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Sourcing of marble used in mosaics at Antioch (Turkey)

Marie Jeanette Archambeault

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Sourcing of Marble Used in Mosaics at Antioch (Turkey)

by

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Arts
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ABSTRACT

Artifacts made of durable materials, such as stone, can provide valuable clues to reconstruct the past. Marble sourcing, in particular, provides information about contact, trade, and other activities in the greater Mediterranean area. The Worcester Art Museum of Massachusetts (WAM) initiated a provenance study by requesting that an analysis of several marble artifacts occur at the University of South Florida’s Archaeological Science Laboratory. The 55 marble samples used in this study are from the Worcester Art Museum’s collection of Antioch mosaics. Positive results might reveal: 1) preferred sources of tesserae, 2) information about trade of specialized stone, 3) changes in preferred sources during different chronological periods, and 4) workshop preferences of stone material. The requested analysis was had two objectives. First, once the provenance of the materials is determined, then the results could reveal meaning behind the images contained within the mosaic floor. Second, the results could reveal new trade routes in the Mediterranean. The first step in this analysis was X-ray diffraction (XRD), which differentiates dolomite and calcite marbles. The second step used stable isotope ratio analysis (SIRA), which measures carbon-13 and oxygen-18 isotopic ratios. These two steps have helped to identify Mediterranean marble sources in previous studies.
Most of the ancient Mediterranean marble sources have been identified. They have different isotopic values and other characteristics that allow for differentiation. Only one source of dolomite marble exists, which is located in the eastern Mediterranean. It has been identified through XRD in previous studies. Many of the calcite marble sources have different carbon and oxygen isotopic values, which were provided from the SIRA. Those marble artifacts with overlapping carbon and oxygen values can be further analyzed using archaeological, historical, and other information and by using other scientific techniques including cathodoluminescence, electron paramagnetic resonance, and strontium isotope analysis.

This thesis discusses the methods used to prepare the samples and analysis conduction; it also discusses the results of the analyses, and presents interpretations regarding the provenance and trade of the marble used for mosaics at Antioch. The results of the SIRA and XRD analysis showed that the materials used for mosaic tesserae come from a variety of sources. Although no definitive matches were found, the results provide the basis for the collection of a colored marble database of sources and artifacts.
Chapter One: Introduction

Archaeologists have examined the importance of interregional contact through trade routes within the Mediterranean Sea for many decades (Craig and Craig 1972; Renfrew 1972; Coleman and Walker 1979; Grimanis and Vassilaki-Grimani 1988; Anderson 1989; Herz 1990; Rapp 1998). Limited by available sources, archaeologists typically have focused on historical documents, artifacts from foreign cultures, and ethnographic information. More recently, with the advent of elemental and isotopic analysis, archaeologists have begun cataloguing the different values for sources of clay, obsidian, marble, and several other durable artifacts. Marble sourcing has provided archaeologists with pieces of the larger Mediterranean trade route puzzle. The samples used in this study come from the Roman site of Antioch in south central Turkey near the border of Syria (Figure 1). The Worcester Art Museum (WAM), which currently houses

Figure 1. Map of Turkey (after Turkey.com 2004)
the artifacts, initiated the minimally destructive analysis of X-ray diffraction (XRD) and stable isotope ratio analysis (SIRA) of samples that they collected.

Archaeologists have studied the provenance of marbles for over one hundred years, basing their analyses on color, grain size, and even smell (Moltesen et al. 1992). Provenance studies today incorporate multiple analytical methods, including visual analysis, SIRA, and historical and archaeological resources. For this study, the author began by using XRD and SIRA of $\delta^{13}C$ and $\delta^{18}O$ to examine several marble tesserae, squared mosaic pieces, from several different Antioch mosaic floors dated to the Roman and the Early Byzantine occupational periods (300 B.C. – A.D. 565). A mosaic is defined as a grouping of stone, marble, glass, or terracotta that is joined by a binder to form a unit (Bergamini and Fiori 1999). This study of marble mosaic tesserae focused on the following research questions:

1. What is the source of the materials used in mosaic tesserae from Antioch?
2. Which of the samples have similar results?
3. Is there a temporal or spatial relationship between the source and the importance of the image created?
4. Is there a correlation between the importance of the materials used with the distance that the materials traveled?

Positive results might 1) reveal preferred sources for tesserae of specific characteristics (color, grain, luster, etc.), 2) reveal information about trade in specialized stone, 3) reveal change in preferred sources in different chronological periods, and 4) reveal workshop preferences in stone selection. In addition, the results could reveal how mosaicists at Antioch selected stones for use as tesserae.
The results of the analysis, presented in subsequent chapters, highlight the importance of a multi-disciplinary approach to archaeological questions. Without additional historical and archaeological information, the XRD and the SIRA results only increase our questions about marble sources, rather than answer the existing questions. The use of SIRA, in combination with XRD and visual identification, can help identify the sources that were used for marble mosaic floors at Antioch. The information obtained from this study will add to the growing body of knowledge concerning ancient Late Roman and Early Byzantine cultures.
Chapter Two: History and Methods of Ancient Marble Extraction

Marble has been used for a variety of purposes including architectural elements, decorative inlays, and sculptures. The final marble products are affected by the individual characteristics of the different marble types. The history of ancient marble extraction methods, the characteristics of marble, and the use of marble in Roman construction will be discussed in the following paragraphs.

