66**	**2.48**	**9.06**	**2.41**	**1.71**	**0.65**	**0.04**	**0.97**	**0.35**	**0.46**	**0.00**	**0.25**	**0.00**	**0.10**	**0.02**
σ	1.26	0.38	0.25	1.39	0.42	0.46	0.08	1.65	0.79	0.04	0.80	0.03	0.48	0.00	0.21	0.00
Ḥiṣn B	**63.97**	**14.50**	**1.61**	**11.92**	**2.74**	**2.72**	**2.25**	**0.06**	**0.05**	**0.10**	**0.00**	**0.00**	**0.00**	**0.01**	**0.00**	**0.78**
σ	1.69	0.97	0.11	0.72	0.11	0.18	0.45	0.90	0.01	0.02	0.00	0.01	0.00	0.00	0.00	0.07
Ḥiṣn C	**54.77**	**19.88**	**4.07**	**5.04**	**4.09**	**9.93**	**1.53**	**0.07**	**0.09**	**0.23**	**0.10**	**0.06**	**0.01**	**0.00**	**0.00**	**0.54**
σ	2.62	0.75	0.24	1.72	1.45	0.52	0.06	1.73	0.04	0.04	0.03	1.92	0.00	0.00	0.00	0.12

The vessels from Ḥiṣn al-Tīnāt showed evidence of three chemical groups of glass made using plant ash soda rather than mineral soda as the alkali fluxing agent; two of these groups (Ḥiṣn Group 4 and Group 5) appear to be somewhat related but differ slightly in terms of their trace element compositions—including in particular Sr, Zr, Ba, Ti, La, Cr—while a loose group of outliers were also distinguished but warrant closer inspection and subdivision in the future. The bracelet fragments (Ḥiṣn Group A) are also plant ash soda glasses, with one group that appears to be somewhat similar in composition to Ḥiṣn Group 4. At Ayla, too, there were three compositionally distinct groups of glasses made using plant ash soda (Ayla Group 6-8), as well as two outlier fragments distinct from the rest and probably representing different raw material sources. Overall Ḥiṣn Group 4, Ayla Group 6, and Ḥiṣn bracelet Group A appear to be similar enough perhaps to be considered the same technological group, or at least as being made using very similar quartzes and/or plant types.

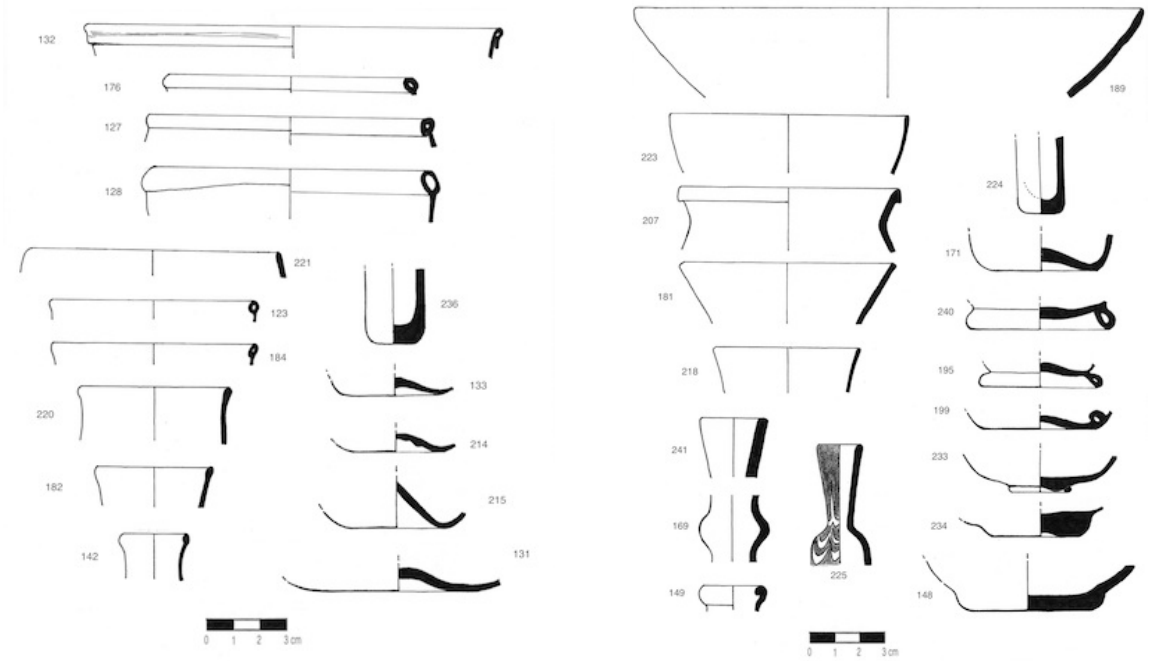
Three further chemical groups were entirely unexpected and are an exciting discovery. These include the high boron glasses (Group B) and the high alumina-high boron glasses (Group C) made using plant ash soda that were identified when analyzing bracelet fragments from Ḥiṣn al-Tīnāt, and the lead-silicate glasses that were identified when analyzing emerald green vessel fragments from Ayla. Although lead-silicate glasses are by no means as common as soda-lime-silica glass in the ancient or medieval periods, they are typically easier to identify visually because of their brilliant emerald-green hue, and this technological type has been acknowledged and characterized in published scholarship. Contrary to this, the bracelets from Ḥiṣn al-Tīnāt give evidence for *new chemical types* of glass, ones that have not been identified in previous studies of

Middle Byzantine and Early Islamic glass or included in the usual discussions of glassmaking technology and change in the post-Roman world. Thus, it is not an understatement to state they are perhaps the most important objects in this study.

Although the Kinet Höyuk fragments are by no means a main focus of this project and have figured only slightly into discussions of the data, their characteristics do provide an interesting diachronic glimpse into medieval glass, illustrating the relationship of glass dating to the 12th-14th centuries CE to that of the preceding period at virtually the same site. Typologically, the fragments clearly indicate that the use of glass and taste was again changing: large, tall, and deep beakers with straight walls were in fashion, and these could be decorated with simple trails of glass like the examples from Kinet Höyük or elaborately gilded and enameled like contemporary examples from Hama (Riis and Poulsen 1957). Chemically, however, these glasses continue the tradition of the 10th-12th century CE plant ash soda glasses from both Ḥiṣn al-Tīnāt and Ayla; mineral soda was increasingly replaced by vegetal ash soda—plant ash soda became the standard flux used in the Islamic world while wood ash fluxes were increasingly being employed by contemporary glassmakers in Western Europe.

Discussion of the Findings

The forms, decorations, and fabric color of the objects recovered from Ḥiṣn al-Tīnāt and Ayla subtly changed over the course of the 8th-12th centuries CE. These details are more distinctive when typo-chronological observations are combined with the results of chemical analysis. In particular, the diagnostic fragments illustrated in the previous chapters can be divided into the mineral soda and plant ash soda groups (Figures 7.2-7.4),



Figures 7.2: The Ḥiṣn al-Tīnāt diagnostic fragments: (left) vessel rims and bases made from <u>mineral soda glass</u>, and (right) vessel rims and bases made from <u>plant ash soda glass</u>.

bringing stylistic trends into shaper focus. The mineral soda group from Ḥiṣn al-Tīnāt includes all the vessels with rolled rims as well as most of the pushed-in bottle bases, while the plant ash soda group from Ḥiṣn al-Tīnāt includes the tubular base rings, thickened pad bases, trail-wound bases, and the "bubble" bottles (bubble necks and bubble rims); both chemical groups include wide-mouthed bottles/flasks and the bases of small squared bottles, although small funnel-necked flasks seem to be more common amongst the plant ash soda group. Naturally aqua-colored and light green glass dominates the mineral soda glasses while more colorless, purple, and strong colors like blue fragments are among the plant ash soda glasses.

As at Ḥiṣn al-Tīnāt, the mineral soda glasses from Ayla include vessels with rolled or folded rims, as well as bowls/cups/beakers with both slightly everted and slightly inverted rims. At Ayla, however, there is also a type of large deep bowl with

vertical walls. Small bottles with thickened lips, vessels with a tubular ring-base, and the two lamp stems were also made with mineral soda glass. Bottles, including large carboy-type vessels as well as small containers, were made from both types of glass; the plant ash soda bottles often seem to have wider necks in comparison to their counterparts made with mineral soda glass. Again, in terms of color, naturally aqua colored and light green glass dominates the mineral soda glasses while colorless and purple are more common for the plant ash soda glasses. Strong colors were made with both mineral and plant ash soda glasses, and with lead-silicate glass in the case of the deep emerald green fragments.

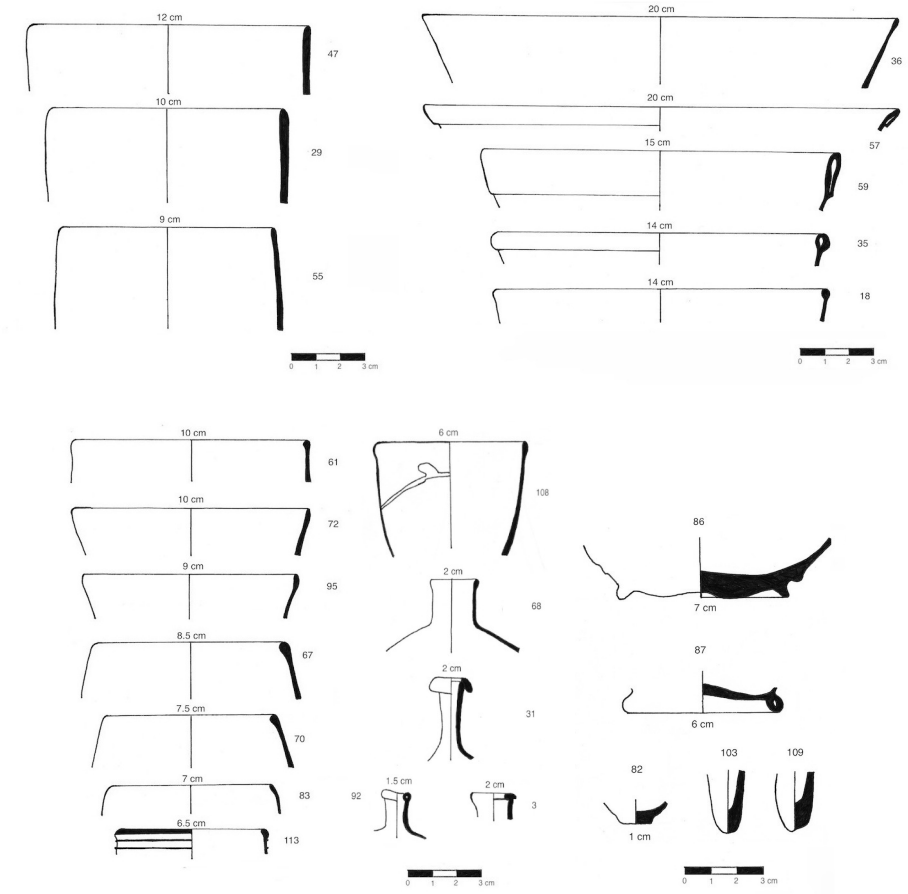


Figure 7.3: The Ayla diagnostic fragments: rims and bases made from <u>mineral soda glass</u>.

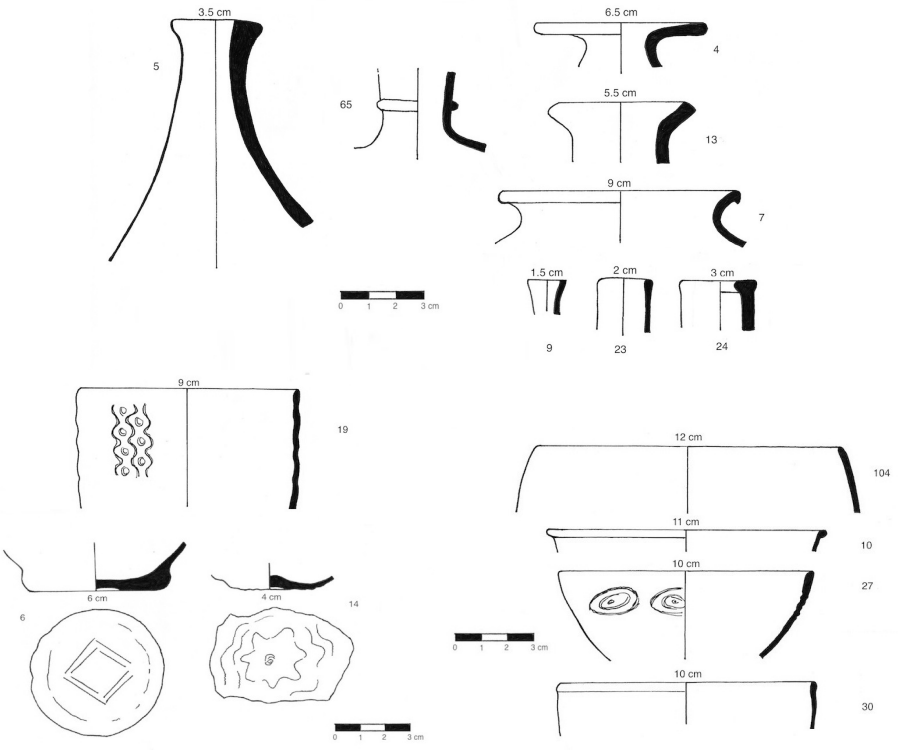


Figure 7.4: The Ayla diagnostic fragments: rims and bases made from <u>plant ash soda glass</u>.

The chronology of the diagnostic fragments illustrated in Figures 7.2-7.4 and in Tables 7.3-7.4 is quite telling: a very large number of the mineral soda glasses come from loci dated by means of ceramic analysis to the 10th century CE, while a great many of the plant ash soda glasses come from contexts dated to the 11th-12th centuries CE.[7] The archaeological contexts alone suggest that mineral soda glasses were made and used into the 10th century CE and thus continued alongside the production of glass that was made using the newly emerging plant ash soda technology. This would slightly modify our chronological-technological understanding about the change from mineral soda to plant

[7] Some of the find contexts of the mineral soda glasses are broadly dated to "the mid-10th-mid-11th centuries CE" or to "the 10th-12th centuries CE," while some plant ash soda glass contexts broadly date to "the 10th-12th centuries CE."

Sample	Color	Decoration	Group	Flux	Date of context
No. 135	Colorless	Purple blob	Ḥiṣn Group 1 (Egyptian II)	Mineral	~10th c. CE
No. 194	Colorless	Yellow blob	Ḥiṣn Group 3 (Levantine II)	Mineral	?
No. 131	Natrl. aqua	Mold-blown	Ḥiṣn Group 3 (Levantine II)	Mineral	~10th c. CE
No. 193	Y-Green	Mold-blown	Ḥiṣn Group 3 (Levantine II)	Mineral	?
No. 196	Natrl. aqua	Nipped fin	Ḥiṣn Group 3 (Levantine II)	Mineral	~10th c. CE
No. 145	Natrl. aqua	Nipped fin	Ḥiṣn Group 2 (Levantine I)	Mineral	11th-12th c. CE
No. 16	Dk. Blue	Incised/scratched	Ayla Group 2 (Egyptian II)	Mineral	10th c. CE
No. 41	Dk. Blue	Incised/scratched	Ayla Group 2 (Egyptian II)	Mineral	?
No. 89	Lt. Green	Incised/scratched	Ayla Group 2 (Egyptian II)	Mineral	9th c. CE
No. 12	Colorless	Tonged/pincered	Ayla Group 2 (Egyptian II)	Mineral	11th c. CE
No. 86	Natrl. aqua	Pulled toes	Ayla Group 2 (Egyptian II)	Mineral	Umayyad?
No. 101	Natrl. aqua	Applied threads	Ayla Group 3 (Levantine I)	Mineral	?
No. 84	Aqua/olive	Marvered thread	Ayla Group 3 (Levantine I)	Mineral	Umayyad?
No. 113	Aqua/blue	Marvered thread	Ayla Group 3 (Levantine I)	Mineral	Umayyad?
No. 73	Natrl. aqua	Ribbon trail	Ayla Group 4 (Levantine II)	Mineral	?

Table 7.3: Decorated fragments of mineral soda glass from Ḥiṣn al-Tīnāt and Ayla, grouped by decorative technique and compositional groups.

Sample	Color	Decoration	Group	Flux	Date of context
No. 158	Colorless	Mold-blown	Ḥiṣn Group 4	Plant ash	10th-12th c. CE
No. 161	Colorless	Bossed	Ḥiṣn Group 4	Plant ash	?
No. 212	Lt. blue	Bossed	Ḥiṣn Group 4	Plant ash	?
No. 208	Purple	Mold-blown	Ḥiṣn Group 4	Plant ash	11th-12th c. CE
No. 171	Colorless	Mold-blown	Ḥiṣn Group 5	Plant ash	10th-12th c. CE
No. 165	Natrl. aqua	Tooled trails	Ḥiṣn Group 5	Plant ash	10th-12th c. CE
No. 168	Natrl. aqua	Tonged/pincered	Ḥiṣn Group 5	Plant ash	10th-12th c. CE
No. 202	Colorless	Tonged/pincered	Ḥiṣn Group 5	Plant ash	11th-12th c. CE
No. 164	Colorless	Tonged/pincered	Ḥiṣn outliers	Plant ash	?
No. 211	Dk. blue	Plain	Ḥiṣn outliers	Plant ash	?
No. 225	Blue/white	Combed/marvered	Ḥiṣn outliers	Plant ash	10th-12th c. CE
No. 27	Colorless	Tonged/pincered	Ayla Group 6	Plant ash	?
No. 14	Colorless	Mold-blown	Ayla Group 6	Plant ash	?
No. 19	Dk. aqua	Mold-blown	Ayla Group 6	Plant ash	10th c. CE
No. 28	Natrl. aqua	Mold-blown	Ayla Group 6	Plant ash	10th c. CE

Table 7.4: Decorated fragments of plant ash soda glass from Ḥiṣn al-Tīnāt and Ayla, grouped by decorative technique and compositional groups.

ash soda that began to take place in the mid-9th century CE—the process of implementing new raw material choices into glassmaking practice was slow and subtle rather than immediate and abrupt, and the 10th century CE in particular appears to be a time of overlapping production until the stabilization and succession of the plant ash soda glass technology in the 11th century CE.

The "compositions of glasses found on consumer sites should closely resemble those of the major primary glass suppliers, rather than producing [secondary] workshop-specific fingerprints" (Freestone *et al.* 2002b: 258). While the raw glasses used to make the glasses at Ḥiṣn al-Tīnāt and Ayla came from the Levant and Egypt, it would be a mistake to assume that all vessels made using Levantine II mineral soda type glass (for example) were formed in secondary workshops also located in the Levant, as this raw glass type is known to have widely circulated. However, it might be appropriate to say that all vessels made with Egyptian I mineral soda type glass *were* indeed made in Egypt, as this chemical type appears to have been extremely restricted in its circulation. In addition, two of the plant ash soda glass types used to make the bracelets found at Ḥiṣn al-Tīnāt were likely made in the Balkans or Anatolia, and in at least the case of the painted bracelet examples there is a very close correlation between object typology and chemical composition, as the closest typological parallels come from Bulgaria. In short, while style might have regional affinities and fabric does less so—as raw glass was shipped around the Mediterranean for use in secondary workshops—it appear that some fabrics may indeed have had significant regional and/or typological affinities. The question of which fabrics (and reasons for why these particular fabrics) have such affinities but not others remains to be addressed.

While it may be an impossible task to pinpoint the location of secondary workshops that produced the glass vessels found on the two sites, in the previous chapters it was observed that certain vessel forms and styles of decoration do appear to show regional affinities (Tables 7.3 and 7.4). Again, while it is perhaps not prudent to make statements about what the assemblage from Ayla is missing in comparison to Ḥiṣn al-

Tīnāt because of sampling differences, it may make sense to do the opposite because virtually all the excavated fragments from Ḥiṣn al-Tīnāt have been examined. Perhaps the most conspicuous difference between the two sites is the lack of incised/scratch-decorated vessels (Ayla samples Nos. 16, 41, and 89) among the finds at Ḥiṣn al-Tīnāt. Ḥiṣn al-Tīnāt clearly imported finished glass items from the Islamic lands (e.g., marvered flask No. 225 and the molar flask KNH23501), at least on occasion. As scratch-decorated vessels were typically ʻAbbāsid period products, the absence of these types of vessels is potentially significant because Ḥiṣn al-Tīnāt was located within Islamic caliphal territory until the mid-10th century CE.

Few publications attempt to go beyond the site report and query the distribution of glass vessel types within the Near East. However, some scholars have looked at the larger picture and have noted that there do seem to be regional peculiarities. This regionalism may explain why it is often difficult to tie together the typologies from different sites, or to explain differences in contemporary assemblages. For example, large relief-carved ewers are only found outside of Iran at coastal settlements, emporia, or major centers of caliphate power like Fusṭāṭ, Beth She'an, and probably Damascus and Jerusalem; thus "provincial areas within the caliphate therefore seem to have been out of the loop as far either common production or importation of relief-cut vessels in the ʻAbbasid period is concerned" (O'Hea 2003: 134). Although no relief-cut vessels were sampled in this project, scratch-decorated cobalt blue beakers seem to have occasionally reached inland sites (O'Hea 2003: 134); thus it is intriguing that Ḥiṣn al-Tīnāt has no evidence of this type despite being a coastal port.

In Chapter 4 it was noted that sample No. 207 from Ḥiṣn al-Tīnāt is the rim of a jar with a unique profile, one for which it is difficult to find parallels within Byzantine assemblages. Similar rim profiles, however, are quite common at Ayla; examples appear several times among the drawings of some of the Ayla glass vessels done by Carol Meyer in the late 1980s,[8] and Ayla sample No. 7 also displays this triangular rim and short splayed neck profile (Figure 7.5). This might possibly suggest that the Ḥiṣn al-Tīnāt vessel is an import from Islamic lands. Both fragments were made using plant ash soda glasses, which is not surprising considering the relatively late date of their archaeological contexts: fragment No. 207 comes from 11th-12th century CE contexts and No. 7 from post-11th century CE contexts. Chemical analysis (Table 7.5) places the No. 207 in Ḥiṣn Group 5 and No. 7 in Ayla Group 7. The former has a higher soda and lower lime content

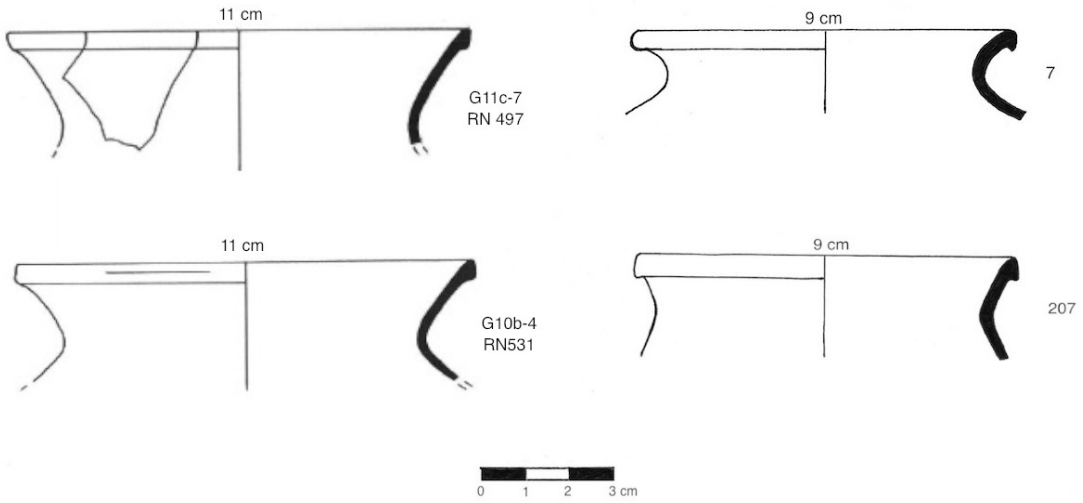


Figure 7.5: Examples of jar profiles dating to ca. 11th century CE: the two vessels to the left are from Ayla (drawings by Carol Meyer, unpublished), as is the vessel at the top right; at the bottom right is a vessel from Ḥiṣn al-Tīnāt with a very similar profile.

[8] These unpublished drawings were generously provided to me by Carol Meyer in 2006.

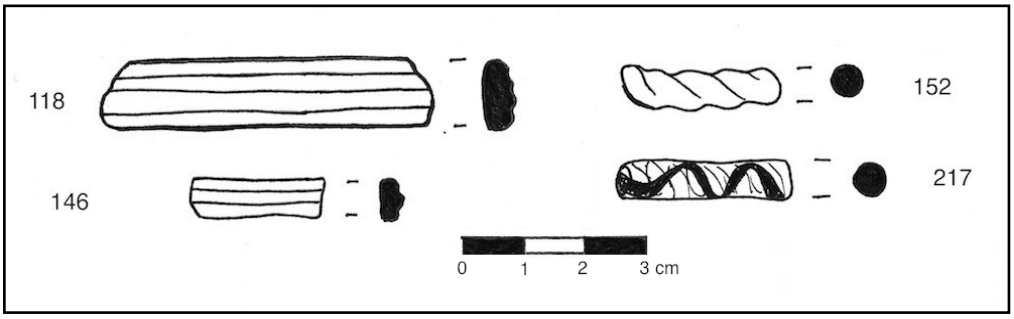
than the latter, as well as lower alumina and iron; these differences in composition may in part relate to the aqua color of the former and the yellowish-colorless hue of the latter, due to the addition of manganese to counteract the higher iron levels.

Sample	SiO2	Na2O	K2O	CaO	MgO	Al2O3	Fe2O3	TiO2	MnO	P2O3	CuO	CoO	PbO2
No. 207	67.52	14.15	2.19	9.46	3.28	1.50	0.47	0.04	0.75	0.31	0.01	0.00	0.01
No. 7	65.55	12.77	2.69	11.03	2.60	2.27	0.77	0.05	1.86	0.41	0.01	0.00	0.00

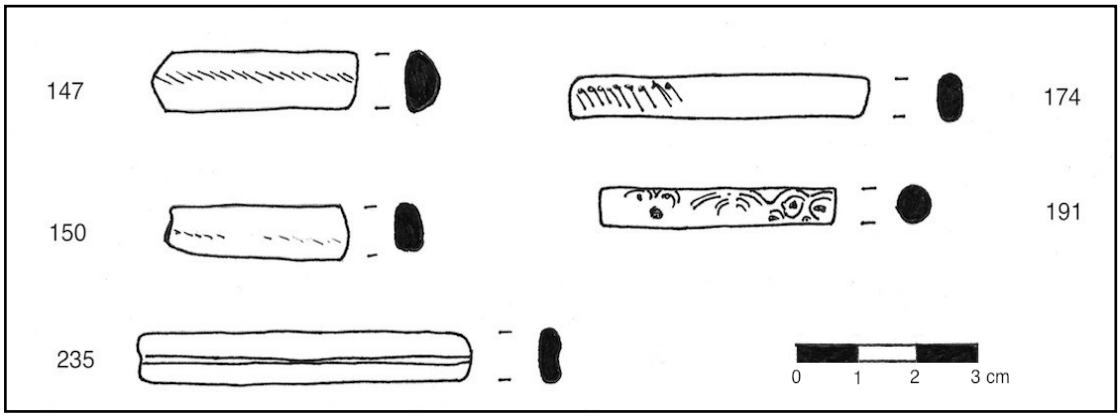
Table 7.5: Comparison of the chemical composition (in wt% oxides) of two unique and very similar jar fragments, Ḥiṣn al-Tīnāt fragment No. 207 and Ayla fragment No. 7.

By far the most obvious correlation between object typology and chemistry—and perhaps the only real correlation—are the bracelets from Ḥiṣn al-Tīnāt. As was discussed in Chapter 5, there are intriguing connections between the cross-section shape, the overall style of decorations, and the color of the glass bracelets on the one hand, and their production technology in terms of the unique chemistry of their raw materials on the other (Figure 7.6).

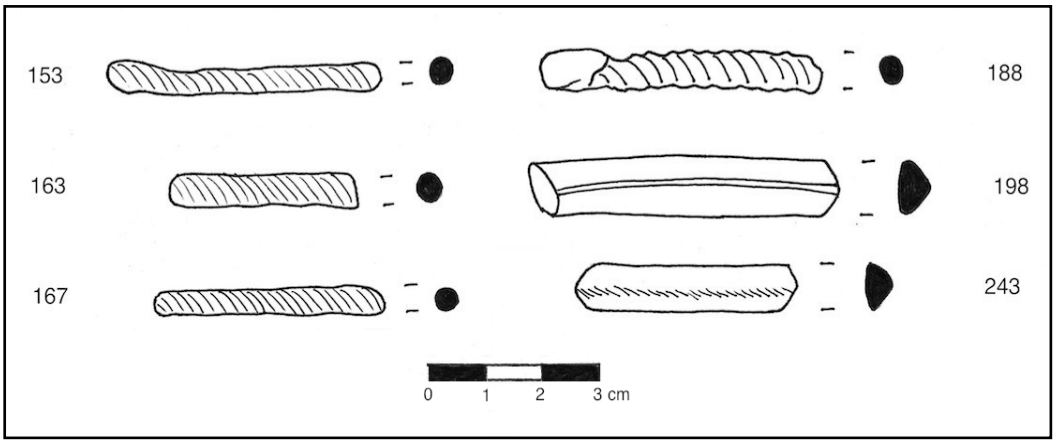
The bracelet fragments in Group A include the horizontally ridged and loosely twisted types, which were made using glass of a similar composition to the vessels of Ḥiṣn Group 4; the bracelet colors include naturally aqua or a combination of colorless and purple glasses, which were also the most common colors for the vessels of Group 4. Bracelet fragments from Group B are somewhat more varied in cross-sectional shape and are either quite plain or colorfully painted; these glasses have by far the highest level of boron of any of the glasses. High boron and high alumina is characteristic of bracelet Group C; this group includes all dark cobalt blue glasses, which are either peaked in cross section or spirally twisted with a notably tighter twist than the twisted bracelets of Group A. All of the bracelet fragments come from contexts that date to the 10th-12th centuries



Group A (similar to Ḥiṣn al-Tīnāt Group 4 plant ash glasses)



Group B (high boron plant ash soda glasses)



Group C (high alumina / high boron plant ash soda glasses)

Figure 7.6: Line-drawings of the Ḥiṣn al-Tīnāt bracelet fragments, divided by chemical type.

CE; cobalt blue twisted bracelet No. 153 came from a context that has only recently been dated to ca. 1022-1150 CE by means of radiocarbon AMS (Asa Eger, personal communication)—the close similarity of color, style, and the unique chemistry might perhaps enable the other bracelets of Group C to be dated to the early 11th-early 12th centuries CE as well.

The bracelet fragments are highly significant not only because of their novelty amongst the archaeological finds of these two sites or because of their unique chemistry; they also give the clearest evidence for ephemeral aspects like aesthetics and taste, which may not be so forthcoming in utilitarian glassware. That there was a fashion for bracelets during the Middle Byzantine period is supported not only by the archaeological record—metal and glass arm-rings and bracelets are a typical find, especially for female burials, in the 10th-12th centuries CE—but also by contemporary artistic representations in paint and mosaic media (Parani 2005). Although there is no way of determining with certainty whether the bracelets in these depictions are actually of metal (bronze) or of glass, it might be assumed that both materials are represented, as they were probably of similar value and were certainly in fashion simultaneously. Gold and silver are likely not shown in such images (Figures 7.7 and 7.8), as the women sporting these items are always from the working classes of society rather than from the aristocracy (midwives and servants).

A very persuasive interpretation for the popularity of bracelets is that they were a response to changing clothing fashions. By the mid-11th century CE dresses with "trumpet-shaped" sleeves were worn by women of all classes; "the lower, pointed end of the sleeves are pulled back and tied in a knot between the shoulder blades, leaving the arms not only unhampered but also visible" (Parani 2005: 153) and thus providing an

opportunity for personal adornment by means of bangles, either single or stacked, on the forearm or upper arm. This Middle Byzantine fashion did not continue into the Late Byzantine period. The decline in popularity is again attested in the archaeological record and by artistic representations; depictions from the 14th century CE, similar in artistic content and iconography to those of the earlier 10th-12th centuries, now depict women at work with bare arms (Figure 7.9).

Figure 7.7: Women depicted wearing bracelets; depiction of the birth of the Virgin from the church of St. Panteleimon in Nerezi, Macedonia, dated ca. 1164 CE (Antonaras 2006: 432, Fig. 13).

Figure 7.8: Women depicted wearing bracelets in a miniature painting of the Birth of St. John, dated to 1122-1142 CE; (left) full scene and (center and right) details of the women (Parani 2005: 152 and Fig. 2; Biblioteca Apostolica Vaticana).

Figure 7.9: Women depicted with no bracelets in a mosaic of the Birth of the Virgin from the Chora monastery, Constantinople, and dated to 1315-1321 CE; (left) full scene and (right) detail of the women (Parani 2005: 153 and Fig. 3; Dumbarton Oaks).

Meaning and Significance of the Findings: Comparison with Other Sites

Although the five known primary production groups of mineral soda glass were produced in Egypt and the Levant during the Early Byzantine period (4th-7th centuries CE), in the case of Levantine II and Egyptian II groups it is known that this production continued into the 9th century CE as well. The identification of these groups in ca. 10th century CE contexts at both Ḥiṣn al-Tīnāt and Ayla (Figure 7.10) confirms this and pushes the chronology of their use into the 10th century CE. The presence of the Egyptian I and HIMT groups of mineral soda glasses at Ayla but not at Ḥiṣn al-Tīnāt speaks to the particular geographic distribution of chemical types, which reflects economic aspects of both the production and consumption of glass. Not all contemporary glass types were

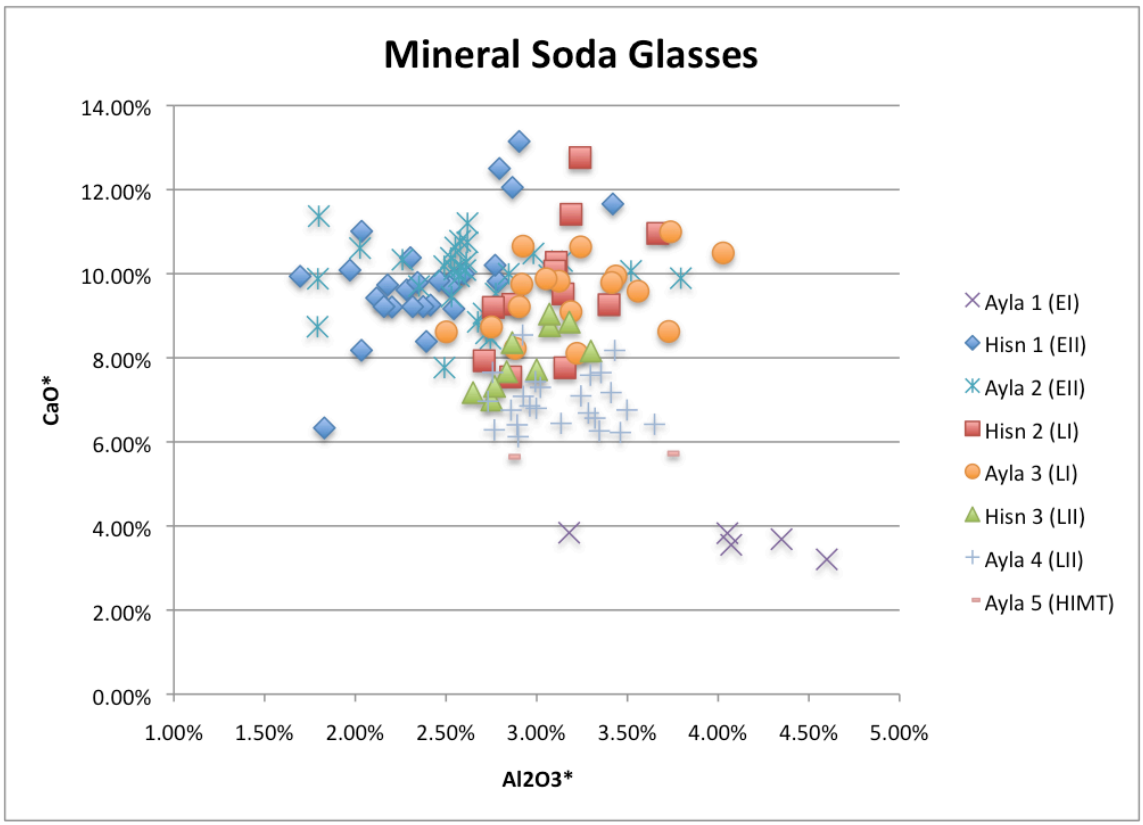


Figure 7.10: Scatter plot of all the mineral soda glasses analyzed from Ḥiṣn al-Tīnāt and Ayla.

equally distributed, traded, or used in all parts of the Mediterranean or even in the eastern Mediterranean. Egyptian I glass did not appear to circulate outside of Egypt, while the archaeological evidence for HIMT glass (which was likely made in the Sinai or in Egypt) is concentrated in the Sinai, Egypt, and the western Mediterranean rather than in the Levant. This difference in geographic distribution of contemporary production groups has been interpreted as reflecting competition between glass producers in the 5th-7th centuries CE, specifically between the Levantine I and HIMT glassmakers (Fiori and Vandini 2004: 168).

If not exactly due to economic competition, this distribution pattern at least represents differing "glass zones" of economic interaction. In light of this, Ayla is one of the few—if not only—find spots of Egyptian I glass outside of Egypt proper. Possible interpretations for this include: 1) Ayla's southerly and adjacent physical location placed it well within the sphere of Egyptian I glasses, 2) Ayla's special position as a trading center and port was a means of circumventing the typical glass distribution pattern, or simply 3) Egyptian I glasses did indeed circulate outside of Egypt but the evidence has not yet been widely found. On the other hand, the absence of HIMT glass at Ḥiṣn al-Tīnāt in southern Anatolia reinforces the interpretation that the Levantine glasses dominated the economies of glass in the northern areas of the Eastern Mediterranean potentially at the expense of some Egyptian glassmakers.

The significance of the ten groups of plant ash soda glasses (Figure 7.11) distinguished from the Ḥiṣn al-Tīnāt and Ayla samples only becomes apparent when the results are compared with those of contemporary Eastern Mediterranean sites. Plant ash soda glasses are still not as well understood or characterized as mineral soda glasses, so

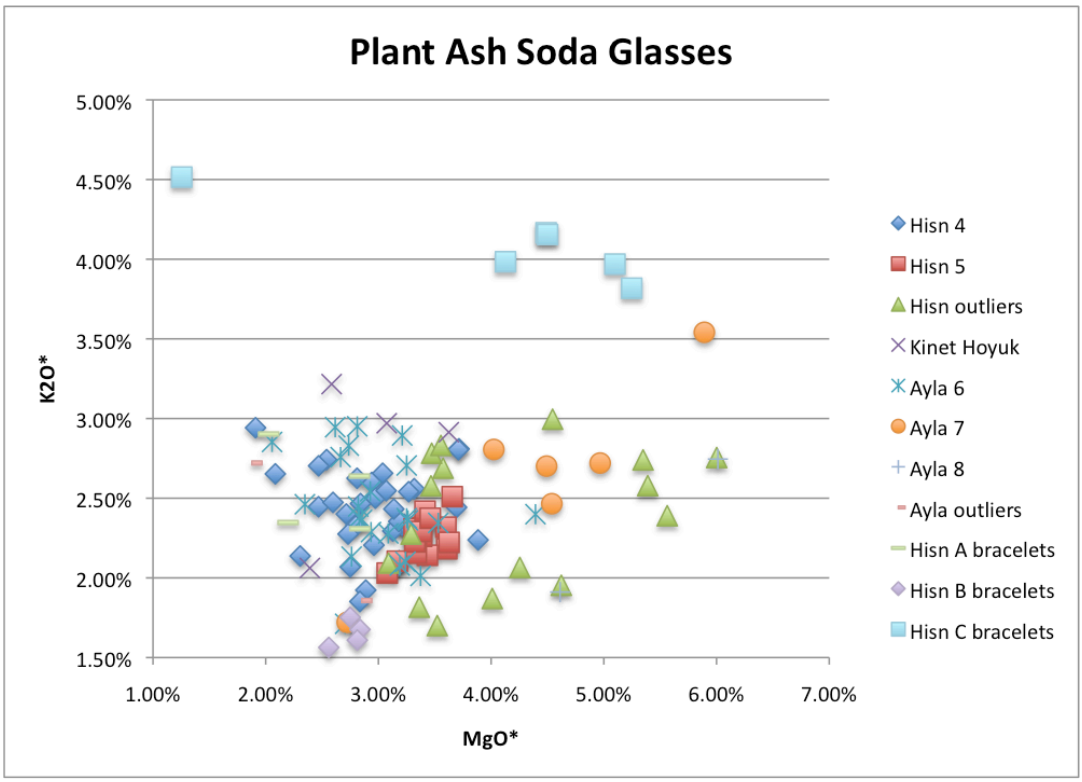


Figure 7.11: Scatter plot of all the plant ash soda glasses analyzed from Ḥiṣn al-Tīnāt and Ayla.

there are no production groups with which to compare any new chemical data. Because of this, a detailed characterization and subdivision of the plant ash glasses must first be made within an individual site, and then these groups compared to glasses found at other sites; only in this way can we begin to tease out possible plant ash soda glass production groups or zones.

Some of the most useful published data for 8th-12th century plant ash soda glasses in the Islamic region come from the archaeological sites of Raqqa in Syria (Henderson *et al.* 2004) and the Serçe Limanı shipwreck off the southern coast of Turkey (Brill 2009), and to some extent Tyre in Lebanon (Freestone 2002) and Banias in Israel (Freestone *et al.* 2000). In the Byzantine regions these include the Turkish sites of Pergamon (Schibille 2011), Sagalassos (Lauwers *et al.* 2010), and the mosques of Zeyrek Camii and Kariye

Camii[9] in Istanbul (Brill 2005b). However, it should be pointed out that these publications have their limitations. No trace element data is published for Banias, Tyre, Raqqa, or Sagalassos and trace element data is limited for Serçe Limanı, Zeyrek Camii, and Kariye Camii. Although the Pergamon publication does give a fuller list of trace elements, only three plant ash glasses were actually analyzed in the study.

As mentioned in Chapter 2, the data from the glassmaking site of Tell Zujaj at Raqqa is highly significant for understanding details about how, when, and where glassmaking technology and production changed in the Early Islamic period (Henderson 1999, 2002, 2004; Henderson *et al.* 2004, 2005).[10] Chemical analyses of vessel fragments and glassmaking debris show that four distinct glass types were in use simultaneously at the site during the 8th-9th centuries CE (Figure 7.12); three of these were actually made on the site using plant ash soda, reflecting experimentation with different glassmaking technologies.

Type 1 is a plant ash soda glass that appears to have become the dominant type of glass produced in Raqqa during the 10^{th-}11th centuries CE (Figure 7.12); these later examples have lower soda and higher lime, and are designated Raqqa Subtype 1. Type 3 is a mineral soda glass that was not made on the site; it was probably imported from Palestine, and by the 10th-11th centuries its presence at Raqqa had dramatically declined indicating an increasing scarcity or an increasing reliance on plant ash soda (but in my opinion probably both). Type 2 seems to be a mixture of Types 1 and 3, interpreted as

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[9] The Zeyrek Camii was the principal church of the Pantokrator monastery and the Kariye Camii was the main church of the Chora monastery.

[10] A typology of the Raqqa finds has not yet been published, making a comparison of the chemical data with object forms and styles impossible for the time being.