Characteristics of Marble

Over time, marble has been defined in many contradictory ways. Today, modern geologists define marble as:

A well-known metamorphic rock composed predominately of calcite or dolomite; its grain size ranges from fine to coarsely granular. Marble results from either contact or regional metamorphism of limestones or dolostones. Pure marble is snowy white or bluish, but varieties of all colors exist because of the presence of mineral impurities in the parent sedimentary rock. The softness of marble, its uniform texture, and its various colors has made it the favorite rock of builders and sculptors throughout history (Monroe and Wicander 1997: 177).

The definition of marble has not always been so precise. The term marble comes from the Greek word, *marmaros*, which means “a snow white and spotless stone;” the
adjective *marmoreos* means “resplendent,” and the verb *marmairo* means “to shine” (Mannoni and Mannoni 1986: 10). This Greek term for marble is vague, leaving room for the inclusion of non-marble and eliminating all colored marble from the definition. The lack of precision in the Greek definition continues to cloud modern understanding of ancient texts referencing marble. Many scholars have expressed a serious distrust of ancient literature that refers to marble, because the definition includes limestone that can take a high polish (Herz 1988). While limestone that takes a high polish might aesthetically resemble marble, its physical structure has not been geologically altered. Scientifically, limestone cannot be included in marble analysis, because its sources may or may not have vastly different characteristics from marble. Consequently, limestone has not received the intense analysis and source characterization that marble has received. To further complicate the issue, modern industrial and commercial developments often classify all ornamental rocks, including limestone and dolomite, as marble.

Marble is formed through a combination of heat, pressure, and fluid activity. Calcite and dolomite can become marble through pressure of a few thousand atmospheres or at a temperature of about 400°C. Regardless of the formation process, all marble has similar structure, physical composition, and working behavior (Mannoni and Mannoni 1986). The main variations in marble come from impurities, which affect the color of the material.

Aesthetic quality and variation in color greatly affect the ornamental and commercial value of marble. The impurities in marble affect not only color, but also the physical characteristics of the stone. A physical characteristic of special interest to mosaicists would have been resistance to wear and tear of foot traffic. Color variations
seem to coordinate with variabilities in durability to weathering and consistency of coloration after contact with air (Mannoni and Mannoni 1986). Color variation derives from either minerals or pigmentation. Commonly found colors of marble minerals are: white (feldspar, calcite, and dolomite), black (biotite, hornblend, augite), green (chlorite, epidote, actinote, diallagio, diopsite, olivine, and serpentine derivative), and clear (quartz, muscovite, and mica) (Anderson 1989: 11; Mannoni and Mannoni 1986: 54, 58).

Pigmentation colors include yellow to orange, red, and violet, which do not exist in pure minerals. Iron oxides (hematite) usually make marble red. Green iron oxides (bivalent iron) are rare, but form in an environment with no oxygen. Hydrous environments cause a brown to yellow coloration (limonite). Manganese oxides cause purple. Residual organic matter causes the more common allochromic colors (pale gray to black). All of these naturally occurring variations in marble made some stones more suitable for specific building projects and provided the motivation for long distance transportation of stones. Variations in color make some marble especially desirable for mosaic images.

Marble Extraction

Marble exportation increased exponentially from the Greek to Roman periods; therefore, addressing Antioch marble sourcing requires a broad examination of marble quarries throughout the central and eastern Mediterranean area, including Italy, Greece, Turkey, Israel, Egypt, and the northeastern border of the African continent. Many studies have focused on Greek marble, because the Greeks began industrial scale production and trade of marble. The Romans generally continued exploiting Greek resources until all usable marble was extracted and then opened new quarries to meet demand. An example
of such Roman extraction procedures is evidenced in a photo taken on Thasos, Greece, of a section of the Aliki quarry (Figure 2).

Marble carving has existed in Greece since c. 5000 to 4500 B.C., when the Neolithic societies began carving anthropomorphic marble figures. Although Neolithic Greece never acquired the techniques necessary to extract marble for architectural means, it developed the skills that produced a long tradition of marble figurines. The Cycladic societies continued this carving, which burgeoned into the well-known figures associated with the Bronze Age Cyclades (Figure 3). Since quarrying technology was not yet prevalent in Greece, most of the material used for figures was composed of pebbles and boulders partially worn by tidal movements (Waelkens et al. 1990: 47). The use of

![Figure 2. Aliki peninsula: marble hillside completely extracted during Roman times (Photo by Author 2003)](image-url)
collected materials, as opposed to extracted materials, limited the size of the final artifact. Prior to the invention of bronze tools, sculptors used various materials for sculpting and smoothing figures, including emery, obsidian, sand, and pumice. With the invention of bronze tools, similar in form to crowbars, sculptors were able to break off larger chunks of stone already separating from the outcrop through erosion.

**Development of Quarrying Technology**

While the Neolithic and Bronze Age cultures of the eastern Mediterranean did not possess methods of marble extraction, such techniques did exist in contemporary Egypt. Egypt had invented extraction tools that enabled them to develop techniques for
extraction of large blocks. Beginning again with collected or broken material, the Egyptians undoubtedly invented real quarrying, which appeared during the Early Dynastic period (c. 3100-2686 B.C.), with the culmination of dressed stone used for architectural purposes (Waelkens et al. 1990: 48). The First and Second Dynasties produced underground tombs and large stelae with progressively improving quality of dressed limestone and granite. During the Third Dynasty (c. 2686-2613 B.C.), these dressed stones were increasingly used in above ground architecture (Robin 1997: 40). King Djoser’s step pyramid at Saqqara was the first Egyptian architectural projects to be made completely out of dressed stone (Waelkens et al. 1990: 48). In addition, monumental stone sculptures began to appear during this time. The Fourth Dynasty (c. 2613-2494 B.C.) rulers began shipping large granite blocks from Aswan to Giza for the construction of the pyramid complexes (Waelkens et al. 1990). As the demand for larger stone blocks increased, the technology for extraction changed as well.

While much is still unknown about the earliest quarrying techniques, current theory suggests that Egyptians were the first to quarry by cutting narrow trenches around a block of stone in an effort to separate it from the parent rock (Figure 4) (Waelkens et al. 1990: 48; Mannoni and Mannoni 1986: 75). For soft stones, quarrymen initially used copper tools, which were replaced during the New Kingdom (c. 1500 B.C.) with bronze tools, and then replaced again during the Ptolemaic (323-330 B.C.) period by iron tools (Waelkens et al. 1990). The quarrying process left groove marks, which changed through time, depending on the tools that were used. Today one can use these marks as a dating method for the period of extraction. Copper tools left short irregular marks on the parent rock. Bronze tools initially left longer marks in a herringbone pattern. Over time bronze
tools left longer and stronger marks, almost parallel and slightly interrupted (Mannoni and Mannoni 1986: 75). Iron tools left long and parallel marks on the parent rock. For harder stones, such as granite and marble, archaeologists are still debating quarry techniques, but it is generally assumed that harder stones were cut by pounding with hard hammers. Many believe that the parent rock was heated up and then splashed with water, systematically weakening sections of the stone (Waelkens et al. 1990: 49). This practice has been connected to an inscription from the Wadi Hammamat. Another theory suggests that changes in wedge marks had little to do with chronological advances in technology, but rather adjustments to specific quarrying problems (Waelkens et al. 1990). Whatever the different quarry marks mean, Egyptians certainly developed quarrying techniques, which were then adopted by neighboring countries.

Figure 4. Evidence of isolation at Aliki quarries, Thasos, Greece (Photo by Author 2003)
Quarrying technology spread to the Aegean via the Minoans, c. 1900 B.C., although the Minoans still only quarried softer stones (Waelkens et al. 1990: 51). Evidence of the technology does not exist on mainland Greece until the Mycenaean civilization (c. 1600 – 1200 B.C.), seems to have disappeared completely for several centuries with the collapse of this civilization, c. 1200 B.C. Besides Egypt, quarrying technology continued only among the neo-Hittite civilizations of southern Turkey and northern Syria. The Hittites quarried a variety of materials including limestone, conglomerate rock, and basalt. Waelkens et al. (1990) suggests that the Greeks were influenced by the post-Hittite culture, seen at Boğazköy. The Greek quarry instrument was the pick, not the punch instruments used by the Egyptians. In addition to carving techniques, orientalizing sculpture styles were reintroduced from the general area of Syria (Waelkens et al. 1990: 54). The earliest surviving Greek sculptures, made of limestone, were found on Crete and date to the ninth century B.C. The orientalizing styles and the carving techniques of the sculpture suggest a direct link to the Phoenicians.

The seventh century B.C. witnessed the beginnings of a re-opening of Egypt to the Greeks with the establishment of Naukratis, a Greek trade colony on the delta of the Nile (Hurwit 1985; Whitley 2001). The abrupt stylistic changes, which were unquestionably influenced by the Near East, ranged from ceramic vessel shape and decoration techniques to architectural styles (Hurwit 1985: 184). Syro-Phoenician influence was also directly responsible for the Cretan, Daedalic style, which spread throughout Greece. This style led to the Greek development of marble sculptures, which were very thin and flat, including the statue of Nikandre and the Naxian colossus on Delos (Waelkens et al. 1990: 54; Whitley 2001: 215). The seventh century B.C. also
witnessed the first large-scale stone temples in Greece, which were constructed at Corinth and composed of dressed limestone (Hurwit 1985: 181). With the advent of megalithic architecture on the mainland and in Ionia, Greeks began to improve their quarrying techniques to obtain larger blocks of stone and harder materials like marble. The Siphnian Treasury at Delphi, erected c. 525 B.C., was one of the first structures on mainland Greece built entirely of marble.