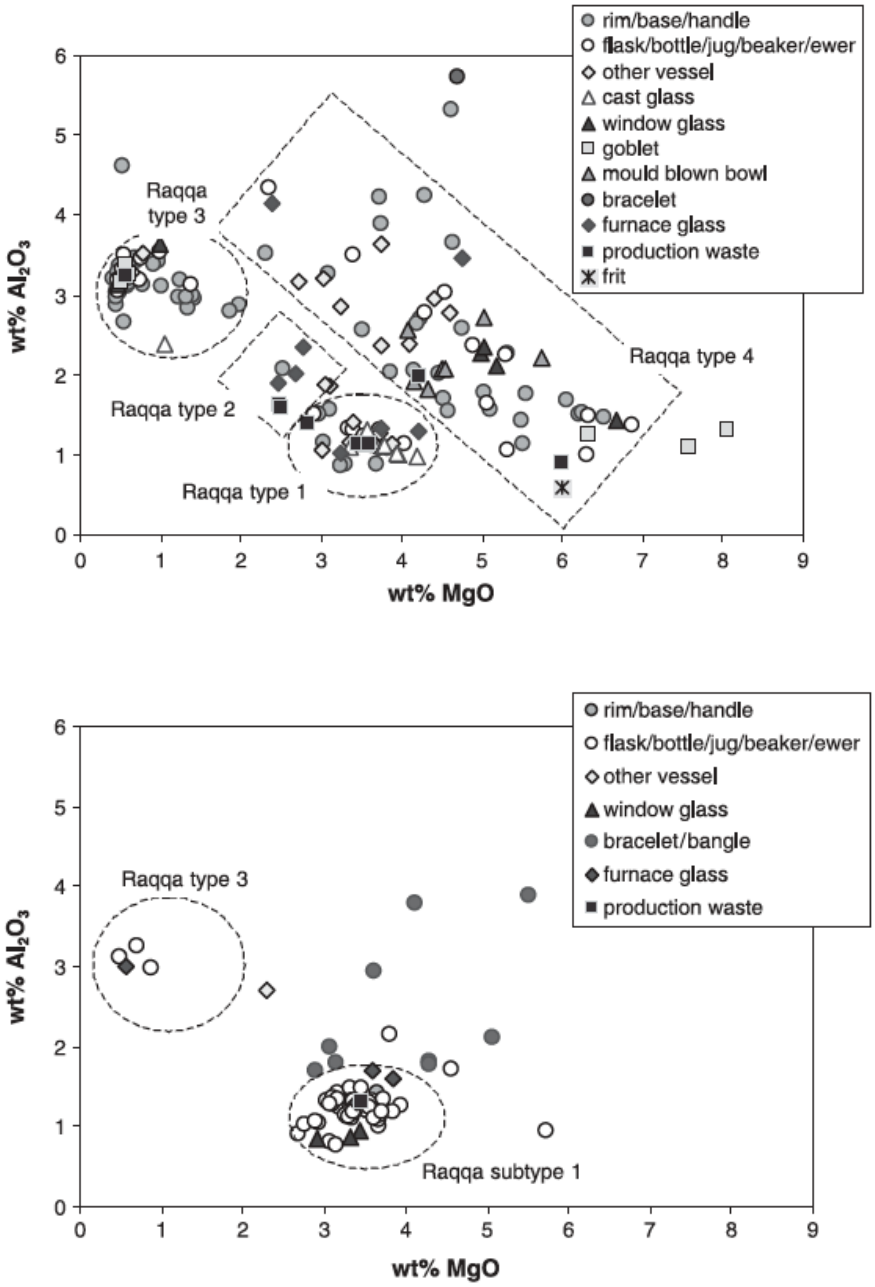

Figure 7.12: (Top) scatter plot of magnesia vs. alumina for the 8th-9th century CE site of Tell Zujaj at Raqqa in Syria (Henderson *et al.* 2004: 452, Figure 2); (bottom) similar scatter plot for the 11th-12th century CE site of Tell Fukhkhur at Raqqa (Henderson *et al.* 2004: 453, Figure 3).

indicating that mineral soda glasses were being recycled and mixed with new plant ash soda glasses. Type 4 is also plant ash soda glass, but this group has a much larger range of compositions. This has been interpreted as representing experiments in raw material

combinations by the glassmakers, including a series of different ratios of mixed raw glasses and/or raw materials—for example the increasing addition of quartz and plant ash to sand in the raw batch (Henderson 2004: 113). Contrary to the failed 9th century CE melt at Bet She'arim, the experimentations at Raqqa in the 8th-9th centuries CE were successful because they presumably involved some degree of filtration or centrifuge to remove shell fragments form the sand, therefore eliminating the excess lime (Henderson 2004: 114).

The chemical data from Raqqa provides a very good point of initial comparison for the Ḥiṣn al-Tīnāt and Ayla chemical analytical results (Figures 7.13 and 7.14). The mineral soda Raqqa Type 3 glasses are similar to Ḥiṣn Groups 2-3 and Ayla Groups 3-4 mineral soda glass samples. Among the plant ash soda samples, it can be seen that some

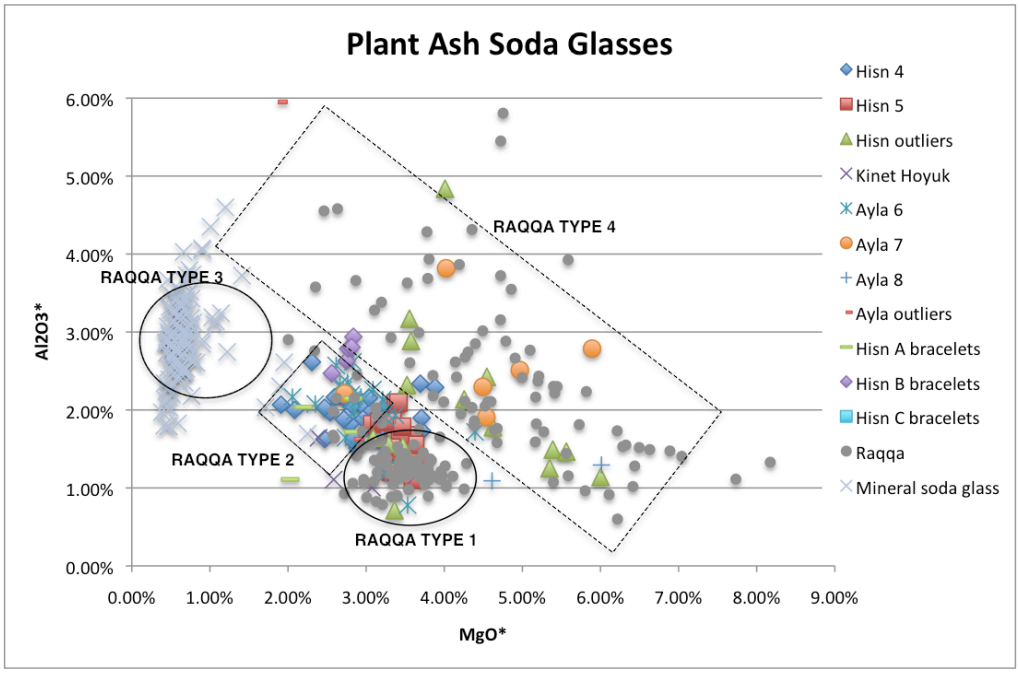

Figure 7.13: Scatter plot of the data from Ḥiṣn al-Tīnāt (except for Group C bracelets) and Ayla, plotted with the plant ash soda glasses from Raqqa and showing Henderson's groupings (Henderson *et al.* 2004: 452, Table 1 and Figure 2).

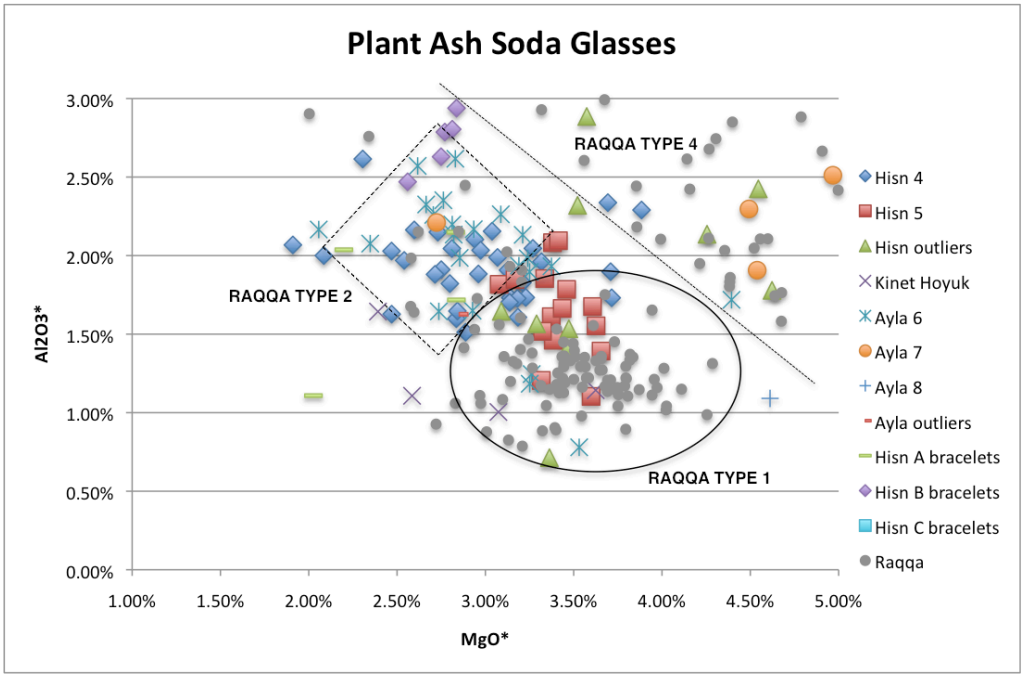

Figure 7.14: Detail view of the previous chart (Figure 7.13), focusing on the Raqqa Types 1 and 2 glasses.

members of the Ḥiṣn outliers and Ayla Group 7 glasses (and possibly Ayla Group 8 as well) plot within the range of Raqqa Type 4 glasses; Ḥiṣn Group 4 and Ayla Group 6 seems to plot more closely with Raqqa Type 2 glasses, while Ḥiṣn Group 5 are more similar to Raqqa Type 1 (Figure 7.14).

The similarity of Ḥiṣn Group 4 glasses with the Raqqa Type 2 glasses on one hand, and the Ḥiṣn Group 5 glasses with the Raqqa Type 1 glasses on the other, is particularly interesting in light of Henderson's interpretation of his two groups. If mineral soda glasses were being mixed with new plant ash soda glasses, this may explain the observed similarities and distinctions of the two groups of Ḥiṣn al-Tīnāt samples: perhaps Ḥiṣn Group 4 plant ash glasses are a mixture of a type of plant ash soda glass (similar in composition to the Raqqa Type 1, Ḥiṣn Group 5, and Ḥiṣn outlier samples) and a mineral

soda glass. However, Henderson's interpretation about mixed soda glasses is not unanimously accepted as far as I know, so this interpretation should remain preliminary.

The single largest—and arguably most important—archaeological assemblage of Islamic glass comes from the 11th century CE Serçe Limanı glass shipwreck. "The glassware is extremely homogenous in appearance" and chemical analysis indicates that the raw glass, wasters, intact glassware, and over 90% of the cullet have an almost uniform composition (Von Doorninck 1990: 61). Chemical analysis of 103 samples shows that the vast majority of these glasses form a very tight compositional group of plant ash soda glasses with little variability (Figure 7.15), which likely reflects a single workshop or several closely related workshops using raw glass from a single source (Brill 2009: 464 and 469).[11]

Brill observes that the Serçe Limanı glass most closely resembles a sample of 13 glasses from Caesarea (dating to the 9th-12th centuries CE), cullet from Tyre (dating to the 10th-12th centuries CE), and four fragments from Qasr al-Hayr al-Sharki (dated as "Islamic"); he also emphasizes that the compositions of the Serçe Limanı glasses differ significantly from the other sixteen or so groups of Islamic glass he examined for his 1999 study[12] (Brill 2009: 480). These conclusions prompted Brill to suggest a common regional origin for the Tyre, Caesarea, and Serçe Limanı glass (Brill 2009: 480), but unfortunately a typological comparison of the Serçe Limanı glasses with the finds from

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[11] Mineral soda glasses and lead-silicate glasses were also identified, although only four of the former and four of the latter (Brill 2009: 463). The mineral soda glasses are chemically similar to the Egyptian I production group.

[12] These include the sites of Nishapur, "Nishapur neighbors" (including Hamadan, Gorgan, and Ray), Fusṭāṭ, Ghubayra, Qasr-es-Seghir, Selçikler, Takht-i-Sulaiman, Aqaba, Quseir al-Qadim, and Timna (Saudia Arabia) as well as larger decorative groups like cameo, luster, scratch-decorated, and enameled glasses. The inclusion of Aqaba among the dissimilar samples may seem noteworthy; however Brill only analyzed one sample of 'Abbāsid period glass from the site (1999a: 95; 1999b: 193).

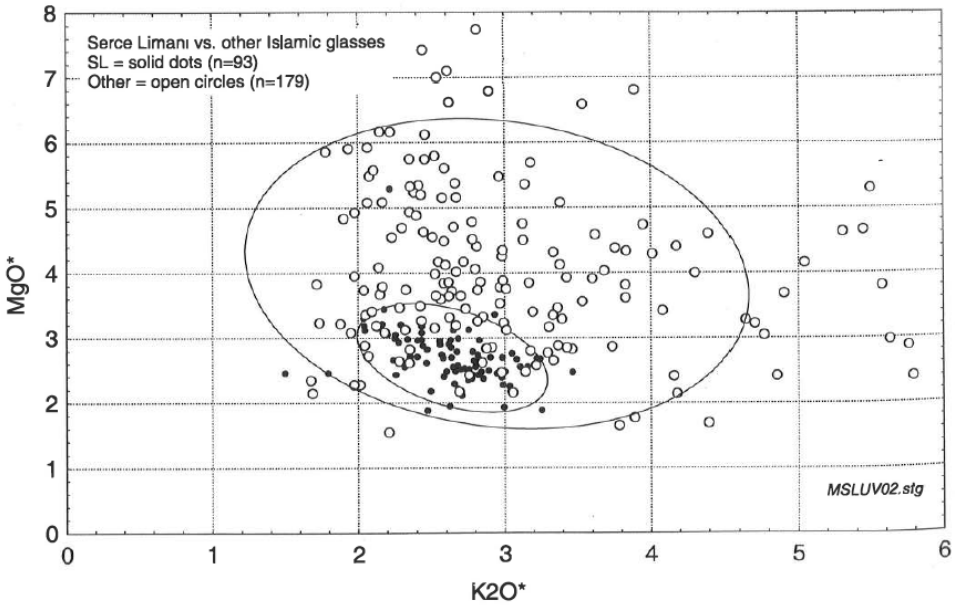

Figure 7.15: Results of chemical analyses of samples from the Serçe Limanı wreck and from the collection of the Corning Museum of Glass, showing the tight clustering of the Serçe Limanı glasses (smaller ellipse with black dots) relative to 179 other Islamic glasses (Brill 2009: Fig. 43-10).

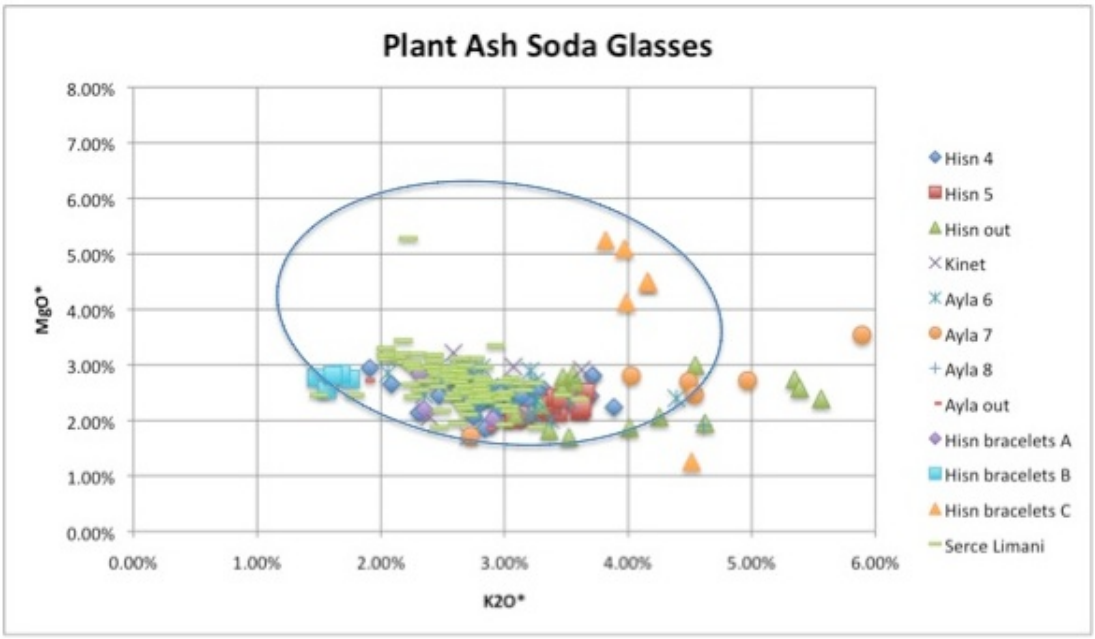

Figure 7.16: The plant ash soda glasses from Ḥiṣn al-Tīnāt and Ayla, plotted with the Serçe Limanı glasses and showing Brill's 95% confidence ellipse for 179 Islamic glass samples (Serçe Limanı data from Brill 2009: Table A-1).

Caesarea, Tyre, and Qasr al-Hayr is not possible: the Caesarea vessel fragments were reported as being too small to determine whether the vessel shapes and mold-blown patterns are similar to those of the Serçe Limanı glass, the Tyre samples are cullet rather than vessel fragments, and the Qasr al-Hayr fragments are not published.

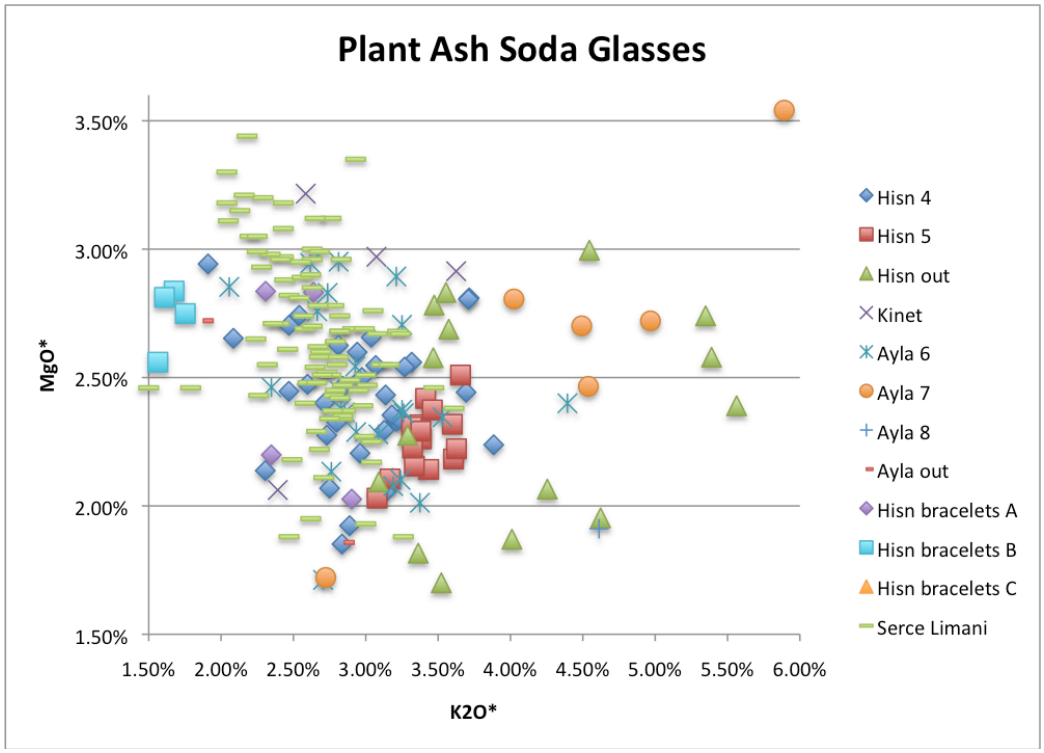

Figure 7.17: Detail of the plant ash soda glasses from Ḥiṣn al-Tīnāt, Ayla, and the Serçe Limanı shipwreck (Serçe Limanı data from Brill 2009: Table A-1).

When the Ḥiṣn al-Tīnāt and Ayla data are compared with Brill's study it becomes immediately apparent that many of the plant ash soda glasses from these two sites are extremely similar to the samples from the Serçe Limanı shipwreck (Figure 7.16), clustering together at the bottom of the 95% confidence ellipse around Brill's 179 total samples of Islamic glass. Looking more closely at the data display in this scatter plot (Figure 7.17), it can be seen that the tight cluster of Serçe Limanı glasses are especially

similar to Ḥiṣn Group 4, Ḥiṣn Group A, and Ayla Group 6. Although not shown here, other bivariate scatter plots of the data confirm the close similarities between these groups.

When the data from Serçe Limanı are plotted with the data from Raqqa, Ḥiṣn al-Tīnāt, and Ayla, these resemblances are again noticeable (Figure 7.18), and this fact is quite important when considering possible interpretations of the meaning of the chemical data. Henderson has described the chemical composition of the majority of the Serçe Limanı glasses (89 out of 103 samples) as compositionally akin to Raqqa Type 2 although he notes the Serçe Limanı samples have more lime than the Raqqa glasses, with "relative mean levels of 9.26% and 5.39% respectively" (Henderson 2004: 117); it should

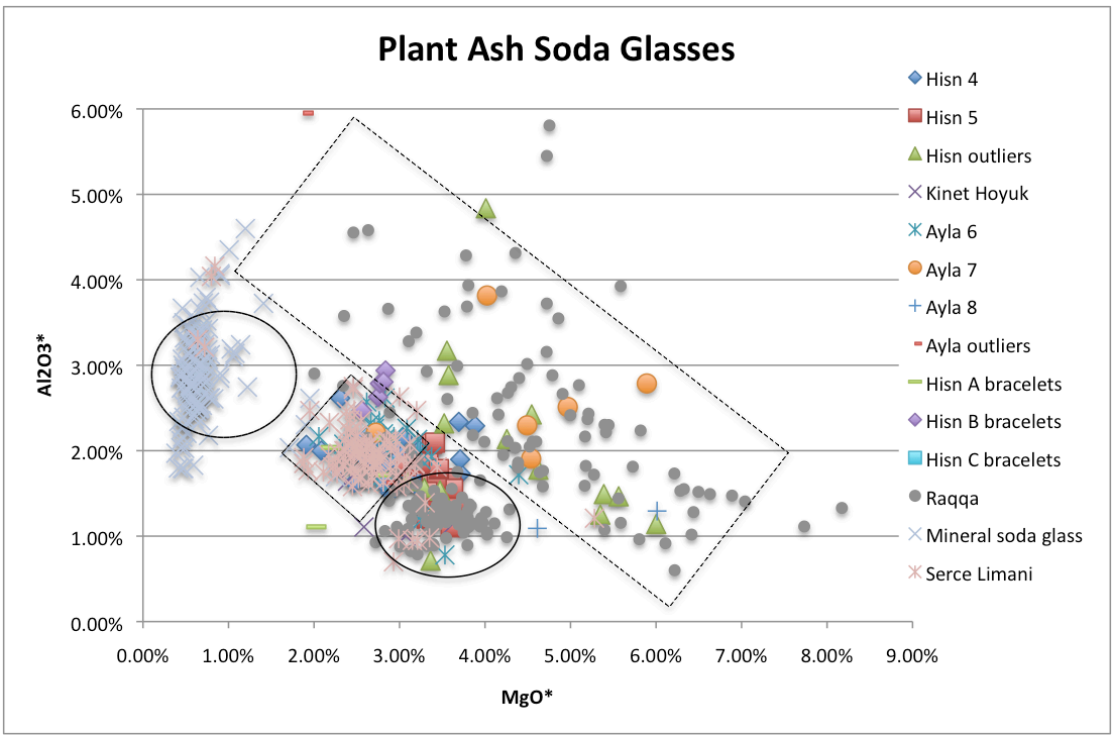

Figure 7.18: (Above) Scatter plot of the data from Ḥiṣn al-Tīnāt (except for Group C bracelets) and Ayla, plotted with the plant ash soda glasses from the Serçe Limanı shipwreck (data from Brill 2009: Table A-1) and from Raqqa; showing Henderson's groupings (Henderson *et al.* 2004: 452, Table 1 and Figure 2);

be noted that the Ḥiṣn al-Tīnāt and Ayla samples have similar levels of lime to the Serçe Limanı glasses. Henderson interprets the Raqqa Type 2 samples as being mixed soda glasses, made by combining mineral soda glass with plant ash soda glass, and concludes that the Serçe Limanı glasses demonstrate that such mixed soda glasses continued to be made in the 10th-11th centuries CE (Henderson 2004: 117).

By this interpretation and the similarities observed, it would then follow that the Ḥiṣn Group 4, Ḥiṣn Group A, and Ayla Group 6 glasses are mixed soda glasses as well. Only five of the Serçe Limanı glasses are true plant ash soda glasses according to Henderson (2004: 117), and these are similar to his Raqqa Type 1. Brill did not offer an interpretation of his 1999 Serçe Limanı data until the recent comprehensive publication of the entire glass corpus (Bass *et al.* 2009), so Henderson's above discussion is based on his own reading of Brill's earlier published raw data (Brill 1999a and 1999b). Brill's own interpretation for the meaning of the Serçe Limanı data is, however, significantly different from that of Henderson. Brill identifies 93 of his samples (four samples being mineral soda glasses and four others lead-silicate glasses) simply as plant ash soda glasses, with no mention of the possibility that they were mixed with mineral soda glasses (Brill 2009).

Turning now to the unique types of plant ash soda glasses identified among the Ḥiṣn al-Tīnāt bracelet fragments, comparative assemblages for high boron and/or high alumina glasses are much more scarce within the published scientific literature. Robert Brill was the first to notice that Byzantine glasses linked to Greece, Cyprus, and Turkey often have a high concentration of the trace element boron. While he has noted this in several publications over his career (Brill 1968, 1999, 2002, and 2005), his keen

observation has largely gone unnoticed and few scholars have included boron or other trace elements in their chemical analysis of glass from this region. Nadine Schibille's recent analysis of Byzantine glass from Pergamon is the rare exception to this, although these glasses date to the Late Byzantine rather than Middle Byzantine period and largely correspond to colorless and pinkish glass from vessel fragments (Schibille 2011: 4, 8 and Table 2); moreover, the bulk chemistry of the Pergamon high boron glasses and the Ḥiṣn al-Tīnāt high boron glasses is not very similar.

The high alumina-high boron type of glass is also significant. Although high-alumina glasses have long been observed for jewelry and ornaments (and in some rare cases, for vessels) found in Southeast Asia and Africa, they have rarely been observed for glasses found in the Near East and Mediterranean, and none are known to have had high boron. Schibille's high alumina group of Byzantine glasses from Pergamon largely date to the Late Byzantine period and have lower alumina levels than the glasses from Ḥiṣn al-Tīnāt; three of her samples are from the Middle Byzantine period and have similarly high levels of alumina (9.90-11.03 wt% Al_2O_3), but she interprets these as being made from mineral soda rather than plant ash soda—and they do not contain high boron.

Despite the difficulty of comparison—or perhaps *because* of this difficulty—Ḥiṣn Groups B and C are of the utmost interest, and these typological groups may have very important implications for our understanding of the economic, technological, and social networks that were in place in the Eastern Mediterranean in the 10th-12th centuries CE. The high boron content of the glass bracelets is significant, not only because high-boron glass types are limited at Ḥiṣn al-Tīnāt to jewelry rather than being used to produce vessels, but also because they represent technological types that have only recently begun

to be identified and characterized; as the work of Brill and Schibille has suggested, these glasses seem to be exclusively linked to the heartland of the Byzantine empire—this is highly significant in light of the fact that it was once believed that Byzantium did not even have a glassmaking industry of its own.

TECHNOLOGICAL CHANGE: THE NATURE AND CULTURE OF GLASS

The glass evidence from Ḥiṣn al-Tīnāt, Ayla, Raqqa, Serçe Limanı, and other 8th-12th century CE archaeological sites provide evidence that this period was one of significant technological and artistic change. In particular, in the mid-9th century CE glassmakers in the Levant and Egypt began using plant ash soda rather than mineral soda, which in turn caused changes in silica sources and processing methods. In addition to the evidence from archaeological excavations and chemical analyses of glass artifacts, a treatise written by Elbayrouni (ca. 990 CE) distinguishes between glass "which is mined" (i.e., mineral soda glass) and that which is made from a mixture of sand, *al-kali* (plant ash), and magnesia (Barkoudah and Henderson 2006: 299-300). These two technologies were used side-by-side for several centuries, but by the 11th century CE plant ash soda glass had become the dominant type produced in the Eastern Mediterranean. Moreover, a similar abandonment of mineral soda glassmaking fluxes occurred at the same moment in Western Europe, where potash-rich wood ash became the main fluxing agent. Although recent studies have made it somewhat clearer as to when and where glassmaking practices changed in the era at the turn of the second millennium CE, the question remains—*why* did glassmakers change their raw materials?

Current Explanations for Glassmaking Changes

Over the last decade, scholars have started to ask why mineral soda fell out of use, given that it had supported a very large and successful glassmaking industry for centuries. The leading theories are closely linked to the idea that the Wadi Natrūn in Egypt was the primary source of mineral soda used by ancient glassmakers. Political unrest or environmental change in the 9th century CE have both been proposed as causing general economic disorder in the area around Wadi Natrūn, thus causing the disruption of the mineral soda supply to glassmakers in the Syro-Palestinian region (Whitehouse 2002; Henderson 2002; Shortland *et al.* 2006). Difficulty of access or the breakdown of trade networks, coupled with the geography of the glassmaking region, is thought to account for the gradual reduction of the soda content in glasses and the eventual wholesale replacement with plant ash soda. Glassmakers who lived the furthest from the Wadi Natrūn—the Syrians—were the first to feel the effects of these events, while the Egyptian glassmakers themselves likely had fewer problems pertaining to the access of raw material and thus were the last to make the switch to plant ash soda.

Political upheavals in the Nile Delta region from the 7th century CE onwards (and particularly during the 9th century CE) could indeed have disrupted trade or even cut off the main supply routes that brought mineral soda from Egypt to primary glassmakers elsewhere. There is no evidence of large-scale internal disruption during the Persian invasion and Arab invasions of Egypt in 619 CE and 639-642 CE, in that there is no indication of a violent conquest or a mass emigration by the local population (Sijpesteijn

2007: 441),[13] but regular small-scale and violent episodes in later centuries may have been enough to effect local industries. Civil wars occurred in Egypt between 811-832 CE and again in 862 CE, and rebels occupied the port of Alexandria in 816-826 CE. Documentary evidence and archaeological excavation of the monastic pilgrimage center at Abu Mina (which was connected by caravan routes with the Wadi Natrūn) have suggested that Wadi Natrūn was severely ravaged in 867/8 and 871 CE (Shortland *et al.* 2006a: 527),[14] and would thus have had a great difficulty maintaining its economic role.

The impact of climatic changes on the exploitation of raw material sources has also been proposed. The mining of mineral soda has been likened to the harvesting of a cereal crop, requiring "careful planning and observation…to ensure that the highest-quality natrūn, with the greatest proportion of trona, was obtained" (Shortland 2004: 514). Natron and trona are evaporate minerals, and it has been demonstrated that there is a distinct seasonal difference in mineralogy for the deposits in the lakes of the Wadi Natrūn; geochemical modeling of the lakes has shown that the formation of trona is limited to a very short season, a one- to two-month period that varies according to the climate of a particular year, "being delayed when the weather was cooler or wetter or shortened if the heat of the summer was particularly intense" (Shortland 2004: 513-514). A temporary increase in rainfall is thought to have taken place during the 8th century CE

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[13] Historical scholarship has long shown the continuity of daily economic, social, and cultural life in the Near East after the Arab conquest; the lands and property of inhabitants were not confiscated by the conquerors, and the administrative systems remained largely the same, but with new Arab officials in place. The overall aim of Egypt's conquest was "to control and take advantage of its resources," part of which was the control of administrative and fiscal organization but otherwise Muslim rulers "made use of the connections, experience, and administrative infrastructure in place" (Sijpesteijn 2007: 445 and 455).

[14] The Wadi Natrūn "had already suffered constant incursions by Berbers from the Libyan Desert for more than 400 years," but "it was only during the 9th century AD that the effects of these incursions became especially severe" (Shortland *et al.* 2006a: 527).

in other regions of the Sahara, which may have been enough to disrupt or considerably reduce the production of mineral soda (Foy and Nenna 2001: 26), although some scholars do not believe environmental and climatic change in this period was great enough to damage economic systems (Shortland *et al.* 2006a: 527).

If there was indeed a disruption in the ability of glassmakers in the Near East to obtain raw materials from sources in Egypt, they may have had to adapt by changing their sources of supply—to the extent that they changed the raw materials themselves—in order to ensure the continuation of the industry. One suggestion has been that glassmakers drew technological inspiration from the East. Glassmakers living in regions east of the Euphrates River had been making glass using plant ash soda since the Bronze Age, and appear not to have participated in the switch to mineral soda technology that took place in regions west of the Euphrates (Whitehouse 2002: Brill 1999a: 92-101; Brill 1999b: 151-205, sections 6A-6E).

Additional or Alternative Explanations for Glassmaking Changes

The narratives of political unrest or environmental impact are useful in many ways, because they illustrate that glass technology was not purely technological, so purely technological reasons for change should not be sought at the expense of other possible factors. Technology (and thus technological stability or change) is in reality much more complex:

> The idea of a 'pure' technology is nonsense. Technologies always embody compromise. Politics, economics, theories of the strength of materials, notions about what is beautiful or worthwhile, professional preferences, prejudices and skills, design tools, available raw materials, theories about the behavior of the natural environment—all of these are thrown into the melting pot whenever an artifact is designed or built. (Bijker and Law 1992: 3)

However, these narratives are also somewhat restrictive in scope, as the entire sequence of events rests on the notion that the Wadi Natrūn was basically the only source of mineral soda used by glassmakers during Late Antiquity. Other evaporitic lakes existed in the Near East and were known to have been exploitable and exploited, so the assumption that there was only one source of mineral soda used by glassmakers during the entire 4th-10th centuries CE period is perhaps reductionist. It would additionally seem strange that glassmakers did not simply return to using mineral soda as a flux after political tensions eased in Egypt, or after environmental conditions became favorable once again; however, plant ash soda (and wood ash in Europe) continued to be used for the rest of the medieval period, and throughout the Renaissance as well—Venetian glass was especially famous for its quality in these later periods, and it was made using plant ash soda imported from the Levant.

Technological Influences East of the Euphrates?

Byzantine glassmakers of the 4th-7th centuries CE adopted and adapted the resources and infrastructure of the glassmaking industry that was established by their Roman predecessors. Although Sasanian glass is not at all well studied or understood (Whitehouse 2005), contemporary 3rd-7th centuries CE Persia did have a glassmaking industry of its own, which used plant ash soda as a flux. With the Arab conquest of Western Asia, Byzantine control of the Levant and the entire Sasanian Empire came to an end; one consequence of this was the unification of formerly separate regions—the Levantine-Egyptian region and Persia—into a virtual Islamic empire.

It may seem quite reasonable to attribute the changing glass technology of the Levant and Egypt to the unification of two different glassmaking regions: the eastern Sasanian plant ash soda glasses could have directly influenced the struggling mineral soda glass industry in the west. However, Sasanian glass typically has a much higher magnesia and potash content than does Levantine-Egyptian plant ash soda glass of the post-9th century CE (Figure 7.19). Thus, it may not be the case that plant ash soda technology simply traveled westwards—otherwise the post-9th century CE Islamic glasses would have similarly high levels of magnesia and potash.

The relationship of Sasanian and Islamic plant ash soda glasses is not well understood, nor is plant ash soda glass in general. According to Freestone, "it is possible that the blanket term 'plant ash glass' conflates different technological traditions, that, when fully understood, will help to refine approaches to this type of glass" (Freestone 2006: 212). Indeed, when the Ḥiṣn al-Tīnāt and Ayla plant ash soda glasses are plotted with examples of Sasanian glass from the 3rd-7th centuries CE site of Veh Ardišīr in Iraq (Figure 7.20), it can be seen that some of the Ḥiṣn al-Tīnāt outliers and all of the Ayla Group 7 glasses plot in the same region, despite being chronologically later glasses.[15] Even if the dividing line between Syrian Islamic and Sasanian glasses in Freestone's scatter-plot was adjusted to include slightly higher levels of magnesia, there would still be samples from Ḥiṣn al-Tīnāt and Ayla that fall well within the Sasanian compositional region. This might suggest that these samples were made in former Sasanian territories (Iraq and Iran); without well-characterized glasses from these areas that date to the contemporary 8th-12th centuries CE period, this cannot be confirmed.

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[15] The Ayla Group 7 glasses come from 9th-11th century CE contexts, while the Ḥiṣn al-Tīnāt outliers date to the mid 10th-mid 11th century CE contexts.

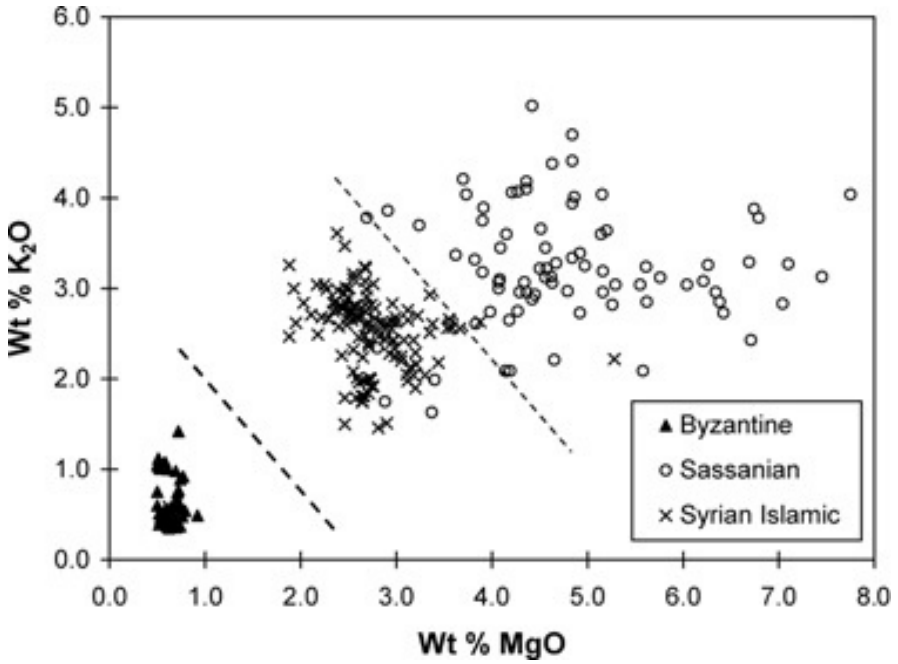

Figure 7.19: Comparison of the chemical composition of mineral soda Byzantine glasses with plant ash Syrian Islamic and Sasanian glasses (Freestone 2006: 204 and Fig. 2).

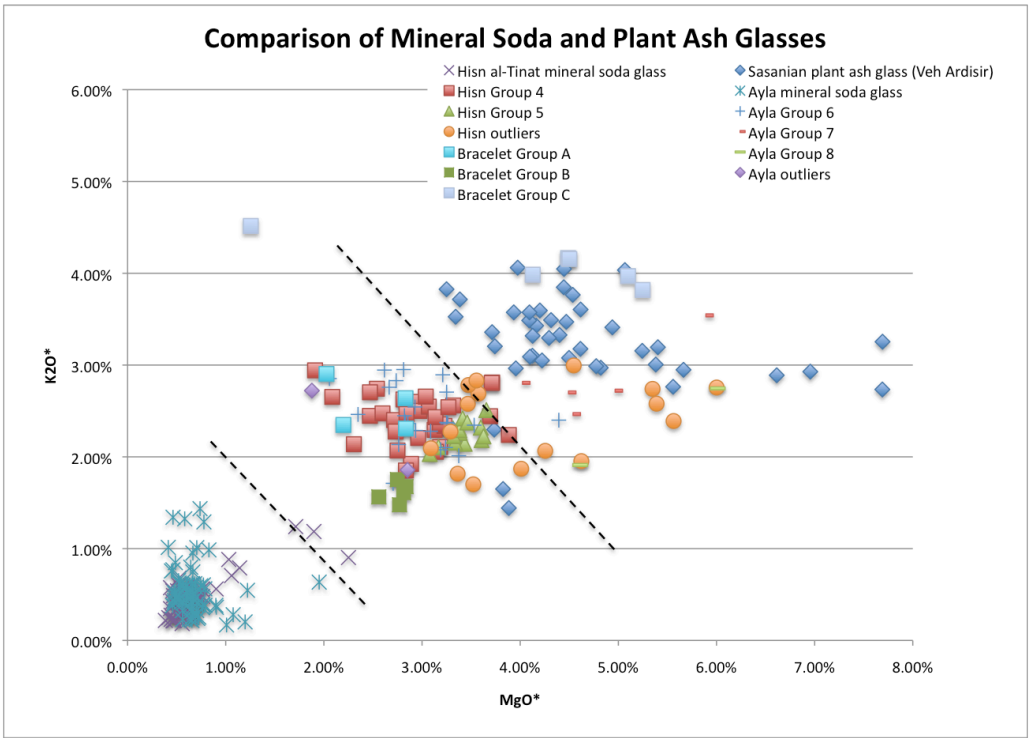

Figure 7.20: Chemical data from Ḥiṣn al-Tīnāt and Ayla, and glass from the 3rd-7th centuries CE Sasanian site Veh Ardišīr in Iraq (data from Mirti *et al.* 2009: 1064-1065 and Table 2) after Freestone (2006: 204 and Fig. 2).

Some of the samples from Ḥiṣn al-Tīnāt (Nos. 156, 164, 178, 179, and 183) were considered outliers in part because they have higher soda and lower lime compared to the other plant ash soda glasses from the site, but these levels are similar to some 4th-7th century CE Sasanian glasses from Nineveh (Freestone 2006: 203). For example, sample No. 164, is the fragment of a colorless tonged/impressed vessel that often plotted as an extreme outlier compared to the other samples; perhaps this fragment does come from as far afield as Mesopotamia, as tonged beakers have indeed been observed among Islamic glasses from Nishapur (Kröger 1995), Samarra (Lamm 1928), and Susa (Lamm 1931). The high boron-high alumina glass bracelets of Ḥiṣn Group C also have high potash and manganese levels that plot with the Sasanian glasses, but it is more likely they came from northern Byzantine regions—this cautions against the immediate association of high manganese-high-potash samples with eastern regions, and highlights the complicated nature of plant ash soda glass chemistry.

Reductions in Soda Content

In addition to possible political and economic reasons for changing sources of soda, it is imperative to think about material and cultural considerations that could have affected how people made things. The "performance characteristics"[16] of a material are a very important consideration to a craftsman—this is a basic principle of modern engineering, and certainly would have been a central concern to people in the past as

[16] "The interaction-specific capabilities that a product possesses" (Skibo and Schiffer 2001: 143-144). Anthropologists and archaeologists identify additional performance characteristics that go beyond the physical and chemical properties of a material. One example of such a "social" performance characteristic that is relevant for glass is visual performance—color, clarity, and brilliance are certainly visual qualities that were of significance to people who made and used glass; these properties are essentially aesthetic preferences and are fluid, changing over time and across space.

well. The specific material properties of mineral soda glasses and plant ash soda glasses may help isolate characteristics that are different enough so as to make one technology more appealing than another.

Perhaps the very first indication that a technological transformation of glass was occurring is the reduction in the amount of the soda that was used to make a glass. This pattern has been observed twice, first in the 1st-4th centuries CE (Fischer and McCray 1999) and then in the 6th-8th centuries CE (Henderson 2002: 601). Evidence indicates a reduction in the soda content of glass may be associated with differences in the working properties of glass, and technological change in some cases is therefore perhaps a response to changes in glassworking needs and techniques.

One example of this comes from Sepphoris in Israel, where the glass that was used to produce cast vessels in the Hellenistic and Early Roman period had a median soda content of 19.0 wt% Na_2O, while the later blown glass contained only 14.5 wt% Na_2O (Fischer and McCray 1999: 899). Because glass with a lower soda content has a higher melting point, "it would not appear to be in the glass worker's best interest to use a composition which raise the temperature of the various working operations by about 100 ºC, as this would have required a greater consumption of fuel" (Fischer and McCray 1999: 904). However, a reduced soda content could have been thought beneficial: 1) it made the glass more viscous and therefore better suited for the technique of blowing rather than casting, and 2) the soda supply could be stretched and used to make more glass, although more fuel would have been necessary to melt a glass with a lower soda content, fuel was probably considerably cheaper and certainly more readily available than as imported mineral soda.

The second episode of soda reduction has been observed in glasses dating to the 6th-8th centuries CE (Freestone *et al.* 2000; Henderson 2002: 598). For example, the mean soda content is 16.5 wt% Na_2O in glass from Dor and 15.2 wt% in glass from Apollonia, while it is 12.1 wt% at Bet Eli'ezer and Ramla (Freestone *et al.* 2000: 72). Contemporary glass from Fulda (Germany), Lorsch (Germany), and Zalavár (Hungary) also shows a reduction in the soda content, as compared to earlier Roman glasses of the region (Wedepohl 2010: 63). However, the reduction in soda was not uniform across the Mediterranean: while some 8th-9th century CE glasses in France and Egypt have 17.0 wt% Na_2O (Foy *et al.* 2003),

The reduction of the soda content in Late Antique and Early Medieval glasses is believed to relate to an increasingly limited availability of mineral soda being exported from Egypt (Wedepohl 2010: 63). A lower soda content in glass means that a higher melting and working temperature must be reached, which thus requires more fuel; an increased melting point also means a more viscous glass (i.e., more resistant to flow), making it somewhat more difficult to blow and giving it a shorter working time (Henderson 2002: 598). These "disadvantages" seem like they would be strong deterrents to using less soda during glass production. However, perhaps this is a case where some performance qualities are more important than others; "not uncommonly, technical choices have polar effects: some performance characteristics are enhanced while others are degraded" (Schiffer and Skibo 1987: 599).

It should be remembered that performance characteristics extend to the entire glass industry, rather than only being a characteristic of the material itself. With this point in mind, "perhaps the *scale* of production dictated that a larger volume of glass needed to

be produced, rather than a smaller volume with a higher soda level and lower melting temperature" (Henderson 2002: 598). It has been estimated that a 20-25% relative reduction in the mineral soda content of the batch would allow a 20% increase in the quantity of glass for the same quantity of alkali (Freestone *et al.* 2000: 72). Perhaps an increased output of raw glass was more important than the consequence that glass would be slightly harder to work with because of its shorter working time. The advent of the huge tank furnaces beginning in the 4th century CE would certainly seem to indicate that the scale of production was an important consideration in the Late Antique-Early Medieval period—perhaps more important than other aspects of glass such as specific working properties.

If the reduction of soda contents began to take place in the 6th-7th centuries CE, then it apparently took almost 200 years before "a solution to the consequent ever-increasing glass melting temperature was found," e.g., replacing mineral soda with plant ash soda (Henderson 2002: 598). Glassmakers possibly begin to use plant ash as an alternative soda source because it was more widely available, certainly renewable, and in all likelihood much cheaper than importing a highly sought-after and possibly limited supply of mineral soda. Moreover, the melting temperature of glass made with plant ash soda is lower than that of glass made with mineral soda; although the soda content of plant ashes is lower than that of mineral forms like natron or trona, plant ash contains a significant amount of another form of alkali: potash. Glass made with plant ash soda would actually result in an *overall* increase in alkali content—and thus a lower melting temperature.

The lower melting temperature of plant ash soda glass would therefore result in lower fuel consumption during the production process. This introduces the idea of technological competition, in which "two or more specific technologies compete for applications" within an arena (Schiffer and Skibo 2001). Technological competition might involve an entire technological system or single parts of those systems; many long-term changes in technology ("but certainly not all") result from technological competitions, or are "embodied" in such competitions (Schiffer 2001: 215). The co-existence of both mineral soda and plant ash soda glass technologies, and the gradual replacement of one by the other, suggests that there was indeed an element of technological competition taking place. However, whether individual glass producers (craftsmen, workshops, or regions) were in intentional competition with other producers, and the identity or motivations of the competing glassmakers, is difficult to access.

'Abbāsid Revolution

The 'Abbāsid period was one of significant innovation in which there were advances in the arts, sciences and scholarship, agriculture, and commerce—especially during the rule of caliph Hārūn al-Rashīd and his son al-Mamun in the late 8th and early 9th centuries CE (Henderson *et al.* 2009: 414). In this period, there was an enormous increase in the demand for consumer goods, "arguably not seen since Rome in its heyday," and an associated growth of a merchant economy (Walmsley 2000: 343). The ceramic repertoire dramatically changed in the late 8th-early 9th century CE as well: "until then Early Islamic pottery barely deviated from prevailing Late Roman/Late Antique ceramic traditions, and even new ceramic types […] were produced utilizing existing

potting techniques," so changes in the ceramic assemblage was the "first significant break with the past following the Islamic conquest" (Walmsley 2000: 329). A number of new technologies also emerged during the 9th century CE, embodying a sort of "industrial revolution" (Henderson *et al.* 2005: 143). These include the introduction of lead glaze and tin glaze (Hallett 1996; Mason and Tite 1997), luster glass and pottery (Pradell *et al.* 2008a, 2008b, and 2008c), lead-silicate glass—and the reintroduction of plant ash soda glass production to Syria-Palestine. The movement of people, raw materials, finished goods, and ideas throughout the Islamic world was likely a great impetus and mechanism for the "revolutionary" character of this period.[17]

The city of Raqqa is important for this study not only because it was a site of glass production and experimentation, but also because glassmaking was just one craft of many taking place within a large industrial complex, which has evidence for overlapping and newly created technologies.

> By the early 9th century only Baghdad was larger than al-Raqqah-Rafiqa, and like Baghdad the influx of state funding creating an economic powerhouse of centralized production, consumption and commerce, the benefits of which radiated throughout the region. (Walmsley 2000: 301)

A 2-3 km long industrial "corridor" was built by Hārūn al-Rashīd after he moved his capital to Raqqa in 796-808 CE. This industrial area was engaged in the production of glazed and unglazed ceramics as well as raw glass and finished glass objects, and these industries produced goods for both local and regional consumption. Raqqa-Rafiqa

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[17] An example of this process in action is the production of lusterware ceramics: in the 10th century CE high-quality lusterwares were being produced in Iraq, and "this knowledge transferred to Egypt with the migration of potters from Iraq," and then to Syria, Iran, and Spain in the 12th-13th centuries CE (Pradell *et al.* 2008b: 2661).

included two major urban centers as well as a palatial complex, and thus had a very large population (Henderson *et al.* 2005: 142).

Analysis of the glazed ceramics produced in Raqqa has also shown that the city was a unique center of production with its own set of glaze technology, with a chronology of development that appears to have been independent from other sites of ceramic production like Basra or Baghdad; this distinctive nature likely "stemmed from Raqqa's border location, which resulted in a multicultural workforce capable of technical experimentation" (Borregaard 2008: 1). The very location of Raqqa is thought to have created favorable conditions for creativity, being at a strategic point in the landscape that connected regions and peoples and thus enabling the city to become an artistic link between different cultures (Meinecke 1991: 18): "a melting pot of technological influence from China to the Byzantine Empire" (Borregaard 2008: 1).

Three types of glaze were used in ceramic production at the Raqqa (alkali, lead-alkali, and high lead glaze), which may correspond to the multi-cultural character of the craftsmen (Borregaard 2008: 8). There are also different kiln types present at the site, which also supports the idea that a multi-ethnic community of potters is responsible for the diversity of the technology at the site: "the two unusual circular kilns Henderson *et al.* (2005: 139) describe could be Greco-Roman style kilns connected to Byzantine artisans or prisoners of war" (Borregaard 2008: 9).

Raqqa is one of the earliest sites to produce high lead tin-opacified glazes (Borregaard 2008: 13), which might be a direct result of the close connection between the various craft industries within the industrial complex. For example, a coin mint was in operation during the time of Hārūn al-Rashīd: "the mint would have utilized a lead-silver

ore, producing quantities of lead as a byproduct of silver cupellation that could then be used for glazes," and there is an intriguing correlation between the period of occupation of the mint and the production period of ceramics decorated with lead glaze and luster (Borregaard 2008: 14). Glazes are like glasses in that they are primarily composed of silica, lime, and an alkali, so innovation in vitreous technology becomes less of a hypothesis and more of a real possibility.

Another intriguing idea is that like the potters, the glassmakers at Raqqa were also of a multi-ethnic background. It is clear that the population living at Raqqa-Rafiqa came from virtually all over the Islamic world. There was a substantial presence of Khurisanian troops stationed at Raqqa, "who probably created a massive demand for pottery and glass;" in addition, Hārūn al-Rashīd's far-reaching influence "ensured that artisans with a range of experience and skills together with exotic or unusual raw materials could be imported from thousands of kilometers away" (Henderson *et al.* 2005: 142). It has been proposed that potters from al-Basra in southern Iraq were working in Raqqa, and "it is not unlikely that Hārūn al-Rashīd ordered the transfer of whole workshops to al-Raqqa in order to provide everyday and luxury wares for the new inhabitants of the palace compounds" (Heidemann 2006: 40)

Again, it is intriguing (and not impossible) to suggest that the same was true for glassmakers. If some of the craftsmen came with the army from eastern regions, they may have brought their craft knowledge of plant ash sodas with them and begun experimenting at Raqqa with local materials; Raqqa was located near the Euphrates River valley and within a limestone steppe region "which provided a natural source of clay, quartz, sand, and plants suitable for large-scale pottery and glass production" (Henderson

et al. 2005: 143). High quality raw materials were available at the nearby Jabal Bishr, which was known to have "fine white sands" (Heidemann 2006: 40-41). In addition, eastern craftsmen could have interacted with craftsmen from the Syro-Palestinian region who were either local residents or prisoners of war. Although much of this is speculation, these scenarios are certainly not impossible and could potentially help explain the developments in glassmaking technology that we see in the mid-9th century CE in a way that does not rely exclusively on economic and political causation from Egypt as an impetus for innovation.

The experimentation in glass and glazing technologies at Raqqa might be interpreted as a mechanism for a total reorganization of the industries in terms of both resource type and demand. Both plant ash soda glasses and lead glazes have relatively low melting points (or "maturing points" in the case of glaze), "creating a lower demand for valuable fuel" (Henderson *et al.* 2005: 143). This performance characteristic is extremely significant within a semi-arid to arid larger regional landscape, as this would make it highly competitive with mineral soda glasses and thus create favorable conditions for technological change.

Understanding Plant Ash Soda Fluxes

The model of glass production put forward by Henderson, in light of his work at Raqqa, is that in the early medieval period a number of centers manufactured glass using locally occurring raw materials. "A logical explanation for apparently localized variation in Islamic glass compositions would be the exploitation of locally occurring species of *Salsola* and *Hammada* plants" (Henderson 2004: 118), and this would also explain why

European glasses were made using a potash flux: woody ash was locally available whereas halophytic shrubs were not. Mineral soda glasses were still being made into the 9th centuries CE in the Levant and Egypt, and these glasses were probably mixed with new plant ash soda glasses until the 12th century CE (Henderson 2004: 118). This same practice seems to have occurred in Europe, as contemporary glassmakers blended traditional soda lime glass with the newly produced wood ash glass (Krueger and Wedepohl 2004: 94). Glass fragments and production debris from a 12th century CE workshop in Murcia, Spain, show that glasses in al-Andalus were made also with plant ash soda as a flux, although this glass has higher soda, magnesia, and alumina contents than do contemporary Syrian and Egyptian glasses (Carmona *et al.* 2009), which also supports the idea of more regional networks of glass production around the Mediterranean. In effect, "the adoption of local raw materials in place of natron meant that the management of the entire production cycle became gradually autonomous, at different speeds and in different ways, during the course of the Middle Ages" (Saguí 2007: 211).

Plant ash is much more complex than the mineral form of soda, because with an organic material there are myriad possible variables and variable combinations that may affect the resulting chemical composition of glass: the precise species of plant, the soil and ground water environment and specific climate in which the plant grows, seasonality and the stage of the growing season at which the plant is harvested, mixing different plant species, and the method of burning and purifying the ash, to name but a few factors. Barkoudah and Henderson give a succinct overview of the main research problem scholars therefore face when studying medieval period glass: 1) we have scant

information about the chemical composition of halophytic plants, 2) we know little about the compositional variation of the same plant growing in different regions and environments, and 3) we do not know how easy it is to relate plant ash composition to plant ash glass composition (2006: 298).

Plant ash soda glass is much more complex than mineral soda glass. Up to 40% of a glass may derive from the plant ash:

> Whereas mineral soda typically contributes less than 25% of a glass composition and is essentially a dilutent of the silica-bearing component, plant ash is a complex material, carrying many minor and trace elements at similar levels of abundance to the source of silica (Freestone 2006: 212).

In addition, it is "still not entirely clear how the composition of the final glass plant ash corresponds to that of the raw material batch" (Freestone 2006: 212). Wood ash glasses from Medieval Europe are better characterized than plant ash glasses from the Near East, and studies of the former show that there can be a very great compositional range for the same species of tree, depending on the part of the tree that was ashed and the geology of where the tree grows (Sanderson and Hunter 1981), as well as the temperatures that are used (Mahendra *et al.* 1993). Complicating the situation, the *Chenopodiaceae* family has some 1300 species in 120 genera and is found in desert and semi-desert regions around the world (Tite *et al.* 2006: 1285). Although scholars typically discuss *Salosa kali* as probably the most common plant used as a sodic flux, recent work has shown that glassmaking and other industries probably did not exclusively rely on salt flat vegetation of desert and coastal regions (Iluz and Amar 2008: 88). In addition, the location of the vegetation and the time of year it was picked is apparently another very important consideration; for example, studies have shown that *Salsola kali* and *Parietaria judaica* (a.k.a. "wall pellitory") contain higher amounts of alkaline material when they grow near

walls or rocks and are gathered during the early summer months (Iluz and Amar 2008: 88).

Strontium isotopic analysis has been proposed as a method for distinguishing the primarily production zones of plant ash soda glasses (Henderson *et al.* 2009). However, more recent studies show that this method is not actually able to determine the specific geographic or geological region of the plants. Strontium is not only, "or even mostly," a function of the local geology of the environment in which the plant grows. Rather, the strontium level:

> is highly likely to be both plant species dependent and dependent on the small-scale hydrology of the area immediately surrounding the plant. In this way, no definite relation between the isotopic composition of a geological outcrop and the plants growing on this bedrock can be inferred. (Degryse *et al.* 2010b: 3129)

Although this suggests that plant ash glasses cannot be ascribed to a particular region based on geology, the authors do note that plant ash soda glasses can still be compared, and they encourage a consideration of strontium isotopic ratios patterns in time and space as another means of discussing technology and production (Degryse *et al.* 2010b: 3129).

SPECIFIC HISTORIES: AN ARCHAEOLOGICAL CONSIDERATION

Although the primary discussion has focused more on issues of glass typology and chemistry, it should not be forgotten that these samples are important not only for the insight they provide into the changing "nature and culture of glass," but also because they derive from archaeological excavations rather than museum collections. As such there is a site-specific history associated with these artifacts—a history that can further contextualize the observations made in this study, and a history that can be in turn enhanced by a thorough consideration of the glass finds.

Although further excavation is needed, it is currently hypothesized that settlement at Ḥiṣn al-Tīnāt included a fortified structure surrounded by an unwalled coastal port during the Early Islamic period (Eger 2010: 62). Although the fortified structures within this frontier region (*thugūr*) probably did have a deterrent or defensive function against the Byzantines, research at Ḥiṣn al-Tīnāt and other Early Islamic sites in the region suggest they served primarily as waystations and should be thought of as part of a connected system rather than lone military outposts (Eger 2010: 73). The sheer amount, range, and value of the Early Islamic pottery at Ḥiṣn al-Tīnāt is indicative of the broad economic and cultural connections of the site during this period (Eger 2010). Imported pottery and glass shows that the site was trading mainly with the central ʻAbbasid lands during the 8th-10th centuries CE (Eger 2010: 67). The ceramic evidence includes three main types: glazed wares, brittlewares, and creamwares. The glazed wares include types produced locally as well as imports from Syria, Iraq, and Palestine;[18] cooking pots include the "holemouth" brittleware that was mainly produced in Cilicia and Syria (near Ḥaleb/Aleppo, Afāmiyya/Apamea, and the zone between Antākiya/Antioch and Tarsūs), as well as buffwares from Jordan, Iraq, and Antākiya/Antioch.

During the Middle Byzantine period another fortified structure was superimposed on top of the Early Islamic remains, measuring 25m x 25m with stone walls and buttressed towers in the corners cutting into earlier 9th-10th century CE architectural remains. Smaller internal walls within the structure divide the various rooms, and were

[18] These include "Syrian yellow wares" dating from the late 8th-early 9th centuries CE and known from (and probably produced in) the Balikh Valley and Antākiya/Antioch; "mustard and cress wares" dating to the 9th century CE and known from Syria (Afāmiyya/Apamea, Raqqa, and Bālis) and Jerusalem; "green and white wares" and lusterware dating to 9th-10th centuries CE Iraq; and widespread polychrome splashwares dating to the 9th-10th centuries CE (Eger 2010).

either built above leveled 9th-10th century CE walls or parallel and beside these. Material culture evidence is confined to the levels above the burning layer within the walled structure itself as well as in refuse pits outside the walls (Eger 2010: 67). Ceramic remains date to the 10th-early 12th centuries CE and also consists of both local and imported pottery, including several varieties of polychrome splashwares, manganese-glazed brittlewares, and brownwares. Large quantities of iron objects suggest there may have additionally been manufacturing of, or trade in, iron during this period. Faunal evidence from Phases II and I shows a significant presence of pig from contexts inside the fortified structure, with an age pattern and butchery marks that typify a herd managed for meat production (Eger 2010: 65); this may be regarded as evidence that the population at this time were not predominantly Muslim and contributes to the identification of this phase as Middle "Byzantine" rather than Middle "Islamic."

The location of Ḥiṣn al-Tīnāt on important land and sea trade-routes combined with the variety, value, and wealth in the range of artifacts—in particular the presence of high-quality fineware ceramics and imported glass—during the entire 8th-12th century CE period suggests the *thugūr* should be considered a complex zone of interaction, exchange, and competition rather than a militarized no-man's land (Gerritsen *et al.* 2008: 274; Eger 2010: 73). The material culture assemblage shows that while there was a strong tie to the local landscape, the *thugūr* took part in wider social and economic networks even during periods of shifting borders and military conflict. Glass and ceramic evidence confirms that during Byzantine political control of Antioch and Cilicia (beginning in the mid-10th century CE), this area maintained close trade links with the caliphal territories (Vorderstrasse 2004). At Ḥiṣn al-Tīnāt, "trade networks with Iraq and Egypt continue

throughout the site's history, implying connections between 'Abbasid central lands and the frontier and a Levantine Mediterranean maritime system of exchange" (Eger 2010: 73). Even when the Amuq Valley and Antioch were under the political control of the Byzantines or the Franks, culturally "the region has much in common with the areas that were under Muslim control," as "the material culture of the Middle Byzantine period shows very little sign of Byzantine influence" (Eger in Gerritsen *et al.* 2008: 274). The material culture of Ḥiṣn al-Tīnāt is considered to be culturally "Syrian" rather than "Anatolian" throughout the site's history (Asa Eger, personal communication).

Although larger in size than Ḥiṣn al-Tīnāt, "Ayla appears only incidentally in the early Islamic narrative sources, and then only as a result of its important position in the overland trade and pilgrimage routes between the Hijaz, Egypt, and Syria" (Cobb 1995: 418). This strategic geographic position certainly played an important role in the history of the site. The "growing commercial prosperity of the city in this period [8th-10th centuries] is unmistakable from the excavated material culture" (Cobb 1995: 421), and this is consistent with the observations of geographers and travelers to the city during the 10th century CE who painted the city as a busy and thriving port and hajj-station: Ayla was the "port of Palestine and storehouse of the Hijaz" according to the late 10th-early 11th century CE geographer al-Maqdisi (Cobb 1995: 419).

From 'Abbāsid Revolutions to Fāṭimid Connections

Alan Walmsley has observed that the early 9th century CE Near East was characterized by a major growth and expansion of commercial activity, "and quite possibly this growth was accompanied by significant changes to the existing trade

networks" (Walmsley 2000: 319). This is indeed the case for the glass industry, as new producers and raw material sources seem to have enabled the gradual replacement of the centuries-old mineral soda technology with newly emerging plant ash soda technology. In addition, "new commercial opportunities arose with the creation of huge urban markets in al-Iraq and the Jazirah, and resulted in the formation of enlarged and increasingly direct trade links with non Muslim territories" (Walmsley 2000: 319). This is also visible through a consideration of glass interaction zones, as the evidence from Ḥiṣn al-Tīnāt clearly shows that trade with Islamic world continued even after the region fell under the sway of the Byzantine Empire. If the 'Abbāsid period was one of commercial innovation and increased production, the Fatimid period was perhaps one of market expansion. Great expansion in Mediterranean trade took place in the 10th century CE; "although the Fāṭimids were not actively involved in directly bringing about this expansion, the attitudes and polices they adopted were instrumental to further the development of trends that already existed" (Lev 2009: 121).

Perhaps the most poignant testament to an "increasingly direct trade links with non-Muslim territories" is again the 11th century CE Serçe Limanı shipwreck. Ancient shipwrecks beg the question of origin, route, and destination. Typological and chemical study has proven that the glass cargo of the ship was made in a single workshop or a few very closely related workshops in the Near East, and the assemblage has close parallels in terms of both vessel shapes and decoration to Islamic glass objects from Tunisia, Egypt, and Persia. While glass objects made up the bulk of the cargo, the ship was also carrying pottery (Figure 7.21), metalwork, jewelry, wooden items, weapons, wine, millstones, orpiment, and probably perishable goods as well (Jenkins 1992: 56). From the materials

Figure 7.21: Objects recovered from the Serçe Limanı shipwreck: glazed Islamic ceramic bowls and Byzantine wine amphorae (images from the Institute of Nautical Archaeology's website: http://inadiscover.com/projects/all/southern_europe_mediterranean_aegean/serce_limani_turkey/full_report/).

onboard, it has been concluded that the ship took much if not all of its cargo onboard along the Levantine coast, most likely at Caesarea or Beirut (or perhaps both).

Similarities between jewelry, copper buckets, glass, and ceramics found at Caesarea and Serçe Limanı suggests the former may indeed be the port where goods were taken onboard the ship (Bass *et al.* 2009: 503). Ten champlevé glazed ceramic bowls from the wreck are typologically identical to 11th century CE ceramic vessels excavated at Caesarea Maritima, and petrographic analysis has suggested an Egyptian provenance for both groups of artifacts (Jenkins 1992: 61). It should also be recalled that the glass cargo is chemically similar to glass samples from Caesarea. Palestinian cookware and millstones, orpiment, and seeds from grapes and sumac were on board; this is all indicative of a Syrian origin for most of the cargo, as Syria was renowned for dried fruits and agricultural products, and orpiment is a Syrian mineral (von Doorninck 1990: 61). Some 110 piriform amphorae, a common 9th-11th century CE Byzantine type were also on board; von Doorninck notes that these amphorae may have been reused as transport jars for Syrian wine (1990: 61). There also appears to have been "a strong Bulgarian ethnic

presence on the ship," as excellent parallels for shipboard tools and weapons from Bulgaria, and many of the amphorae "have marks of potters and owners that as a group have been found only in medieval Bulgaria" (Bass *et al.* 2009: 3).

All this evidence—the cargo from Syria-Palestine or even Egypt, the location of the shipwreck, and the material connections to the Byzantine world—strongly suggests that the Serçe Limanı was transporting items picked up from the Islamic regions to western Black Sea region, most likely en route to a home port near Constantinople (von Doorninck 1990: 62). This port was probably in the general area of Rhaidestos along the northern shore of the Sea of Marmara; this interpretation is further supported by chemical analysis of some of the Byzantine amphorae that indicates clay from this region, and from analysis of lead objects that shows it came from lead mines in eastern Rhodope mountains of southeastern Bulgaria (Bass *et al.* 2009: 3).

In the mid-1980s the Incirli Limanı "glass shipwreck" was discovered near Mamaris, some 30 km to the east of Serçe Liman. Although this shipwreck has not been excavated or salvaged, it also appears to have been loaded with Byzantine transport amphorae and orpiment, as well as with raw glass, glass waste, and glass cullet (von Doorninck 1990: 62); the similarity in the types and decoration of the glass fragments may make it contemporary to the Serçe Limanı ship and possibly coming from the same glassmaking region (Pulak 1985: 39-41). A late 9th-late 10th century CE ship loaded with Byzantine transport amphorae and intact "probably Levantine" glassware also sank near the island of Mljet off coast of Yugoslavia (Han and Brusic 1978). These other shipwrecks suggest that trade between the Islamic and Byzantine regions was healthy and rather extensive. Cullet was clearly an important commodity in the 9th-11th centuries CE.

This makes sense, as "factories importing cullet could make do with smaller, less-sophisticated furnaces and had lower fuel costs, since the melting of glass requires a lower temperature than does the making of glass" (von Doorninck 1990: 63). There may be evidence of cullet from the same source being imported to Dvin in Armenia (Janpoladian 1974: Pl. III, nos. 42 and 48), and there is evidence of Fāṭimid-period glass from the Levant being used in a workshop in Preslav, Bulgaria (Djingova and Kuleff 1992).

Another fascinating aspect of the glass-related cargo of the Serçe Limanı ship is that the glass cullet was not the only ballast. Von Doorninck has interpreted the glass baskets to have been stored in the "after third of the cargo hold of the ship, probably arranged in four rows between frames 4 and 12 of the hull," so "in order for the ship that carried all this glass to have sailed safely trimmed, it must have carried in the forward part of its hold additional ballast that left no trace" (Bass *et al.* 2009: 500). Bass suggests that this "ghost cargo" may have been plant ashes from the Levant, and documentary sources dating to a slightly later period would certainly support such a possibility. Glass factories in Venice and the neighboring mainland are known to have heavily imported Levantine soda ash (especially high-quality Syrian ash) to supply their thriving glassmaking industry during the 13th-15th centuries CE (Ashtor and Cevidalli 1983; Jacoby 1993), and "because these ashes were heavy and bulky, and because Venice needed large quantities of them, they were used as ballast to balance the cargo of the Venetian cogs returning from Syria with cotton. For this reason, they were transported at low cost" (Jacoby 1993: 68-70). In ca. 985 CE the Arab geographer Muqaddasi mentions *kali* as an export of Aleppo (Barkoudah and Henderson 2006: 299), while later

documentary evidence from Italy shows that Venetians in the 12th-14th centuries considered plant ashes from the Syrian region to be of the highest quality (Ashtor and Cevidalli 1983; Jacoby 1993): "decrees of the Venetian authorities were quite specific about the parts of the Middle East from which plants could be imported," suggesting that the quality of ashed plants in part related to the geological zone in which plants grew (Barkoudah and Henderson 2006: 300). As trade between the Muslim world and Italian merchants has been attested in the 10th century CE, it may indeed be appropriate to extend the trade of Syrian plant ash back to earlier periods as well.

The Serçe Limanı shipwreck is an important piece of evidence for this project not only because it provides information about the scale of use of recycled glass in the glassmaking industry, or because it can provide valuable typological and chemical glass comparanda, but also because it provides insight into the social and political realities of economic networks of the period. The Near Eastern world of the 11th century CE was divided between the Byzantine Empire and the Fāṭimid Empire, the former based in Constantinople and controlling southern Italy to the Caucasus and from the Danube to Antioch,[19] and the latter based in Cairo and controlling North Africa and the Levant until a point just south of the city of Antioch in Syria. A Peace Treaty was concluded between the Byzantines and Fāṭimids in 1027 CE; this treaty and the fact that ships were plying the seas carrying a cargo of Islamic glass from Fāṭimid lands westwards to the Byzantine region has been considered proof that the early 11th century CE was a time of improving relationships between the two powers (von Doorninck 1990: 58).

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[19] This was the greatest territorial extent of the Byzantine Empire since the Arab conquests 400 years previously; this also notably includes Bulgaria, which was outside Byzantine control (part of the First Bulgarian Empire ca. 681-1018 CE) until Byzantine emperor Basil II began fighting wars to reclaim the region ca. 1000 CE.

CHAPTER EIGHT: CONCLUSIONS, REFLECTIONS, AND FURTHER RESEARCH

INTRODUCTION

"Glass" is a single word, but one that embodies many aspects and concepts: it is a type of material but it is also a type of object, and there are a variety of other materials, techniques, and networks involved in the creation of both these things (i.e., glass as a material and glass as an object). As such, glass can prove to be a very complex subject for research, which is perhaps why it is often reduced to a study of its individual parts: as a material (investigated scientifically), as an object/artifact (investigated artistically), and as a network (investigated anthropologically—or socially, politically, economically, etc.).

Even if it is not possible to accomplish a full or unified consideration of glass, it does need to be recognized that there is a connection between "the nature and culture of glass." There are intimate links between glass technology and glass artistry, and these directly relate to the structure, properties, and processing of glass. Although the glass industry was divided into specializations (e.g., primary, secondary, and tertiary stages), changes in aspects of any of these three stages would have had a direct and possibly powerful influence on the other stages. This structure-properties-processing concept can thus be extended to serve as a metaphor or thinking tool for the entire interrelated glass system or network. For example, in viewing raw glass production as a network, we can start to think about the *structure* of this network in terms of supplies and supply chains

(the location of the various raw ingredients), the *properties* of this network in terms of time and efficiency (how long it takes to gather raw materials, produce glass, and distribute it to secondary workshops), and the *processing* of this network in terms of technologies and techniques (how the materials have to be prepared and treated during the melting and refining stages; the very actions and procedures). While such theoretical considerations are potentially enormous in scale and complexity—and therefore probably unmanageable beyond a theoretic level—it is useful to remember that "glass" extends far beyond the raw material or finished object itself.

It is in the glassmaking *flux* that we find an important key for understanding the links between the nature and culture of glass, as well as the changes that took place over the course of glassmaking history. In short, if the fluxing agent used to make a glass changes, then the other raw materials inevitably change as well—as do the working properties and processing characteristics of the material and the object, and therefore the various networks that are in place, particularly economic networks. Although the title of this project refers specifically to this notion—that it is within the flux itself that we must look for and understand the nature and culture of glass—it also alludes to the dynamic history of glass and emphasizes that the materials, objects, and technologies of glass were never entirely static. That the fluxing agent used in glass production is termed the network "modifier" is certainly an accurate description on many different levels.

SUMMARY OF THE QUESTIONS, THEMES, AND FINDINGS OF THIS PROJECT

Almost 50 years ago, Sayre and Smith (1961) outlined some of the chemical characteristics that distinguish various groups of ancient glasses, highlighting the fact that

glass technology changed throughout the course of history and often in significant ways. In particular, their paper underscores the technological differences between Roman and Islamic glass, the former type being made with mineral soda and the latter with plant ash soda, thus indicating that the changes to the alkali flux also represent technological breaks with earlier glassmaking traditions. While it is tempting to discuss glass history in terms of "Roman" mineral soda technology and "Islamic" plant ash soda technology, the technological history of glass cannot be neatly placed into culturally-specific chemical categories; such practice sustains a false dichotomy that limits our understanding of the intricacies of glassmaking in the ancient world.

Early Byzantine and Early Islamic glasses were not considered in Sayre and Smith's early chemical studies, but in the last 20 years or so researchers have noted that the late first millennium to the turn of the second millennium CE was a subtly-complex period of glassmaking history. Glass of the Early Byzantine and Early Islamic periods continued to be made using the basic raw materials, techniques, and industrial structure of the preceding Roman industry. In the mid-9th century CE, however, these things noticeably begin to change. Plant ash soda fluxes were increasingly employed and by the 11th century CE had entirely replaced mineral soda. Similar patterns are visible in the Western Mediterranean and also in Europe, where glassmakers north of the Alps began using wood ash as a flux to make glass, probably due to the lack of suitable local plant species.

Only in the last decade have researchers really paused to ask *why* glassmakers changed their raw materials, and political and environmental factors are the two most popular current explanations. This is important, because "the stories we tell about

technology reflect and can also affect our understanding of the place of technology in our lives and our society" (Bijker 1995: 1)—and apparently in our history as well. That the Late Antique and Early Medieval glassmakers and glassworkers were the inheritors of a glassmaking industry is not in question. The underpinnings of the glass industry were established during the Roman period, with the post-Roman glassmaking successors making use of traditional raw materials, sources of supply, techniques, and networks of production and consumption for a long period of time. What is questionable is the idea that a disruption to one source of raw materials due to political or environmental factors was enough to bring this tradition to a resounding end. The glass industry had survived countless invasions, wars, and cultural/political ups and downs over the centuries, so it is somewhat difficult to believe that the civil wars of the 9th century CE in northern Egypt were truly any more significant in terms of their impact on the glass industry.

For some 200 years after the Arab armies conquered the glassmaking regions of the Near East there was continued stability in glass technology and artistry. When glass began to visibly change in the mid-9th century CE, there was then another 200-year period of overlapping techniques and regional differences that likely had much to do with material and social changes, rather than political events and economic factors exclusively. The most likely explanation for these developments is that is was another effect of the burst of innovation and activity embodied by the so-called 'Abbāsid Revolution. The working properties of glass—not just of the material but also of the entire glass system of production—were clearly being negotiated by glassmakers at this time, and these changes may possibly be linked to experiments in the efficiency or the ability to control glass production at a more local level (in terms of the supply, access,

and cost of fuel and soda resources). The changes that glass production was undergoing at this time might also be indicative of broader stabilizations that took place as the Islamic elites gave a material definition to their territory, heritage, and identity.

The very chronology of glass production indicates that artistic and technological changes came about "not because of the intrusion of new cultural factors such as Islam, but because of the breakup of a former cultural unity, that of the decaying Roman Empire, and the isolation of the new cultural entities from each other" (Allen 1989: 238). The year 900 CE has been put forward as a defining moment in Islamic art history:

> By the end of the 9th century, most of what Romania had to offer them had been internalized […] after that time, a distinct and integrated Islamic culture began to develop, one which would generate its principal problems and solutions from within its self; within the perspective provided by the evolution of the Islamic world, then, the year 900 is perhaps the most satisfactory point at which to set the end of antiquity. (Allen 1989: 15)

Although Allen is specifically referring to Islamic art history in this passage, his theories fit with the larger cultural history of the Near East as similar developments were taking place for the other inheritors of the post-Roman world: Byzantium and Western Europe. This assessment of larger art historical trends also serves to illustrate that the 9th century CE was indeed a moment of significant change not only for technology, as might be suggested merely by looking at the details of glass chemistry, but also for other aspects of society and culture.

Ḥiṣn al-Tīnāt and Ayla were founded in the Early Islamic era and both were occupied during the 8th-12th centuries CE, the critical period in which glassmaking fundamentally changed in terms of technology (glass began to be made using plant ashes), industry (glassworkers may have relied less on traditional economic networks), and artistry (glass became much more regionally and culturally distinct). Although both

Aqaba and Ḥiṣn al-Tīnāt were port cities, they had very different histories due to the fact that the former was located in the heart of the Islamic territories, while the latter was on the northern Islamic-Byzantine frontier and spent half of its history under Byzantine control. Similar glass types (typological and chemical) were found at both sites over multiple periods of the sites' occupation, but we also see an indication of increasing technological, artistic, and economic independence in the form of new sources of raw materials and raw glass, new producers, and new glass interaction zones.

In the 8th-10th centuries CE Ayla obtained glass from all over the glassmaking world, as represented by the presence of all five known primary production groups of mineral soda glass (Levantine I and II, Egyptian I and II, and HIMT). Only three of these groups ever reached Ḥiṣn al-Tīnāt; as these two sites are both accessible ports, this immediately suggests differences in "glass interaction zones." This difference continues in later periods as well. In the 10th-12th centuries at Ḥiṣn al-Tīnāt there is evidence for new glass types that are not found in regions of the Islamic world; these high boron and high boron-high alumina glasses were likely made in the northern Byzantine regions and apparently were distributed throughout a more limited glass interaction zone than contemporary glasses. The close similarity of certain plant ash glasses at Ḥiṣn al-Tīnāt and Ayla, coupled with the archaeological and chemical evidence from the 11th century CE Serçe Limanı shipwreck, shows that some plant ash glasses were very widely distributed: this particular type was likely made in Islamic regions but was traveling to Byzantine regions as well.

A close study of the glass typology and chemistry from these two sites reveals details about local industries and 'global' trends and styles, as well as about regional

trade and the exchange of products, people, and ideas. While both Byzantine and Islamic glassmakers inherited a unified Eastern Mediterranean tradition put into place by the Late Roman industry, the development of ultimately distinct Byzantine and Islamic industries, markets, and uses of glass began to take shape after the late 9th century CE. That these two entities were going their separate ways is exemplified by the changing perceptions and functions of glass, as well as by the changing nature and supply of raw glass itself: for example, similar bowls decorated with impressed geometric designs were found at both Ayla and Ḥiṣn al-Tīnāt, but painted glass bracelets were only found at Ḥiṣn al-Tīnāt. In addition, both sites had vessels made of raw glass from traditional Egyptian and Levantine sources, but Ḥiṣn al-Tīnāt also had items made of raw glass from a new Anatolian source that became active after the 10th century CE. These examples help to illustrate on the one hand how the Byzantine and Islamic glass industries were becoming more distinct, yet on the other hand how the two regions maintained some commercial and artistic connections despite their different trajectories and outlooks.

SIGNIFICANCE OF THIS PROJECT

That the 8th-12th centuries CE represent a "black hole" in our knowledge and understanding of the history of the Eastern Mediterranean is a situation lamented by archaeologists of the Byzantine and Islamic worlds alike, and one that seems to be common across all forms of material culture and not unique to glass. It is therefore not an overstatement to consider data produced in this dissertation as inherently important, because it provides much-needed information about and interpretation of archaeological material from this hazy 8th-12th century CE period; moreover, this material comes from

two different regions of the Byzantine and Islamic worlds and can thus provide insight into contemporary but culturally distinct sites. If this new group of data is important in its own right because it serves to fill gaps in our knowledge, it is also important for the details it provides about cultural interaction and technological change.

Another way in which this project makes its mark is its insistence on studying typological and chemical data together, rather than privileging one approach over the other. Rigorous art historical and scientific analysis can be effectively integrated with the social and cultural concerns of archaeology and anthropology. Although glass research is typically divided between art historical study (typological analysis) and technological study (chemical analysis), combining these two approaches is highly advantageous because both art and technology involve the application of craft skill to produce an object. Material culture studies and materials science studies fundamentally investigate the same things—the connection between people and objects, the social and the material—albeit from different perspectives. Analyzing materials, material culture, and technology together can access a variety of historical and art historical questions, particularly those concerned with issues of continuity and change.

Although a careful attempt has been made to ensure a balanced consideration of the artistic and technological aspects of the artifacts sampled for this study, there is more emphasis on the chemical data. This is simply because typological information often cannot get to questions of technology: looking at a small, weathered fragment of glass cannot tell you what raw materials were used in the production process. To that end, a significant contribution of this project is its emphasis on the importance of trace elements in archaeometric analysis—the element boron is enough to make this point. LA-ICPMS

has proved to be an invaluable technique for characterizing glass: it has a very high detection limit, making it ideal for quantifying trace elements; it is fast and virtually non-destructive, making it well suited for the analysis of a large number of archaeological samples.

A final way in which this project makes a contribution is that it highlights the reductionist models of technological change that focus on external factors (such as war and climate change) to the exclusion of other possible causes or combination of causes. Questioning these interpretations opens up a dialog about the relationship of structure, properties, and processing on many levels; it also serves to highlight important theoretical considerations gathered from the disciplines of anthropology and materials science (like performance characteristics, the functional field, and possible polar effects—see Schiffer and Skibo 1987); these elements can relate directly to a single element or to combinations of elements that make up something else (e.g., the individual raw materials, the raw glass, or the larger glass production system). There are of course many—and often complex or linked—reasons or mechanisms of technological change. Mannoni (2007) has presented an outline of some possible scenarios for technological change, and it is worth including them here to illustrate the diversity:

- The product is no longer useful
- The product is replaced by another product
- New uses for old products
- Demand for a specific product disappears, causing production to cease or evolve
- New experiments are undertaken
- Irrational ideas inspire change
- Despite the closure of industrial units, technical ability is retained, by re-ordering production
- The organization of production is modified in some other way
- Adoption of techniques from other manufacturing trades or other cultures
- Changes in artistic techniques related to taste

- Subtle changes in overall demand
- Generalized economic collapse
- Limited availability of raw materials
- Limited availability of specialized labor
- Limited availability of unspecialized labor
- Changes in communication needs

Technology is not purely technological, and although the source of flux that was used to make glass is perhaps the most important aspect of glass production, technological change cannot even be reduced to this one element—there was an entire glass system in play, and objects of material culture are inextricably linked to or part of larger social forces: taste, fashion, style, knowledge, trade, diplomacy, warfare, conquest—the list is very long.

FUTURE DIRECTIONS FOR RESEARCH

The fragments studied in this project have highlighted some interesting details and identified intriguing typological and chemical patterns. However, as this study is far from a complete consideration of the glass finds from Ḥiṣn al-Tīnāt and Ayla—nor is it entirely representative in the case of Ayla—there are several specific, as well as some more general, avenues for future research that might be suggested.

Excavations at Ḥiṣn al-Tīnāt continued in 2011 and will again take place in 2012, so the glass finds from these two seasons will need to be examined and included in the overall assessment of the site's glass assemblage; a specialist report will eventually be included in the final publication. The glass corpus from Ḥiṣn al-Tīnāt may seem quite small in comparison with other sites, but the information that has so far been provided by a typological and chemical study has been truly remarkable. The data show continued cultural connections with the Islamic regions even after the site was absorbed into the

Byzantine Empire, and it also suggests fascinating connections to Bulgaria and the rest of Anatolia. Most significantly, chemical analysis of bracelets from this site has confirmed the production of an entirely new type of high boron glass, which may actually involve the exploitation of Anatolian raw materials and thus indicate a Bulgarian, Balkan, or Anatolian origin or production zone.

In order to clarify these observations, more in-depth study is also needed on the glass finds from regions located within the Byzantine and First Bulgarian Empires; in particular, publications of Turkish, Bulgarian, and Greek sites with secure archaeological sequences dating to the Middle Byzantine period should be examined and chemical analytical reports sought. It must additionally be emphasized to researchers that chemical studies of materials from this region should definitely include an analysis of the trace elements: special attention must be paid to the boron, lithium, and strontium contents of glasses from these regions, as well as the rare earth elements. Once there is a larger corpus of chemical data for boron glasses, it can then be addressed whether there are any object-specific patterns. As high boron and high boron-high alumina glasses from Ḥiṣn al-Tīnāt were only used for bracelets, we need to investigate how the production of glass for objects and for jewelry was related: bracelets are small and easily formed, decorated, and transported objects, so it is possible they may represent a unique industry that used scraps of raw or recycled glass from a completely different supply chain.