Evidence also suggests that all of the major quarries of the Greek and Anatolian world were fully active by the end of the sixth century B.C. Absolute dating of quarries and quarry sections still remains a problem, with the continual modern extraction of marble from larger quarries; however, some ancient evidence still survives (Figures 4 and 5). Greek extraction suggests particular quarrying of specific dimensions and finishes, with no industrial collecting similar to Roman hoarding. Greek quarry workers do not seem to have taken more than they needed. Some preserved quarry marks (which are very regular, almost horizontal, or only slightly curved grooves, consisting of shallow ledges, the result of crushing) were most likely produced by a long-handled, light pick, possibly resembling the tykos of modern Greek quarry workers (Figure 6). Possibly, the tool is the latomis of ancient Greek sources (Waelkens et al. 1990). The tool did not penetrate very deep after each strike, and created a horizontal, crushed groove. The traces of this tool are found on quarry walls that date from the early sixth century B.C. through the Roman Imperial period (Waelkens et al. 1990). Although the light pick was well suited for extracting marble blocks of specific dimensions, the method was time consuming. The teams had to be small to allow for continuous movement along a line, and operations must have been run by private individuals with experience and knowledge
Figure 5. Quarrying techniques: the left side shows the hand-cut vertical grooves that were used to split the block from the parent rock; and the right shows the different kinds of groove marks left on the parent rock (after Mannoni and Mannoni 1986: 73)

Figure 6. Roman and Greek tools used for cutting stone (after Mannoni and Mannoni 1986:73)
of stone cutting. The virtual elimination of the light pick in favor of the bulkier pickhammer occurred during the first century A.D. The pick-hammer produced deep, strongly curved grooves, in a “garlandlike pattern or festoni” suggesting continuous action from one position (Waelkens et al. 1990: 59). The Roman quarrying techniques produced an irregular quarry face and led to a greater loss of material. The high demand and cost of marble extraction suggests free quarryworkers passing the knowledge on through generations. It is thought that slave labor would have been minimal, mostly used for dumping wasted material (Waelkens et al. 1990: 62). Modern quarrying in Italy and Turkey still operates on a familial basis.

The Greeks were largely responsible for carrying the quarrying knowledge into the Roman world. In addition to iron tools, wooden wedges have also been found in some Roman quarries. Although no artifacts have been found in the Greek quarries, wooden wedge holes have been found. Regardless of the tools used, the skills and knowledge of the Greek quarryworker were extremely important in his endeavor. Greek slaves, or technitēs, and their skill and advanced technologies were largely responsible for the flourishing of the marble industry during the Roman Empire (Mannoni and Mannoni 1986: 78). Willingly or unwillingly, the Greeks passed on their knowledge and skills to the Romans, who are credited with quarrying on a scale that has never been repeated (Waelkens et al. 1990).

**Importance of Marble in Roman Construction**

Throughout history the use of marble has held many meanings. The Roman Republic exploited marble resources across the Mediterranean (Figure 7 and 8). In the
Figure 7. Map of colored marble sources used during Roman period: 2-giallo antico, 3-Carrara, 11-rosso antico, 12-Thasos, 13-Proconnesos, 14-portasanta, 16-Paros, 17-cipolinno rosso, 18-Aphrodisias, and 20-pavonazzetto (after Anderson 1989: 10)

Figure 8. Map of white marble quarries (after Moens 1992: 112)
beginning of the second century B.C., white marbles were imported to Italy from numerous quarries, including Carrara, Prokonnesos, Dokimeion, and Aphrodisias. Vitruvius (3.2.5) writes that the Temple of Jupiter Stator (146 B.C.) was the first structure in Rome made entirely of marble. Construction of marble monuments and buildings increased, and soon colored marbles began to be used. In the second century B.C., *giallo antico*, a yellow marble with red veining quarried in Tunisia, and *pavonazzetto*, a yellowish-white marble with gray to purple veining quarried in Asia Minor, began to be used for statues of barbarians as a means of separation from elite individuals (Anderson 1989). Demands for particular colors arose as artisans began to use certain colors for specific representations (Gregarek 2002). “*Giallo antico* was preferred for representations of Dionysos himself, recalling the theater costume of the god or the color of saffron, which is often connected to him. *Rosso antico* was favored for satyrs, recalling the red color of the wine and the color of the tanned body” (Gregarek 2002: 212). These changing marble demands affected the cost of some marble types. Strabo (9.5.16) writes that the increase in trade for colored marble actually led to the decrease in prices for white marble. As the market demand continued to change, colored marble began to be used for multiple purposes (Guidobaldi and Salvatori 1988). Plutarch writes that the first colored marble victory monument was displayed on the Capitoline Hill in Rome c. 91 B.C. (*Moralia* 32). When these extravagant stones made their way into the Roman Republican world, the public campaign against luxuries was at its height. The fascination with embellishment and decoration was viewed as a threat to the Republic’s worldview (Anderson 1989: 13). Roman trade in marble increased during the first century B.C. It was common for individuals to adorn public buildings with costly
materials from distant lands as a means of displaying one’s political strength (Anderson 1989). Adornment of public buildings immediately affected the decoration of private residences with an increase in the use of marble in sculpture, mosaics, and inlay. Architectural and sculptural materials were constantly reused as a means of saving money and time (Giuliano 1989).