The Islamic glass assemblage from Aqaba desperately needs a complete study and publication. This glass collection is on par in terms of size and range with assemblages from other major Islamic cities such as Fusṭāṭ, Raqqa, and Nishapur and would thus greatly further our understanding of the characteristics and development of Islamic glass

and glassmaking. As a thriving port city on the Red Sea, Aqaba was at the crossroads of the Near East, connecting North Africa with the Levant and Mesopotamia by land and participating in the Red Sea and Indian Ocean trade; the Aqaba glass is likely therefore to provide additional insight into larger commercial and artistic links in this region and period of time. Although only 144 samples from among thousands of glass fragments is hardly representative, the data presented here do provide tantalizing results: the glass used at Ayla includes all five known production groups of mineral soda glasses, as well as the same plant ash soda glass that was being transported by the Serçe Limanı ship. However, studying the Ayla glass will be an enormous job that could potentially take up to a decade of sorting, recording, cataloging, identifying, classifying, drawing, analyzing, and interpreting.

In addition to these specific site-related suggestions for future research, there are more general aspects that should continue to examined and assessed. Typological analysis of 8th-12th century CE glass from secure archaeological contexts in the Byzantine and Islamic regions must continue in order to fill the obvious gaps in our knowledge. In addition, more Sasanian and Islamic glasses from Iraq and Iran need to be investigated to enable a comparison of plant ash soda glasses in terms of both typology and chemistry. I believe that Mark Wypyski of the Metropolitan Museum of Art in New York City is currently conducting his doctoral research (under the guidance of Ian Freestone) on 8th-12th century CE Islamic glasses from Iraq and Iran, so the results of his work are eagerly awaited.

Glass scholars must also continue to refine the defining chemical characteristics, chronological details, and geographic range of the Levantine I, Levantine II, Egyptian I,

Egyptian II, and HIMT mineral soda glasses. The data from Ḥiṣn al-Tīnāt and Ayla indicate that many of these groups may have also been in circulation during the 8th-10th centuries CE, as well as the earlier periods (5th-8th centuries CE) that are typically acknowledged. There should also be more consideration about how these glass groups compare regionally—this has been started with the contrast of the Levantine I and HIMT glasses, but more such discussions would be interesting. Finally, and not surprisingly, perhaps the most important avenue for future research is the examination of the characteristics, variations, and effects of different plants in the production of plant ash soda glasses, including an examination of exactly how and why Sasanian and Islamic plant ash glasses are different. Important steps in this direction are already being taken, and since 2006 plant ash analysis and plant ash soda glass studies have been very popular. Characterizing and understanding plant ash soda will likely be the most productive and interesting project undertaken by glass specialists in future years, and one day yet we may have established primary production groups with which to compare new data.

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APPENDIX A: GLOSSARY OF GLASS AND GLASSMAKING TERMINOLOGY ("GLASSARY")

Note: the following terms and definitions come primarily from Weinberg 1988 (xiv-xv) and Tate 2004 (242-247), although many of these have been altered and expanded.

Annealing: the process of gradually cooling a finished glass object, by allowing the thicker and thinner parts of the object to cool at a uniform rate, in order to prevent internal strain and cracking.

Base (or *foot*): an addition or extension to a vessel, as opposed to "bottom" (which is the underside of he body).

Batch: the mixture of raw materials—sand-soda, lime, lead, etc.—which are heated together in order to make raw glass.

Bit: a very small gather of glass that is used typically to create additional elements like handles, punts, trails, spouts, etc.

Blob: a small, rounded bit of hot glass that is attached to the exterior surface of a vessel for a decorative effect (also called a *prunt* when it stands proud of the vessel's surface); can be left plain or be manipulated with tweezers, stamped with relief ornament, and inflated by the glassblower.

Blowing: the process of forming an object by inflating a gob of hot glass using a blowpipe—literally blowing air into a gather of hot glass in order to expand it. After forming a bubble, a vessel can then be shaped through a combination of reheating, continued blowing, and tooling.

Blowpipe: a hollow (typically metal) tube used for blowing glass.

Body: the main/largest portion of a vessel (typically between the rim and the foot/base).

Bubbles: air pockets trapped in the glass during the manufacturing process.

Carboy: a bottle with a large volume (~20-60 liters) that is typically used to transport or store liquids.

Coil: see *trail*.

Cracking-off: the process of removing a vessel from the blowpipe, either because the vessel has been completed, or in order to transfer the vessel to the pontil rod for further shaping; the extra portion of glass adhering to the blowpipe is chilled and struck so as to literally crack the glass, and thereby detach an object from the blowpipe.

Cullet: chunks of glass or broken vessels that can be remelted (recycled) to form new objects.

Devitrification: the process of crystallization of a formerly crystal-free glass (i.e. the structure of glass changes from an amorphous to crystalline structure); this typically involves the development of white scum, crazing, or wrinkles in the surface of a glass.

Fin: a small projection in the surface of a glass vessel, typically semi-circular in shape and thin, either horizontal or vertical in relation to the plane of the vessel; fins are formed by pinching or nipping the glass with tweezers or a similar tool.

Foot: see *base.*

Free-blowing: forming glass vessels with the blowpipe, without the use of molds.

Gather (or gob): the mass of molten glass that is taken from a furnace or crucible, using a blowpipe or metal rod (the process is called *gathering*); this gather/gob is then worked by the glassmaker, either to form an object or to add to an object.

Glasshouse: the name of the building or workshop where glass objects are produced.

Iridescence: a common weathering feature, typically very thin and flakey layers of silica that produces shiny, rainbow-like colors. Typically whitish or grayish in background color, but may be black as well.

Kick: the depression that is made in the bottom of a vessel while it is hot; the base is pushed upwards and inwards by the punty or other tool.

Knocking-off: the process of removing a vessel from the pontil rod, after a vessel has been completed; this often results in a *punty scar*.

Lip: the very edge of the rim.

Liquidus: the maximum temperature at which crystals can co-exist with the melt in thermodynamic equilibrium; the liquid is homogenous above this point, while many crystals can form below this point. This point is important for glassmaking, because crystallization can be problematic for glass formation.

Marver: a flat surface of stone or metal on which a gather of glass can be rolled in order to smooth and shape it; glass that has been treated in such a way has been *marvered*.

Moil: the glass that was originally in contact with the lower end of the blowpipe, which becomes cullet after the vessel is cracked-off. Also called *overblow* when referring to the moil produced by the mold-blowing process.

Mold: a form of one or more parts (in stone, ceramic, or metal) in which glass is shaped.

Mold-blowing: the process of blowing a bubble of hot glass into a mold.

Neck: typically present for closed-form pouring vessels like bottles and jugs, the portion above the body and below the rim that is narrowed.

Parison: a bubble of glass formed at the end of a blowpipe, the preliminary shape from which a vessel or other object is then manipulated.

Pontil rod (or *punty*): a solid metal rod to which vessels may be transferred from the blowpipe for further working; this tool is also used to gather hot bits/gathers of glass.

Pontil mark (*punty scar*): a mark left on the bottom of a vessel after it has been knocked-off the punty.

Prunt: see *blob*.

Punty: see *pontil rod*.

Rim: the upper part of a vessel, above the sides/wall.

Slag: waste from glassmaking, including partially-fused or over-flowed glass.

Tank furnace: large, rectangular masonry structure used to melt raw glass from batch, on the order of tons.

Thread: see *trail*.

Tooling: the process of shaping soft glass by squeezing or pressing it with a tool while the object is being rotated on the blowpipe or pontil rod.

Trail: a strip of hot glass that is applied to the surface of a vessel, either to forma handle, coiled foot, or for decorative effect; thin trails are often called *threads* and thicker trails are often called *coils*.

Wall: the sides of a vessel.

Waster: a cast-off object or fragment of an object that was damaged in some way during the production process and is therefore undesirable.

Weathering: (verb) the process of deterioration or decomposition that glass undergoes over time; (noun) the layers that form on the surface of a vessel due to chemical interaction of the glass with the burial environment (the most detrimental aspects being changes in temperature and contact with water). Weathering includes cracking, pitting, and the formation of non-glassy layers. In many cases, the soda content of the glass is actually leached out of the matrix, leaving a silica 'skeleton;' this process first occurs at the surface and proceeds inwards to the core. Common weathering products include filmy substances as well as harder, enamel-like materials; iridescent, white, black, brown, tan, and yellow are all common colors.

<u>Base treatments:</u>

Coiled or trailed: a thread of glass is wrapped around the bottom of a vessel to form a ring on which the vessel rests; may be wound around once or multiple times.

Pad: formed by applying another parison beneath the body and splaying out the edges; the pad may be pushed-in or remain thick and solid.

Pushed-in: the base ring is formed by pushing in the bottom of the parison and folding it; the resulting base-ring may be hollow or solid.

Tubular-ring: hollow ring added to the bottom of a vessel.

Rim treatments:

Cracked-off, or unworked: sharp, unfinished edge.

Ground: cracked-off edge is smoothed by means of grinding it flat with an abrasive.

Folded: rim is turned inwards or outwards while hot, using a tool; the fold may be pressed flat or left rounded to create a hollow tube.

Fire-rounded: the process of allowing a portion of a glass vessel (typically the rim/lip) to heat slightly, so that the glass becomes soft and hard edges become round.

Decorative techniques:

Appliqué: a piece of hot glass that is applied to the surface of an object; a stamped disc, a decoratively-wound thread/trail, and a handle are some examples of what might be considered appliqué.

Enameling: decoration with paints composed of powdered glass and an adhesive, which is applied to an annealed object and then re-fired to fix the enamel to the surface.

Faceting/facet-cutting: a decorative process that is done when an object has annealed and is cold; an abrasive substance is used to grind down the surface of an object to produce a flat and polished area. Facet-cut vessels typically have honeycomb or netted patterns, rectangles, circles, or other geometric shapes. The Islamic molar-flask is a good example of a facet-cut vessel.

Festooning: a decorative technique that involves three steps, first applying multicolored threads of glass around an object, then combing the threads upwards at intervals, and then marvering the object so that the trails become flush with the surface of the object. Small unguent jars from the Late Bronze Age and Hellenistic period are characteristic of this decorative look.

Gilding: decoration with gold leaf, gold paint, or gold dust; the gold is either applied with an adhesive to the surface of a cold glass object and reheated, or it may be marvered directly into the surface of a hot gob of glass.

Luster painting: metal oxides (usually copper and silver) are used to create a colored stain. An object is decorated with this luster paint and then heated in the furnace; the

metal compounds change color because they become "reduced" (all oxygen is burned off), leaving a amber or reddish-brown film that is fused into the glass. "Metallic stain" is the best way to describe this technique when used for glass; in comparison, ceramic objects decorated with a similar technique does produce a lustrous sheen.

Mold-forming: refers either to pressing or slumping warm glass into a mold to create a shape, or to blowing hot glass into a relief mold to quickly create a textured/patterned vessel.

Painting: applied to cold glass, which is left to dry or refired to "fix" the design into the surface of an object; may use paint, metallic stain, enamel, or gilding.

Pinching/nipping: pulling a portion of the surface horizontal away from the body of an object while the glass is still soft, often produces small projecting feet or fins.

Scratching (incising, engraving): the process of incising a design onto the exterior surface of an object using a pointed tool like a diamond; typically used on colored (blue and purple) glass so that the design is visible, but sometimes used on colorless glass as well.

Tonging/pincering/impressing: the process of creating a design in warm glass by using tong-like tools to squeeze a pattern into the vessel. Typically only possible for open vessels like bowls or beakers, due to the nature of the tongs; the impressions can be felt and seen on both the inside and outside of the vessel (until mold-blowing, the pattern of which is only felt on the exterior while the interior is smooth).

Wheel-cutting: the process of turning a finish object while it is cold on a wheel while a tool is used to carve out horizontal lines from the surface.

APPENDIX B: CATALOG OF SAMPLES

Sample ID #	Site Name	Registration number (RN or KT)	Proven-ance	Archaeological Context	Approx. Date	Form/part	Color	Fragment description
1	Ayla (Aqaba)	485	J13d-18	Fill, tower south of Hijazi room	?	Goblet stem	Aqua	Complete, hollow ring with stem
2	Ayla (Aqaba)	529	L8b-2	Wall collapse/tip	post-11th c	Jar/jug shoulder	Colorless?	Thick, rounded shoulder; large mouth
3	Ayla (Aqaba)	530	L8b-3	Levelling fill	post-11th	Bottle rim	Aqua	Small; folded inwards and flattened to form wide lip, also extends outwards from flattening
4	Ayla (Aqaba)	531 sample1	L8b-4	Fill	post-11th c	Bottle rim	?	Narrow neck, large flat/flaring rim with thickened lip
5	Ayla (Aqaba)	531 sample2	L8b-4	Fill	post-11th c	Bottle rim	?	Large, milk-bottle shape
6	Ayla (Aqaba)	531 sample3	L8b-4	Fill	post-11th c	Bottle base	Yellow-colorless?	Thick, flattened disk base with no kick and no PS; an etched/incsed diamond where PS would be
7	Ayla (Aqaba)	532 sample1	L8b-5	Tip-fill	post-11th c	Jar rim	Yellow-colorless?	Everted rim with lip that pulls down almost to a point; almost horizontal shoulders
8	Ayla (Aqaba)	532 sample2	L8b-5	Tip-fill	11th c, post-11th c	Bottle neck	Emerald	Neck narrows slighly to top; thick walls, facet cut: oblong facets form oblong with points in higher relief and line below
9	Ayla (Aqaba)	533 sample1	L8b-7	Doorway test, floor?	11th c.	Bottle rim	Light green	Lip slighly thickened/rounded on one side; very irregular mouth; straight, slightly tapering neck walls
10	Ayla (Aqaba)	533 sample2	L8b-7	Doorway test, floor?	11th c.	Bowl rim	Aqua	ca. 11cm D with thickened and everted/slighly horizontal FR lip
11	Ayla (Aqaba)	533 sample3	L8b-7	Doorway test, floor?	11th c.	Wall ring of bowl	Aqua	Hollow circular ring in body
12	Ayla (Aqaba)	534 sample1	L8b-10	SW of room	11th c.	Bowl/btl base	Aqua	Raised geometric design of concentric circle and net on

								exterior, slightly on inside
13	Ayla (Aqaba)	534 sample2	L8b-10	SW of room	11th c.	Bottle rim	Colorless	Thick; vertical neck and flaring mouth same thickness; lip is everted and squared but thick/irregular finish
14	Ayla (Aqaba)	536	L8b-11	Fill?	?	Btl/jg base	Colorless?	Thickened center; on ext see molded design of star with 6 rounded points, with wavy lines outlining as radiate outwards
15	Ayla (Aqaba)	537 sample1	L8b-12	Fill?	10th c.	Bowl/btl bse	Colorless?	Large complete base with thickened center and large chunky PS
16	Ayla (Aqaba)	537 sample2	L8b-12	Fill?	10th c.	Bowl/btl body	Blue	Incised geometric design on exterior (two horizontal lines, vertical stripes of three, horizizontal lines)
17	Ayla (Aqaba)	537 sample3	L8b-12	Fill?	10th c.	Flask rim	Colorless?	Narrow-necked flask; wide, flat horizontal rim with squared and rounded lip
18	Ayla (Aqaba)	537 sample4	L8b-12	Fill?	10th c.	Bowl rim	Colorless?	Rounded and thickened lip; rounder on interior; sloping walls
19	Ayla (Aqaba)	538 sample1	L8b-13	Surface and "makeup"	10th c.	Beaker rim	Aqua	Slightly pointed fire-rounded lip, almost the same thickness as walls; vertical mouth and walls; oblong honey-comb pattern on exterior
20	Ayla (Aqaba)	538 sample2	L8b-13	Surface and "makeup"	10th c.	Bowl? Base	Colorless?	Smooth curved interior; exterior base is slightly rounded, a bit thicker on ring area and hint of depression near the center
21	Ayla (Aqaba)	538 sample3	L8b-13	Surface and "makeup"	10th c.	Type? Body	Aqua	Relatively thick wall
22	Ayla (Aqaba)	538 sample4	L8b-13	Surface and "makeup"	10th c.	Type? Body	?	Relatively thick wall
23	Ayla (Aqaba)	539 sample1	L8b-14	Rubble fill	10th c.	Vial/btl rim	Colorless	Rim with part of neck; vertical, cracked off and squared lip
24	Ayla	539 sample2	L8b-14	Rubble fill	10th c.	Vial/btl rim	Aqua?	Vertical rim/neck; lip is flattened

	(Aqaba)							on top and irregular
25	Ayla (Aqaba)	540 sample1	L8b-15	Levelling fill	11th c.	Type? Body	Purple and ?	Medium thickness wall
26	Ayla (Aqaba)	540 sample2	L8b-15	Levelling fill	11th c.	Btl/jg body	Purple and ?	Medium thickness wall
27	Ayla (Aqaba)	541	L8b-16	Rubble fill	?	Bowl rim	Aqua	Exterior molded semicircles (two nested with a dot in center) in a horizontal band beneath a firerounded rim
28	Ayla (Aqaba)	542 sample1	L8b-21	Occupation level? Plaster	10th c.	Bowl base	Aqua?	Curving, with four external ribs
29	Ayla (Aqaba)	542 sample2	L8b-21	Occupation level? Plaster	10th c.	Bowl rim	Aqua	Vertical walls with rounded, vertical lip
30	Ayla (Aqaba)	542 sample3	L8b-21	Occupation level? Plaster	10th c.	Bowl rim	?	Wall with slightly everted lip almost squared but round
31	Ayla (Aqaba)	543	L8b-27	Sandy fill	9th c.	Bottle rim	Aqua	Small vial with complete neck and rim; firerounded lip with an attached coil at the lip to make it thicker, rolled out and slightly flattened to downward point; top of shoulders present
32	Ayla (Aqaba)	546	L8b-34	Sandy fill	?	Bracelet	?	Oblong section, diameter would be child's size; 0.5cm thick and 0.7cm wide
33	Ayla (Aqaba)	547	L8b-35	Sandy fill	?	Bottle base	Aqua	Rounded center with PS
34	Ayla (Aqaba)	549	L8b-40	Fill	?	Bottle base	Aqua	Rounded edges, slightly rounded kick in center with no punty scar
35	Ayla (Aqaba)	550	L8b-41	Test trench against wall B, defining doorway	? (9th?)	Bowl rim	Yellow-green	Rim is thick, oblong, hollow, and rolled with slight teardrop shape and heavier on the exterior and bottom
36	Ayla (Aqaba)	360 FN3 sample8	J10d-12	Occupation debris (= locus 8) w/I house; later phase, possibly abandon/post-	post-11th	Bowl rim	Aqua	Firerounded rim the same thickness as the body

				occupation				
37	Ayla (Aqaba)	360 FN3 sample9	J10d-12	Occupation debris (= locus 8) w/I house; later phase, possibly abandon/post-occupation	post-11th	Bowl rim	Aqua	Thickened lip with a roll slightly to the exterior of the lip; Hole-Mouth shape?
38	Ayla (Aqaba)	360 FN3 sample10	J10d-12	Occupation debris (= locus 8) w/I house; later phase, possibly abandon/post-occupation	post-11th	Type? Base?	Aqua	Flattish with curved edge
39	Ayla (Aqaba)	395 FN1	J10d-40	Room E, floor level/occupation debris	?	Type? Body	Aqua	Plain
40	Ayla (Aqaba)	396 FN1 sample1	J10d-41	Room F, balk cut against N. face of wall K south and bench	?	Type? Body	Aqua	Relatively thick
41	Ayla (Aqaba)	396 FN1 sample2	J10d-41	Room F, balk cut against N. face of wall K south and bench	?	Type? Body	Blue	Feathered vertical columns with four horizontal lines at top
42	Ayla (Aqaba)	402 FN1 sample1	J10d-46	Room D; ash b/w cobbles, hearth?	10th c.	Type? Body	Aqua	Relatively thick, flat
43	Ayla (Aqaba)	402 FN1 sample2	J10d-46	Room D; ash b/w cobbles, hearth?	10th c.	Type? Base?	Aqua	Relatively thick; curving (part of base?)
44	Ayla (Aqaba)	403 FN4 sample3	J10d-46	Room D; ash b/w cobbles, hearth?	10th c.	Type? Body	Colorless	Relatively thick
45	Ayla (Aqaba)	403 FN4 sample4	J10d-46	Room D; ash b/w cobbles, hearth?	10th c.	Type? Body	Aqua	Relatively thick
46	Ayla (Aqaba)	403 FN4 sample5	J10d-46	Room D; ash b/w cobbles, hearth?	10th c.	Bowl rim	Colorless	Almost flat, suggests large diameter; firerounded lip is the same thickness as the walls
47	Ayla (Aqaba)	403 FN4 sample6	J10d-46	Room D; ash b/w cobbles, hearth?	10th c.	Bowl rim	Aqua	Firerounded lip is the same thickness as the vertical walls
48	Ayla (Aqaba)	403 FN4 sample7	J10d-46	Room D; ash b/w cobbles, hearth?	10th c.	Btl/jg base	Purple	Large; slight kick; curved edge

49	Ayla (Aqaba)	404 FN10 sample8	J10d-46	Room D; ash b/w cobbles, hearth?	10th c.	Type? Body	Aqua	Plain
50	Ayla (Aqaba)	404 FN10 sample9	J10d-46	Room D; ash b/w cobbles, hearth?	10th c.	Type? Body	Aqua	Plain
51	Ayla (Aqaba)	404 FN10 sample10	J10d-46	Room D; ash b/w cobbles, hearth?	10th c.	Bowl rim	Aqua	Vertical walls with firerounded lip
52	Ayla (Aqaba)	405 FN1 sample1	J10d-47	Room B; ash and floor	?	Jar/btl base	Aqua	Very deep kick
53	Ayla (Aqaba)	405 FN1 sample2	J10d-47	Room B; ash and floor	?	Bowl rim	Aqua	Vertical firerounded lip, vertical walls the same thickness
54	Ayla (Aqaba)	405 FN1 sample3	J10d-47	Room B; ash and floor	?	Bowl rim	Aqua	Firerounded lip; dark color
55	Ayla (Aqaba)	406 FN1 sample1	J10d-48	Room B; ash and floor	10th c.	Bowl rim	Aqua	Vertical walls, same thickness as rim with firerounded lip
56	Ayla (Aqaba)	406 FN1 sample2	J10d-48	Room B; ash and floor	10th c.	Bowl rim	Aqua	Firerounded, slightly pointed lip; wall slopes slightly inwards
57	Ayla (Aqaba)	406 FN1 sample3	J10d-48	Room B; ash and floor	10th c.	Bowl rim	Aqua	Flat with folded/rolled, hollow band; large diameter
58	Ayla (Aqaba)	725 FN4 sample6	J10d-48	Room B; ash and floor	10th c.	Type? Body	Light green	Plain
59	Ayla (Aqaba)	725 FN4 sample7	J10d-48	Room B; ash and floor	10th c.	Bowl/bkr rim	Aqua	1 flat folded rim to ext, 0.8cm wide fold, hollow int, walls curve out as go to mouth (15cm diam)
60	Ayla (Aqaba)	725 FN4 sample8	J10d-48	Room B; ash and floor	10th c.	Jar/btl handle	Aqua	Rounded section, straight with pad slightly pushed in to 90 degree angle
61	Ayla (Aqaba)	725 FN4 sample9	J10d-48	Room B; ash and floor	10th c.	Bowl/bkr rim	Aqua	Almost vertical walls; slight thickness of lip on interior; faint diagonal ridges on exterior/interior
62	Ayla (Aqaba)	726 FN6 sample5	J10d-48	Room B; ash and floor	MODERN	Stopper	Colorless	2.5cm long; 2.5cm diam, 0.7cm thick flattened disc on top
63	Ayla (Aqaba)	727 FN4 sample4	J10d-48	Room B; ash and floor	10th c.	Type? Base?	Aqua	Thick
64	Ayla (Aqaba)	728 FN2 sample1	J10d-49	Room A, floor level in W. room, associated with wall G phase 1;	?	Bowl/btl base	Aqua	Flat bottom and slightly thickened center; gently curving walls

				greatest depth reached here				
65	Ayla (Aqaba)	728 FN2 sample2	J10d-49	Room A, floor level in W. room, associated with wall G phase 1; greatest depth reached here	9th c.	Bottle neck	Blue	Relatively horizontal, gently sloping shoulder with narrow neck; trailed glass around neck above shoulder
66	Ayla (Aqaba)	728 FN2 sample3	J10d-49	Room A, floor level in W. room, associated with wall G phase 1; greatest depth reached here	9th c.	Bowl rim	Aqua	Solid rolled/thickened lip; curve slightly inward (like Hole-mouth?)
67	Ayla (Aqaba)	728 FN2 sample4	J10d-49	Room A, floor level in W. room, associated with wall G phase 1; greatest depth reached here	9th c.	Bowl rim	Aqua	Thickened, lip rolled slightly to interior
68	Ayla (Aqaba)	729 FN1 sample1	J10d-50	Room A; fill beneath L49 floor	9th c.	Bottle rim	Light green	Neck (2cm long) and straight with cracked off badly finished lip of 2.4cm diam mouth, shoulders horiz for almoust 2cm
69	Ayla (Aqaba)	729 FN1 sample2	J10d-50	Room A; fill beneath L49 floor	9th c.	Type? Body	Aqua	Dark color
70	Ayla (Aqaba)	729 FN1 sample3	J10d-50	Room A; fill beneath L49 floor	9th c.	Bowl rim	Aqua	Bowl with firerounded lip that is slightly thickened to interior; walls taper inward gently from base to mouth (Hole-mouth style?)
71	Ayla (Aqaba)	729 FN1 sample4	J10d-50	Room A; fill beneath L49 floor	9th c.	Type? Body	Aqua	Plain
72	Ayla (Aqaba)	731 FN1 sample1	J10d-51	Room A; rill beneath L50	?	Bowl/bkr rim	Aqua	Firerounded lip
73	Ayla (Aqaba)	731 FN1 sample2	J10d-51	Room A; rill beneath L50	?	Btl/jr trail	Aqua	Trail with four crests; small bit of walls remaining
74	Ayla (Aqaba)	732 FN2	J10d-52	Room A; floor beneath L51 (1st occupation of room, phase I)	?	Type? Body	Aqua	Plain

75	Ayla (Aqaba)	733 FN1 sample1	J10d-53	Room A; gravel layer beneath floor	?	Window pane?	Aqua	Flat
76	Ayla (Aqaba)	733 FN1 sample2	J10d-53	Room A; gravel layer beneath floor	?	Window pane?	Aqua	Rounded edge but very flat and large 20cm diam with no sign of curving; slight roundness of lip on one side
77	Ayla (Aqaba)	?	E8b-2	?	post-11th c	Type? Body	Blue	Plain
78	Ayla (Aqaba)	792 FN4 sample1	E8b-18	MB pavement/stones with dump below (= locus 32)	?	Bottle body	Aqua	Thin
79	Ayla (Aqaba)	792 FN4 sample2	E8b-18	MB pavement/stones with dump below (= locus 32)	?	Bottle base	Aqua	Edges of base with shallow rising walls; medium-high kick
80	Ayla (Aqaba)	792 FN4 sample3	E8b-18	MB pavement/stones with dump below (= locus 32)	?	Type? Body	Blue	Medium thickness
81	Ayla (Aqaba)	792 FN4 sample4	E8b-18	MB pavement/stones with dump below (= locus 32)	?	Chunk	AQ	Irregular with multiple breaks
82	Ayla (Aqaba)	792 FN4 sample5	E8b-18	MB pavement/stones with dump below (= locus 32)	?	Bottle base	Aqua	Very small bottle; pad base with punty scar and some wall attached
83	Ayla (Aqaba)	792 FN4 sample6	E8b-18	MB pavement/stones with dump below (= locus 32)	?	Bowl/cp rim	Light green	Slightly concave walls (hole-mouth style?); slightly thickened firerounded lip
84	Ayla (Aqaba)	792 FN4 sample7	E8b-18	MB pavement/stones with dump below (= locus 32)	?	Bowl/cp rim	Aqua, yellow-brown	Thick, rounded lip of Y-BR/amber trail; 3 thin exterior Y-BR trails that are slightly raised; maybe hole-mouth profile?
85	Ayla (Aqaba)	793 FN8 sample8	E8b-18	MB pavement/stones with dump below (= locus 32)	?	Bottle body	Aqua	Plain

86	Ayla (Aqaba)	793 FN8 sample9	E8b-18	MB pavement/stones with dump below (= locus 32)	?	Bottle base	Aqua	Slight central bulge on interior/depression on exterior with chunky punty scar in center; circle of pulled toes, each about 1.5cm apart from next and 0.5cm high (5.5 are visible), maybe a second ring beyond that (two more toes w/ broken tips); hint of vertical trail on one wall
87	Ayla (Aqaba)	793 FN8 sample10	E8b-18	MB pavement/stones with dump below (= locus 32)	?	Bowl base	Green	Center and ring, with only hint of walls; hollow base ring, slightly squat/flaring
88	Ayla (Aqaba)	794 FN1	E8b-19	Fill(?); = locus 33	?	tube	Aqua	Fragment of a slightly curved, hollow tube with rounded bottom
89	Ayla (Aqaba)	621 FN2	E8b-31	Dump inside room, same as L22, 24, 31, 10 (merges with L12)	9th c.	Bowl rim	Light green	Incised with geometric design; firerounded lip is the same thickness as the vertical walls
90	Ayla (Aqaba)	622 FN2 sample1	E8b-33	Fill(?); = locus 19; between B, C, D	?	Bottle body	Aqua	Plain
91	Ayla (Aqaba)	622 FN2 sample2	E8b-33	Fill(?); = locus 19; between B, C, D	?	Bottle body	Green	Plain
92	Ayla (Aqaba)	622 FN2 sample3	E8b-33	Fill(?); = locus 19; between B, C, D	?	Bottle rim	Light green	Complete neck/mouth 1.5cm tall with thickend lip; shoulders extend slightly horizontal and down
93	Ayla (Aqaba)	622 FN2 sample4	E8b-33	Fill(?); = locus 19; between B, C, D	?	Bowl rim	Aqua	Thick firerounded lip forms ridge beneath lip on interior; slightly hole-mouth/vertical walls
94	Ayla (Aqaba)	623 sample1	E8b-34	Fill; = locus 20; between B, C, D	?	Bottle neck	Light green	Plain
95	Ayla (Aqaba)	623 sample2	E8b-34	Fill; = locus 20; between B, C, D	?	Bowl rim	Aqua	Very thin with slightly thickened firerounded lip
96	Ayla (Aqaba)	519 FN1 sample1	H11a-16	Compacted stones/sand	8th c.?	Bowl body	Light green	Plain
97	Ayla (Aqaba)	519 FN1 sample2	H11a-16	Compacted stones/sand	8th c.?	Btl/jg handle	Aqua	Flattish/straight from attachment, probably rose not far from wall; oblong, not well done, can see slight twist/edge in glass along

								handle, not smoothed
98	Ayla (Aqaba)	765 FN 1 sample1	F9d-18	Levels of fill; Umayyad; street level/bottom of wall, occupation	mid 7th mid-8th c	Btl/bwl base	Aqua	Flattish on one side and rounded bulge on the other
99	Ayla (Aqaba)	765 FN 1 sample2	F9d-18	Levels of fill; Umayyad; street level/bottom of wall, occupation	mid 7th mid-8th c	Bowl body	Light green	S-shape in wall, but wide curve
100	Ayla (Aqaba)	323 sample1	B1d-30	Occupation fill capped by gray ash; Annex 1	(pre-U and U?)	Type? Body	Aqua	Plain
101	Ayla (Aqaba)	323 sample2	B1d-30	Occupation fill capped by gray ash; Annex 1	(pre-U and U?)	Bottle neck	Aqua	Vertical neck; 12 thin AQ trails on ext close together horizontally around NK; cluster of trails to make thicker band 2mm wide; 7 trails beneath that are visible
102	Ayla (Aqaba)	325 sample1	B1d-31	Greenish silt/organic; Annex 1	(pre-U and U?)	Type? Body	Aqua	Plain
103	Ayla (Aqaba)	325 sample2	B1d-31	Greenish silt/organic; Annex 1	(pre-U and U?)	Lamp stem	Aqua	Hollow with solid tip
104	Ayla (Aqaba)	325 sample3	B1d-31	Greenish silt/organic; Annex 1	(pre-U and U?)	Bowl rim	Aqua	Thick firerounded lip; slightly concave walls (hole-mouth?)
105	Ayla (Aqaba)	325 sample4	B1d-31	Greenish silt/organic; Annex 1	(pre-U and U?)	Type? Base?	Light green	Plain
106	Ayla (Aqaba)	325 sample5	B1d-31	Greenish silt/organic; Annex 1	(pre-U and U?)	Type? Body	Blue	Plain
107	Ayla (Aqaba)	326 sample1	B1d-35	Fill adjacent to wall B with some interlensing with L31	(pre-U and U?)	Type? Body	Aqua	Plain
108	Ayla (Aqaba)	326 sample2	B1d-35	Fill adjacent to wall B with some interlensing with L31	(pre-U and U?)	Beaker rim	Light green	Slightly thickened firerounded lip, thickness more to exterior; thin horiz trail on exterior just below lip thickness, thicker blob of trail and two legs wrapping around
109	Ayla	334 sample1	B1d-38	Fill adjacent to wall B	(pre-U and	Lamp stem	Light green	Half of the tip of the stem; bottom

	(Aqaba)			- bottom arbitrary	U?)			1cm solid
110	Ayla (Aqaba)	334 sample2	B1d-38	Fill adjacent to wall B - bottom arbitrary	(pre-U and U?)	Btl/jg handle	Light green	Oval attachment to wall; flattish oval handle; hollow; slight pinch and curving start at end
111	Ayla (Aqaba)	334 sample3	B1d-38	Fill adjacent to wall B - bottom arbitrary	(pre-U and U?)	Bottle rim	Aqua	Narrow; firerounded lip
112	Ayla (Aqaba)	348 sample1	B2b-18	Cobble and plaster surface and foundation below	(pre-U and U?)	Type? Body	Aqua	Plain
113	Ayla (Aqaba)	348 sample2	B2b-18	Cobble and plaster surface and foundation below	(pre-U and U?)	Bowl rim	Aqua, blue	Thickend lip with applied blue trail, with two very thin horiztonal trails below the lip on the exterior
114	Ayla (Aqaba)	349	B2b-19	Occupation fill - arbitrary	(pre-U and U?)	Bowl rim	Light green	Very thick roll
115	Ḥiṣn al-Tīnāt (Tupras field of Kinet Höyuk)	25778	TF8-2-2	SE quadrant, topsoil and mixed fill EI/MI (sgraffiato, polychrome, creamware and greenish buff)	MODERN	Bottle body	Colorless	Raised lines on exterior form crossed line decoration
116	Ḥiṣn al-Tīnāt (Tupras field of Kinet Höyuk)	025990	TF8-2-29	SE quadrant, topsoil and mixed fill EI/MI (sgraffiato, polychrome, creamware and greenish buff, 1 African Red Slip)	c. 10th c.	Type? Body	Aqua	Thick
117	Ḥiṣn al-Tīnāt (Tupras field of Kinet Höyuk)	25789 sample1	TF8-3-5	SE quadrant, topsoil and mixed fill EI/MI (sgraffiato, polychrome, creamware and greenish buff, 1 African Red Slip), poor/mixed EI	10-12th c	Type? Base?	Colorless	Flat with slight hint of raised center

118	Ḥiṣn al-Tīnāt (Tupras field of Kinet Höyuk)	25789 sample2	TF8-3-5	SE quadrant, topsoil and mixed fill EI/MI (sgraffiato, polychrome, creamware and greenish buff, 1 African Red Slip), poor/mixed EI	10-12th c	Bracelet	Purple and colorless?	Flat with rounded ends in section, looks like 4 parallel canes forming shallow ridges on exterior; interior is smooth; CL with purple line along one edge and maybe thinner lines throughout?
119	Ḥiṣn al-Tīnāt (Tupras field of Kinet Höyuk)	25794 sample1	TF8-3-7	SE quadrant, topsoil and mixed fill EI/MI (sgraffiato, polychrome, creamware and greenish buff, 1 African Red Slip), poor/mixed EI	10-12th c	Jug/lamp handle	?	Pad of glass attached to body and flattened against it; pulled up vertically, out at right angle and then up at right angle to make vertical handle
120	Ḥiṣn al-Tīnāt (Tupras field of Kinet Höyuk)	25794 sample2	TF8-3-7	SE quadrant, topsoil and mixed fill EI/MI (sgraffiato, polychrome, creamware and greenish buff, 1 African Red Slip), poor/mixed EI	10-12th c.	Bottle base	Aqua	Small vessel; slight punty scar
121	Ḥiṣn al-Tīnāt (Tupras field of Kinet Höyuk)	025852 sample1	TF8-3-15	NE quadrant, topsoil and mixed fill EI; north of E-W running wall 4 and pit in NE corner (lot 15 is part of this pit)	10-12th c.	Type? Body	Blue	Shatter of a blue line/ridge? Thickens at the deepest blue and gets less blue. Would have been trailed on and reheated (expllains thickness) so part of body
122	Ḥiṣn al-Tīnāt (Tupras field of Kinet Höyuk)	025852 sample2	TF8-3-15	NE quadrant, topsoil and mixed fill EI; north of E-W running wall 4 and pit in NE corner (lot 15 is part of this pit)	10-12th c.	Type? Base?	Aqua	High kick (rises more than 1cm)

123	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025856 sample1	TF8-3-16	NE quadrant, topsoil; good/mixed fill EI; south of E-W running wall 4 (becomes locus 8)	c. 10th c.	Type? Rim	Aqua	Rolled rim with circular section and hollow; typical 0.4cm thick roll
124	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025856 sample2	TF83-16	NE quadrant, topsoil; good/mixed fill EI; south of E-W running wall 4 (becomes locus 8)	c. 10th c.	Type? Base?	Aqua	Flat base with thickened center; no kick or punty scar
125	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025856 sample3	TF8-3-16	NE quadrant, topsoil; good/mixed fill EI; south of E-W running wall 4 (becomes locus 8)	c. 10th c.	Type? Body	Aqua	Plain
126	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026070	TF8-4-36	E-W stone wall in NE quadrant; EI, discrete – below wall	c. 10th c.	Type? Body	Colorless	Plain
127	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025838 sample1	TF8-5-12	NW quadrant, topsoil, on N end of wall 6; mixed EI	10-12th c.	Bowl/jr rim	Aqua	Rounded rolled/hollow rim; lip folded past its join slightly and flattened, forming an inner collar below the lip (related to R in KT025847?)
128	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025838 sample2	TF8-5-12	NW quadrant, topsoil, on N end of wall 6; mixed EI	10-12th c.	Bowl/jr rim	Green	Large and slightly triangular hollow ring

129	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025838 sample3	TF8-5-12	NW quadrant, topsoil, on N end of wall 6; mixed EI	10-12th c.	Type? Base	Aqua	Flat with slightly thickened center and punty scar
130	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025843	TF8-5-14	NW quadrant, topsoil, on S end of wall 6; good/mixed fill, EI	c. 10th c.	Type? Body	Aqua	Plain
131	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025847 sample1	TF8-5-17	NW quadrant, topsoil, on N end of wall 6; mixed EI	c. 10th c.	Type? Base	Aqua-green	Flat base with thickened center and PS; on exterior are raised ridges radiating out and away from the base up the walls of the vessel, circle of this beginning ~2cm from central PS; flat, no curvature in fragment (because of large size)
132	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025847 sample2	TF8-5-17	NW quadrant, topsoil, on N end of wall 6; mixed EI	c. 10th c.	Bowl rim	Aqua-green	Outfolded and flattened rim with two parallel raised bits
133	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025847 sample3	TF8-5-17	NW quadrant, topsoil, on N end of wall 6; mixed EI	c. 10th c.	Bottle base	Aqua-green	Small bottle with gentle kick and slight punty scar
134	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025847 sample4	TF8-5-17	NW quadrant, topsoil, on N end of wall 6; mixed EI	c. 10th c.	Type? Base?	Aqua	Plain, thick

135	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025847 sample5	TF8-5-17	NW quadrant, topsoil, on N end of wall 6; mixed EI	c. 10th c.	Type? Body	Aqua and purple	Thicker where two purple "thumbprint" size/shaped ovals are – can see in section the two layers of glass
136	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025848	TF8-5-18	NW quadrant, topsoil, on S end of wall 6; good/mixed EI; patches of white plaster floor(?)	c. 10th c.	Bottle neck	Aqua	Tightly curving neck fragment of small bottle; some body wall
137	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025997	TF8-7-32	N-S running wall perpendicular to wall 4 in NE quadrant; discrete EI	c. 10th c.	Type? Body	Aqua	Plain
138	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025873	TF8-8-20	NE quandrant; S of wall 4, E of wall 7 – interior of room; mixed/good EI (above floor surface)	c. 10th c.	Type? Base	Aqua-green	Thick fragment; rising kick and part of thick punty scar
139	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025978	TF8-12-28	SW quadrant, between walls 7 and 12, poor/mixed fill, EI and MI?	10-12th c.	Type? Rim	Aqua	Rolled rim with no hollow; vertical walls
140	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025987 sample1	TF8-12-30	SW quadrant, mixed fill, EI	c. 10th c.	Type? Body	Aqua	Part of a base? Double layer?