During the Roman Empire, marble represented luxury, wealth, and power; and therefore, marble had a royal association (Fant 1988). Suetonius (Augustus 28.3) writes, “Augustus so embellished Rome, a city not adorned in proportion to the greatness of its empire and prey to fires and floods that he was able to boast deservedly that he was leaving to posterity a city clad with marble where he had found one of brick.” Augustus commissioned an enormous network of quarries, which continued to flourish until the late first or early second century A.D. (Fant 1988; 1999). For example, evidence of a quarry from this period can be seen at the Aliki peninsula in Figure 2. The demand for marble was so great that quarries like Aliki were exploited to the extreme, so much so that at Aliki the entire peninsula was removed. Although the original intent of the quarries was not commercial, during the late first or early second century A.D. the quarries acquired a more economic role. A system of business class marble entrepreneurs arose, not as a result of higher demand for marble, but rather as a change in attitude towards fiscal independence of the realm (Fant 1988: 148).
Chapter Three: Archaeology of the Area Studied

One of many Roman-period Mediterranean cities, Antioch-on-the-Orontes was known for the grandiose lifestyle of its residents. With large avenues, stylish buildings, healing spring-fed waters, and the availability of goods, both exotic and luxurious, at local markets, Antioch operated at a level congruent with Rome, Alexandria, and Constantinople (Jones 1981; Kondoleon 2000). Despite its size and complexity, we still know relatively little about the Roman city of Antioch. Ten Antioch mosaic floors were included in this study. Titles for each panel reflect early interpretations of the images portrayed. For ease of description in this thesis, the titles have been retained. The Antioch marble mosaic floors sampled include the following named panels: *Worcester Hunt* (WAM 1936.30), *Funerary Symposium* (WAM 1936.26), *Agora* (WAM 1936.39), *Eukarpia* (WAM 1936.38), *Drinking Contest* (WAM 1933.36), *Aphrodite and Adonis* (upper section: Princeton University 40.156; lower section: Wellesley College Museum/WAM 1933.10), *Hermes and the Infant Dionysos* (WAM 1936.32), *Ktisis* (WAM 1936.90), *Dionysos and Ariadne* (WAM 1936.25), and *Peacock* (WAM 1936.23).

A total of 55 samples were taken from the mosaic floors. Typically subjects for analysis of art historians, mosaics recently have received more scientific analysis in an effort to aid conservation and restoration efforts (Bergamini and Fiori 1999). This study attempts to ascertain the provenance of the materials used in the Antioch mosaics in an effort to
1) establish the preferred sources of tesserae, 2) determine information about trade of specialize stone, 3) reveal chronological changes in source preference, and 4) establish workshop preferences of stone in the Mediterranean.

Geography and Geology

The site of Antioch, which is today called Antakya, is located in modern-day Turkey near the border of Syria. The ancient city dominated settlements at Daphne and Seleucia (Figures 9 and 10), which acted like suburbs. The primary driving force behind the development of Antioch was the environmental advantages of the site. Ideally situated, Antioch is on the eastern side of the navigable Orontes River (today called the Asi River) (Jones 1981). Located within about 25 km, or a day’s sail, from the Mediterranean port at Seleucia Pieria, Antioch gained economic advantages. To the southeast, Mount Silpios (with an elevation of 500 m) provided defensive advantages. The Amuk plain and the lower Orontes valley were extremely fertile, and in combination with a temperate climate and Roman technology, Antioch was fully supplied with necessaries and luxuries. Local agriculture supplied grain, produce, oil, and wine. The local springs were modified with aqueducts, tunnels, and dams to nurture crops and meet public and private demands. The local geology, a combination of calcareous rocks, including basalt and limestone, provided building materials (Downey 1963: 19). During the fourth and third centuries B.C., the area was used as a limestone quarry. The complete environment allowed for an autonomous city to thrive into a metropolitan area.
Figure 9. Antioch in the Mediterranean (Kondoleon 2000: xiv)

Figure 10. Antioch map (Kondoleon 2000: xiv)
Site History

Antioch served as the governmental center of Syria and the capital of the eastern region of the Roman Empire. Seleukos I officially founded Antioch in 300 B.C.; although, it had already existed as a Greek *polis* for many years (Jones 1981). So rich in Hellenic culture, Antioch even had a school of rhetoric led by Libanios in the fourth century A.D. Antioch proved to be a consumer city, interacting with the ports of the Mediterranean to the west, the Euphrates to the east, Ephesos to the north, and Jerusalem to the south. Antioch was the city where the east met the west. Influenced from the east by Persia, and from the west by Rome, and every place in between, the city of Antioch existed as a “melting pot” for economic and cultural trends (Dunbabin 1999; Kondoleon 2000). The Christian orator, John Chrysostom, captured in written history what life was like in Antioch during the fourth century A.D., and revealed that a small percent of Antioch society was poor, suggesting the existence of a large middle class (Kondoleon 2000: 3-4).