141	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025987 sample2	TF8-12-30	SW quadrant, mixed fill, EI	c. 10th c.	Type? Rim	Aqua	Rolled lip
142	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025987 sample3	TF8-12-30	SW quadrant, mixed fill, EI	c. 10th c.	Bottle rim	Aqua	Small bottle mouth ~2.5cm diam
143	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026004	TF8-13-34	SW quadrant, stone pavement on S end; discrete EI; slag – industrial use in ctyd?	c. 10th c.	Jug/jr base?	Aqua	Relatively thick
144	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	25748 sample1	TF9-2-4	SE quadrant, topsoil; mixed fill	11-12th	Bottle base	Aqua and ?	Base edge of squared bottle (longest side is 3cm)
145	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	25748 sample2	TF9-2-4	SE quadrant, topsoil; mixed fill	11-12th c	Bottle body	Aqua	Shallow fin on the exterior; probably vertical; would have been others
146	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	25748 sample3	TF9-2-4	SE quadrant, topsoil; mixed fill	11-12th	Bracelet	Aqua-blue	2.3cm long, 0.7cm wide, 0.3cm thick; flattened on interior with raised ridge on exterior (flattened semi-circular cross section)

147	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	25748 sample4	TF9-2-4	SE quadrant, topsoil; mixed fill	11-12th	Bracelet	Aqua-green	3.6cm long, 0.9cm wide, 0.4cm thick; slightly pointed semicircular/semipeaked cross section
148	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025806 sample1	TF9-4-17	NW quadrant, topsoil; mixed fill	10-12th c	Type? Base	Aqua	Pad foot base (~0.6-0.7cm thick); horizontally flaring walls and then curve out/up
149	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025806 sample2	TF9-4-17	NW quadrant, topsoil; mixed fill	10-12th c	Bottle rim	Aqua	Narrow-mouth to bottle, rolled to interior forming internal ridge just below lip
150	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025807	TF9-4-17	NW quadrant, topsoil; mixed fill	10-12th c	Bracelet	Aqua	3.2cm long fragment of rounded cane of uneven thickness; oblong section 0.7-0.9cm thick
151	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025817	TF9-4-18	NW quadrant, topsoil; mixed fill; could be associated with fire? (not stratified)	?	Bottle base	?	Small bottle that is warped (in a fire?); difficult to see, but ring base
152	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025818	TF9-4-18	NW quadrant, topsoil; mixed fill; could be associated with fire? (not stratified)	?	Bracelet	Gray-aqua	**Round section, large/loose twists**

153	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026149	TF9-6-57	E-W running stone wall in SE quadrant; discrete	?	Bracelet	Dark blue	5.2cm long frag; 0.4cm circular section; tightly twisted cane; not perfect – kink and 0.8cm thickness at one point; very similar to TF9 KT026021 (13-47)
154	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	25768 sample1	TF9-7-10	SE quadrant, to S of wall 6 (inside room); discrete fill; burning evidence	?	Type? Body	Aqua	Plain
155	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	25768 sample2	TF9-7-10	SE quadrant, to S of wall 6 (inside room); discrete fill; burning evidence	?	Jar handle	Purple	5.5cm long fragment with body attachment, thins to ~0.6-0.7cm where break is (also looks like a change of direction from outwards to upwards takes place here)
156	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	25768 sample3	TF9-7-10	SE quadrant, to S of wall 6 (inside room); discrete fill; burning evidence	?	Type? Body	Blue	Plain
157	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025824	TF9-7-20	SE quadrant, to S of wall 6 (inside room); discrete fill; burning evidence	?	Type? Body	Colorless	Plain
158	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025830	TF9-7-21	SE quadrant, to S of wall 6 (inside room); discrete fill; burning evidence (2 frag lusterware?)	10-12th c	Type? Body	Aqua	Curved, prismatic body; maybe facet cut instead of mold-blown

159	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	25767 sample1	TF9-8-12	NE quadrant, E-W running "fortification wall;" discrete fill; trying to delimit area	?	Type? Body	Yellow	Plain
160	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	25767 sample2	TF9-8-12	NE quadrant, E-W running "fortification wall;" discrete fill; trying to delimit area	?	Type? Rim	Aqua	Slightly fire rounded lip with a slight swell below the lip
161	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025812 sample1	TF9-8-15	NE quadrant, E-W running "fortification wall;" discrete fill; trying to delimit area	?	Type? Body	Colorless?	Circular indents, and circular raised boss with central raisted dot on exterior
162	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025812 sample2	TF9-8-15	NE quadrant, E-W running "fortification wall;" discrete fill; trying to delimit area	?	Type? Body	Colorless?	Circular indents
163	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025803	TF9-9-13	Between NE and SE quadrants; room between E-S walls 6 and 8, burnt; mixed fill	?	Bracelet	Dark blue	0.4cm in section; tightly twisted blue cane
164	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025820 sample1	TF9-9-19	Between NE and SE quadrants; room between E-W walls 6 and 8, burnt; discrete fill	?	Beaker? Body	?	Heavy weathering but feels like stamped geometric pattern; maybe a "V" with three parallel short lines?

165	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025820 sample2	TF9-9-19	Between NE and SE quadrants; room between E-W walls 6 and 8, burnt; discrete fill	10-12th c	zoomorphic or jar? Body	?	curving fragment with ribbon trail; parallel trail below has pulled out rounded bit
166	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026019	TF9-13-47	Just west to middle of OP, N-S running stone wall, perp to fortification wall 8 (walls 8 and 6 abutt on E – continuation of fortification wall 8); discrete fill	?	Bottle body	Aqua	Probably the edge of the bottom of a small bottle
167	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026021	TF9-13-47	Just west to middle of OP, N-S running stone wall, perp to fortification wall 8 (walls 8 and 6 abutt on E – continuation of fortification wall 8); discrete fill	?	Bracelet	Dark blue	0.4cm circular section; tightly twisted cane; very similar to TF9 KT026149 (6-57)
168	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025921	TF9-15-28	SE quadrant, room bounded by walls 13, 6, and 12; mixed fill	10-12th c	Beaker? RIm	Aqua	Rounded lip, same thickness as walls; vertical walls; can feel (not see) geometric relief from clamped tool – lozenge and maybe a 'T'?
169	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025959 sample1	TF9-15-38	SE quadrant, room bounded by walls 13, 6, and 12; discrete fill	10-12th c	Bottle neck?	Aqua	Bulbous round section with slight constrictions at top and bottom

170	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025959 sample2	TF9-15-38	SE quadrant, room bounded by walls 13, 6, and 12; discrete fill	10-12th c.	Bottle body	Aqua	Possibly base
171	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026006 sample1	TF9-15-43	SE quadrant, room bounded by walls 13, 6, and 12; discrete fill	10-12th c	Bottle/bker base	Aqua	3 frags, 2 larger ones poss same vessel: 1 frag almost half of pushed up BT base with small kick and no visible PS and walls standing 2.5cm, possibly faceted or clamp molded on walls?; small and thin frag with similar BT curvature
172	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026006 sample2	TF9-15-43	SE quadrant, room bounded by walls 13, 6, and 12; discrete fill	10-12th c	Type? Handle	Aqua?	Short vertical loop
173	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026006 sample3	TF9-15-43	SE quadrant, room bounded by walls 13, 6, and 12; discrete fill	10-12th c	Type? Handle	Aqua?	Thick blob at body and pulled out straight and slightly outward, tapers (smaller than TF8 handle of same type)
174	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025936	TF9-16-33	SE quadrant, fill to E of wall 12, N of wall 11 and S of wall 10; mixed fill	?	Bracelet	Aqua	Flatter on interior and semi-rounded; looks like translucent aqua or blue glass beneath opaque yellow paint with 10 diagonal lines with thicker red dot-ish top
175	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	25974	TF9-16-42	SE quadrant, fill to E of wall 12, N of wall 11 and S of wall 10; mixed fill	?	Type? Base	Aqua	Roll with hollow and irregular curving; perhaps base foot with ring to small vessel?

176	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025972 sample1	TF9-17-41	W of OP, outside wall 13 and tower 22	mid10-mid11th	Type? Rim	Aqua and ?	Circular hollow ring with no walls remaining
177	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025972 sample2	TF9-17-41	W of OP, outside wall 13 and tower 22	mid10-mid11th	Type? Rim	Aqua and ?	Fire rounded rim with slight swelling below lip
178	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025972 sample3	TF9-17-41	W of OP, outside wall 13 and tower 22	mid10-mid11th	Type? Body	Blue	Plain
179	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026015 sample1	TF9-17-46	W of OP, outside wall 13 and tower 22	mid10-mid11th	Type? Body	Green	Plain
180	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026015 sample2	TF9-17-46	W of OP, outside wall 13 and tower 22	mid10-mid11th	Bottle base	Aqua	Slight kick with punty scar
181	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026174	TF9-17-60	W of OP, outside wall 13 and tower 22; sounding 2.25x2.65m	mid10-mid11th	Type? Rim	Aqua	Slightly squared at lip and about the same thickness as walls; walls tapper inwards significantly

182	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025928	TF9-18-31	Area between walls 13, 6, 8, and 10 (was renamed from Locus 9)	c. 10th c.	Bottle rim	Aqua	Fire rounded lip
183	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025941 sample1	TF9-18-34	Area between walls 13, 6, 8, and 10 (was renamed from Locus 9)	c. 10th c.	Type? Body	Colorless?	Plain
184	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025941 sample2	TF9-18-34	Area between walls 13, 6, 8, and 10 (was renamed from Locus 9)	c. 10th c.	Type? Rim	Aqua	Rolled lip with hollow, slightly flattened against the interior; vertical stance/walls
185	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025941 sample3	TF9-18-34	Area between walls 13, 6, 8, and 10 (was renamed from Locus 9)	c. 10th c.	Type? Body	Aqua	Plain
186	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025967 sample1	TF9-18-40	Area between walls 13, 6, 8, and 10 (was renamed from Locus 9); (sounding 1.2x2.45m south of 18)	c. 10th c.	Type? Body	Aqua-green	Plain
187	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025967 sample2	TF9-18-40	Area between walls 13, 6, 8, and 10 (was renamed from Locus 9); (sounding 1.2x2.45m south of 18)	c. 10th c.	Type? Body	Colorless-yellow?	Plain

188	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025968	TF9-18-40	Area between walls 13, 6, 8, and 10 (was renamed from Locus 9); (sounding 1.2x2.45m south of 18)	c. 10th c.	Bracelet	Dark blue	A bit irregular and not totally circular; 5cm section twisted cane, not as tight as others but not as loose as KT025818 (medium loose); overlapped end onto ext side of cane and slightly flattened
189	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026012	TF9-18-45	Whole area between walls 13, 6, 8, and 10 (was renamed from Locus 9)	c. 10th c.	Bowl/dish rim	Colorless?	Almost no rim curvature, rounded edge with change of direction, is almost flat with flattened ledge forming band
190	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026045 sample1	TF9-19-48	NE quadrant, N of wall 8 after removal of collapse of stones locus 14 (from wall 8)	?	Type? Body	Yellow	Plain
191	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026045 sample2	TF9-19-48	NE quadrant, N of wall 8 after removal of collapse of stones locus 14 (from wall 8)	?	Bracelet	Polychrom e	Round section, 0.6-0.7cm thick cane; looks like AQ TP core, and painted design? Milky white wiht like red painted netted pattern with red central dots?
192	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026143 sample1	TF9-19-56	NE quadrant, N of wall 8 after removal of collapse of stones locus 14 (from wall 8)	?	Beaker base	Aqua	Punty scar but little left remaining
193	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026143 sample2	TF9-19-56	NE quadrant, N of wall 8 after removal of collapse of stones locus 14 (from wall 8)	?	Type? Body	Yellow-green	Glass is not uniform thickness; perhaps x-pattern netting where swells out and more Y color (MBL and then BL to make less sharp?)

194	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026143 sample3	TF9-19-56	NE quadrant, N of wall 8 after removal of collapse of stones locus 14 (from wall 8)	?	Type? Body	Colorless-yellow?	Curving yellow patch within CL glass; walls of uniform thickness
195	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026143 sample4	TF9-19-56	NE quadrant, N of wall 8 after removal of collapse of stones locus 14 (from wall 8)	?	Beaker base	Aqua	Rolled hollow ring base and pushed up kick, some walls remaining
196	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026184	TF9-19-62	Removal of MB wall/pavement 24 (in SE corner of locus 19)	c. 10th c.	Type? Body	Aqua	Pulled out fin 1.5cm long that extends 0.4cm from body; slightly larger than fin of TF9 KT25748 2-4
197	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026170	TF9-23-59	Combined locus 15 and 16 after removed walls 6 and 12 (which were perpendicular and attached to fortification wall 13), and S of wall 29; 2x3.3m sounding	?	Jar handle	Colorless	Thick attachment at body, and straight as pulls out 45 degrees and then thins out
198	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026171	TF9-23-59	Combined locus 15 and 16 after removed walls 6 and 12 (which were perpendicular and attached to fortification wall 13), and S of wall 29; 2x3.3m sounding	?	Bracelet	Dark blue	Somewhat irregular/non-circular; triangular/peaked section with flattened int and peak on ext; overlapped end on ext

199	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026197	TF9-28-66	Pavement under locus 18, bordered by walls 13 and 8, 10 and 29	9-10th c	Bottle base	Aqua	Round base slightly pushed up in center but no kick; interior can see a hollow ring
200	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025825 sample1	TF10-1-2	Coastline/harbor area (2x10m trench); topsoil; poor/mixed; EI-MI	MODERN	Type? Body	Colorless	Three changes of direction (prismatic?)
201	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025825 sample2	TF10-1-2	Coastline/harbor area (2x10m trench); topsoil; poor/mixed; EI-MI	11-12th c	Jar handle	Aqua	Looks like handle 0.5-0.8cm wide cane; widens at one end and three ridges lead to round tipped points and breaks
202	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025825 sample3	TF10-1-2	Coastline/harbor area (2x10m trench); topsoil; poor/mixed; EI-MI	11-12th	Beaker? Body	Aqua	Easy to see clamp design on ext/int surfaces; rounded indents create S-shaped/bird shaped area
203	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025825 sample4	TF10-1-2	Coastline/harbor area (2x10m trench); topsoil; poor/mixed; EI-MI	11-12th	Type? Neck	Colorless-yellow?	Narrow body bulges out to a colar and then comes back to same diameter
204	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025876 sample1	TF10-1-3	Coastline/harbor area (2x10m trench); topsoil; poor/mixed; EI-MI	MODERN	Type? Body	Colorless	White in cross section - modern?

205	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025876 sample2	TF10-1-3	Coastline/harbor area (2x10m trench); topsoil; poor/mixed; EI-MI	11-12th	Type? Body	Aqua-blue	Plain
206	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025876 sample3	TF10-1-3	Coastline/harbor area (2x10m trench); topsoil; poor/mixed; EI-MI	11-12th c	Type? Body	Aqua-green	Small, thick chunks
207	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025876 sample4	TF10-1-3	Coastline/harbor area (2x10m trench); topsoil; poor/mixed; EI-MI	11-12th	Type? Rim	Aqua	Rounded triangular profile with an exterior edge and thick walls
208	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	25800	TF10-1-3	Coastline/harbor area (2x10m trench); topsoil; poor/mixed; EI-MI	11-12th	Complete jar	Purple	9 frags, partly restored; almost complete bottom and part of shoulder/NK/R; honey-comb pattern of round indents that can be felt on int/ext, light trace of PS (but removed scar); rounded bottom edges and almost flat but slightly thickened center and only very slightly pushed up; thin 0.1cm thick walls; constriction at neck and then short outward flare to rim (NK about 0.5cm tall); cracked off rim and ground? Irregular shoulder with slight ring of depression on one side
209	Ḥiṣn al-Tīnāt (Tüpraş field of	025880 sample1	TF10-2-1	Coastline/harbor area (wet and organic soil); mixed context	?	Type? Base?	Light green	Near kick?

	Kinet Höyuk)							
210	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025880 sample2	TF10-2-1	Coastline/harbor area (wet and organic soil); mixed context	?	Type? Body	Colorless	Plain
211	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025880 sample3	TF10-2-1	Coastline/harbor area (wet and organic soil); mixed context	?	Type? Body	Dark blue	Plain
212	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025880 sample4	TF10-2-1	Coastline/harbor area (wet and organic soil); mixed context	?	Type? Body	Blue	Exterior raised pattern: 5 dots surrouning thin line of a circle with a central dot
213	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025880 sample5	TF10-2-1	Coastline/harbor area (wet and organic soil); mixed context	?	Bottle base	Blue	Looped ring with large hollow and only hint of walls
214	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025880 sample6	TF10-2-1	Coastline/harbor area (wet and organic soil); mixed context	?	Bottle base	Aqua	Kick and chunk of punty scar off center
215	Ḥiṣn al-Tīnāt (Tüpraş	025880 sample7	TF10-2-1	Coastline/harbor area (wet and organic soil); mixed context	?	Bottle base	Green	High kick and sharp change of direction between kick and wall rises

	field of Kinet Höyuk)							
216	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025907	TF10-2-6	Coastline/harbor area (wet and organic soil); mixed context; window trench in middle of 2x10m: b/w 3 and 7m; burning evidence, wetter/coarser sand withorganics/charcoal/ wood	?	Bottle body	Aqua	Perhaps near base because of slight flattening; striations on exterior
217	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025947	TF11-1-1	N third of OP; topsoil	surface	Bracelet	Colorless and purple	0.6cm section; CL background with one purple internal twist (parallels? Modern?); can see striations where CL is twisted, but the twists are pretty smooth so almost feels just like a cane
218	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025951 sample1	TF11-1-3	N third of OP; topsoil	surface	Flask? Rim	?	Rim is the same thickness as walls; gently tapering inwards; squared
219	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	025951 sample2	TF11-1-3	N third of OP; topsoil	surface	Type? Body	Colorless	Relatively thick with applied rounded blob that is mostly gone – can see where pushed through to interior slightly
220	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet	026201	TF11-1-22	N third of OP; topsoil	?	Jar? Rim	Aqua	Thickened firerounded lip

	Höyuk)							
221	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026029 sample1	TF11-2-4	Room W of N-S running wall 4 (and E of OP9's wall 10)	11-12th c	Bowl/jr rim	Green-yellow	Firerounded rim the same thickness as almost vertical walls
222	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026029 sample2	TF11-2-4	Room W of N-S running wall 4 (and E of OP9's wall 10)	?	Bracelet	Blue	0.4cm thick and 0.9cm wide; rectangular section with rounded edges (flattened on both surfaces)
223	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026039 sample1	TF11-2-9	Room W of N-S running wall 4 (and E of OP9's wall 10) (sounding lot)	11-12th	Type? Rim	Colorless?	Slightly firerounded lip, rim about same thickness as walls
224	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026039 sample2	TF11-2-9	Room W of N-S running wall 4 (and E of OP9's wall 10) (sounding lot)	11-12th	Bottle base	Yellow-amber	Small and squared with rounded edges; blown; 1.9x1.9cm; 0.3cm thick walls remaining to height of 3.3cm; interior space/wall thickness is irregular because at one corner of the base the walls are thicker; slight hint of punty scar
225	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026063	TF11-2-9	Room W of N-S running wall 4 (and E of OP9's wall 10) (sounding lot)	10-12th c	Bottle rim	Polychrome	Complete mouth/neck and part of shoulder of small perfume flask/bottle; probably torpedo shape; blue or purple with white festoons; corrosion makes difficult to distinguish precise color and if opaque; lip is rounded and only slightly thicker than walls, slightly

								uneven roundness
226	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026099	TF11-2-13	Room W of N-S running wall 4 (and E of OP9's wall 10) (sounding lot)	?	Type? Rim?	Colorless	Thick, flattened, tear-drop shapped edge (rim or base lip?); relatively flat but slight rise/fall
227	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026105 sample1	TF11-2-14	Room W of N-S running wall 4 (and E of OP9's wall 10) (N part of locus)	?	Bottle? Base	Light green	Large base 0.7cm thick at center of kick with rough/large punty scar
228	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026105 sample2	TF11-2-14	Room W of N-S running wall 4 (and E of OP9's wall 10) (N part of locus)	?	Type? Body	Aqua	Plain
229	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026105 sample3	TF11-2-14	Room W of N-S running wall 4 (and E of OP9's wall 10) (N part of locus)	?	Bottle neck	?	Narrow diameter
230	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026129 sample1	TF11-2-17	Room W of N-S running wall 4 (and E of OP9's wall 10) (N part of locus)	?	Type? Base	Green	Mostly central part of base (0.5cm thick) with punty scar; clean break matches frag in previous bag of same locus/lot info

231	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026129 sample2	TF11-2-17	Room W of N-S running wall 4 (and E of OP9's wall 10) (N part of locus)	?	Jar? Handle/rim	?	Thin fire-rounded rim with blob of glass attached and extending up and outwards, with thin round-section handle emerging from blob at roughly a horizontal line angle (probably extends out and then down and then in to attach to vessel)
232	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026164	TF11-2-20	Room W of N-S running wall 4 (and E of OP9's wall 10) (N part of locus)	?	Type? Base	Aqua	Slight kick and punty scar
233	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026040	TF11-3-5	Room E of N-S running wall 4	11-12th	Bowl? Base	?	Curving base with some walls attached; punty scar; small and ugly trail applied as base ring
234	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026093	TF11-6-11	Area S of walls 9, 5, 7	11-12th	Type? Base	Aqua	Thick pad base, very uneven thickness; lage chunk of punty scar; some walls extending horizontal
235	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026128	TF11-6-16	Area S of walls 9, 5, 7	?	Bracelet	Aqua-green	0.3cm thick and 0.8cm wide; flattened and rounded edge section, with slight depressed ridge in exterior center
236	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet	026142	TF11-8-18	Top of wall inside locus 3 (earlier phase)	?	Bottle base	Aqua	Complete; roughly square bottle with rounded corners and edges, 2.25cm sides, 0.2cm thick walls, 0.8cm thick bottom with punty scar walls remain to 3cm high

	Höyuk)							
237	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026059 sample1	TF12-1-2	Entire 5x5m OP, topsoil; poor/mixed Ei/MI	?	Type? Body	Brown-yellow	Plain
238	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026059 sample2	TF12-1-2	Entire 5x5m OP, topsoil; poor/mixed Ei/MI	?	Type? Handle	Brown-yellow	Small portion of wall with blobbed base of a handle, curvy and messy blob (swirled on?)
239	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026135	TF12-2-4	SE quandrant, E (inside) of N-S fortification wall 5; late Ei, MI mixed	?	Type? Base?	Light blue	Plain
240	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026202	TF12-4-9	SW quadrant,outside fortification wall 5 poor/mixed fill, EI/MI	?	Type? Base	Colorless	Hollow rolled ring and only break of walls; slight indent in the center and uneven overall; the base ring thicker/higher on one side and center of bottom dips accordingly; 0.2cm thick wall/ring and 0.4cm base center
241	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026160	TF12-7-8	SE quadrant, E (inside) of fortification wall 5, S of locus 9 and N of wall 10; mixed EI/MI	10-12th c	Bottle rim	Light blue	Rim with squared lip; narrow diameter

242	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026182 sample1	TF12-13-14	SW extension of wall 11; mixed fill	?	Type? Body	Green	Plain
243	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026182 sample2	TF12-13-14	SW extension of wall 11; mixed fill	?	Bracelet	Light blue	Smaller than others (child's bracelet or something else?); section is slightly peaked on ext and relatively flattened on int.; 0.7cm wide and 0.5cm thick section
244	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026267	TF15-2-2	Quadrant, topsoil, mixed	?	Chunk	Aqua	Thick
245	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	026271	TF15-3-4	Quadrant, topsoil, mixed	?	Type? Body	Light aqua	Irregular shape with changes in thickness; part of base?
246	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	25532	K/K2/K3 -122-241	Surface cleaning	12-14th	Type? Body	Purple	Plain
247	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	25549	K/K2/K3 -123-249	? (medieval)	12-14th	Type? Rim	Aqua	Thin, fire-rounded rim, slightly everted

248	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	25605	K/K2/K3 -125-250	? (medieval)	12-14th	Beaker body	Colorless	Two very thin threads almost parallel and horizontal on ext surface near bottom
249	Ḥiṣn al-Tīnāt (Tüpraş field of Kinet Höyuk)	25640	K/K2/K3 -128-273	? (medieval)	12-14th	Beaker base	Light green	Round rolled base with high kick; straight walls

APPENDIX C: TABLE OF CHEMICAL ANALYSES

Part A (major and minor elements, in wt% oxides)

Sample	SiO_2	Na_2O	K_2O	CaO	MgO	Al_2O_3	Fe_2O_3	TiO_2	MnO	P_2O_2	CuO	CoO	PbO_2	Sb_2O_5	SnO_2
1	66.30%	16.74%	0.99%	10.49%	0.66%	4.03%	0.73%	0.04%	0.03%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
2	66.69%	13.57%	2.89%	9.01%	2.57%	2.52%	0.83%	0.05%	1.53%	0.35%	0.01%	0.00%	0.00%	0.00%	0.00%
3	74.05%	14.16%	0.49%	6.76%	0.48%	3.50%	0.53%	0.03%	0.02%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
4	66.92%	13.04%	2.91%	10.11%	2.77%	2.16%	0.56%	0.04%	1.16%	0.33%	0.01%	0.00%	0.00%	0.00%	0.00%
5	66.74%	13.39%	2.85%	9.62%	3.16%	2.10%	0.62%	0.04%	1.21%	0.25%	0.01%	0.00%	0.00%	0.00%	0.00%
6	68.05%	14.10%	2.73%	6.99%	5.98%	1.29%	0.36%	0.02%	0.47%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
7	65.55%	12.77%	2.69%	11.03%	2.60%	2.27%	0.77%	0.05%	1.86%	0.41%	0.01%	0.00%	0.00%	0.00%	0.00%
8	55.07%	8.58%	2.16%	6.92%	3.29%	3.61%	1.01%	0.05%	0.07%	0.18%	1.31%	0.00%	17.42%	0.00%	0.10%
9	62.82%	14.93%	2.77%	9.30%	3.97%	3.77%	1.15%	0.07%	0.73%	0.53%	0.00%	0.00%	0.00%	0.00%	0.00%
10	67.54%	15.34%	2.70%	3.97%	1.86%	5.91%	1.93%	0.22%	0.38%	0.27%	0.01%	0.00%	0.03%	0.00%	0.00%
11	69.66%	13.04%	2.26%	8.13%	3.06%	2.25%	0.81%	0.05%	0.34%	0.41%	0.00%	0.00%	0.00%	0.00%	0.00%
12	69.11%	15.18%	0.36%	9.80%	0.63%	2.54%	1.01%	0.09%	0.26%	0.07%	0.01%	0.00%	0.06%	0.00%	0.00%
13	70.39%	13.65%	2.51%	7.31%	2.89%	1.63%	0.47%	0.03%	0.82%	0.29%	0.00%	0.00%	0.00%	0.00%	0.00%
14	69.57%	12.33%	2.77%	8.60%	2.68%	1.61%	0.44%	0.03%	0.93%	0.26%	0.00%	0.00%	0.00%	0.00%	0.00%
15	67.19%	13.30%	2.36%	8.99%	4.32%	1.69%	0.45%	0.03%	0.93%	0.21%	0.00%	0.00%	0.00%	0.00%	0.00%
16	70.40%	13.82%	0.38%	9.32%	0.68%	2.49%	1.48%	0.09%	0.27%	0.08%	0.13%	0.09%	0.01%	0.00%	0.00%
17	69.10%	12.39%	2.31%	8.57%	2.79%	1.94%	0.63%	0.04%	1.10%	0.31%	0.00%	0.00%	0.00%	0.00%	0.00%
18	74.66%	13.50%	0.52%	6.22%	0.60%	3.32%	0.51%	0.03%	0.02%	0.04%	0.00%	0.00%	0.00%	0.00%	0.00%
19	70.31%	11.71%	2.34%	7.94%	2.79%	2.58%	0.83%	0.06%	0.89%	0.44%	0.02%	0.00%	0.12%	0.00%	0.00%
20	70.53%	13.49%	2.80%	6.66%	2.02%	2.13%	0.63%	0.04%	1.32%	0.39%	0.00%	0.00%	0.00%	0.00%	0.00%
21	68.93%	13.42%	2.07%	8.45%	3.19%	1.95%	0.49%	0.03%	1.21%	0.27%	0.01%	0.00%	0.00%	0.00%	0.00%
22	68.56%	13.64%	2.11%	8.56%	2.73%	2.32%	0.80%	0.05%	0.80%	0.33%	0.03%	0.00%	0.08%	0.01%	0.01%
23	74.96%	11.20%	1.90%	5.40%	4.59%	1.09%	0.38%	0.01%	0.39%	0.07%	0.00%	0.00%	0.00%	0.00%	0.00%
24	71.99%	12.80%	2.34%	7.89%	3.52%	0.78%	0.31%	0.02%	0.05%	0.32%	0.00%	0.00%	0.00%	0.00%	0.00%
25	71.06%	12.96%	2.33%	7.05%	3.19%	1.16%	0.37%	0.03%	1.48%	0.36%	0.01%	0.00%	0.01%	0.00%	0.00%
26	70.67%	13.05%	2.31%	7.18%	3.20%	1.22%	0.38%	0.03%	1.59%	0.36%	0.01%	0.00%	0.01%	0.00%	0.00%
27	66.94%	13.64%	2.38%	8.55%	2.74%	2.07%	0.79%	0.04%	1.12%	0.55%	0.04%	0.00%	0.42%	0.00%	0.01%
28	68.69%	12.81%	2.24%	8.43%	2.87%	2.12%	0.68%	0.04%	0.87%	0.45%	0.02%	0.00%	0.14%	0.00%	0.01%
29	75.10%	12.14%	0.17%	7.69%	0.66%	2.47%	0.79%	0.08%	0.02%	0.14%	0.00%	0.00%	0.00%	0.00%	0.00%

Sample	SiO_2	Na_2O	K_2O	CaO	MgO	Al_2O_3	Fe_2O_3	TiO_2	MnO	P_2O_2	CuO	CoO	PbO_2	Sb_2O_5	SnO_2
30	68.24%	12.70%	2.65%	9.02%	3.19%	1.86%	0.45%	0.03%	0.93%	0.25%	0.01%	0.00%	0.00%	0.01%	0.00%
31	69.92%	14.99%	0.21%	10.21%	0.45%	2.23%	0.81%	0.08%	0.02%	0.02%	0.00%	0.00%	0.00%	0.00%	0.00%
32	71.84%	14.20%	0.52%	8.45%	0.64%	2.89%	0.42%	0.02%	0.03%	0.03%	0.00%	0.00%	0.00%	0.00%	0.00%
33	70.19%	13.17%	1.42%	9.73%	0.78%	3.09%	0.66%	0.04%	0.09%	0.18%	0.00%	0.00%	0.01%	0.00%	0.00%
34	69.64%	16.50%	0.84%	8.14%	0.66%	2.85%	0.38%	0.02%	0.02%	0.03%	0.00%	0.00%	0.00%	0.00%	0.00%
35	68.04%	16.69%	0.38%	5.48%	0.87%	2.77%	2.87%	0.16%	1.97%	0.06%	0.01%	0.00%	0.00%	0.00%	0.00%
36	72.68%	14.05%	0.20%	8.57%	0.65%	2.72%	1.02%	0.09%	0.02%	0.06%	0.00%	0.00%	0.00%	0.00%	0.00%
37	70.06%	13.50%	0.55%	10.27%	1.07%	3.13%	1.15%	0.10%	0.12%	0.12%	0.00%	0.00%	0.00%	0.00%	0.00%
38	71.63%	13.92%	0.27%	9.52%	0.70%	2.77%	1.08%	0.11%	0.02%	0.08%	0.00%	0.00%	0.00%	0.00%	0.00%
39	72.98%	14.96%	0.62%	7.09%	0.52%	3.24%	0.47%	0.03%	0.03%	0.05%	0.01%	0.00%	0.00%	0.00%	0.00%
40	71.31%	13.33%	0.33%	9.95%	0.76%	3.07%	1.13%	0.11%	0.02%	0.08%	0.00%	0.00%	0.00%	0.00%	0.00%
41	71.10%	13.72%	0.38%	8.99%	0.76%	2.69%	1.63%	0.10%	0.36%	0.16%	0.14%	0.04%	0.01%	0.00%	0.00%
42	67.46%	13.73%	1.69%	9.98%	2.67%	2.23%	0.81%	0.08%	0.67%	0.24%	0.03%	0.01%	0.03%	0.00%	0.00%
43	69.37%	15.45%	0.43%	10.08%	0.56%	2.56%	0.87%	0.13%	0.03%	0.08%	0.00%	0.00%	0.00%	0.00%	0.00%
44	58.74%	18.01%	3.48%	8.92%	5.80%	2.74%	0.71%	0.06%	0.87%	0.33%	0.00%	0.00%	0.00%	0.00%	0.00%
45	69.10%	15.85%	0.28%	10.10%	0.65%	2.47%	0.83%	0.13%	0.04%	0.07%	0.00%	0.00%	0.00%	0.00%	0.00%
46	67.51%	13.16%	1.98%	10.39%	3.33%	1.90%	0.32%	0.03%	0.72%	0.21%	0.00%	0.00%	0.00%	0.00%	0.00%
47	69.19%	14.36%	0.32%	11.12%	0.78%	2.60%	0.86%	0.14%	0.05%	0.09%	0.00%	0.00%	0.00%	0.00%	0.00%
48	67.45%	15.31%	0.38%	10.37%	0.62%	2.49%	1.00%	0.14%	1.67%	0.11%	0.01%	0.00%	0.01%	0.00%	0.00%
49	70.11%	14.28%	0.35%	9.93%	0.71%	2.83%	1.10%	0.20%	0.03%	0.10%	0.00%	0.00%	0.00%	0.00%	0.00%
50	69.96%	13.85%	0.32%	10.41%	0.72%	2.96%	1.08%	0.21%	0.03%	0.10%	0.00%	0.00%	0.00%	0.00%	0.00%
51	69.27%	14.79%	0.35%	10.70%	0.64%	2.56%	0.94%	0.18%	0.03%	0.09%	0.00%	0.00%	0.00%	0.00%	0.00%
52	69.88%	13.81%	0.38%	10.64%	0.76%	2.59%	0.96%	0.18%	0.31%	0.10%	0.01%	0.00%	0.01%	0.00%	0.00%
53	70.22%	14.50%	0.23%	10.30%	0.65%	2.51%	0.87%	0.17%	0.02%	0.07%	0.00%	0.00%	0.00%	0.00%	0.00%
54	70.65%	17.90%	0.45%	3.80%	0.90%	4.02%	1.56%	0.31%	0.05%	0.09%	0.00%	0.00%	0.00%	0.00%	0.00%
55	70.23%	14.85%	0.24%	10.03%	0.56%	2.53%	0.85%	0.16%	0.02%	0.07%	0.00%	0.00%	0.00%	0.00%	0.00%
56	74.70%	14.32%	0.57%	6.09%	0.44%	2.88%	0.42%	0.05%	0.02%	0.06%	0.00%	0.00%	0.00%	0.00%	0.00%
57	72.15%	13.93%	0.49%	8.13%	0.76%	3.41%	0.51%	0.05%	0.03%	0.06%	0.00%	0.00%	0.00%	0.00%	0.00%
58	73.59%	14.69%	0.41%	6.76%	0.52%	2.98%	0.44%	0.05%	0.02%	0.07%	0.00%	0.00%	0.00%	0.00%	0.00%
59	70.59%	14.05%	0.54%	8.54%	0.70%	3.69%	0.90%	0.10%	0.08%	0.12%	0.05%	0.00%	0.30%	0.00%	0.04%
60	64.14%	15.19%	2.66%	8.75%	4.42%	2.26%	0.91%	0.09%	0.84%	0.34%	0.01%	0.01%	0.01%	0.00%	0.00%
61	75.49%	12.95%	0.43%	6.40%	0.54%	3.12%	0.49%	0.05%	0.03%	0.06%	0.00%	0.00%	0.00%	0.00%	0.00%
62	76.07%	18.30%	0.18%	4.55%	0.09%	0.53%	0.09%	0.04%	0.02%	0.02%	0.00%	0.00%	0.03%	0.00%	0.00%

Sample	SiO_2	Na_2O	K_2O	CaO	MgO	Al_2O_3	Fe_2O_3	TiO_2	MnO	P_2O_2	CuO	CoO	PbO_2	Sb_2O_5	SnO_2
63	75.90%	12.22%	0.46%	6.19%	0.53%	3.44%	0.76%	0.08%	0.03%	0.06%	0.00%	0.00%	0.00%	0.00%	0.00%
64	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
65	63.74%	15.72%	2.67%	6.93%	4.87%	2.46%	1.63%	0.05%	0.94%	0.24%	0.20%	0.09%	0.04%	0.00%	0.03%
66	75.01%	11.97%	0.62%	7.64%	0.66%	3.35%	0.64%	0.04%	0.03%	0.06%	0.00%	0.00%	0.00%	0.00%	0.00%
67	71.19%	15.50%	0.25%	8.85%	0.51%	2.67%	0.93%	0.09%	0.02%	0.05%	0.00%	0.00%	0.00%	0.00%	0.00%
68	74.27%	13.17%	0.75%	6.38%	0.67%	3.63%	0.57%	0.06%	0.03%	0.08%	0.00%	0.00%	0.00%	0.00%	0.00%
69	70.29%	18.47%	0.40%	3.52%	0.89%	4.04%	1.62%	0.33%	0.05%	0.07%	0.00%	0.00%	0.00%	0.00%	0.00%
70	69.77%	15.31%	0.38%	9.61%	0.67%	2.33%	0.96%	0.16%	0.15%	0.16%	0.02%	0.00%	0.06%	0.00%	0.00%
71	69.99%	13.39%	0.60%	9.99%	0.74%	3.49%	1.03%	0.12%	0.06%	0.16%	0.02%	0.00%	0.16%	0.00%	0.02%
72	74.79%	13.19%	0.65%	6.54%	0.48%	3.31%	0.60%	0.07%	0.03%	0.06%	0.00%	0.00%	0.00%	0.00%	0.00%
73	74.81%	13.12%	0.61%	6.66%	0.50%	3.27%	0.60%	0.07%	0.02%	0.06%	0.00%	0.00%	0.00%	0.00%	0.00%
74	70.10%	17.30%	0.93%	3.65%	1.00%	4.31%	1.77%	0.33%	0.05%	0.25%	0.00%	0.00%	0.00%	0.00%	0.00%
75	70.85%	17.29%	0.60%	6.81%	0.48%	2.94%	0.42%	0.05%	0.02%	0.06%	0.00%	0.00%	0.00%	0.00%	0.00%
76	70.04%	20.02%	0.50%	3.81%	0.65%	3.15%	1.04%	0.16%	0.04%	0.12%	0.03%	0.00%	0.01%	0.00%	0.00%
77	71.21%	11.20%	1.68%	5.67%	2.66%	2.16%	3.11%	0.06%	0.77%	0.16%	0.72%	0.10%	0.02%	0.00%	0.00%
78	75.24%	12.29%	0.45%	7.25%	0.67%	3.00%	0.45%	0.03%	0.02%	0.05%	0.00%	0.00%	0.00%	0.00%	0.00%
79	69.01%	18.17%	0.25%	8.65%	0.47%	1.77%	0.70%	0.08%	0.03%	0.06%	0.01%	0.00%	0.00%	0.00%	0.00%
80	64.82%	15.80%	2.44%	7.61%	4.49%	1.89%	1.83%	0.05%	0.34%	0.21%	0.07%	0.03%	0.01%	0.00%	0.01%
81	73.73%	14.81%	0.61%	6.36%	0.46%	2.87%	0.44%	0.03%	0.02%	0.05%	0.00%	0.00%	0.00%	0.00%	0.00%
82	74.05%	14.92%	0.43%	6.24%	0.47%	2.75%	0.42%	0.03%	0.02%	0.05%	0.00%	0.00%	0.00%	0.00%	0.00%
83	69.12%	15.72%	0.22%	11.27%	0.41%	1.78%	0.61%	0.07%	0.01%	0.06%	0.00%	0.00%	0.00%	0.00%	0.00%
84	70.63%	11.68%	0.63%	10.93%	0.77%	3.72%	1.03%	0.08%	0.04%	0.11%	0.03%	0.00%	0.12%	0.00%	0.01%
85	73.66%	13.65%	0.50%	7.38%	0.66%	2.97%	0.46%	0.03%	0.02%	0.05%	0.00%	0.00%	0.00%	0.00%	0.00%
86	69.43%	16.31%	0.44%	9.77%	0.46%	1.77%	0.74%	0.10%	0.02%	0.23%	0.00%	0.00%	0.00%	0.00%	0.00%
87	70.45%	11.70%	0.45%	9.24%	0.57%	3.43%	0.58%	0.04%	0.02%	0.08%	0.01%	0.00%	3.05%	0.00%	0.03%
88	67.08%	17.17%	1.00%	8.35%	1.21%	2.71%	1.17%	0.08%	0.59%	0.17%	0.01%	0.00%	0.01%	0.00%	0.00%
89	68.01%	16.24%	0.30%	9.99%	0.82%	2.58%	1.07%	0.13%	0.03%	0.08%	0.00%	0.00%	0.00%	0.00%	0.00%
90	71.42%	11.91%	0.59%	9.83%	0.73%	3.77%	1.08%	0.08%	0.05%	0.10%	0.03%	0.00%	0.18%	0.00%	0.01%
91	71.36%	15.87%	0.54%	3.18%	1.19%	4.56%	2.40%	0.37%	0.06%	0.10%	0.00%	0.00%	0.00%	0.00%	0.00%
92	74.34%	12.96%	0.47%	7.13%	0.56%	3.39%	0.53%	0.04%	0.02%	0.05%	0.00%	0.00%	0.00%	0.00%	0.00%
93	67.77%	16.99%	0.41%	10.49%	0.48%	2.00%	0.77%	0.11%	0.02%	0.20%	0.00%	0.00%	0.00%	0.00%	0.00%
94	73.66%	14.53%	0.50%	6.71%	0.52%	2.84%	0.54%	0.04%	0.02%	0.07%	0.00%	0.00%	0.01%	0.00%	0.00%
95	71.76%	16.50%	0.49%	6.91%	0.45%	2.71%	0.38%	0.03%	0.02%	0.05%	0.00%	0.00%	0.00%	0.00%	0.00%

Sample	SiO_2	Na_2O	K_2O	CaO	MgO	Al_2O_3	Fe_2O_3	TiO_2	MnO	P_2O_2	CuO	CoO	PbO_2	Sb_2O_5	SnO_2
96	67.46%	17.42%	0.55%	9.06%	0.54%	2.85%	0.36%	0.03%	1.01%	0.07%	0.00%	0.00%	0.00%	0.00%	0.00%
97	69.26%	16.60%	0.94%	8.53%	0.66%	2.48%	0.48%	0.03%	0.02%	0.17%	0.05%	0.01%	0.11%	0.00%	0.00%
98	68.44%	15.80%	1.00%	9.66%	0.68%	2.89%	0.63%	0.05%	0.05%	0.19%	0.00%	0.00%	0.00%	0.00%	0.00%
99	64.50%	17.61%	1.26%	10.41%	0.56%	2.86%	0.50%	0.04%	1.68%	0.16%	0.01%	0.00%	0.00%	0.00%	0.00%
100	67.37%	17.34%	0.59%	9.80%	0.58%	3.03%	0.50%	0.03%	0.03%	0.06%	0.00%	0.00%	0.00%	0.00%	0.00%
101	70.22%	16.07%	0.42%	8.66%	0.56%	2.73%	0.44%	0.03%	0.03%	0.05%	0.00%	0.00%	0.00%	0.00%	0.00%
102	68.91%	13.05%	1.33%	10.15%	1.93%	2.58%	0.85%	0.11%	0.52%	0.18%	0.02%	0.00%	0.02%	0.00%	0.00%
103	70.62%	17.26%	0.60%	7.03%	0.49%	2.90%	0.35%	0.04%	0.04%	0.08%	0.00%	0.00%	0.00%	0.00%	0.00%
104	67.54%	13.52%	2.05%	9.80%	3.14%	1.91%	0.59%	0.05%	0.71%	0.27%	0.03%	0.01%	0.01%	0.00%	0.00%
105	71.56%	11.46%	2.42%	7.92%	2.31%	2.04%	0.47%	0.05%	0.92%	0.37%	0.00%	0.00%	0.00%	0.00%	0.00%
106	66.45%	14.56%	1.81%	7.98%	2.77%	1.58%	2.02%	0.04%	1.69%	0.22%	0.37%	0.18%	0.01%	0.00%	0.00%
107	70.14%	16.18%	0.74%	8.05%	0.60%	3.20%	0.38%	0.04%	0.02%	0.10%	0.00%	0.00%	0.00%	0.00%	0.00%
108	73.07%	13.80%	0.77%	7.55%	0.61%	3.28%	0.41%	0.04%	0.02%	0.06%	0.00%	0.00%	0.00%	0.00%	0.00%
109	71.76%	15.43%	0.79%	7.60%	0.57%	2.74%	0.39%	0.04%	0.02%	0.14%	0.00%	0.00%	0.00%	0.00%	0.00%
110	68.99%	16.52%	0.61%	9.04%	0.60%	3.17%	0.41%	0.03%	0.02%	0.13%	0.00%	0.00%	0.00%	0.00%	0.00%
111	69.48%	15.01%	0.40%	9.88%	0.65%	3.41%	0.46%	0.04%	0.02%	0.06%	0.00%	0.00%	0.00%	0.00%	0.00%
112	66.92%	15.82%	1.30%	9.63%	0.68%	3.36%	0.66%	0.05%	0.96%	0.19%	0.03%	0.00%	0.01%	0.00%	0.00%
113	69.85%	13.88%	0.60%	10.57%	0.71%	3.22%	0.49%	0.04%	0.03%	0.10%	0.00%	0.00%	0.01%	0.00%	0.00%
114	66.32%	16.83%	0.45%	5.59%	1.38%	3.64%	3.50%	0.30%	1.55%	0.14%	0.01%	0.00%	0.00%	0.00%	0.00%
115	70.31%	7.93%	0.14%	19.83%	0.49%	0.84%	0.18%	0.03%	0.05%	0.01%	0.00%	0.00%	0.02%	0.00%	0.00%
116	73.99%	13.34%	0.45%	7.61%	0.50%	2.81%	0.55%	0.04%	0.06%	0.11%	0.00%	0.00%	0.01%	0.00%	0.00%
117	66.56%	13.23%	2.46%	10.42%	3.59%	1.37%	0.59%	0.03%	0.92%	0.29%	0.00%	0.00%	0.00%	0.00%	0.00%
118	67.74%	11.43%	2.56%	9.76%	2.75%	2.09%	0.70%	0.04	1.93%	0.33%	0.18%	0.00	0.02%	0.00%	0.00%
119	67.08%	13.21%	2.54%	10.31%	3.41%	1.39%	0.43%	0.03%	0.81%	0.30%	0.00%	0.00%	0.00%	0.00%	0.00%
120	69.06%	15.72%	0.27%	10.93%	0.44%	2.02%	0.83%	0.11%	0.03%	0.04%	0.00%	0.00%	0.00%	0.00%	0.00%
121	69.44%	15.24%	0.37%	9.13%	0.59%	2.38%	1.52%	0.08%	0.08%	0.10%	0.23%	0.15%	0.02%	0.00%	0.01%
122	70.53%	15.81%	0.26%	9.14%	0.51%	2.19%	0.80%	0.08%	0.03%	0.07%	0.00%	0.00%	0.00%	0.00%	0.00%
123	70.71%	13.65%	0.49%	10.22%	0.74%	3.09%	0.56%	0.03%	0.03%	0.10%	0.00%	0.00%	0.00%	0.00%	0.00%
124	71.70%	13.92%	0.48%	9.22%	0.72%	2.85%	0.57%	0.03%	0.03%	0.11%	0.00%	0.00%	0.00%	0.00%	0.00%
125	68.10%	14.18%	0.27%	12.40%	0.56%	2.77%	0.89%	0.09%	0.04%	0.08%	0.00%	0.00%	0.00%	0.00%	0.00%
126	73.60%	14.30%	0.67%	7.13%	0.52%	2.63%	0.52%	0.03%	0.02%	0.13%	0.00%	0.00%	0.00%	0.00%	0.00%
127	73.05%	13.05%	0.18%	9.11%	0.55%	2.53%	0.95%	0.10%	0.03%	0.06%	0.00%	0.00%	0.00%	0.00%	0.00%
128	74.96%	11.97%	0.34%	8.30%	0.43%	2.84%	0.42%	0.02%	0.02%	0.08%	0.00%	0.00%	0.02%	0.00%	0.00%