Excavation reports by William Campbell (1936) described the history of the northeast section of the ancient city, which represents most of the buildings dating from the Early Roman Empire. Construction of buildings began in the second century B.C., which continued to be reused and rebuilt until the second century A.D. In addition to minor repairs during the Imperial period, earthquakes in A.D. 115 and 526 caused major destruction. The earthquake of A.D. 115 nearly killed the emperor Trajan during an extended visit to the city. This earthquake negatively effected the growth of the city until the third century. The fifth century A.D. saw architectural changes, while the sixth century saw great disasters that ultimately caused the demise of Antioch and Daphne.
(Campbell 1936). Brickwork and masonry rebuilding was characteristic of the reign of Justinian I (A.D. 527 – 565). Shortly after, Antioch was abandoned, possibly in connection with the invasion of Chosroës (Campbell 1936). Before the invasion, Antioch achieved greatness as the capital of Eastern Rome. Within the Aurelian walls, it was actually larger than Rome (Campbell 1934: 201). Sections of the city were used in the Middle Ages and an apse was used as a pottery kiln for glazed wares before the site eventually became a cultivated field.

Although geographical location led to Antioch’s greatness, it appears that the accessibility of the site, natural disasters, and active tectonics also led to the city’s demise. In addition to a series of earthquakes, which reduced the strength of the city, Antioch’s proximity to the Mediterranean made it a continual target of the Persians. Flash floods were also a constant threat. A series of disasters within a short period of time, a fire in 525, an earthquake in 526 and then again in 528, the Persian invasion of 540, and the bubonic plague in 560, led to the ultimate collapse of Byzantine Antioch during the seventh century. Despite the multiple disasters, a relatively large number of Roman mosaics survived the tumultuous sixth century A.D. and are preserved today.

**Excavation History**

The first excavation of Antioch-on-the-Orontes began in 1932 and continued until 1939. Under the leadership of Professor Charles Rufus Morey of Princeton University, the “Committee for the Excavation of Antioch and its Vicinity” was formed to organize the numerous sponsors, committees, museums, and universities willing to help the
excavation efforts of the enormous site. These institutions included the Worcester Art Museum (WAM), the Musée du Louvre, the Baltimore Museum of Art, Princeton University, and Wellesley College. In 1939, the Fogg Art Museum at Harvard University and its affiliate Dumbarton Oaks joined the committee (Campbell 1934; Jones 1981; Kondoleon 2000), which included nine members from seven different institutions. The committee members were responsible for obtaining proper clearance from the various governmental institutions. At the end of World War I, the Ottoman territories of Hatay (including Antakya) and Cilicia, just to the north, were placed under French mandate. The French High Commissioner granted permission for excavation, with the approval of then director of antiquities for the Syrian Government, M. Henri Seyrig. Work at the site was postponed in 1939 due to World War II and the region was annexed to Turkey after a League of Nations vote on June 23, 1939 (Downey 1963; Jones 1981; Kondoleon 2000).

Several individuals were active in the preliminary survey and early excavation process. In addition to directing field crews, Campbell was also largely responsible for the early publications of the site excavations. The extensive staff changed from year to year in response to altering research goals and demands of the site (Campbell 1934; 1936). The excavations explored a large area of the region including Antioch proper; Daphne, about 8 km south of Antioch; the port city of Seleucia Pieria; Yakto; and a few isolated sites in the area. The initial excavation research goal was to locate a series of large, elaborate structures and monuments including the palace, the hippodrome, the Forum of Valens, the octagonal Golden Church of Constantine, and the round Church of the Virgin of Justinian (Kondoleon 2000). None of these structures or monuments was found, and this caused conflicts between the major parties concerned with the project,
including committee and crew members. To whatever extent the original committee was disappointed, excavation of the site did yield over 80 small buildings and nearly 300 mosaic floors in this region during the excavations between 1932 and 1939. Because none of the public and private structures were discovered and because the majority of major finds were mosaics, the research goals were adjusted to focus on salvation and conservation of the mosaics. The majority of the buildings were used as private residences; therefore, the majority of information derived from site excavation focused on Antioch’s private elite (Kondoleon 2000: 63). Mosaic floors were most common in elite homes. The plethora of mosaics also suggested the enormity of the elite population in Antioch. All of the mosaics analyzed in this study were from residences in the Antioch and Daphne area.

**Mosaic Production and Function**

Mosaic materials have received little analytical attention, because mosaics were considered an unimportant art form for many years; however, mosaics provide a glimpse into the world of Roman art forms that no longer exist, like wall paintings (Dunbabin 1999). The emphasis of the art historical analysis has generally focused on the iconography of the images rather than the materials used. Most wall paintings have collapsed or have been destroyed, particularly in the Eastern Roman Empire. Mosaic floors were more durable and captured some of these same images.