Sample	SiO_2	Na_2O	K_2O	CaO	MgO	Al_2O_3	Fe_2O_3	TiO_2	MnO	P_2O_2	CuO	CoO	PbO_2	Sb_2O_5	SnO_2
129	70.79%	14.91%	0.33%	9.12%	0.59%	2.35%	0.90%	0.08%	0.18%	0.10%	0.01%	0.00%	0.02%	0.00%	0.00%
130	72.54%	13.52%	0.21%	9.55%	0.46%	2.27%	0.74%	0.07%	0.02%	0.06%	0.00%	0.00%	0.00%	0.00%	0.00%
131	74.34%	11.98%	0.48%	8.11%	0.67%	3.28%	0.50%	0.03%	0.05%	0.09%	0.01%	0.00%	0.01%	0.00%	0.00%
132	74.55%	13.44%	0.55%	6.94%	0.56%	2.73%	0.48%	0.02%	0.04%	0.09%	0.01%	0.00%	0.01%	0.00%	0.00%
133	74.29%	13.47%	0.56%	7.27%	0.54%	2.75%	0.43%	0.02%	0.03%	0.10%	0.00%	0.00%	0.00%	0.00%	0.00%
134	69.62%	16.28%	0.22%	10.01%	0.38%	1.96%	0.80%	0.10%	0.02%	0.05%	0.00%	0.00%	0.00%	0.00%	0.00%
135	68.44%	16.02%	0.35%	8.99%	0.50%	2.26%	0.98%	0.09%	1.62%	0.07%	0.00%	0.00%	0.00%	0.00%	0.00%
136	72.07%	14.22%	0.23%	9.35%	0.44%	2.10%	0.79%	0.07%	0.08%	0.06%	0.00%	0.00%	0.00%	0.00%	0.00%
137	73.84%	13.54%	0.48%	7.67%	0.47%	2.98%	0.38%	0.02%	0.02%	0.08%	0.00%	0.00%	0.00%	0.00%	0.00%
138	70.42%	14.40%	0.47%	9.74%	0.72%	2.77%	0.73%	0.06%	0.10%	0.11%	0.03%	0.00%	0.02%	0.00%	0.00%
139	69.48%	13.98%	0.70%	9.97%	1.05%	3.07%	0.81%	0.05%	0.21%	0.14%	0.03%	0.00%	0.10%	0.00%	0.01%
140	73.16%	13.81%	0.22%	8.32%	0.47%	2.37%	0.82%	0.07%	0.02%	0.07%	0.00%	0.00%	0.00%	0.00%	0.00%
141	70.01%	14.98%	0.29%	9.92%	0.55%	2.58%	0.90%	0.09%	0.02%	0.08%	0.00%	0.00%	0.00%	0.00%	0.00%
142	70.56%	16.86%	0.54%	7.89%	0.51%	2.70%	0.40%	0.02%	0.02%	0.09%	0.00%	0.00%	0.00%	0.00%	0.00%
143	72.04%	13.34%	0.21%	9.79%	0.46%	2.52%	0.85%	0.08%	0.02%	0.07%	0.00%	0.00%	0.00%	0.00%	0.00%
144	71.29%	13.51%	1.80%	8.23%	3.33%	0.71%	0.25%	0.02%	0.02%	0.26%	0.00%	0.00%	0.00%	0.00%	0.00%
145	71.62%	15.15%	0.59%	7.70%	0.61%	3.13%	0.44%	0.02%	0.03%	0.07%	0.01%	0.00%	0.01%	0.00%	0.00%
146	70.28%	11.79%	2.79%	7.72%	1.95%	1.07%	0.63%	0.02	0.04%	0.36%	1.66%	0.00	0.98%	0.01%	0.42%
147	64.20%	13.77%	1.75%	11.72%	2.74%	2.62%	2.98%	0.05	0.04%	0.08%	0.00%	0.00	0.00%	0.01%	0.00%
148	66.41%	13.75%	2.28%	10.53%	3.32%	1.59%	0.63%	0.05%	0.80%	0.28%	0.01%	0.00%	0.02%	0.00%	0.00%
149	67.73%	10.92%	2.10%	11.65%	2.26%	2.57%	0.92%	0.08%	0.95%	0.42%	0.00%	0.00%	0.00%	0.00%	0.00%
150	66.44%	13.40%	1.47%	10.75%	2.76%	2.78%	2.08%	0.07	0.05%	0.09%	0.00%	0.00	0.00%	0.01%	0.00%
151	68.03%	11.09%	2.59%	11.42%	2.04%	1.95%	0.58%	0.05%	1.38%	0.40%	0.00%	0.00%	0.00%	0.00%	0.00%
152	69.24%	11.29%	2.31%	10.65%	2.16%	2.00%	0.72%	0.06	0.75%	0.41%	0.00%	0.00	0.00%	0.00%	0.00%
153	54.28%	18.87%	3.94%	5.88%	5.06%	9.76%	1.52%	0.07	0.11%	0.26%	0.09%	0.08	0.01%	0.00%	0.00%
154	69.14%	13.31%	0.29%	11.97%	0.67%	2.85%	1.11%	0.18%	0.02%	0.07%	0.00%	0.00%	0.00%	0.00%	0.00%
155	69.92%	11.75%	2.08%	9.81%	3.14%	1.59%	0.32%	0.04%	0.79%	0.19%	0.00%	0.00%	0.00%	0.00%	0.00%
156	68.14%	12.11%	2.70%	7.89%	5.27%	1.23%	1.23%	0.03%	0.61%	0.10%	0.17%	0.05%	0.08%	0.00%	0.01%
157	67.80%	13.94%	2.29%	9.55%	3.55%	1.09%	0.43%	0.04%	0.58%	0.32%	0.00%	0.00%	0.00%	0.00%	0.00%
158	68.43%	13.04%	2.29%	9.54%	2.75%	1.79%	0.53%	0.05%	0.83%	0.31%	0.02%	0.00%	0.03%	0.00%	0.00%
159	66.09%	12.67%	2.54%	10.64%	2.87%	2.05%	0.78%	0.03%	1.62%	0.30%	0.01%	0.00%	0.00%	0.00%	0.00%
160	66.59%	12.24%	2.51%	11.05%	3.26%	1.92%	0.58%	0.03%	1.10%	0.31%	0.01%	0.00%	0.01%	0.00%	0.00%
161	66.70%	12.21%	2.44%	10.84%	2.90%	1.99%	0.55%	0.05%	1.63%	0.30%	0.01%	0.00%	0.00%	0.00%	0.00%

Sample	SiO_2	Na_2O	K_2O	CaO	MgO	Al_2O_3	Fe_2O_3	TiO_2	MnO	P_2O_2	CuO	CoO	PbO_2	Sb_2O_5	SnO_2
162	66.38%	12.61%	2.48%	10.51%	2.99%	1.94%	0.57%	0.05%	1.74%	0.37%	0.01%	0.00%	0.00%	0.00%	0.00%
163	54.35%	20.80%	3.96%	5.10%	4.10%	9.46%	1.57%	0.08	0.09%	0.20%	0.09%	0.07	0.01%	0.00%	0.00%
164	66.28%	16.76%	2.70%	5.00%	5.89%	1.12%	0.38%	0.07%	1.22%	0.12%	0.00%	0.00%	0.00%	0.00%	0.00%
165	68.26%	12.72%	1.99%	9.77%	3.02%	1.78%	0.61%	0.05%	0.72%	0.25%	0.11%	0.00%	0.30%	0.00%	0.04%
166	68.24%	15.60%	0.54%	10.94%	0.46%	3.66%	0.40%	0.03%	0.02%	0.02%	0.00%	0.00%	0.00%	0.00%	0.00%
167	52.98%	20.28%	4.14%	6.01%	4.46%	10.07%	1.41%	0.07	0.08%	0.17%	0.06%	0.06	0.01%	0.00%	0.00%
168	64.94%	14.19%	2.15%	11.27%	3.55%	1.65%	0.58%	0.05%	0.99%	0.28%	0.02%	0.00%	0.02%	0.00%	0.00%
169	65.92%	13.70%	2.19%	11.05%	3.57%	1.53%	0.58%	0.05%	0.74%	0.30%	0.02%	0.00%	0.02%	0.00%	0.00%
170	69.55%	12.76%	1.17%	10.26%	1.88%	2.28%	0.93%	0.11%	0.41%	0.24%	0.02%	0.01%	0.01%	0.00%	0.00%
171	68.08%	12.82%	2.11%	10.04%	3.39%	1.64%	0.52%	0.04%	0.72%	0.27%	0.01%	0.00%	0.01%	0.00%	0.00%
172	71.34%	11.72%	1.90%	9.16%	2.85%	1.49%	0.30%	0.03%	0.57%	0.25%	0.00%	0.00%	0.00%	0.00%	0.00%
173	68.85%	13.72%	1.83%	9.44%	2.80%	1.58%	0.38%	0.04%	0.73%	0.26%	0.00%	0.00%	0.00%	0.00%	0.00%
174	64.43%	14.39%	1.56%	12.47%	2.55%	2.46%	1.77%	0.06	0.04%	0.14%	0.00%	0.00	0.00%	0.01%	0.00%
175	66.75%	15.51%	0.88%	11.32%	1.02%	3.16%	0.58%	0.05%	0.10%	0.13%	0.02%	0.02%	0.00%	0.00%	0.00%
176	66.99%	13.50%	0.56%	13.00%	0.89%	2.87%	1.11%	0.12%	0.23%	0.17%	0.06%	0.00%	0.15%	0.00%	0.03%
177	67.42%	13.00%	2.58%	9.98%	2.76%	2.01%	0.51%	0.04%	1.04%	0.28%	0.01%	0.00%	0.00%	0.00%	0.00%
178	63.05%	15.05%	2.93%	8.32%	4.45%	2.37%	1.64%	0.08%	0.97%	0.28%	0.18%	0.18%	0.04%	0.00%	0.00%
179	66.80%	15.30%	2.52%	6.08%	5.28%	1.46%	0.45%	0.04%	1.57%	0.13%	0.00%	0.00%	0.00%	0.00%	0.00%
180	66.81%	15.79%	0.36%	11.61%	0.55%	3.41%	1.07%	0.14%	0.02%	0.03%	0.00%	0.00%	0.00%	0.00%	0.00%
181	66.50%	15.02%	2.04%	7.98%	4.19%	2.10%	0.71%	0.06%	1.02%	0.13%	0.01%	0.00%	0.01%	0.00%	0.00%
182	70.56%	15.45%	0.50%	9.13%	0.55%	2.74%	0.35%	0.03%	0.03%	0.10%	0.00%	0.00%	0.00%	0.00%	0.00%
183	68.24%	14.58%	2.35%	5.55%	5.46%	1.44%	0.50%	0.04%	1.38%	0.13%	0.01%	0.00%	0.00%	0.00%	0.00%
184	70.56%	14.68%	0.60%	9.47%	0.52%	3.13%	0.54%	0.05%	0.03%	0.11%	0.00%	0.00%	0.00%	0.00%	0.00%
185	67.12%	14.95%	1.92%	7.41%	4.55%	1.75%	0.69%	0.06%	1.04%	0.14%	0.01%	0.00%	0.01%	0.00%	0.00%
186	72.69%	14.97%	0.57%	7.50%	0.43%	2.84%	0.38%	0.04%	0.02%	0.09%	0.00%	0.00%	0.00%	0.00%	0.00%
187	67.49%	10.95%	2.68%	11.72%	2.48%	1.93%	0.55%	0.05%	1.32%	0.40%	0.01%	0.00%	0.00%	0.00%	0.00%
188	59.87%	19.83%	4.48%	1.69%	1.25%	10.55%	1.61%	0.04	0.03%	0.23%	0.15%	0.04	0.01%	0.00%	0.00%
189	69.54%	11.57%	2.65%	9.66%	2.42%	1.59%	0.48%	0.04%	1.23%	0.40%	0.01%	0.00%	0.00%	0.00%	0.00%
190	66.08%	12.57%	2.60%	10.85%	2.97%	2.11%	0.53%	0.04%	1.73%	0.25%	0.01%	0.00%	0.00%	0.00%	0.00%
191	62.49%	15.24%	1.67%	12.43%	2.83%	2.93%	2.16%	0.06	0.05%	0.08%	0.00%	0.00	0.00%	0.01%	0.00%
192	71.23%	14.74%	0.25%	9.74%	0.42%	2.33%	0.78%	0.10%	0.02%	0.06%	0.00%	0.00%	0.00%	0.00%	0.00%
193	72.78%	13.41%	0.55%	8.72%	0.60%	3.06%	0.41%	0.03%	0.02%	0.07%	0.00%	0.00%	0.00%	0.00%	0.00%
194	73.31%	12.90%	0.42%	9.00%	0.46%	3.06%	0.40%	0.03%	0.03%	0.10%	0.00%	0.00%	0.00%	0.00%	0.00%

Sample	SiO_2	Na_2O	K_2O	CaO	MgO	Al_2O_3	Fe_2O_3	TiO_2	MnO	P_2O_2	CuO	CoO	PbO_2	Sb_2O_5	SnO_2
195	65.13%	14.51%	2.65%	8.94%	3.52%	2.84%	0.88%	0.07%	0.87%	0.30%	0.03%	0.01%	0.03%	0.00%	0.00%
196	72.86%	12.96%	0.55%	8.80%	0.75%	3.16%	0.41%	0.03%	0.02%	0.07%	0.00%	0.00%	0.00%	0.00%	0.00%
197	67.10%	12.32%	2.77%	10.72%	3.67%	1.71%	0.37%	0.03%	0.76%	0.25%	0.00%	0.00%	0.00%	0.00%	0.00%
198	54.50%	19.14%	4.13%	5.15%	4.47%	10.47%	1.53%	0.06	0.08%	0.23%	0.10%	0.07	0.00%	0.00%	0.00%
199	65.00%	12.65%	2.06%	12.70%	3.11%	1.81%	0.73%	0.04%	1.33%	0.28%	0.02%	0.00%	0.02%	0.00%	0.00%
200	72.16%	17.73%	0.07%	7.63%	1.85%	0.31%	0.07%	0.07%	0.01%	0.02%	0.00%	0.00%	0.00%	0.00%	0.00%
201	72.13%	14.61%	0.25%	9.17%	0.46%	2.15%	0.68%	0.08%	0.02%	0.10%	0.00%	0.00%	0.00%	0.00%	0.00%
202	67.33%	14.82%	2.23%	8.94%	3.34%	1.44%	0.48%	0.03%	0.67%	0.36%	0.01%	0.00%	0.01%	0.00%	0.00%
203	67.07%	12.25%	2.21%	10.52%	3.83%	2.26%	0.46%	0.04%	0.81%	0.27%	0.00%	0.00%	0.00%	0.00%	0.00%
204	72.48%	14.41%	0.01%	10.18%	2.56%	0.12%	0.17%	0.00%	0.00%	0.02%	0.00%	0.00%	0.00%	0.00%	0.00%
205	66.75%	14.27%	2.13%	9.78%	3.29%	1.83%	0.57%	0.04%	0.65%	0.33%	0.03%	0.01%	0.01%	0.00%	0.00%
206	69.68%	15.71%	0.27%	9.63%	0.64%	2.50%	0.87%	0.11%	0.03%	0.10%	0.00%	0.00%	0.00%	0.00%	0.00%
207	67.52%	14.15%	2.19%	9.46%	3.28%	1.50%	0.47%	0.04%	0.75%	0.31%	0.01%	0.00%	0.01%	0.00%	0.00%
208	66.28%	11.74%	2.39%	11.03%	3.61%	2.29%	0.47%	0.03%	1.58%	0.33%	0.01%	0.00%	0.00%	0.00%	0.00%
209	69.82%	14.11%	0.44%	9.65%	0.61%	2.42%	1.08%	0.11%	1.19%	0.12%	0.00%	0.00%	0.00%	0.00%	0.00%
210	69.14%	11.75%	2.26%	10.21%	3.09%	1.88%	0.36%	0.03%	0.71%	0.24%	0.00%	0.00%	0.00%	0.00%	0.00%
211	69.12%	12.07%	1.67%	6.42%	3.45%	2.27%	3.00%	0.06%	0.62%	0.30%	0.59%	0.19%	0.02%	0.00%	0.00%
212	66.47%	12.45%	2.78%	11.22%	3.68%	1.88%	0.73%	0.03%	0.07%	0.32%	0.03%	0.01%	0.00%	0.00%	0.00%
213	65.88%	14.90%	2.27%	10.02%	3.26%	1.19%	0.82%	0.03%	0.80%	0.38%	0.08%	0.04%	0.02%	0.00%	0.00%
214	69.40%	16.01%	0.48%	9.67%	0.76%	2.16%	0.85%	0.10%	0.09%	0.10%	0.01%	0.00%	0.00%	0.00%	0.00%
215	72.81%	16.73%	0.27%	6.29%	0.59%	1.82%	0.78%	0.09%	0.02%	0.05%	0.00%	0.00%	0.00%	0.00%	0.00%
216	66.99%	13.18%	2.30%	10.72%	3.18%	1.71%	0.47%	0.04%	0.75%	0.25%	0.01%	0.00%	0.01%	0.00%	0.00%
217	70.49%	12.13%	2.26%	8.10%	2.78%	1.68%	0.54%	0.05	1.16%	0.32%	0.01%	0.00	0.00%	0.00%	0.00%
218	68.74%	11.55%	2.37%	9.27%	2.39%	1.97%	0.65%	0.05%	1.35%	0.32%	0.75%	0.00%	0.08%	0.00%	0.04%
219	69.02%	12.65%	2.03%	9.91%	3.10%	1.71%	0.38%	0.04%	0.53%	0.21%	0.02%	0.00%	0.00%	0.00%	0.00%
220	66.30%	13.90%	0.78%	12.62%	1.13%	3.20%	0.98%	0.07%	0.23%	0.14%	0.07%	0.00%	0.20%	0.00%	0.04%
221	69.83%	14.63%	0.25%	10.12%	0.64%	2.75%	0.96%	0.14%	0.02%	0.07%	0.00%	0.00%	0.00%	0.00%	0.00%
222	67.85%	16.07%	1.22%	8.06%	1.69%	2.01%	1.71%	0.05%	0.50%	0.21%	0.10%	0.07%	0.04%	0.00%	0.00%
223	69.37%	12.28%	2.88%	8.86%	1.87%	2.02%	0.53%	0.04%	1.29%	0.35%	0.00%	0.00%	0.00%	0.00%	0.00%
224	67.97%	15.60%	2.75%	6.01%	3.43%	1.52%	1.56%	0.05%	0.10%	0.50%	0.00%	0.00%	0.02%	0.00%	0.00%
225	62.34%	15.31%	1.85%	8.73%	3.97%	4.79%	2.02%	0.14%	0.07%	0.32%	0.00%	0.00%	0.02%	0.00%	0.04%
226	66.32%	13.37%	2.31%	10.97%	3.12%	1.70%	0.43%	0.04%	1.10%	0.25%	0.01%	0.00%	0.00%	0.00%	0.00%
227	66.14%	15.50%	2.39%	9.07%	3.08%	1.67%	0.47%	0.04%	0.86%	0.28%	0.00%	0.00%	0.00%	0.00%	0.00%

Sample	SiO_2	Na_2O	K_2O	CaO	MgO	Al_2O_3	Fe_2O_3	TiO_2	MnO	P_2O_2	CuO	CoO	PbO_2	Sb_2O_5	SnO_2
228	67.75%	13.85%	2.05%	10.35%	2.73%	1.90%	0.60%	0.03%	0.08%	0.23%	0.01%	0.01%	0.00%	0.00%	0.00%
229	65.43%	13.81%	2.23%	11.01%	3.22%	1.53%	0.70%	0.05%	1.30%	0.30%	0.01%	0.00%	0.01%	0.00%	0.00%
230	64.12%	13.22%	2.24%	11.11%	3.09%	1.76%	0.68%	0.05%	3.04%	0.28%	0.02%	0.00%	0.03%	0.00%	0.00%
231	65.59%	12.63%	2.36%	9.53%	2.48%	2.06%	0.75%	0.06%	1.24%	0.36%	2.25%	0.00%	0.16%	0.01%	0.05%
232	65.14%	11.98%	2.26%	13.08%	3.33%	2.05%	0.63%	0.05%	0.92%	0.23%	0.01%	0.00%	0.02%	0.00%	0.00%
233	69.38%	12.43%	2.34%	8.37%	2.65%	1.84%	0.64%	0.05%	1.19%	0.37%	0.07%	0.00%	0.20%	0.00%	0.00%
234	66.51%	12.27%	2.38%	11.24%	3.36%	2.06%	0.58%	0.05%	0.98%	0.25%	0.01%	0.00%	0.02%	0.00%	0.00%
235	62.28%	15.71%	1.60%	12.25%	2.80%	2.80%	2.26%	0.07	0.06%	0.09%	0.00%	0.00	0.00%	0.01%	0.00%
236	71.33%	13.75%	0.61%	9.20%	0.66%	3.38%	0.45%	0.04%	0.07%	0.13%	0.07%	0.00%	0.01%	0.00%	0.00%
237	71.06%	13.85%	0.90%	9.93%	2.25%	1.69%	0.24%	0.07%	0.01%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%
238	66.89%	17.31%	2.07%	6.47%	3.06%	1.63%	1.50%	0.08%	0.05%	0.40%	0.00%	0.00%	0.01%	0.00%	0.00%
239	68.19%	13.01%	2.45%	10.55%	2.82%	1.64%	0.66%	0.04%	0.03%	0.25%	0.01%	0.01%	0.00%	0.00%	0.00%
240	68.03%	12.37%	2.17%	10.82%	2.92%	1.86%	0.39%	0.03%	0.77%	0.22%	0.01%	0.00%	0.00%	0.00%	0.00%
241	66.06%	12.73%	2.33%	11.41%	3.40%	1.76%	0.66%	0.05%	1.01%	0.24%	0.03%	0.01%	0.03%	0.00%	0.00%
242	62.95%	14.73%	2.77%	9.69%	3.48%	3.10%	1.06%	0.09%	1.45%	0.32%	0.03%	0.00%	0.02%	0.00%	0.01%
243	52.65%	20.33%	3.79%	6.44%	5.21%	9.29%	1.53%	0.08	0.14%	0.27%	0.09%	0.04	0.00%	0.00%	0.00%
244	68.57%	12.34%	2.25%	10.38%	2.70%	2.12%	0.45%	0.04%	0.47%	0.34%	0.00%	0.00%	0.00%	0.00%	0.00%
245	67.08%	13.19%	2.50%	9.84%	3.21%	2.01%	0.49%	0.04%	0.95%	0.27%	0.00%	0.00%	0.00%	0.00%	0.00%
246	63.67%	17.99%	2.90%	8.70%	3.00%	0.98%	0.36%	0.03%	1.56%	0.34%	0.00%	0.00%	0.00%	0.00%	0.00%
247	66.43%	16.12%	2.02%	8.91%	2.35%	1.61%	0.66%	0.04%	0.88%	0.25%	0.03%	0.00%	0.16%	0.02%	0.01%
248	65.91%	15.71%	2.87%	8.70%	3.57%	1.12%	0.50%	0.04%	0.82%	0.29%	0.00%	0.00%	0.00%	0.00%	0.00%
249	67.22%	16.37%	3.17%	7.96%	2.55%	1.09%	0.34%	0.04%	0.38%	0.37%	0.01%	0.00%	0.00%	0.00%	0.00%

Part B.1 (trace elements, in ppm)

Sample	Li	Be	B	Sc	Ti	V	Cr	Ni	Co	Zn	As	Rb	Sr	Zr	Nb	Ag	Sb	Cs	Ba	La	Ce
1	8.3	5.3	51.5	4.4	241.4	13.6	26.3	14.5	2.8	12.6	0.0	13.1	403.6	60.4	2.5	0.5	0.7	0.2	255.9	8.2	15.4
2	6.5	2.5	62.8	3.8	299.8	20.7	21.4	13.3	4.2	28.1	0.0	15.6	556.3	50.2	3.3	0.2	0.3	0.1	236.7	7.3	13.5
3	3.8	2.3	30.0	2.8	198.2	9.9	14.9	5.6	1.4	5.9	0.0	10.0	335.5	45.2	2.2	0.1	0.2	0.1	224.0	6.7	12.7
4	5.7	2.1	58.2	2.7	227.2	13.1	12.2	8.4	3.9	23.8	0.0	15.2	569.6	41.7	2.6	0.2	0.3	0.1	277.1	6.4	11.2
5	5.4	2.8	60.9	3.1	241.3	15.1	15.9	10.4	4.1	29.7	0.0	18.5	474.9	43.0	2.5	0.2	1.5	0.1	262.6	6.6	12.2
6	22.7	3.0	51.1	2.5	94.6	8.0	21.7	14.4	2.7	19.0	0.0	18.6	370.4	27.7	1.4	0.2	0.3	0.2	150.8	3.3	6.4
7	5.4	1.3	61.9	3.1	273.5	21.3	19.8	12.3	4.2	28.9	0.0	14.2	555.1	42.1	2.9	0.1	0.3	0.1	247.9	7.2	13.8
8	11.6	1.3	52.8	3.0	323.4	21.7	55.0	55.5	5.7	1869.6	215.8	16.8	368.9	65.1	3.2	26.2	21.6	0.4	170.2	7.6	14.1
9	15.4	1.2	142.5	4.3	412.0	25.1	116.3	35.2	7.1	42.3	5.6	14.6	487.7	86.7	3.5	0.1	0.3	0.2	158.1	7.6	15.4
10	11.6	1.9	73.6	5.5	1339.2	37.3	36.1	15.2	6.3	52.3	0.0	17.1	327.8	346.9	11.2	0.2	1.1	0.1	336.0	14.6	34.5
11	5.4	2.5	57.6	3.5	289.2	18.2	15.4	10.1	2.8	26.9	0.0	13.3	390.4	39.1	3.1	0.1	0.3	0.1	182.3	6.6	13.9
12	3.4	0.7	79.4	3.0	543.7	20.6	28.0	8.7	13.8	63.7	17.6	4.8	195.7	165.2	4.5	0.7	2.7	0.1	168.4	7.0	13.5
13	5.5	1.0	84.7	2.2	174.6	11.0	10.7	7.6	3.2	24.4	3.4	16.4	368.8	28.2	1.7	0.1	0.5	0.2	199.7	4.9	9.4
14	4.0	0.8	62.2	1.9	155.7	11.6	15.3	7.5	3.3	23.3	18.4	14.9	623.6	32.6	1.8	0.1	0.3	0.1	224.7	5.5	11.4
15	5.9	0.6	87.9	2.0	164.0	11.3	10.4	8.3	3.0	25.7	9.9	15.2	489.5	31.4	1.8	0.1	0.2	0.2	195.3	5.5	11.1
16	4.7	0.7	91.1	3.1	530.5	21.6	26.3	13.2	743.3	404.9	13.6	4.8	166.8	157.6	4.3	0.3	1.2	0.1	155.9	6.0	12.0
17	5.4	0.7	58.7	2.4	224.5	16.3	13.6	9.8	4.3	24.6	13.4	11.6	535.6	36.8	2.5	0.0	0.4	0.1	229.9	5.9	12.1
18	4.0	0.7	44.7	1.9	174.1	10.1	11.3	4.9	1.7	7.5	19.8	9.6	379.5	36.6	2.2	0.3	0.3	0.1	231.2	5.8	12.5
19	6.4	0.8	76.7	3.1	338.4	18.0	17.7	10.2	6.6	39.7	17.2	12.6	439.4	60.9	3.1	1.0	3.9	0.1	195.7	6.7	12.5
20	4.9	1.0	60.4	2.8	221.6	16.1	12.3	9.7	4.6	22.5	5.4	11.2	559.9	35.0	2.2	0.1	0.3	0.1	184.9	5.5	10.5
21	5.2	1.3	85.3	2.8	181.3	13.0	13.4	8.7	2.6	18.6	5.5	16.5	341.9	31.0	2.1	0.1	0.2	0.1	191.2	5.4	10.0
22	6.4	1.3	86.7	2.9	302.5	17.0	19.4	12.1	12.9	52.0	3.8	14.0	414.4	61.5	2.8	0.8	44.7	0.1	218.1	6.3	11.4
23	21.3	0.8	60.1	2.0	88.4	6.2	22.9	10.8	1.7	12.1	15.7	13.0	241.2	29.2	1.1	0.1	0.1	0.1	82.4	2.5	5.1
24	6.4	1.0	116.5	2.0	118.7	8.3	14.8	11.2	1.2	27.3	22.9	8.9	378.3	28.0	1.2	0.1	0.2	0.1	47.0	4.2	7.9
25	6.4	0.9	92.3	2.4	177.5	12.2	13.9	7.2	3.3	33.4	15.6	14.1	310.4	43.6	1.8	0.1	0.3	0.1	186.8	3.5	7.8
26	6.3	0.9	90.5	2.7	186.9	12.7	14.0	7.8	3.6	35.7	16.5	15.0	321.1	46.0	1.8	0.1	0.3	0.2	192.8	3.8	8.1
27	6.7	6.9	90.7	2.7	268.2	18.4	17.4	13.1	11.1	71.3	6.0	13.4	494.7	46.6	2.5	0.6	22.8	0.2	211.9	6.0	12.0
28	7.4	1.0	101.5	2.3	246.8	15.8	15.7	9.2	6.7	43.9	24.6	11.2	459.7	43.2	2.4	0.4	10.5	0.1	180.5	5.2	10.0
29	3.3	0.7	133.2	2.7	489.1	17.4	45.4	6.5	2.6	10.8	47.0	2.4	129.2	139.9	3.5	0.1	0.1	0.0	108.1	5.0	9.8
30	6.5	1.1	80.3	2.0	163.9	11.9	11.4	7.9	3.1	28.4	7.5	15.0	521.3	33.6	1.7	0.1	30.9	0.1	214.2	5.5	9.7
31	4.0	0.9	65.0	2.8	478.9	18.0	20.6	5.6	2.7	12.7	5.4	3.4	150.9	133.7	3.8	0.1	0.2	0.1	119.7	5.5	11.2

Sample	Li	Be	B	Sc	Ti	V	Cr	Ni	Co	Zn	As	Rb	Sr	Zr	Nb	Ag	Sb	Cs	Ba	La	Ce
32	3.6	0.7	75.2	2.0	137.4	8.7	14.7	4.8	2.5	6.6	2.5	7.0	452.9	34.3	1.7	0.3	0.8	0.1	226.8	5.4	11.2
33	4.3	0.9	76.5	2.3	233.4	13.4	13.9	7.2	4.9	12.2	2.0	13.4	442.1	58.6	2.6	0.1	5.2	0.1	232.4	6.9	14.0
34	3.1	0.9	103.2	1.7	128.1	7.5	10.2	3.4	1.3	6.6	0.0	11.4	461.2	30.2	1.7	0.1	0.4	0.4	218.3	5.8	12.5
35	3.9	0.8	152.4	5.1	944.2	84.1	57.9	32.4	14.8	34.9	6.3	6.1	451.8	245.7	6.3	0.1	1.3	0.1	316.2	14.4	18.4
36	3.5	1.9	88.1	3.6	537.3	22.7	27.6	8.3	3.1	15.4	7.7	4.4	138.1	114.2	4.1	0.1	0.2	0.1	144.8	5.8	12.9
37	6.0	1.1	94.7	4.0	629.3	24.7	29.9	9.1	4.6	16.6	3.7	5.9	207.3	160.3	4.5	0.1	0.2	0.0	153.4	6.7	12.5
38	4.3	1.3	107.6	3.6	668.6	23.7	32.1	7.6	3.5	14.7	11.1	4.5	142.6	184.5	4.8	0.2	0.2	0.1	142.0	6.4	13.2
39	4.4	1.3	54.3	2.4	162.9	8.2	15.3	5.6	14.9	20.5	8.6	10.9	317.6	35.8	1.9	0.1	0.3	0.1	195.8	5.4	11.5
40	5.0	1.1	115.9	3.9	674.2	25.0	32.6	8.0	3.0	12.9	5.4	5.3	155.6	192.8	5.1	0.1	0.1	0.1	151.8	7.3	13.7
41	4.4	1.5	90.2	3.5	580.5	22.8	30.1	11.7	319.8	358.5	9.0	4.8	149.1	149.7	4.4	0.4	1.8	0.1	156.0	6.0	12.9
42	7.8	0.5	88.3	2.9	493.5	19.6	24.7	23.4	53.1	72.9	8.8	13.9	508.0	90.0	3.1	0.2	3.7	0.2	210.4	6.5	12.7
43	3.9	0.4	95.0	3.3	809.2	20.4	25.7	6.7	3.4	15.7	6.0	5.3	171.7	167.0	4.9	0.5	0.2	0.1	131.3	6.5	13.1
44	17.0	0.5	137.1	2.8	344.8	15.3	71.8	24.5	3.5	30.0	9.1	15.6	689.0	55.3	2.4	0.1	0.3	0.2	164.0	5.5	11.0
45	3.7	0.6	45.3	3.3	767.2	20.5	28.9	7.2	3.1	14.4	6.1	4.4	175.9	170.1	4.5	0.1	0.2	0.1	134.5	6.4	13.1
46	6.8	0.5	72.5	2.1	186.7	9.5	9.6	5.8	2.6	22.9	8.2	16.4	678.4	32.5	1.7	0.1	0.3	0.2	232.9	5.5	10.3
47	4.2	0.5	88.4	3.4	838.8	22.9	29.0	6.5	3.0	15.4	5.8	4.9	210.9	208.9	5.1	0.1	0.2	0.1	157.0	7.3	14.9
48	4.4	1.0	81.8	3.4	810.9	26.7	30.5	11.4	10.9	102.3	8.4	5.9	199.8	171.0	4.6	0.3	5.6	0.1	262.1	6.6	14.2
49	4.5	0.5	95.8	3.8	1195.1	26.0	33.3	7.8	3.3	19.9	6.0	6.3	188.6	186.6	5.4	0.1	0.6	0.1	171.6	7.5	15.5
50	4.1	0.4	95.2	4.0	1249.9	26.1	33.2	7.7	3.3	15.0	6.4	5.7	195.7	220.1	5.7	0.0	0.2	0.1	177.4	8.2	15.9
51	3.9	0.5	106.2	3.4	1053.0	22.4	29.5	7.3	2.8	15.4	8.3	5.8	174.9	183.0	4.9	0.1	0.2	0.1	164.8	7.2	14.5
52	4.6	0.6	84.6	3.7	1057.1	22.3	29.2	7.9	12.8	42.1	8.8	4.9	169.3	181.8	4.7	0.2	0.7	0.1	153.8	6.2	11.9
53	4.2	0.5	86.5	3.6	995.5	21.4	28.3	6.3	2.7	13.1	6.0	4.0	152.7	169.3	4.5	0.0	0.1	0.1	132.4	5.9	11.7
54	3.5	0.6	85.9	6.5	1845.7	41.2	74.5	11.3	5.2	21.6	5.7	8.5	173.0	167.1	6.2	0.0	0.1	0.1	158.4	7.4	15.8
55	3.6	0.5	90.5	3.6	986.0	20.2	28.4	6.2	2.5	11.4	6.2	3.9	150.6	156.4	4.3	0.0	0.1	0.0	124.0	6.0	11.1
56	4.1	0.4	44.9	2.5	295.5	8.4	15.5	4.3	1.2	4.9	5.6	11.8	307.4	41.5	2.1	0.0	0.2	0.1	176.8	5.4	10.9
57	5.5	0.4	68.4	2.6	321.0	11.0	13.0	5.2	1.6	5.6	6.6	9.7	431.9	37.6	2.2	0.0	0.1	0.1	212.9	6.3	13.1
58	5.1	0.6	52.5	2.4	311.5	9.1	15.2	4.6	1.2	5.3	13.2	8.4	316.5	39.2	2.1	0.0	0.2	0.1	183.1	5.5	11.3
59	7.9	0.7	52.9	3.3	588.4	17.6	21.0	9.2	5.4	38.7	9.4	9.3	302.8	65.9	3.5	0.9	5.8	0.2	192.2	7.6	15.1
60	15.9	0.5	116.3	3.4	512.2	20.1	53.9	32.2	42.6	126.8	11.3	12.7	423.8	73.5	2.9	0.7	0.5	0.2	145.2	6.9	14.4
61	6.2	0.5	41.3	2.6	310.6	9.5	12.9	5.3	1.8	6.8	6.4	8.4	323.7	36.7	2.1	0.1	0.2	0.1	185.1	5.4	11.5
62	9.6	0.2	297.5	1.8	262.3	3.8	5.8	2.5	0.7	28.2	507.4	45.5	41.5	59.9	1.6	0.1	5.6	1.2	359.4	1.9	3.8
63	7.1	0.5	37.6	3.1	493.0	14.8	17.7	6.8	2.2	7.9	7.0	9.6	294.7	52.4	3.3	0.0	0.2	0.2	190.4	6.8	14.2
64	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Sample	Li	Be	B	Sc	Ti	V	Cr	Ni	Co	Zn	As	Rb	Sr	Zr	Nb	Ag	Sb	Cs	Ba	La	Ce
65	20.9	1.6	111.9	3.3	290.6	18.3	75.4	31.7	689.9	3949.8	16.7	11.9	405.1	97.5	2.6	1.8	2.3	0.1	167.1	6.3	12.2
66	6.3	0.9	35.5	2.5	228.7	11.8	17.7	6.7	2.2	10.5	9.7	11.3	317.6	41.5	2.3	0.1	0.4	0.1	193.2	6.1	13.0
67	3.4	1.7	90.1	3.3	545.3	20.3	28.6	7.4	2.5	12.2	10.8	4.8	125.9	127.5	4.0	0.1	0.2	0.0	132.6	5.7	11.4
68	6.2	0.5	58.4	2.6	349.2	11.2	15.1	5.8	2.3	7.8	7.1	10.0	319.3	40.5	2.3	5.6	0.2	0.1	178.9	5.4	12.0
69	3.8	0.6	125.6	6.2	1955.4	44.2	76.4	11.0	5.1	23.6	7.7	8.2	182.2	162.5	6.2	0.1	0.2	0.1	166.1	7.5	15.9
70	4.2	0.5	87.4	3.5	963.1	21.3	27.6	7.6	16.7	132.9	8.5	5.0	153.9	140.3	4.2	1.9	2.6	0.1	128.0	5.9	12.1
71	7.9	0.9	67.6	3.4	696.4	20.4	24.8	11.1	4.7	27.2	10.3	9.1	277.4	79.1	4.2	0.4	3.1	0.2	218.7	7.8	15.3
72	5.2	0.4	37.9	2.7	408.6	12.2	18.6	5.6	1.9	6.9	5.0	13.0	316.4	49.4	2.6	0.2	0.1	0.2	186.6	6.1	12.2
73	5.7	0.4	36.7	2.7	419.6	12.1	17.8	6.0	1.8	7.2	5.9	12.8	325.9	47.9	2.7	0.0	0.1	0.2	193.4	6.2	12.7
74	5.7	0.6	87.3	6.4	1980.4	48.5	78.2	12.6	6.0	31.8	17.1	13.2	208.2	186.9	6.8	0.1	0.3	0.2	187.4	8.8	18.6
75	5.6	0.5	48.6	2.3	271.9	9.2	12.4	4.7	1.3	5.3	5.3	11.4	331.2	33.9	1.8	0.1	0.2	0.1	192.8	5.3	11.3
76	4.0	0.4	69.7	4.1	932.6	23.9	39.8	8.4	3.7	41.3	7.0	9.0	200.9	73.6	3.7	0.2	13.2	0.1	164.1	5.9	13.3
77	28.1	0.3	126.1	4.3	385.8	22.6	75.5	170.2	777.0	710.8	19.1	10.0	229.0	101.8	3.5	0.7	2.6	0.4	145.2	7.6	15.1
78	5.3	0.5	61.3	2.8	187.3	9.0	9.9	4.7	1.5	5.2	1.5	8.2	348.0	31.7	1.8	0.0	0.1	0.1	165.4	4.7	9.9
79	3.4	0.4	100.9	3.1	501.5	14.4	17.9	8.6	2.4	11.8	1.0	3.5	116.9	96.9	3.3	0.1	0.4	0.0	84.9	4.3	8.7
80	18.9	0.4	114.8	3.2	312.4	17.6	59.2	23.3	235.0	64.5	2.2	11.2	433.9	120.4	2.5	0.2	0.5	0.2	92.3	5.3	10.0
81	4.8	0.4	56.2	2.8	209.7	9.3	14.3	5.3	2.0	5.1	1.3	11.0	268.3	35.9	1.8	0.0	0.1	0.1	153.4	4.5	9.2
82	5.5	0.5	71.4	2.7	187.7	9.1	11.6	4.5	1.4	4.3	1.2	8.4	283.1	33.9	1.8	0.0	0.1	0.1	150.1	4.6	9.2
83	3.7	0.4	111.5	2.8	429.0	12.9	15.7	7.4	2.2	8.9	1.0	3.3	120.9	87.5	2.9	0.0	0.1	0.0	90.7	4.7	9.1
84	7.2	1.0	47.0	3.6	461.4	19.9	23.2	9.0	3.9	25.1	1.4	10.4	284.4	73.1	4.0	0.2	2.2	0.1	169.6	7.6	14.8
85	5.2	0.3	70.1	2.6	191.3	9.8	11.2	5.2	1.5	5.6	2.3	10.2	354.7	32.9	1.8	0.0	0.1	0.1	182.2	4.9	10.6
86	3.8	0.5	126.4	3.0	611.0	16.0	18.7	4.7	2.3	19.9	2.2	5.8	119.6	129.0	3.9	0.1	0.1	0.1	101.8	4.9	10.3
87	4.8	0.5	40.6	2.6	250.9	12.4	18.3	6.2	1.6	8.1	2.0	7.0	308.5	41.7	2.2	4.0	17.6	0.1	213.8	7.1	13.3
88	6.5	0.4	150.7	3.3	469.5	26.0	18.7	15.3	12.6	32.1	4.2	9.5	600.6	97.0	3.9	0.0	8.9	0.1	213.5	8.4	15.4
89	5.2	0.3	104.1	3.7	754.5	23.5	28.4	7.4	3.2	14.4	2.2	5.8	181.0	189.3	5.3	0.1	0.1	0.1	168.5	7.4	14.8
90	8.5	0.8	44.9	3.6	484.3	20.3	24.6	9.6	4.2	23.4	3.7	12.2	328.2	81.7	4.4	0.3	3.4	0.2	215.8	9.1	18.2
91	4.9	0.6	106.6	8.5	2243.8	67.8	122.9	14.2	6.9	34.7	2.7	11.2	174.1	358.6	10.0	0.1	0.1	0.1	209.4	11.6	24.3
92	4.7	0.4	56.2	2.7	224.9	10.0	12.3	5.2	1.6	5.5	2.1	10.5	357.3	42.4	2.3	0.0	0.1	0.1	223.8	6.5	13.0
93	4.0	0.4	122.1	3.1	644.3	16.6	22.3	5.3	2.4	17.2	2.2	6.1	140.4	149.3	4.4	0.0	0.2	0.1	125.7	6.2	12.1
94	4.8	0.3	40.9	2.7	241.5	10.3	17.1	5.8	1.6	5.8	1.9	10.4	320.0	43.7	2.3	0.1	0.2	0.1	197.4	6.1	12.6
95	3.4	0.4	37.6	2.2	156.1	6.9	11.9	6.6	1.2	8.0	2.9	10.3	330.7	32.3	1.5	0.1	0.4	0.1	206.0	5.1	11.3
96	2.9	0.5	73.4	2.2	158.2	10.8	11.2	6.9	3.0	13.0	3.3	10.8	408.5	35.4	1.7	0.1	3.4	0.1	270.3	6.4	12.2
97	3.6	0.3	87.6	2.3	200.0	8.3	22.8	17.0	57.0	8.4	7.4	12.0	335.3	45.1	1.8	0.1	1.8	0.1	182.5	5.8	11.4

Sample	Li	Be	B	Sc	Ti	V	Cr	Ni	Co	Zn	As	Rb	Sr	Zr	Nb	Ag	Sb	Cs	Ba	La	Ce
98	4.0	0.4	77.7	2.8	319.7	12.7	17.8	6.2	4.1	9.0	2.8	13.0	376.9	67.2	2.7	0.1	2.0	0.1	208.8	6.9	14.0
99	3.7	0.5	43.3	2.2	229.2	28.6	12.4	12.3	6.2	22.8	5.3	20.5	495.7	40.4	1.7	0.2	3.6	0.2	378.8	7.1	13.2
100	4.6	0.5	47.2	2.3	205.3	11.0	11.6	4.9	1.8	7.0	4.5	12.0	472.0	37.1	2.2	0.0	0.3	0.1	239.2	6.7	14.1
101	4.1	0.4	47.7	2.5	180.9	8.1	12.4	4.9	1.4	7.0	1.5	8.6	420.2	32.4	1.8	0.2	0.2	0.1	215.4	5.6	13.2
102	7.4	0.6	86.8	3.5	662.4	20.4	26.5	17.2	32.2	53.3	6.8	10.6	405.6	136.1	4.0	0.3	9.8	0.1	179.5	6.5	12.2
103	3.4	0.4	86.7	2.3	216.2	8.4	13.5	4.1	2.2	6.5	5.0	9.4	393.6	41.5	1.8	0.0	1.4	0.1	167.1	5.0	10.2
104	8.4	0.5	89.4	2.5	314.2	13.2	18.0	25.4	90.2	60.4	7.6	15.3	562.5	57.0	2.2	0.2	1.7	0.2	179.3	5.3	9.8
105	5.2	0.4	73.2	2.6	290.5	12.3	10.2	8.3	4.5	26.4	6.1	11.6	621.8	38.6	2.3	0.1	0.2	0.1	213.2	5.1	9.5
106	22.4	0.4	161.6	3.0	245.5	28.5	98.9	183.6	1431.4	302.2	18.0	10.0	262.7	17.9	1.7	0.3	1.8	0.2	125.6	3.6	6.8
107	3.9	0.6	102.5	2.2	213.1	8.4	12.8	4.4	2.3	7.6	5.1	10.5	415.7	39.7	1.9	0.0	0.6	0.1	191.7	5.7	11.7
108	5.6	0.4	46.9	2.4	220.4	9.8	16.0	4.9	1.6	6.0	5.1	15.8	390.8	35.5	1.9	0.0	0.2	0.2	208.3	5.7	12.9
109	3.7	0.5	81.1	2.2	217.2	8.8	17.4	5.3	3.6	8.8	6.5	11.0	378.6	40.0	2.0	0.0	0.8	0.1	178.9	5.3	11.6
110	3.6	0.3	67.9	2.1	206.2	10.4	16.1	5.2	1.6	10.8	5.1	9.1	454.7	35.4	1.8	0.0	0.2	0.1	208.2	6.0	12.3
111	4.1	0.6	45.0	2.2	237.9	8.8	13.7	4.8	1.7	7.9	5.0	8.0	557.3	43.4	2.1	0.0	0.1	0.1	209.8	6.7	14.0
112	3.8	0.6	83.2	2.4	320.4	21.6	17.8	10.2	11.8	37.3	9.9	16.6	538.3	60.2	2.4	0.1	8.6	0.1	475.9	7.6	13.6
113	4.0	0.4	82.5	2.3	236.2	10.6	14.8	7.4	3.8	10.4	5.9	9.2	526.5	38.4	2.0	0.1	0.6	0.1	288.9	6.6	13.6
114	5.1	0.7	188.3	6.7	1824.9	100.9	78.3	44.6	11.8	58.0	19.1	7.3	458.3	272.9	8.6	0.1	0.5	0.1	210.0	16.1	21.5
115	8.5	0.4	5.9	1.9	155.0	6.3	7.0	3.7	0.5	132.8	295.7	4.0	87.2	30.2	1.2	0.0	0.6	0.1	1279.9	2.6	4.6
116	3.1	0.3	81.3	2.5	248.2	11.6	21.1	5.8	4.1	18.0	1.8	7.6	285.7	66.2	2.4	0.3	2.8	0.1	180.2	5.9	11.5
117	12.2	1.0	97.1	2.9	206.9	14.6	27.3	28.2	4.8	49.6	11.7	12.5	550.8	107.2	2.5	0.2	0.2	0.3	413.7	8.8	15.6
118	7.5	0.6	63.5	2.9	235.1	19.3	18.3	15.7	8.1	32.7	0.0	14.8	521.5	45.9	2.7	0.5	1.7	0.2	276.7	6.4	12.3
119	11.5	0.7	95.2	2.8	204.6	16.1	18.9	12.9	6.5	46.2	0.0	11.9	614.1	112.8	2.4	0.1	0.1	0.2	143.6	8.0	15.8
120	4.6	0.5	115.6	3.4	501.3	18.5	25.8	17.1	1152.0	2449.4	6.0	4.6	139.8	125.7	3.7	1.0	3.6	0.1	107.0	5.4	10.6
121	3.2	0.7	95.4	3.1	642.3	17.0	23.6	5.7	2.4	12.4	0.0	3.7	135.9	190.8	5.0	0.2	0.1	0.1	101.4	5.9	11.6
122	3.9	0.5	148.6	3.1	478.1	17.2	23.3	5.9	10.1	27.7	3.4	3.6	124.4	120.8	3.8	0.1	0.2	0.0	102.4	5.2	10.4
123	3.3	0.7	77.0	2.7	196.8	11.3	161.7	15.7	4.3	12.8	4.7	7.2	349.0	50.2	2.0	0.1	0.8	0.1	164.3	5.4	10.7
124	3.3	0.6	79.3	2.6	187.9	11.5	155.1	12.1	3.5	11.8	3.5	7.3	335.4	42.7	1.9	0.0	0.8	0.1	163.9	5.0	10.7
125	3.7	0.6	88.5	3.4	531.5	19.7	43.7	11.1	3.0	13.7	2.4	4.3	163.3	166.6	4.1	0.1	0.1	0.1	130.2	5.7	11.1
126	3.6	0.4	83.7	2.4	180.9	9.6	56.3	12.4	2.3	11.3	1.6	11.6	304.0	39.6	2.0	0.1	0.6	0.1	200.5	5.1	12.4
127	2.8	0.5	70.7	3.5	570.3	20.1	28.0	6.7	3.2	13.9	6.9	3.3	119.9	161.8	4.4	0.1	0.2	0.0	90.4	5.7	11.3
128	3.3	0.4	41.6	2.3	141.9	8.0	16.7	5.1	3.1	11.1	6.6	6.2	293.4	32.5	1.6	0.1	0.3	0.1	165.3	4.7	10.3
129	4.0	0.6	92.3	3.2	487.6	19.2	27.9	13.4	5.9	38.3	8.6	4.3	146.6	129.9	3.8	0.4	0.9	0.1	125.8	5.3	11.2
130	3.5	0.4	123.1	3.0	417.4	15.5	18.4	5.4	2.2	9.7	5.6	3.1	116.8	94.0	3.4	0.0	0.1	0.0	97.0	5.0	9.8

Sample	Li	Be	B	Sc	Ti	V	Cr	Ni	Co	Zn	As	Rb	Sr	Zr	Nb	Ag	Sb	Cs	Ba	La	Ce
131	3.6	0.4	89.1	2.4	151.6	10.0	127.4	9.4	2.7	11.3	5.2	7.1	317.8	33.3	1.6	0.1	6.7	0.1	177.5	4.9	9.4
132	3.9	0.4	90.9	2.5	140.3	10.7	128.4	12.8	2.6	11.5	0.6	8.6	293.0	28.5	1.5	0.1	7.7	0.1	169.7	4.3	9.2
133	3.7	0.4	93.6	2.3	127.3	8.8	95.3	10.0	2.0	8.0	0.1	8.5	306.9	26.7	1.4	0.0	2.5	0.1	175.4	4.4	9.9
134	3.2	0.6	111.5	2.9	584.6	15.7	25.4	4.6	2.3	11.6	0.0	3.4	120.1	174.9	4.8	0.1	0.3	0.0	96.6	5.5	10.9
135	4.8	0.7	127.4	3.2	520.9	23.7	25.5	9.8	5.2	112.1	2.1	4.7	160.4	121.2	4.0	0.0	0.5	0.1	275.8	5.3	11.2
136	3.7	0.6	112.6	3.0	429.3	17.1	19.9	6.0	2.5	14.6	2.9	3.5	120.5	93.4	3.5	0.0	0.2	0.0	106.1	4.9	10.5
137	3.1	0.5	51.3	2.3	128.6	7.6	60.2	7.4	1.5	7.3	1.3	8.6	328.0	32.4	1.5	0.1	0.9	0.1	204.0	5.1	11.0
138	4.7	0.4	88.1	2.8	334.3	13.2	40.8	8.1	34.1	97.5	3.8	6.0	245.4	87.8	2.9	5.0	5.2	0.1	141.5	5.4	10.8
139	3.9	0.5	63.7	2.3	198.9	9.4	60.0	9.8	2.6	13.6	3.3	9.3	373.2	36.9	1.8	0.1	1.1	0.1	189.4	5.4	11.1
140	3.4	0.6	61.1	3.2	438.6	18.8	24.6	6.6	2.6	10.7	1.6	3.4	126.8	98.5	3.4	0.0	0.1	0.0	110.1	4.7	10.0
141	4.0	0.5	72.0	3.3	521.2	20.4	26.1	7.1	2.6	12.2	2.6	4.5	142.0	131.3	4.0	0.1	0.1	0.1	119.9	5.3	10.4
142	4.1	0.4	59.9	2.2	138.1	7.9	15.4	5.5	1.5	8.1	2.3	9.0	305.8	28.2	1.5	0.0	0.2	0.1	167.3	4.5	10.2
143	2.8	0.5	55.9	3.1	466.4	18.4	24.7	5.6	2.5	13.0	1.6	3.7	151.4	124.5	4.0	0.1	0.2	0.1	139.4	6.2	12.1
144	7.9	0.4	88.2	1.9	92.6	7.8	15.4	9.9	1.0	28.5	1.2	8.7	480.3	25.4	1.0	0.0	0.2	0.1	79.5	4.3	8.8
145	3.8	0.5	52.7	2.2	145.3	8.9	15.7	5.8	2.5	12.3	1.4	11.5	402.0	36.9	1.8	0.2	0.4	0.1	232.5	6.4	12.9
146	15.8	0.7	70.3	2.3	139.2	11.2	38.6	36.0	5.3	44.7	74.9	8.8	247.7	33.8	1.6	8.0	21.4	0.2	36.6	5.0	9.9
147	493.3	2.0	2147.6	4.4	274.8	28.5	79.0	88.8	7.9	29.2	57.6	104.3	2366.1	32.4	4.3	0.1	56.0	62.6	95.7	8.4	18.3
148	18.9	0.8	83.8	2.6	290.5	14.7	25.2	16.6	24.0	57.0	4.6	18.0	603.3	61.6	2.7	0.3	1.8	0.2	235.7	6.5	13.5
149	7.2	0.5	76.8	3.3	459.2	20.2	23.1	13.6	4.5	31.8	5.0	12.9	666.2	47.9	3.3	0.1	0.3	0.2	292.0	7.6	13.3
150	441.6	1.7	2508.7	4.2	406.9	24.4	73.2	78.2	8.7	24.5	48.9	78.9	1955.0	30.4	3.7	0.4	39.2	47.4	87.7	7.2	14.8
151	6.5	0.6	55.3	2.4	315.1	15.3	19.3	15.7	5.1	31.9	3.7	13.6	923.0	40.4	2.3	0.2	0.3	0.1	426.7	5.8	10.8
152	5.4	0.5	63.5	2.7	377.1	16.3	17.1	10.3	3.7	27.1	3.5	12.5	531.5	37.3	2.5	0.1	0.4	0.1	227.9	5.9	11.4
153	125.1	2.9	2016.4	4.7	395.6	14.4	15.9	26.9	657.5	131.9	11.5	92.7	241.2	101.5	23.4	0.3	1.7	1.8	201.5	23.5	47.4
154	3.3	0.6	94.4	4.1	1069.1	26.4	32.9	7.6	3.8	12.8	1.4	5.6	241.1	259.5	6.2	0.1	0.1	0.1	181.8	8.5	16.0
155	4.8	0.6	62.5	2.1	213.3	9.3	10.5	7.0	2.0	28.5	1.3	20.6	714.3	39.5	2.0	0.1	0.1	0.2	247.3	6.6	11.1
156	21.4	0.8	53.0	2.2	197.1	11.6	26.9	24.5	401.4	1475.2	9.8	19.2	480.6	54.1	1.7	0.4	6.5	0.2	130.5	4.0	8.5
157	12.5	0.3	119.3	2.4	232.7	11.5	19.0	11.9	2.5	41.7	12.7	8.9	596.1	75.3	1.7	0.1	0.1	0.1	220.2	6.0	12.4
158	6.1	0.6	88.3	2.3	277.6	12.4	14.6	9.9	5.4	30.3	14.0	13.9	453.7	33.9	1.9	0.2	3.7	0.1	188.1	5.0	9.8
159	54.0	0.9	301.7	2.9	193.6	17.9	22.2	17.4	4.5	27.0	3.0	29.6	615.8	37.0	2.6	0.1	5.1	6.4	241.0	7.1	13.4
160	9.9	0.6	84.2	2.5	180.9	14.3	18.4	11.3	5.7	37.6	2.0	20.5	544.6	41.5	2.2	0.1	1.3	0.5	243.8	6.7	12.4
161	5.1	0.6	68.8	2.9	293.9	16.4	16.1	10.0	4.1	27.0	3.4	20.3	487.7	38.3	2.2	0.1	0.2	0.2	245.6	6.8	12.1
162	5.6	0.6	69.8	2.9	293.7	19.1	16.2	14.9	6.1	35.3	3.5	20.9	479.3	35.4	2.2	0.1	0.3	0.2	246.1	6.9	12.6
163	112.3	2.5	1676.7	4.7	490.3	12.2	9.5	17.9	568.3	134.1	4.9	112.4	246.2	116.3	29.3	0.3	1.3	2.1	241.0	27.2	57.0

Sample	Li	Be	B	Sc	Ti	V	Cr	Ni	Co	Zn	As	Rb	Sr	Zr	Nb	Ag	Sb	Cs	Ba	La	Ce
164	29.3	0.5	95.9	2.3	397.5	13.0	29.5	11.7	4.3	15.8	1.8	11.4	435.4	312.9	3.0	0.1	0.2	0.1	173.3	7.3	13.9
165	9.5	0.5	82.5	2.5	303.4	13.1	23.1	15.4	16.2	68.4	6.7	14.1	490.7	55.0	2.1	1.2	7.5	0.2	196.2	5.4	10.4
166	5.0	0.6	77.6	2.3	322.0	11.1	24.5	11.9	124.4	254.4	4.4	11.0	486.4	47.6	2.1	0.1	0.3	0.1	197.4	6.3	11.7
167	110.2	2.6	1318.5	5.1	409.4	12.4	6.8	14.8	482.4	94.0	5.3	114.9	284.8	126.4	31.1	0.2	0.9	2.0	248.8	27.8	57.5
168	11.2	0.4	83.8	2.3	295.7	15.0	24.4	18.7	29.6	49.0	5.6	12.3	570.0	69.2	2.1	0.3	2.0	0.2	247.4	6.0	11.4
169	12.9	0.6	95.9	2.4	273.1	13.2	24.3	20.3	36.3	51.6	7.1	13.7	552.4	59.6	2.0	0.3	0.9	0.2	190.0	5.6	11.3
170	7.5	0.7	92.6	3.0	685.0	20.1	27.6	20.1	41.8	71.0	4.3	9.5	349.3	128.0	3.6	0.2	4.4	0.1	174.9	6.1	12.1
171	9.4	0.4	95.4	2.4	258.3	12.0	18.4	13.4	11.9	37.8	8.3	15.0	573.9	51.1	1.9	0.3	3.1	0.2	217.8	6.0	11.2
172	5.3	0.5	82.7	2.0	182.3	8.0	10.5	5.9	1.9	26.9	7.0	16.4	530.2	27.0	1.4	0.1	0.2	0.2	192.4	4.8	8.8
173	5.7	0.4	75.1	2.1	227.7	9.5	11.2	6.3	2.5	22.4	7.1	15.5	468.1	29.3	1.6	0.1	0.2	0.2	192.7	4.8	9.4
174	496.1	1.0	2651.8	3.4	386.9	19.4	67.3	56.0	6.0	25.4	40.5	72.7	2439.1	37.0	3.3	0.1	29.1	46.8	76.2	6.3	12.2
175	0.9	0.1	14.6	0.3	50.0	1.9	63.0	5.2	1.0	10.9	1.2	1.6	58.9	7.5	0.3	0.2	1.2	0.1	25.1	0.6	1.0
176	6.1	0.9	72.7	3.2	745.2	21.6	48.8	18.6	19.1	67.9	1.2	9.7	292.8	144.9	4.4	2.5	13.9	0.5	169.1	7.2	13.4
177	5.3	0.6	61.8	2.3	257.0	14.1	16.9	8.6	3.2	27.0	0.8	21.5	488.7	34.8	2.1	0.1	0.3	0.2	224.8	6.5	12.2
178	19.7	0.6	88.0	3.4	479.2	23.8	88.5	38.3	1424.5	3376.6	3.3	14.5	548.2	124.0	2.9	0.4	1.2	0.2	210.0	6.5	13.5
179	22.6	0.5	90.4	2.3	256.8	31.4	39.2	14.1	5.6	16.8	7.3	13.5	482.0	97.8	1.9	0.0	0.2	0.2	229.5	5.3	10.4
180	2.9	1.8	30.2	4.9	828.9	27.0	32.2	9.7	4.0	12.9	0.0	7.4	224.9	253.0	7.1	0.2	0.2	0.1	205.3	9.8	18.7
181	21.3	0.8	116.3	2.9	364.6	22.0	39.7	16.4	28.6	38.0	6.4	12.8	362.2	123.3	3.3	0.8	2.4	0.2	198.7	6.5	12.6
182	3.5	0.4	85.3	2.1	184.2	8.3	36.5	5.1	1.5	6.0	3.0	8.8	498.8	27.8	1.4	0.0	1.9	0.1	193.9	5.2	11.6
183	31.2	0.7	108.8	2.1	238.2	29.4	41.1	16.9	29.6	43.8	5.2	14.3	499.1	79.2	1.7	0.1	0.5	0.8	232.5	5.0	9.9
184	6.1	0.5	56.1	2.4	296.8	11.8	19.1	5.8	1.9	10.0	3.9	10.7	357.6	40.1	2.2	0.0	0.3	0.2	199.3	5.9	12.2
185	19.7	0.4	91.7	2.6	382.1	22.9	39.5	17.2	16.3	28.6	5.1	11.3	403.6	109.8	2.4	0.6	4.8	0.1	230.5	5.8	10.9
186	3.3	0.4	46.4	2.0	220.1	6.6	13.2	10.0	2.2	7.6	2.8	10.7	348.3	34.1	1.7	0.1	0.3	0.1	180.0	4.8	9.8
187	6.1	0.5	70.0	2.7	317.8	14.3	14.4	8.9	4.7	30.4	4.0	14.1	749.3	38.6	2.2	0.1	0.2	0.1	265.2	5.6	9.5
188	90.7	3.8	1189.9	2.7	213.2	3.8	5.3	12.5	295.8	376.2	4.6	195.7	62.6	96.4	27.9	0.5	3.8	5.9	25.8	18.5	38.0
189	6.3	0.4	77.5	2.3	255.0	13.6	13.0	9.1	4.8	32.1	9.6	14.9	674.7	29.4	1.8	0.1	0.2	0.1	248.0	4.6	9.2
190	5.1	0.9	58.7	3.1	239.6	17.4	15.2	12.4	4.5	25.5	3.9	20.3	479.4	39.4	2.4	0.1	0.2	0.2	255.9	7.1	13.2
191	464.4	1.6	2261.4	4.7	336.7	26.4	73.4	82.6	8.0	23.4	39.1	84.1	2273.9	33.7	4.1	0.3	31.1	52.2	84.0	7.6	14.6
192	3.0	1.0	73.2	3.4	590.3	17.4	23.4	10.4	2.5	10.0	4.1	4.1	151.2	133.6	4.3	0.1	0.8	0.1	119.8	6.4	12.2
193	3.5	0.7	58.1	2.4	181.2	10.8	14.3	5.6	1.7	5.9	3.3	10.1	402.3	33.2	1.8	0.1	0.3	0.1	216.5	5.6	11.7
194	3.2	1.0	39.6	2.4	163.2	8.1	65.8	13.3	2.1	11.6	3.5	7.2	397.4	33.4	1.6	0.2	3.0	0.1	202.8	5.7	11.4
195	15.5	1.0	86.1	3.5	396.2	19.9	84.1	25.8	51.1	251.1	9.0	13.5	475.9	103.3	3.2	0.6	2.1	0.2	207.5	7.2	15.0
196	4.3	1.5	70.8	2.3	174.0	8.9	14.6	14.9	3.9	8.9	5.5	9.9	425.2	33.0	1.7	0.2	0.3	0.1	198.4	5.8	11.7

Sample	Li	Be	B	Sc	Ti	V	Cr	Ni	Co	Zn	As	Rb	Sr	Zr	Nb	Ag	Sb	Cs	Ba	La	Ce
197	5.5	0.8	67.8	2.3	195.5	10.4	11.0	6.9	2.1	24.0	4.0	18.3	664.8	34.2	1.9	0.1	0.5	0.1	194.5	5.2	9.6
198	114.1	3.2	1882.7	4.9	360.7	10.9	5.7	20.7	535.4	111.6	12.2	104.3	215.9	107.6	26.4	0.3	1.8	1.9	215.6	26.0	52.4
199	10.5	0.6	80.7	2.7	256.6	17.2	31.3	25.6	21.6	61.9	9.9	13.2	481.7	65.0	2.2	0.2	3.9	0.2	309.7	6.0	11.1
200	2.8	0.4	292.1	2.0	428.6	6.1	3.9	3.8	1.4	47.6	86.9	2.0	38.2	113.7	4.9	0.1	1.2	0.1	372.3	3.2	7.6
201	6.6	0.5	110.6	2.9	489.0	15.7	20.0	6.0	2.3	11.1	19.9	3.2	118.6	85.9	3.0	0.1	0.2	0.0	92.9	4.5	9.5
202	14.2	0.8	127.5	2.4	205.7	13.6	26.8	19.2	20.2	44.1	24.9	10.4	441.2	65.0	1.7	0.4	0.6	0.2	179.4	5.5	11.5
203	6.5	0.5	93.6	2.5	212.4	12.2	14.5	8.4	2.9	20.2	18.7	14.9	463.4	31.9	1.8	0.1	0.2	0.1	173.2	5.3	9.2
204	2.1	0.5	5.4	1.6	23.1	1.7	12.4	27.4	1.4	8.1	5.7	1.0	52.4	50.4	0.2	0.1	0.2	0.1	4.6	1.3	2.5
205	9.3	0.7	94.9	2.4	263.0	12.7	17.9	24.0	74.9	58.6	7.6	14.0	486.3	50.8	2.0	0.2	1.6	0.1	175.1	4.9	9.4
206	4.5	0.5	79.7	3.6	684.6	22.0	28.8	9.2	4.1	15.1	4.6	4.0	154.9	162.4	4.4	0.1	0.2	0.0	131.2	6.0	12.1
207	13.6	0.5	103.4	2.5	210.6	13.7	20.9	14.0	11.9	47.3	7.3	13.0	489.1	53.9	1.8	0.2	0.8	0.2	197.3	5.3	11.3
208	8.0	0.8	89.8	3.1	209.4	16.2	15.8	12.4	3.8	28.3	15.1	15.4	481.2	32.7	1.9	0.1	0.3	0.2	229.0	5.5	10.0
209	5.0	0.7	55.8	3.4	663.2	24.7	28.5	10.1	5.3	154.5	8.0	6.7	166.0	151.0	4.2	0.1	0.1	0.1	292.2	5.7	12.4
210	6.4	0.7	80.0	2.3	162.3	10.3	10.2	8.4	2.7	24.9	4.3	18.5	603.6	29.5	1.6	0.1	0.4	0.2	242.6	5.9	10.6
211	28.5	0.8	158.2	3.8	370.1	23.5	86.9	406.5	1488.5	631.3	23.3	8.0	394.7	88.7	3.2	0.4	2.9	0.3	160.4	7.4	15.4
212	8.5	0.9	101.7	2.0	162.1	8.4	13.8	27.2	99.9	59.1	5.3	17.4	681.5	28.2	1.5	0.1	0.5	0.2	188.9	5.4	9.6
213	15.4	0.5	113.8	2.5	208.3	18.0	30.7	58.4	283.7	108.1	7.5	12.0	544.1	74.5	1.9	0.2	0.7	0.2	220.5	6.3	14.3
214	4.9	0.6	64.3	3.2	591.9	21.0	26.3	11.8	28.0	21.0	2.8	5.4	177.9	120.9	3.8	0.1	0.2	0.1	135.4	5.5	12.3
215	4.2	0.5	97.8	3.6	556.8	16.2	15.3	7.7	2.8	11.2	2.5	3.9	150.0	81.9	3.7	0.1	0.1	0.1	102.0	5.2	11.1
216	5.8	0.4	68.5	3.0	241.8	10.6	10.8	12.4	10.0	27.8	3.7	16.2	596.3	36.0	1.9	0.8	0.4	0.1	197.6	5.3	9.1
217	4.7	0.5	66.2	3.1	278.6	14.3	10.7	8.4	3.6	24.9	0.0	14.2	389.1	32.9	2.1	0.0	0.1	0.1	195.0	5.1	10.9
218	6.2	0.3	66.1	3.3	321.9	14.9	13.6	13.0	8.6	51.8	16.1	13.1	564.9	41.8	2.3	3.4	7.0	0.2	267.2	5.6	10.6
219	6.3	0.5	71.7	3.0	213.1	9.8	10.2	7.9	2.2	22.0	0.0	16.6	615.6	28.9	1.7	0.2	0.2	0.1	211.3	4.7	8.7
220	5.7	0.7	80.9	2.9	299.7	15.0	54.9	16.8	13.6	46.8	4.9	8.0	298.9	85.7	2.9	2.4	11.4	0.1	167.2	5.9	11.2
221	4.1	0.4	68.8	4.3	840.8	21.3	28.0	6.5	3.0	11.7	1.6	4.4	160.3	178.9	4.6	0.1	0.1	0.0	141.8	6.4	11.8
222	45.1	0.6	571.3	3.1	289.8	17.6	20.0	23.6	512.9	130.1	37.3	16.2	389.6	36.3	2.2	0.3	11.0	3.9	148.8	4.7	9.4
223	5.4	0.4	72.4	2.8	268.0	14.7	11.1	11.4	11.8	27.6	2.8	14.4	624.7	31.6	1.9	0.1	0.3	0.2	212.5	4.8	9.8
224	14.8	0.2	107.8	3.4	315.7	14.1	49.6	25.6	5.0	34.3	3.5	6.7	348.1	18.7	1.8	0.1	2.3	0.1	52.4	2.9	5.9
225	10.0	0.5	68.1	6.9	835.6	42.7	119.7	42.8	7.0	40.5	1.3	13.6	409.8	46.9	4.5	0.1	1.5	0.2	102.6	7.1	13.1
226	5.1	0.3	72.4	2.7	261.7	11.6	11.4	7.9	3.0	25.0	1.0	17.1	532.4	35.0	1.9	0.0	0.2	0.1	212.2	5.4	9.7
227	5.5	0.4	70.5	2.6	266.1	10.7	9.8	7.9	3.7	23.9	1.5	16.7	419.2	33.0	2.0	0.1	0.2	0.2	171.8	5.3	9.7
228	6.5	0.4	69.7	2.4	195.3	8.7	8.8	7.4	43.6	26.8	1.6	18.4	587.4	27.6	1.5	0.0	0.2	0.2	208.3	5.8	10.1
229	13.3	0.4	88.8	3.2	326.7	20.8	28.0	22.9	26.4	53.0	1.9	12.4	597.6	99.2	2.6	0.3	0.8	0.2	258.2	7.7	15.3

Sample	Li	Be	B	Sc	Ti	V	Cr	Ni	Co	Zn	As	Rb	Sr	Zr	Nb	Ag	Sb	Cs	Ba	La	Ce
230	12.8	0.6	92.8	2.6	308.7	22.7	27.2	25.5	34.7	72.1	3.1	13.5	512.6	69.3	2.2	0.9	4.6	0.4	598.4	6.1	10.9
231	11.5	0.5	101.2	2.9	339.5	16.3	35.5	34.5	21.2	488.2	64.9	13.9	525.7	46.4	2.4	9.7	30.3	0.5	268.5	5.9	11.3
232	7.8	0.4	59.2	2.9	295.6	15.6	20.5	15.0	9.1	41.4	2.6	17.4	621.8	50.1	2.2	0.3	2.0	0.2	247.8	6.6	11.8
233	6.2	0.4	83.0	3.0	285.7	13.8	20.1	12.4	8.7	36.8	4.5	12.7	481.8	33.7	2.1	0.5	1.6	0.1	238.9	5.3	10.6
234	7.5	0.5	69.4	3.1	282.5	14.0	17.6	12.3	7.2	37.4	1.3	18.2	613.8	47.8	2.3	0.1	1.8	0.2	245.6	6.9	12.0
235	489.3	1.0	2545.4	4.6	391.4	24.9	68.1	76.0	7.4	23.5	35.5	81.4	2195.4	32.0	3.7	0.3	34.4	48.8	85.7	7.2	14.1
236	3.8	0.4	53.0	2.5	221.6	8.7	63.3	18.4	3.6	39.9	5.1	9.5	388.5	35.0	1.7	0.5	3.8	0.1	213.7	5.8	11.0
237	1.8	0.4	27.7	2.0	441.6	16.5	11.0	4.9	2.0	12.0	0.7	26.2	41.9	158.1	4.8	0.1	1.0	0.2	63.7	3.6	8.1
238	11.9	0.4	70.7	3.3	486.9	19.7	51.5	32.9	5.2	36.2	0.0	6.5	322.8	23.5	3.2	0.1	0.6	0.2	62.1	4.1	7.8
239	7.5	0.3	84.4	2.2	222.7	8.8	11.0	8.4	64.3	29.5	1.8	17.1	569.7	30.4	1.7	0.1	0.3	0.2	174.4	4.8	8.5
240	7.7	0.5	95.5	2.4	194.3	10.3	9.9	8.7	5.6	25.6	1.8	19.6	602.1	27.7	1.8	0.1	0.2	0.1	250.7	5.6	10.7
241	10.7	0.7	71.1	2.6	291.3	14.6	23.0	27.3	51.2	62.3	1.4	15.2	575.4	67.1	2.2	0.3	1.9	0.2	242.8	6.1	11.6
242	14.5	0.5	100.0	4.2	568.3	30.2	93.1	32.7	13.4	51.7	1.6	14.9	504.5	105.5	3.5	2.3	0.8	0.2	223.7	7.8	14.9
243	129.1	2.1	1996.3	4.6	496.5	15.1	15.0	24.5	283.6	94.9	4.8	84.3	271.0	93.4	22.0	1.3	2.1	1.4	207.2	21.6	44.4
244	6.8	0.6	73.7	2.3	217.8	10.3	10.3	7.7	3.1	23.7	0.9	18.8	495.5	30.6	1.7	0.1	0.2	0.2	214.4	5.9	10.2
245	6.8	0.5	75.4	2.6	233.5	13.2	13.3	10.0	2.8	25.0	2.5	19.1	504.4	30.6	1.9	0.1	0.3	0.3	233.6	6.3	12.2
246	14.0	0.3	107.4	2.1	206.2	12.2	20.8	15.7	1.8	37.1	1.2	10.6	474.4	45.2	1.6	0.1	0.3	0.2	345.8	5.2	10.4
247	8.7	0.3	105.2	2.5	236.6	15.7	41.2	24.5	25.6	62.2	6.4	11.4	450.1	40.6	1.7	0.6	109.4	0.1	207.7	4.6	9.9
248	25.9	0.5	127.2	2.5	256.5	16.9	19.9	11.9	10.6	35.4	7.2	12.0	519.7	66.0	1.8	0.2	1.3	0.2	116.5	6.1	12.8
249	13.2	0.3	111.7	2.1	238.8	12.2	32.8	28.7	2.6	31.5	7.8	10.5	534.2	50.8	1.7	0.1	0.4	0.2	148.5	5.5	10.6

Part B.2 (trace elements, CONTINUED, in ppm)

Sample	Pr	Ta	Au	Y	Bi	U	W	Mo	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Th
1	1.9	0.2	0.0	10.5	2.5	0.9	0.6	0.9	7.4	1.4	0.6	1.5	0.3	1.5	0.4	1.0	0.2	1.0	0.6	1.6	1.2
2	1.8	0.2	0.1	9.0	0.1	0.7	0.7	4.9	7.9	1.6	0.4	1.3	0.2	1.4	0.3	0.8	0.1	0.6	0.1	1.4	1.0
3	1.8	0.1	0.1	7.6	0.1	0.6	0.3	0.4	6.5	1.1	0.4	1.3	0.2	1.2	0.2	0.7	0.1	0.6	0.1	1.1	0.9
4	1.6	0.2	0.1	6.7	0.1	0.4	9.0	3.3	6.3	1.4	0.3	1.1	0.2	0.9	0.2	0.6	0.1	0.6	0.1	1.2	1.0
5	1.6	0.2	0.1	7.7	0.1	0.5	0.4	3.7	6.3	1.1	0.3	1.2	0.2	1.3	0.2	0.7	0.1	0.8	0.1	1.3	1.0
6	0.8	0.2	0.1	3.6	0.2	0.5	0.6	2.1	2.8	0.8	0.2	0.7	0.1	0.7	0.2	0.4	0.1	0.5	0.1	0.8	1.0
7	1.9	0.2	3.4	8.6	0.1	0.7	0.6	5.0	7.0	1.4	0.4	1.3	0.2	1.4	0.2	0.6	0.1	0.6	0.1	1.1	1.1
8	1.9	0.3	0.2	5.8	2.5	1.5	0.3	0.6	7.3	1.5	0.4	1.5	0.2	1.4	0.3	0.8	0.1	0.7	0.1	2.9	2.6
9	1.9	0.2	0.0	6.7	0.0	1.0	0.3	3.7	6.8	1.5	0.3	1.0	0.2	1.1	0.2	0.7	0.1	0.7	0.1	2.2	2.0
10	4.0	0.5	0.1	13.3	0.1	1.1	0.3	0.8	14.4	2.6	0.6	2.3	0.4	2.3	0.4	1.4	0.2	1.6	0.2	8.6	4.0
11	1.7	0.1	0.2	6.5	0.1	0.5	0.4	1.8	6.0	1.3	0.3	1.1	0.2	1.2	0.2	0.6	0.1	0.5	0.1	1.1	1.0
12	1.7	0.3	0.0	7.5	0.1	1.2	0.2	0.3	6.7	1.2	0.4	1.3	0.2	1.2	0.2	0.8	0.1	0.7	0.1	4.2	1.5
13	1.3	0.1	0.6	5.8	0.0	0.3	0.2	1.9	4.9	0.9	0.3	0.9	0.1	0.9	0.2	0.5	0.1	0.4	0.1	0.7	0.7
14	1.5	0.1	0.0	6.0	0.1	0.5	0.4	2.6	5.8	1.2	0.3	1.1	0.2	1.1	0.2	0.5	0.1	0.5	0.1	0.9	0.8
15	1.5	0.1	0.1	6.3	0.1	0.9	0.3	2.9	5.6	1.3	0.3	1.1	0.2	1.0	0.2	0.5	0.1	0.5	0.1	0.8	1.6
16	1.6	0.2	0.4	6.4	0.0	0.9	0.1	1.2	5.7	1.2	0.3	1.0	0.2	1.0	0.2	0.9	0.1	0.6	0.2	3.8	1.4
17	1.7	0.1	0.1	6.3	0.0	0.4	0.3	3.0	6.3	1.3	0.4	1.1	0.2	1.1	0.2	0.6	0.1	1.1	0.1	0.9	0.9
18	1.6	0.1	0.1	6.3	0.0	0.8	0.2	0.6	5.9	1.1	0.4	1.3	0.2	1.1	0.2	0.6	0.1	0.5	0.1	0.9	0.8
19	1.7	0.2	0.0	7.3	0.1	0.5	0.4	2.6	6.7	1.5	0.4	1.4	0.2	1.2	0.2	0.7	0.1	0.6	0.1	1.6	1.1
20	1.4	0.1	0.6	5.7	0.0	0.5	0.2	3.3	5.6	1.1	0.3	1.0	0.1	1.0	0.2	0.5	0.1	0.5	0.1	1.0	0.9
21	1.4	0.1	0.8	6.4	0.1	0.4	0.5	4.5	5.6	1.0	0.3	0.9	0.1	0.9	0.2	0.5	0.1	0.5	0.1	0.8	0.7
22	1.6	0.2	0.1	6.8	0.1	0.6	0.3	3.1	5.8	1.2	0.3	1.1	0.2	1.2	0.2	0.6	0.1	0.6	0.1	1.6	1.0
23	0.6	0.1	0.0	2.6	0.0	0.5	0.3	1.0	2.4	0.3	0.2	0.4	0.1	0.4	0.1	0.2	0.0	0.2	0.0	0.9	0.7
24	1.0	0.1	0.1	3.5	0.1	0.4	0.2	1.3	3.7	0.8	0.2	0.7	0.1	0.6	0.1	0.3	0.0	0.3	0.0	0.8	0.8
25	0.9	0.1	0.1	3.3	0.0	0.4	0.5	4.9	3.4	0.7	0.2	0.5	0.1	0.6	0.1	0.3	0.1	0.3	0.0	1.0	0.7
26	1.0	0.1	0.0	3.5	0.0	0.5	0.5	5.3	3.9	0.7	0.2	0.7	0.1	0.5	0.1	0.3	0.0	0.4	0.0	1.1	0.7
27	1.6	0.1	0.1	6.6	0.1	0.5	0.4	3.1	5.9	1.3	0.3	1.1	0.2	1.0	0.2	0.6	0.1	0.5	0.1	1.1	1.1
28	1.3	0.1	0.1	5.6	0.1	0.5	0.3	3.0	5.1	1.0	0.3	0.8	0.2	1.0	0.2	0.5	0.1	0.5	0.1	1.1	0.8
29	1.3	0.2	0.1	5.2	0.1	0.7	0.1	0.1	5.1	1.0	0.2	0.9	0.1	0.9	0.2	0.5	0.1	0.5	0.1	3.3	1.1
30	1.4	0.1	0.0	6.3	0.0	0.5	0.2	2.7	5.4	1.1	0.3	1.0	0.2	1.0	0.2	0.5	0.1	0.4	0.1	1.0	0.8
31	1.4	0.2	0.1	6.1	0.1	1.0	0.2	0.2	5.3	0.9	0.3	1.0	0.2	0.9	0.2	0.5	0.1	0.5	0.1	3.0	1.2