Mosaic production had evolved greatly over time. The first mosaics were formed out of pebbles rounded by running water (Dunbabin 1999: 5). Early examples of black and white, patterned mosaic floors are located at Mira in Mesopotamia (2000 B.C.), at
Gordion in Phrygia, Anatolia (800 B.C.), and the Assyrian palaces of Arslan-Tash and Til Barsip in Northern Syria (800 B.C.) (Bergamini and Fiori 1999: 199). In Greece, the earliest surviving decorative mosaics date from the late fifth century B.C. In contrast to the plain pebble floors, which were found in temples, the mosaics of the late Classical period (early fourth century to c. 340 B.C.), were found almost exclusively in private houses (Dunbabin 1999: 6).

The pebble mosaic became a true art form by the end of the fifth century B.C. in Greece. Examples of the pebble mosaic art form can be found at Corinth, as well as Olynthos and Pella in northern Greece (Figures 11 and 12). Many changes occurred in mosaic design and production during the late fourth and early third centuries B.C. To create continuous lines that pebbles could not, mosaicists began employing thin pieces of lead to outline figures (Bergamini and Fiori 1999). Eventually, *emblemata*, or self-contained panels, were created at workshops and then brought to their final destination (Dunbabin 1999: 29). Color ranges increased, adding grays, reds, and yellows, achieving the artistic effect of a painting. In addition to artistic changes, mosaics spread geographically to as far east at the palace of Ai Khanoum in Afghanistan, during the Hellenistic period. The Hellenistic influence continued through the Roman period. During the third century B.C., mosaicists began using hybrid techniques, such as *opus tessellatum* (tesserae work), with pebbles for the border and background and cut marble for the central figure (Figure 13). Mosaicists continued to refine their work with square tesserae to create the *opus vermiculatum* technique (wormlike work). *Opus vermiculatum* refers to the mosaic technique that uses fine gradations of color creating outlines and shadows in much the same way as the art medium of paint (Bergamini and Fiori 1999).
Figure 11. Corinth, Centaur Bath, detail of centaur, end of the fifth century B.C. (Dunbabin 1999: 6)

Figure 12. Detail of Lion Hunt pebble mosaic, Pella, Greece (Dunbabin 1999: Plate I)
Most of the Antioch mosaics are composed of *opus tessellatum*. Several common mosaic styles include black and white geometric designs, color geometric designs, two-dimensional black and white images, and two- and three-dimensional color images. Eventually glass and ceramics were used to increase the color range further, adding most notably Egyptian faience blue. Stones used for mosaic tesserae had to fulfill specific
requirements including low hardness, homogeneous color, and compact fine-grained texture. The material had to be hard enough not to break during use as a floor, but also soft and fine-grained enough to allow clear cutting of the right size for the image (Bergamini and Fiori 1999).

Roman mosaics served many purposes. The elaborate displays in doorways, dining areas, and gardens expressed the owner’s personality. Many displays are associated with religious affiliation, while others suggest a warning to strangers, such as the Pompeian Cave Canem, or “Beware of Dog,” mosaic (Figure 14) (Dunbabin 1999). Besides self-expression, mosaics served a primary, yet simple utilitarian function. Lavagne (1988) described mosaics as a functional art, which extended to wall decorations, thus attaining aesthetic qualities. They also served as camouflage for dirt and food debris on floors (Dunbabin 1999: 7). Especially in the dining room, the mosaic floor provided a distraction for visitors’ critical eyes. The best example of this visual distraction is the Asarotos Oikos, or Unswept Room, mosaic that ironically shows everything a good host would not want to see on their floors (Figure 15). Visitors to this dining room would see shells, bones, foodstuffs, and even a mouse. A variety of styles were used in Roman mosaic floors. Many articles describing the Antioch mosaics refer to their style as copies of Hellenistic paintings (Hanfmann 1939; Jones 1981; Kondoleon 2000). Campbell (1934) suggested that by viewing the mosaics in the House of Ge one experiences four centuries of style in ancient painting. This, of course, only refers to colored mosaics with detailed images. Other styles continued to be used, such as a black and white combination to depict geometric designs or simple two-dimensional images. Many of the framed images included in mosaic pavements at Antioch were created using
Figure 14. *Cave Canem*, “Beware of Dog,” from Pompeii house doorway (Dunbabin 1999: 60)

Figure 15. *Asarotos Oikos*, or Unswept Room, from Rome (Dunbabin 1999: 27)
small *emblemata*, surrounded by two borders: one border made of common motifs such as fish or birds and a second exterior border of a geometric design (Dunbabin 1999). In a few cases, the division between *emblema* and border was several millimeters wide, suggesting the *emblema* was created at a workshop and then set into a floor (Campbell 1938).