Sample	Pr	Ta	Au	Y	Bi	U	W	Mo	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Th
32	1.4	0.1	0.1	7.0	0.0	0.5	0.2	0.8	5.5	0.9	0.3	1.1	0.2	1.1	0.2	0.6	0.1	0.6	0.1	0.8	0.8
33	1.8	0.5	3.6	8.0	1.4	1.3	1.9	1.0	6.7	1.4	0.4	1.2	0.2	1.4	0.4	0.7	0.1	1.1	0.2	1.9	3.2
34	1.6	0.5	1.5	6.7	0.3	0.8	4.1	0.6	6.0	1.1	0.5	1.3	0.2	1.1	0.2	0.5	0.3	2.0	0.1	1.3	1.1
35	3.5	0.4	0.1	14.7	0.1	1.7	0.7	7.3	13.3	3.0	0.8	2.9	0.4	2.7	0.5	1.5	0.2	1.6	0.3	6.5	2.3
36	1.4	0.4	0.5	5.8	0.1	1.5	0.6	0.5	5.5	1.2	0.4	1.4	0.2	1.2	0.2	0.6	0.1	0.7	0.1	3.0	1.7
37	1.7	0.2	0.0	7.6	0.0	0.9	0.2	0.6	6.4	1.3	0.3	1.2	0.2	1.2	0.2	0.8	0.1	0.7	0.1	4.1	1.6
38	1.7	0.3	0.0	7.0	0.1	0.8	0.2	0.4	6.0	1.3	0.3	1.1	0.2	1.1	0.2	0.7	0.1	0.8	0.1	5.0	1.6
39	1.3	0.1	0.1	6.1	0.1	0.7	0.2	0.5	5.2	1.1	0.3	1.0	0.1	1.0	0.2	0.4	0.1	0.6	0.1	0.9	0.7
40	1.8	0.3	0.0	7.6	0.0	0.8	0.2	0.4	6.6	1.3	0.4	1.2	0.2	1.2	0.2	0.8	0.1	0.8	0.1	4.8	1.8
41	1.6	0.2	0.0	6.5	0.1	0.9	0.3	1.5	5.8	1.2	0.3	1.0	0.1	1.0	0.2	0.7	0.1	0.6	0.1	3.9	1.6
42	1.7	0.2	0.1	6.9	0.0	0.8	0.2	2.5	6.4	1.6	0.4	1.3	0.2	1.1	0.2	0.7	0.1	0.6	0.1	2.3	1.2
43	1.8	0.3	0.1	7.1	0.0	1.2	0.1	0.2	5.9	1.4	0.3	1.1	0.2	1.2	0.3	0.7	0.1	1.1	0.2	4.1	1.4
44	1.3	0.1	0.0	5.2	0.0	0.6	0.1	2.2	5.0	0.9	0.2	0.8	0.1	0.9	0.2	0.5	0.1	0.5	0.1	1.5	1.4
45	1.7	0.2	0.0	6.8	0.0	1.2	0.1	0.1	6.3	1.3	0.3	1.1	0.2	1.1	0.2	0.6	0.1	0.7	0.1	4.0	1.5
46	1.5	0.1	0.2	6.0	0.0	0.6	0.4	3.2	5.5	1.2	0.3	0.9	0.1	1.0	0.2	0.5	0.1	0.5	0.1	0.9	0.7
47	1.9	0.3	0.4	7.6	0.1	1.1	0.4	0.3	6.7	1.7	0.4	1.5	0.2	1.2	0.3	0.8	0.1	1.1	0.1	5.0	1.8
48	1.8	0.3	0.0	7.5	0.0	1.5	0.2	0.5	6.2	1.3	0.3	1.2	0.2	1.1	0.2	0.7	0.1	0.6	0.1	4.1	1.5
49	2.0	0.3	0.0	8.0	0.0	1.1	0.1	0.3	7.2	1.4	0.4	1.3	0.2	1.2	0.3	0.7	0.1	0.8	0.1	4.4	1.7
50	2.1	0.3	0.2	9.3	0.0	1.1	0.1	0.2	7.6	1.7	0.4	1.4	0.2	1.4	0.3	0.8	0.1	0.9	0.1	5.4	1.8
51	1.9	0.2	0.0	7.8	0.0	1.0	0.1	0.3	6.7	1.4	0.3	1.3	0.2	1.2	0.3	0.6	0.1	0.7	0.1	4.5	1.6
52	1.6	0.2	0.0	7.7	0.0	0.8	0.1	0.3	5.7	1.2	0.3	1.1	0.2	0.9	0.2	0.6	0.1	0.7	0.1	3.7	1.4
53	1.5	0.2	0.0	6.9	0.0	0.7	0.0	0.1	5.3	1.0	0.2	0.9	0.1	0.9	0.2	0.6	0.1	0.5	0.1	3.5	1.2
54	1.9	0.2	0.0	9.7	0.0	0.9	0.1	0.1	7.5	1.6	0.4	1.5	0.2	1.4	0.3	0.8	0.1	0.8	0.1	3.5	1.5
55	1.5	0.2	0.0	7.2	0.0	0.8	0.1	0.1	5.4	1.0	0.3	1.0	0.2	0.9	0.2	0.6	0.1	0.6	0.1	3.4	1.3
56	1.4	0.1	0.0	6.9	0.0	0.5	0.1	0.2	5.1	1.0	0.3	1.0	0.2	0.8	0.2	0.5	0.1	0.5	0.1	1.0	0.7
57	1.6	0.1	0.0	7.7	0.0	0.6	0.1	0.5	6.1	1.3	0.4	1.2	0.2	1.1	0.2	0.6	0.1	0.5	0.1	0.9	0.8
58	1.4	0.1	0.0	6.7	0.0	0.6	0.1	0.3	5.3	1.1	0.3	0.9	0.1	0.9	0.2	0.5	0.1	0.5	0.1	1.0	0.7
59	1.9	0.2	0.2	8.5	0.6	0.9	0.2	0.6	7.6	1.6	0.4	1.4	0.2	1.3	0.3	0.7	0.1	0.7	0.1	1.7	1.3
60	1.6	0.1	0.1	5.4	0.0	0.8	0.3	2.8	5.6	1.1	0.2	1.1	0.1	0.8	0.2	0.5	0.1	0.6	0.1	1.8	1.5
61	1.4	0.1	0.1	6.5	0.1	0.5	0.1	0.3	5.1	1.1	0.3	0.9	0.2	0.8	0.2	0.5	0.1	0.5	0.1	0.9	0.7
62	0.4	0.1	0.0	2.6	0.3	0.3	0.3	0.2	1.4	0.2	0.0	0.3	0.0	0.3	0.1	0.2	0.0	0.2	0.0	1.4	0.7
63	1.8	0.1	0.0	7.7	0.0	0.6	0.1	0.3	6.4	1.3	0.4	1.1	0.2	1.1	0.2	0.6	0.1	0.5	0.1	1.2	1.0
64	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Sample	Pr	Ta	Au	Y	Bi	U	W	Mo	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Th
65	1.5	0.1	0.1	5.4	0.1	0.7	0.4	4.0	5.3	1.0	0.3	1.0	0.1	0.7	0.2	0.5	0.1	0.5	0.0	2.5	1.5
66	1.6	0.1	0.0	7.0	0.1	0.6	0.1	0.3	6.0	1.3	0.4	1.0	0.2	1.1	0.2	0.6	0.1	0.6	0.1	1.2	0.9
67	1.4	0.2	0.1	5.9	0.0	1.0	0.2	0.2	5.2	1.1	0.3	1.0	0.1	0.8	0.2	0.6	0.1	0.7	0.1	3.4	1.2
68	1.4	0.1	0.3	6.5	0.0	0.6	0.1	0.4	4.8	1.0	0.3	0.8	0.1	0.8	0.2	0.5	0.1	0.5	0.0	1.0	0.8
69	2.0	0.3	0.0	9.8	0.0	0.9	0.1	0.1	7.4	1.6	0.4	1.3	0.2	1.3	0.3	0.8	0.1	0.8	0.1	3.5	1.5
70	1.5	0.2	0.0	6.6	0.0	0.9	0.1	0.3	5.3	1.1	0.3	1.0	0.1	0.8	0.2	0.5	0.1	0.6	0.1	3.1	1.2
71	2.0	0.2	0.1	8.9	0.2	0.8	0.2	0.5	7.2	1.5	0.3	1.3	0.2	1.1	0.3	0.7	0.1	0.7	0.1	1.9	1.3
72	1.5	0.1	0.1	7.7	0.0	0.5	0.1	0.3	5.7	1.2	0.3	1.2	0.2	1.0	0.2	0.6	0.1	0.5	0.1	1.1	0.9
73	1.6	0.1	0.0	7.5	0.0	0.6	0.1	0.3	5.7	1.1	0.3	1.1	0.2	1.1	0.2	0.6	0.1	0.5	0.1	1.2	0.9
74	2.3	0.3	0.1	10.7	0.0	1.0	0.1	0.2	8.4	1.7	0.5	1.7	0.2	1.5	0.3	0.9	0.1	0.9	0.1	4.1	1.8
75	1.4	0.1	0.1	6.3	0.0	0.9	0.1	0.4	5.0	1.1	0.3	0.9	0.1	0.9	0.2	0.5	0.1	0.4	0.1	0.8	0.7
76	1.6	0.1	0.0	6.8	0.0	1.1	0.1	0.2	5.9	1.3	0.4	1.1	0.2	1.0	0.2	0.6	0.1	0.6	0.1	1.8	1.0
77	1.8	0.2	0.0	6.7	0.2	0.7	0.2	7.0	6.7	1.3	0.2	1.1	0.2	0.9	0.2	0.5	0.1	0.5	0.1	2.3	1.9
78	1.2	0.1	0.0	6.2	0.0	0.4	0.1	0.6	4.3	0.9	0.3	0.9	0.1	0.8	0.1	0.4	0.1	0.4	0.1	0.7	0.6
79	1.1	0.2	0.1	5.3	0.0	0.6	0.1	0.5	3.9	0.8	0.2	0.9	0.1	0.7	0.1	0.4	0.1	0.4	0.1	2.0	0.8
80	1.2	0.1	0.0	5.5	0.0	0.5	0.1	3.7	4.3	0.8	0.2	0.8	0.1	0.7	0.1	0.4	0.1	0.4	0.1	2.5	1.4
81	1.1	0.1	0.0	5.8	0.0	0.4	0.1	0.4	4.1	0.8	0.3	0.8	0.1	0.7	0.1	0.4	0.1	0.4	0.1	0.7	0.6
82	1.1	0.1	0.0	6.1	0.0	0.4	0.1	0.8	4.3	0.9	0.3	0.8	0.1	0.8	0.2	0.4	0.1	0.4	0.1	0.7	0.6
83	1.1	0.2	0.0	5.7	0.0	0.8	0.1	0.2	4.4	0.9	0.2	0.8	0.1	0.8	0.2	0.5	0.1	0.5	0.1	1.9	0.8
84	1.8	0.2	0.1	9.1	0.2	0.8	0.1	0.6	7.4	1.4	0.4	1.5	0.2	1.2	0.2	0.8	0.1	0.7	0.1	1.7	1.3
85	1.3	0.1	0.0	6.5	0.0	0.5	0.1	0.7	4.7	1.0	0.3	1.0	0.1	0.8	0.2	0.5	0.1	0.4	0.1	0.7	0.6
86	1.3	0.2	0.1	5.8	0.0	0.7	0.1	1.0	4.5	1.1	0.2	0.8	0.1	0.8	0.2	0.5	0.1	0.5	0.1	2.7	1.0
87	1.8	0.2	0.1	7.2	3.5	0.9	0.1	0.4	7.4	1.7	0.5	1.6	0.2	1.4	0.3	0.8	0.1	0.8	0.1	1.5	1.3
88	2.1	0.2	0.0	9.0	0.0	1.1	0.2	2.3	8.2	1.7	0.4	1.6	0.2	1.4	0.3	0.8	0.1	0.8	0.1	2.6	1.5
89	1.9	0.3	0.1	7.8	0.0	0.9	0.1	0.5	7.0	1.5	0.4	1.3	0.2	1.2	0.2	0.7	0.1	0.8	0.1	4.6	1.6
90	2.4	0.3	0.1	10.1	0.2	0.9	0.1	0.6	9.1	1.9	0.5	1.7	0.2	1.5	0.3	0.9	0.1	0.8	0.1	2.1	1.6
91	3.2	0.5	0.0	14.6	0.0	1.3	0.2	0.3	11.6	2.6	0.6	2.4	0.4	2.3	0.4	1.3	0.2	1.3	0.2	8.2	3.0
92	1.7	0.1	0.0	7.9	0.0	0.6	0.1	0.6	6.3	1.4	0.4	1.2	0.2	1.2	0.2	0.6	0.1	0.6	0.1	1.1	0.9
93	1.6	0.2	0.0	6.9	0.0	0.8	0.1	0.8	6.1	1.2	0.3	1.0	0.2	1.1	0.2	0.6	0.1	0.7	0.1	3.5	1.3
94	1.6	0.1	0.1	7.0	0.0	0.6	0.1	0.5	5.8	1.2	0.4	1.1	0.2	1.0	0.2	0.6	0.1	0.5	0.1	1.1	0.8
95	1.4	0.1	0.2	6.1	0.1	0.7	0.1	0.4	5.1	1.1	0.3	0.9	0.1	0.9	0.2	0.5	0.1	0.5	0.1	0.9	0.6
96	1.6	0.1	0.3	7.9	0.0	0.9	0.1	2.9	6.1	1.3	0.4	1.3	0.2	1.1	0.2	0.7	0.1	0.7	0.1	0.9	0.8
97	1.5	0.1	0.0	6.8	0.0	0.5	0.1	0.7	5.9	1.3	0.3	1.1	0.2	1.0	0.2	0.6	0.1	0.6	0.1	1.2	0.8

Sample	Pr	Ta	Au	Y	Bi	U	W	Mo	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Th
98	1.9	0.2	0.0	8.3	0.0	0.6	0.1	0.9	7.0	1.4	0.4	1.3	0.2	1.2	0.3	0.7	0.1	0.7	0.1	1.8	1.1
99	1.8	0.1	0.1	8.8	1.6	0.7	0.4	4.3	6.8	1.4	0.4	1.5	0.2	1.3	0.3	0.8	0.1	0.7	0.1	1.1	0.8
100	1.8	0.1	0.3	7.7	0.1	1.2	0.1	0.7	6.6	1.3	0.4	1.2	0.2	1.0	0.2	0.7	0.1	0.5	0.1	1.0	0.8
101	1.5	0.1	0.2	6.7	0.0	0.7	0.1	0.3	5.6	1.3	0.4	1.2	0.2	1.0	0.2	0.6	0.1	0.6	0.1	0.9	0.7
102	1.6	0.2	0.0	7.8	0.0	0.8	0.2	1.2	5.9	1.2	0.3	1.2	0.2	1.0	0.2	0.6	0.1	0.6	0.1	2.8	1.3
103	1.3	0.1	0.0	6.5	0.0	0.5	0.1	0.5	4.7	1.0	0.3	0.9	0.1	0.8	0.2	0.5	0.1	0.4	0.1	0.9	0.6
104	1.3	0.1	0.2	5.8	0.1	0.5	0.3	2.7	5.0	1.1	0.3	1.1	0.2	0.9	0.2	0.5	0.1	0.5	0.1	1.4	0.9
105	1.3	0.1	0.0	6.2	0.0	0.5	0.1	1.9	4.9	1.0	0.3	1.0	0.2	0.9	0.2	0.5	0.1	0.4	0.1	0.9	0.8
106	0.9	0.1	0.0	4.2	0.0	1.0	0.2	7.8	3.1	0.7	0.2	0.8	0.1	0.6	0.1	0.3	0.0	0.3	0.1	0.4	0.8
107	1.5	0.1	0.1	6.9	0.1	0.5	0.1	0.6	5.5	1.3	0.4	1.2	0.2	1.0	0.2	0.6	0.1	0.5	0.1	1.0	0.7
108	1.5	0.1	0.2	6.4	0.0	0.6	0.1	0.4	5.5	1.1	0.3	1.1	0.2	1.0	0.2	0.5	0.1	0.5	0.1	0.9	0.7
109	1.4	0.1	0.1	6.1	0.0	0.6	0.2	0.7	5.3	1.1	0.3	1.0	0.1	0.9	0.2	0.5	0.1	0.5	0.1	1.0	0.7
110	1.6	0.1	0.0	7.3	0.0	1.0	0.1	0.5	5.8	1.2	0.4	1.1	0.2	1.1	0.2	0.6	0.1	0.5	0.1	1.0	0.8
111	1.8	0.1	0.2	8.5	0.1	0.6	0.2	0.2	6.7	1.5	0.4	1.3	0.2	1.2	0.3	0.7	0.1	0.6	0.1	1.1	0.9
112	2.0	0.1	0.0	9.4	0.0	0.8	0.2	2.3	7.3	1.6	0.4	1.4	0.2	1.4	0.3	0.8	0.1	0.7	0.1	1.6	1.0
113	1.8	0.1	0.0	7.8	0.0	0.7	0.1	0.9	6.5	1.4	0.4	1.3	0.2	1.1	0.2	0.7	0.1	0.6	0.1	1.1	0.8
114	4.2	0.6	0.1	17.4	0.1	1.1	0.6	4.3	15.7	3.5	0.9	3.4	0.5	3.0	0.6	1.7	0.2	1.6	0.3	6.7	2.4
115	0.6	0.0	0.0	4.1	0.1	0.4	0.1	0.3	2.1	0.4	0.1	0.4	0.1	0.4	0.1	0.2	0.0	0.2	0.0	0.7	0.6
116	1.5	0.1	1.0	7.0	0.0	1.4	0.0	0.4	5.5	1.1	0.3	1.1	0.1	1.0	0.2	0.6	0.1	0.6	0.1	1.6	1.0
117	2.0	0.1	0.0	8.3	0.0	0.7	0.2	4.3	7.3	1.5	0.2	1.1	0.2	1.1	0.2	0.6	0.1	0.6	0.1	2.3	1.9
118	1.5	0.1	0.0	8.2	0.1	0.3	0.7	4.5	6.2	1.4	0.2	1.4	0.2	1.0	0.2	0.6	0.1	0.5	0.0	0.9	0.9
119	1.8	0.1	0.0	7.3	0.0	0.5	0.1	3.9	6.7	1.2	0.2	1.2	0.2	1.0	0.2	0.6	0.1	0.5	0.1	2.5	2.1
120	1.3	0.2	0.0	6.5	0.1	0.8	0.1	1.1	5.1	1.0	0.2	0.9	0.1	0.9	0.2	0.5	0.1	0.6	0.1	2.9	1.1
121	1.4	0.2	0.0	7.0	0.0	1.1	0.1	0.2	5.1	1.1	0.2	1.0	0.1	1.0	0.2	0.6	0.1	0.6	0.1	3.9	1.2
122	1.3	0.2	0.3	6.0	0.2	1.0	0.1	0.2	4.8	1.0	0.2	0.8	0.1	0.9	0.2	0.5	0.1	0.5	0.1	2.7	1.1
123	1.3	0.1	2.7	7.4	0.0	0.9	0.1	0.5	5.2	1.2	0.3	1.0	0.1	0.9	0.2	0.6	0.1	0.5	0.1	1.8	0.8
124	1.3	0.1	0.0	6.3	0.0	0.9	0.0	0.5	5.0	1.0	0.2	0.9	0.1	0.9	0.2	0.5	0.1	0.5	0.1	1.1	0.8
125	1.4	0.2	0.0	6.8	0.0	1.0	0.1	0.2	5.1	1.0	0.2	0.9	0.1	1.0	0.2	0.5	0.1	0.6	0.1	3.7	1.5
126	1.4	0.1	2.9	5.8	0.3	0.9	0.1	0.5	4.9	1.0	0.3	0.9	0.1	0.9	0.2	0.4	0.1	0.5	0.1	1.1	0.9
127	1.5	0.2	0.0	6.5	0.0	0.7	0.1	0.1	5.4	1.0	0.2	1.1	0.1	0.9	0.2	0.6	0.1	0.6	0.1	3.6	1.3
128	1.2	0.1	0.0	5.8	0.0	0.5	0.0	0.2	4.5	1.0	0.2	0.8	0.1	0.7	0.2	0.4	0.1	0.4	0.1	0.7	0.6
129	1.3	0.2	1.5	6.0	0.0	0.9	0.1	0.2	4.9	1.0	0.2	1.0	0.1	0.9	0.2	0.5	0.1	0.5	0.1	2.9	1.1
130	1.2	0.2	0.8	5.7	0.0	0.8	0.1	0.1	4.6	0.9	0.2	0.9	0.1	0.8	0.2	0.5	0.1	0.5	0.1	2.1	0.9

Sample	Pr	Ta	Au	Y	Bi	U	W	Mo	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Th
131	1.2	0.1	0.0	6.3	0.0	0.5	0.0	0.5	4.8	0.9	0.3	0.9	0.1	0.9	0.2	0.5	0.1	0.4	0.1	0.8	0.6
132	1.1	0.1	0.0	5.5	0.0	0.6	0.1	0.5	4.0	0.9	0.2	0.8	0.1	0.7	0.2	0.4	0.1	0.4	0.0	0.7	0.5
133	1.1	0.1	1.0	5.4	0.0	0.6	0.1	0.4	4.3	0.9	0.2	0.8	0.1	0.7	0.1	0.4	0.1	0.4	0.0	0.7	0.6
134	1.4	0.2	1.4	6.6	0.0	1.0	0.1	0.1	5.0	1.0	0.2	1.0	0.1	0.9	0.2	0.6	0.1	0.6	0.1	3.8	1.2
135	1.4	0.2	0.0	6.3	0.0	1.4	0.1	0.5	5.1	1.0	0.2	1.0	0.1	0.9	0.2	0.5	0.1	0.5	0.1	2.7	1.1
136	1.2	0.2	0.0	5.6	0.0	0.9	0.0	0.1	4.7	1.0	0.2	0.9	0.1	0.8	0.2	0.5	0.0	0.5	0.1	2.1	1.0
137	1.4	0.1	0.3	6.3	0.2	1.0	0.1	0.2	5.3	1.1	0.3	0.9	0.1	0.9	0.2	0.5	0.1	0.5	0.1	0.8	1.4
138	1.4	0.2	0.4	6.8	0.0	0.9	0.7	0.4	5.1	1.1	0.3	1.0	0.2	0.9	0.2	0.6	0.1	0.6	0.1	2.1	1.0
139	1.4	0.1	0.5	6.7	0.1	0.9	0.1	0.4	5.3	1.1	0.3	1.0	0.1	0.9	0.2	0.5	0.1	0.5	0.1	1.0	0.8
140	1.2	0.1	0.0	5.4	0.0	0.8	0.0	0.1	4.2	0.9	0.2	0.8	0.1	0.7	0.2	0.4	0.1	0.5	0.1	2.2	0.9
141	1.3	0.2	0.0	6.2	0.0	0.9	0.1	0.1	5.0	1.0	0.2	0.9	0.1	0.9	0.2	0.5	0.1	0.5	0.1	2.9	1.2
142	1.2	0.1	0.0	5.6	0.0	0.6	0.0	0.1	4.5	0.9	0.3	0.8	0.1	0.7	0.2	0.5	0.1	0.4	0.0	0.7	0.6
143	1.6	0.3	0.6	6.8	0.1	1.2	0.4	0.1	5.8	1.3	0.3	1.2	0.2	1.0	0.2	0.7	0.1	0.8	0.1	3.0	2.1
144	1.0	0.1	0.0	3.2	0.0	0.4	0.1	1.5	3.5	0.7	0.1	0.6	0.1	0.5	0.1	0.2	0.0	0.3	0.0	0.7	0.7
145	1.7	0.1	1.0	7.7	0.3	1.5	0.1	0.5	6.4	1.3	0.3	1.3	0.2	1.2	0.2	0.7	0.1	0.6	0.1	1.3	1.5
146	1.2	0.1	0.2	5.5	2.6	1.7	0.1	1.4	4.6	1.0	0.2	0.9	0.1	0.8	0.2	0.4	0.1	0.5	0.1	1.0	1.6
147	2.1	0.3	0.9	11.1	0.6	2.0	0.7	1.7	7.3	1.6	0.3	1.6	0.2	1.6	0.4	1.2	0.2	1.2	0.2	0.9	2.9
148	1.6	0.2	0.1	6.8	0.0	0.6	0.5	4.1	5.7	1.1	0.2	1.0	0.2	1.1	0.2	0.6	0.1	0.5	0.1	1.7	1.5
149	1.9	0.2	0.0	9.4	0.0	0.7	0.3	2.6	7.3	1.6	0.4	1.3	0.2	1.3	0.3	0.8	0.1	0.7	0.1	1.3	1.3
150	1.8	0.2	0.0	7.8	0.0	1.5	0.6	1.3	6.3	1.3	0.2	1.1	0.2	1.2	0.3	0.7	0.1	0.8	0.1	0.9	2.7
151	1.5	0.1	0.0	7.0	0.0	0.5	0.4	4.2	5.6	1.0	0.3	1.0	0.2	1.0	0.2	0.5	0.1	0.5	0.1	1.0	0.8
152	1.5	0.1	0.0	6.6	0.0	0.5	0.2	2.0	5.6	1.1	0.3	1.0	0.1	1.0	0.2	0.6	0.1	0.5	0.1	1.0	0.9
153	5.5	1.2	1.1	33.0	0.3	4.4	1.7	4.8	19.5	4.6	0.8	5.3	0.7	5.0	1.1	3.1	0.6	3.2	0.4	3.0	17.2
154	2.1	0.4	0.0	10.3	0.0	1.0	0.2	0.3	8.2	1.7	0.3	1.4	0.3	1.4	0.3	0.9	0.1	1.0	0.1	5.7	2.0
155	1.6	0.1	0.0	8.5	0.0	0.4	0.4	3.5	6.3	1.2	0.3	1.2	0.2	1.2	0.3	0.7	0.1	0.6	0.1	1.0	0.9
156	1.0	0.1	0.1	4.3	0.2	0.6	0.3	11.9	3.7	0.7	0.1	0.5	0.1	0.6	0.1	0.4	0.0	0.4	0.1	1.4	1.2
157	1.5	0.1	0.0	5.4	0.0	0.5	0.2	3.2	5.2	1.0	0.2	0.8	0.1	0.8	0.2	0.5	0.1	0.5	0.1	1.8	1.5
158	1.3	0.1	0.0	5.6	0.1	0.4	0.3	2.6	5.1	1.0	0.2	0.8	0.1	0.8	0.2	0.4	0.0	0.5	0.1	0.8	0.8
159	1.8	0.1	8.6	8.6	0.7	1.3	0.7	5.4	7.1	1.4	0.3	1.4	0.2	1.2	0.3	0.7	0.1	1.6	0.1	1.0	7.4
160	1.6	0.1	1.2	8.0	0.3	1.9	0.4	3.7	6.4	1.4	0.3	1.2	0.2	1.1	0.2	0.6	0.1	0.6	0.1	1.1	2.9
161	1.8	0.1	0.0	8.4	0.0	0.4	0.7	6.1	6.7	1.4	0.4	1.2	0.2	1.2	0.2	0.6	0.1	0.6	0.1	0.9	0.8
162	1.8	0.1	0.1	7.7	0.0	0.6	0.7	6.7	6.9	1.4	0.3	1.2	0.2	1.1	0.2	0.7	0.1	0.5	0.1	0.8	0.9
163	6.6	1.4	0.1	38.6	0.2	5.0	1.6	5.9	22.5	5.7	0.8	5.1	0.9	5.8	1.2	3.5	0.5	3.6	0.6	3.5	19.3

Sample	Pr	Ta	Au	Y	Bi	U	W	Mo	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Th
164	1.7	0.2	0.0	6.4	0.0	0.7	0.4	2.7	5.8	1.2	0.2	0.9	0.2	1.0	0.2	0.6	0.1	0.8	0.1	7.3	2.5
165	1.4	0.1	0.1	5.7	0.1	0.5	0.3	2.7	5.0	1.0	0.3	0.9	0.1	1.0	0.2	0.5	0.1	0.6	0.1	1.5	1.1
166	1.5	0.1	0.1	8.0	0.1	0.6	0.2	0.7	5.9	1.1	0.3	1.1	0.2	1.0	0.2	0.6	0.1	0.5	0.1	1.2	0.9
167	6.9	1.3	0.1	42.5	0.1	5.2	1.6	5.1	24.1	6.2	0.9	5.6	0.9	6.2	1.3	3.8	0.5	4.0	0.5	3.8	21.1
168	1.5	0.1	0.2	6.1	0.0	0.5	0.6	3.2	5.7	1.1	0.2	0.9	0.2	1.0	0.2	0.5	0.1	0.6	0.1	1.7	1.3
169	1.4	0.1	0.0	5.4	0.0	0.5	0.3	3.0	5.3	0.9	0.2	0.9	0.1	0.9	0.2	0.4	0.1	0.4	0.1	1.5	1.3
170	1.6	0.2	0.1	6.7	0.0	0.8	0.2	1.4	5.8	1.3	0.3	1.1	0.2	1.1	0.2	0.6	0.1	0.6	0.1	3.1	1.4
171	1.5	0.1	0.0	6.1	0.0	0.4	0.3	2.8	5.6	1.1	0.3	0.9	0.1	1.0	0.2	0.5	0.1	0.5	0.1	1.4	1.1
172	1.2	0.1	0.1	5.7	0.0	0.3	0.3	2.5	4.7	0.9	0.2	0.9	0.1	0.9	0.2	0.5	0.0	0.4	0.1	0.8	0.6
173	1.3	0.1	0.0	5.4	0.0	0.3	0.3	2.3	4.6	1.0	0.2	0.8	0.1	0.7	0.2	0.4	0.0	0.4	0.1	0.8	0.7
174	1.5	0.2	0.0	6.9	0.0	1.0	0.7	0.8	5.3	1.1	0.2	0.9	0.2	1.2	0.2	0.6	0.1	0.7	0.1	0.9	2.4
175	0.1	0.0	1.0	0.7	0.1	0.3	0.0	0.2	0.6	0.1	0.0	0.2	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.3	0.3
176	1.8	0.2	0.2	8.4	0.3	0.9	0.4	0.9	6.8	1.4	0.4	1.2	0.2	1.1	0.3	0.7	0.0	0.8	0.1	3.5	1.6
177	1.6	0.1	0.1	8.6	0.1	0.4	0.4	3.9	5.8	1.4	0.3	1.1	0.2	1.2	0.3	0.6	0.1	0.6	0.1	0.9	0.8
178	1.6	0.2	0.0	5.9	0.0	0.8	0.6	4.4	5.5	1.1	0.2	0.8	0.1	0.8	0.2	0.5	0.1	0.5	0.1	3.1	1.8
179	1.3	0.1	0.0	4.8	0.0	0.5	1.0	3.1	4.6	1.0	0.2	0.8	0.1	0.7	0.2	0.5	0.0	0.5	0.1	2.5	1.3
180	2.3	0.4	2.5	11.5	0.5	1.8	2.5	0.3	9.7	2.0	0.6	1.8	0.3	2.0	0.4	1.1	0.2	1.1	0.2	6.8	2.9
181	1.6	0.2	0.0	6.4	0.0	0.7	0.4	3.0	5.6	1.1	0.3	1.0	0.1	0.9	0.2	0.6	0.1	0.6	0.1	3.0	1.8
182	1.4	0.1	0.0	6.5	0.0	0.9	0.1	0.5	5.2	1.0	0.3	0.9	0.1	0.9	0.2	0.5	0.1	0.4	0.1	0.7	0.6
183	1.2	0.1	0.0	4.7	0.0	0.5	0.8	3.0	4.1	0.9	0.1	0.6	0.1	0.6	0.1	0.3	0.0	0.5	0.1	1.8	1.2
184	1.5	0.1	0.0	6.9	0.0	0.8	0.1	0.3	5.7	1.2	0.3	1.1	0.1	1.0	0.2	0.5	0.1	0.5	0.1	1.0	0.8
185	1.3	0.1	0.0	5.6	0.0	0.6	0.4	2.3	5.0	1.0	0.2	0.9	0.1	0.8	0.2	0.5	0.1	0.5	0.1	2.7	1.4
186	1.2	0.1	0.0	5.8	0.0	0.5	0.1	0.2	4.8	1.0	0.3	0.8	0.1	0.8	0.2	0.5	0.1	0.4	0.1	0.9	0.7
187	1.4	0.1	0.0	6.8	0.0	0.5	0.2	3.6	5.3	1.0	0.2	1.0	0.2	0.9	0.2	0.5	0.1	0.5	0.1	1.0	0.9
188	4.3	1.9	0.1	30.8	0.2	9.0	2.2	4.6	14.4	3.6	0.0	3.6	0.6	4.1	0.9	2.5	0.4	3.0	0.5	3.9	37.2
189	1.2	0.1	0.0	5.2	0.0	0.4	0.2	3.9	4.5	0.9	0.2	0.6	0.1	0.7	0.1	0.4	0.0	0.4	0.1	0.8	0.7
190	1.9	0.1	0.0	8.6	0.0	0.6	0.7	6.6	7.3	1.5	0.4	1.5	0.2	1.3	0.2	0.6	0.1	0.7	0.1	0.9	1.0
191	1.7	0.2	0.0	9.0	0.0	1.3	0.6	1.2	6.3	1.4	0.3	1.5	0.2	1.3	0.3	0.8	0.1	0.9	0.1	1.0	2.8
192	1.7	0.3	0.6	7.8	0.3	1.2	0.5	0.3	6.3	1.5	0.4	1.2	0.1	1.2	0.3	0.7	0.1	0.8	0.1	2.9	1.4
193	1.4	0.1	0.1	6.5	0.0	0.7	0.3	0.7	5.2	1.1	0.4	1.1	0.2	0.9	0.2	0.5	0.1	0.6	0.1	0.8	0.7
194	1.6	0.1	0.4	7.1	0.3	0.7	0.4	0.3	6.1	1.8	0.5	1.8	0.2	1.0	0.2	0.6	0.1	1.2	0.2	0.9	0.9
195	1.7	0.2	0.3	6.7	0.1	1.0	0.9	3.2	6.3	1.4	0.3	1.1	11.8	1.0	0.2	0.7	0.1	1.1	0.1	2.6	1.8
196	1.4	0.1	0.0	7.1	0.0	0.6	0.1	0.7	5.3	1.1	0.3	1.2	0.2	1.0	0.2	0.6	0.1	0.5	0.1	0.9	0.8

Sample	Pr	Ta	Au	Y	Bi	U	W	Mo	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Th
197	1.3	0.1	0.0	6.5	0.0	0.4	0.3	3.1	4.8	1.1	0.3	0.9	0.1	0.9	0.2	0.6	0.1	0.5	0.1	0.8	0.8
198	6.2	1.3	0.1	37.0	0.2	4.7	1.4	5.0	21.6	5.6	0.8	5.0	0.8	5.6	1.1	3.4	0.5	3.4	0.5	3.4	19.0
199	1.5	0.1	0.2	6.1	0.0	0.7	1.2	3.6	5.5	1.2	0.3	1.1	0.2	1.5	0.2	0.6	0.2	1.0	0.1	1.8	1.3
200	0.8	0.2	0.2	5.0	0.0	0.4	0.3	0.1	2.9	0.6	0.1	0.7	0.1	0.7	0.2	0.4	0.1	0.5	0.1	2.6	0.5
201	1.1	0.2	0.0	5.0	0.0	0.8	0.1	0.2	4.4	0.9	0.3	0.8	0.1	0.8	0.2	0.4	0.1	0.6	0.1	2.0	0.9
202	1.4	0.1	0.2	4.9	0.1	0.5	0.2	2.9	5.0	1.0	0.2	0.8	0.1	0.7	0.1	0.4	0.1	0.4	0.0	1.6	1.3
203	1.3	0.1	0.1	6.2	0.0	0.4	0.3	2.9	5.0	1.1	0.3	1.0	0.1	0.9	0.2	0.5	0.1	0.5	0.1	0.8	0.8
204	0.3	0.0	0.0	0.9	0.0	0.4	0.1	0.2	1.0	0.2	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.1	0.0	1.2	0.3
205	1.3	0.1	0.0	5.2	0.0	0.5	0.2	2.5	4.9	0.9	0.3	0.9	0.1	0.8	0.1	0.4	0.1	0.4	0.1	1.2	0.9
206	1.5	0.2	0.0	6.4	0.0	0.8	0.1	0.2	5.8	1.1	0.3	1.0	0.2	1.0	0.2	0.6	0.1	0.7	0.1	4.1	1.4
207	1.4	0.1	0.0	5.2	0.0	0.5	0.2	3.0	5.1	1.0	0.2	0.9	0.1	0.8	0.1	0.5	0.1	0.4	0.1	1.4	1.0
208	1.4	0.1	0.0	7.6	0.0	0.5	0.5	5.0	5.4	1.1	0.3	1.1	0.2	0.9	0.2	0.6	0.1	0.5	0.1	0.7	0.8
209	1.5	0.2	0.0	6.3	0.0	0.9	0.2	0.5	5.4	1.1	0.3	0.9	0.1	1.0	0.2	0.5	0.1	0.5	0.1	3.5	1.2
210	1.6	0.1	0.0	6.7	0.0	0.4	0.3	2.8	6.1	1.2	0.3	1.1	0.2	1.0	0.2	0.5	0.1	0.5	0.1	0.8	0.7
211	1.7	0.2	0.1	6.3	0.1	0.9	0.2	34.7	6.6	1.4	0.3	1.1	0.2	1.0	0.2	0.5	0.1	0.5	0.1	2.4	2.2
212	1.4	0.1	0.0	6.1	0.0	0.3	0.2	2.6	5.1	1.0	0.3	1.0	0.1	0.9	0.2	0.5	0.1	0.4	0.1	0.8	0.8
213	1.6	0.1	0.0	4.4	0.0	0.7	0.2	5.5	5.3	1.0	0.2	0.8	0.1	0.7	0.1	0.4	0.1	0.5	0.1	1.9	1.5
214	1.5	0.2	0.0	5.5	0.0	0.9	0.1	0.6	5.5	1.1	0.3	0.9	0.1	0.9	0.2	0.5	0.1	0.6	0.1	2.8	1.2
215	1.4	0.2	0.0	6.3	0.1	0.8	0.1	0.4	5.2	1.4	0.3	1.0	0.2	0.8	0.2	0.5	0.1	0.5	0.1	1.8	0.9
216	1.4	0.1	0.1	6.0	0.0	0.4	0.2	2.9	5.0	1.1	0.3	1.3	0.2	0.8	0.3	0.5	0.1	0.4	0.1	0.8	0.7
217	1.4	0.1	0.1	6.0	0.0	0.3	0.3	2.9	5.1	1.0	0.3	0.9	0.2	0.9	0.2	0.5	0.1	0.5	0.1	0.8	0.7
218	1.4	0.1	0.2	6.9	0.9	0.4	0.4	3.1	5.2	1.1	0.3	1.0	0.1	1.0	0.2	0.5	0.1	0.5	0.1	1.0	0.8
219	1.1	0.1	0.0	5.7	0.0	0.3	0.2	2.3	4.4	0.9	0.2	0.7	0.1	0.8	0.2	0.4	0.1	0.4	0.1	0.7	0.6
220	1.4	0.2	0.1	7.4	0.1	0.7	0.1	0.8	5.7	1.2	0.3	1.1	0.2	1.0	0.2	0.6	0.1	0.6	0.1	2.0	1.1
221	1.5	0.2	0.0	7.4	0.0	0.6	0.1	0.1	5.8	1.3	0.3	1.0	0.2	1.0	0.2	0.6	0.1	0.7	0.1	4.1	1.4
222	1.2	0.2	0.1	5.6	0.1	1.9	0.4	3.7	4.4	0.9	0.2	0.8	0.1	0.8	0.2	0.5	0.1	0.5	0.1	0.9	1.1
223	1.3	0.1	0.0	6.0	0.0	0.5	0.3	3.8	4.8	1.1	0.3	0.9	0.1	0.8	0.2	0.5	0.1	0.4	0.1	0.8	0.7
224	0.7	0.1	0.0	3.2	0.0	0.3	0.1	1.0	2.7	0.6	0.1	0.5	0.1	0.5	0.1	0.3	0.0	0.3	0.0	0.5	0.7
225	1.6	0.3	0.0	8.8	0.1	0.5	0.1	0.5	6.2	1.3	0.3	1.3	0.2	1.3	0.3	0.7	0.1	0.8	0.1	1.1	1.7
226	1.3	0.1	0.0	6.2	0.0	0.4	0.3	3.4	5.1	1.0	0.3	0.9	0.1	0.8	0.2	0.5	0.1	0.4	0.1	0.9	0.8
227	1.4	0.1	0.6	5.3	0.0	0.4	0.2	2.2	5.1	1.1	0.3	1.1	0.1	0.8	0.2	0.5	0.1	0.4	0.1	0.8	0.8
228	1.4	0.1	0.0	6.4	0.0	0.3	0.1	1.2	5.6	1.1	0.3	1.0	0.1	1.0	0.2	0.5	0.1	0.4	0.1	0.7	0.6
229	1.8	0.1	0.5	6.8	0.4	0.7	0.5	5.4	6.5	1.4	0.3	1.2	0.2	1.1	0.2	0.5	0.1	0.7	0.1	2.4	1.9

Sample	Pr	Ta	Au	Y	Bi	U	W	Mo	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Th
230	1.5	0.2	1.2	6.7	0.4	0.8	2.4	5.3	6.6	2.4	0.8	2.7	0.4	2.3	0.5	1.1	0.3	1.0	0.2	2.5	1.5
231	1.5	0.2	0.5	6.6	1.8	0.7	0.5	2.8	5.6	1.3	0.5	1.2	0.2	1.2	0.2	0.6	0.2	0.8	0.1	1.3	1.1
232	1.6	0.1	0.0	7.8	0.1	0.5	0.5	3.4	6.2	1.4	0.4	2.0	0.2	1.3	0.3	0.7	0.1	0.6	0.2	1.3	1.2
233	1.4	0.1	0.0	5.9	0.1	0.4	0.3	2.8	4.9	1.0	0.3	1.0	0.1	1.0	0.2	0.5	0.1	0.4	0.1	0.9	0.8
234	1.7	0.1	0.0	8.5	0.0	0.4	0.3	3.4	6.5	1.4	0.3	1.3	0.2	1.2	0.2	0.7	0.1	0.6	0.1	1.1	1.0
235	1.7	0.2	0.3	8.9	0.0	1.4	0.7	1.2	6.3	1.6	0.3	1.6	0.3	1.9	0.4	1.0	0.2	1.3	0.1	0.9	2.6
236	1.4	0.1	0.1	7.1	0.1	1.1	0.1	0.5	5.8	1.2	0.3	1.0	0.2	1.0	0.2	0.6	0.1	0.6	0.1	0.9	0.8
237	0.9	0.3	0.2	7.1	0.0	0.6	0.3	0.2	2.9	0.7	0.2	0.7	0.1	0.9	0.2	0.6	0.1	0.8	0.1	3.9	0.8
238	1.0	0.2	1.0	3.7	0.1	0.3	0.2	1.0	4.0	1.4	0.4	1.7	0.1	0.8	0.2	0.6	0.1	0.5	0.1	0.7	0.9
239	1.2	0.1	0.0	5.1	0.0	0.3	0.1	1.6	4.5	1.1	0.3	1.1	0.1	0.7	0.2	0.4	0.1	0.4	0.1	0.8	0.7
240	1.4	0.1	0.3	6.3	0.0	0.4	0.3	2.9	5.5	1.2	0.3	1.0	0.2	0.9	0.2	0.5	0.1	0.5	0.1	0.8	0.9
241	1.5	0.1	0.1	6.4	0.0	0.6	0.3	3.2	5.5	1.0	0.3	1.0	0.2	0.9	0.2	0.5	0.1	0.5	0.1	1.6	1.3
242	1.9	0.2	0.1	7.0	0.0	1.1	0.3	8.1	6.8	1.4	0.3	1.2	0.2	1.1	0.2	0.6	0.1	0.6	0.1	2.5	2.0
243	5.1	1.0	0.1	28.9	0.1	4.0	1.4	4.0	17.1	4.1	0.7	3.8	0.6	4.3	0.9	2.6	0.4	2.8	0.4	3.0	15.8
244	1.5	0.1	0.4	5.9	0.1	0.5	0.2	2.2	6.3	1.7	0.5	1.5	0.2	1.1	0.2	0.5	0.1	0.5	0.1	0.8	0.9
245	1.7	0.2	1.5	7.5	0.1	0.5	1.4	3.6	6.9	1.6	0.4	1.6	0.2	1.6	0.2	0.8	0.2	0.9	0.2	1.3	0.9
246	1.3	0.2	0.9	3.4	0.1	0.7	0.6	2.5	4.4	1.1	0.2	0.8	0.1	0.6	0.2	0.3	0.0	0.3	0.1	1.4	1.2
247	1.3	0.1	0.1	4.6	0.1	0.8	0.4	2.5	4.5	1.0	0.3	1.0	0.1	0.9	0.2	0.6	0.1	0.5	0.1	1.1	0.9
248	1.5	0.1	0.3	4.8	0.1	0.8	0.8	2.4	5.0	1.3	0.3	1.0	0.1	1.0	0.2	0.7	0.1	0.6	0.1	2.1	1.7
249	1.3	0.1	0.1	3.5	0.1	0.7	0.2	2.0	4.7	1.0	0.2	0.7	0.1	1.1	0.1	0.5	0.1	1.3	0.1	1.6	1.0

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