Styles varied across the vast Roman Empire. In Rome, the preferred style did not include *emblemata* or painting-like designs, but was closer to a carpet or tapestry with an overall decorative design (Dunbabin 1999). Reflective of styles in Sicily and the rest of Italy, mosaics in Punic Carthage employed a *signina* technique, with mortar and aggregates of crushed pottery or tile forming a red-toned pavement. In addition, black and white patterned designs were common in Sicily, Italy, and Punic Carthage (Dunbabin 1999). The Palestine and Transjordan regions reflect the Hellenistic styles that are visible at Antioch. In fact, at Sepphoris, Israel, one mosaic contains an image of the drinking contest between Dionysos and Herakles (Dunbabin 1999: 188). This same contest is represented at Antioch in the *Drinking Contest* mosaic of the Atrium House. Mosaics of Asia Minor, Cyprus, and Constantinople were definitely influenced by Hellenistic styles; but around the first century B.C. Italian *signina* and black and white patterned designs began to replace Hellenistic styles (Dunbabin 1999).

*Workshops*

One aspect of understanding mosaic images and materials used is the workshop. Sourcing the materials used for tesserae may reveal new workshops, as well as solidify
information about known workshops. Depending on the size and location of the workshop, different types of material were available. Workshops are difficult to identify due to a lack of survival both of records and signatures associated with mosaics. Several techniques exist to associate mosaics with workshops: 1) color connections, 2) similar geometric or ornamental designs, 3) images connections, and 4) similarities in technique. The primary factor of associating mosaics with the workshop of origin is often geographical proximity. Sheila Campbell (1979) suggested that similarities of color or geometric motifs often lead to mistakes in links between workshops and mosaics; however, repeated themes or subject matters that are not similar in appearance, but cover multiple rooms might suggest a connection. Besides geography and color or image connections, a third workshop identification method exists. Often artists used a combination of patterns or a variation of standard motifs as a signature for their work. Other factors include transmission of ideas through “pattern books” and itinerant workmen. One could argue that the similarities in mosaic images of the drinking contest between Dionysos and Herakles, represented at both Sepphoris, Israel, and Antioch, Turkey, suggest the two sites had at least one workshop in common. The similarities do not, however, inform archaeologists as to where the workshop might be. Provenance studies can aid in this identification. Campbell (1979: 288) suggested three stylistic traits that can be used to identify workshops:

(1) variations on standard geometric forms;

(2) repeated combinations of geometric forms; and

(3) repeated themes or iconography.
The first two could have been transferred through pattern books of itinerant artists or workmen. We must remember that many mosaics were lost through destruction over multiple time periods; therefore, the survival of excavated, intentionally or otherwise, mosaics is essential for a more complete analysis of material remains. All of these methods are imprecise; however, because surviving pavements represent only a fraction of the whole corpus. An additional method may prove to be more precise. The identification of exotic or local types of stone may also aid in workshop identification.

Mosaic Destruction

The Antioch expedition of 1936 realized its obligation to preserve mosaic pavements that were discovered accidentally by locals (Campbell 1936). In addition to saving mosaics, the expedition recorded evidence of earlier destruction, including fragments of broken pavements in terrace walls, excavated pavements with most of the scenes chipped out, and the testimony of locals who had either broken up pavements themselves or had witnessed their destruction (Campbell 1938: 208). William Campbell (1938) recorded every possible destruction mechanism from planting trees to road construction during the expedition’s many years at the site. Most of the later mosaics close to the surface were destroyed through modern cultivation and planting. Another way mosaics were destroyed was through modern road construction. “During the construction of the road from Antioch to Daphne the road builders broke through the mosaic floor of a long colonnaded hall with a continuous central panel representing a series of five pairs of animals grouped heraldically” (Campbell 1936: 8). Although many
mosaic floors were destroyed by modern activities, the excavation managed to collect and salvage almost 300 floors.

**Individual Mosaics: Images Contained and Symbolism**

The Antioch marble mosaic floors sampled in this study include the following named scenes: the *Worcester Hunt*, the *Funerary Symposium, Eukarpia, Agora*, the *Drinking Contest, Aphrodite and Adonis, Hermes and the Infant Dionysos, Ktisis, Dionysos and Ariadne*, and the *Peacock* (Table 1). These floors, which range in date from the second century to the sixth century A.D., were found in houses and baths at Antioch and its suburb Daphne (Figure 16). Basic descriptions of the mosaic panels contain vital information about the context of the samples included in this analysis. An evaluation of the colors and types of tesserae included in each of the mosaics provides important clues for understanding the source of the tesserae.

**Table 1.** Location, Date, and Color of Mosaic Samples Included in Analysis

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<th>Museum #</th>
<th>Mosaic Name</th>
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<th>City</th>
<th>Century</th>
<th>Color</th>
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<td>House of the Bird Rinceau</td>
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The earliest room tested in this thesis is found in Antioch’s Atrium House, which dates to the second century A.D. The *Drinking Contest* and the *Aphrodite and Adonis* mosaics were discovered in a *triclinium*, or dining room, in the Atrium House. The *triclinium* was “t-shaped” and had five panels, which was very common for Antiochene dining rooms (Figure 17). The *triclinium* had evidence that the panels were created as *emblemata* prior to setting in the floor. The *Aphrodite and Adonis* mosaic, located the farthest away from the entrance to the room, was mostly destroyed. The *Drinking*
Figure 17. Atrium House *triclinium* pavement (Kondoleon 2000: 63)
Contest mosaic was located closest to the entrance of the room. The other panels depict a dancing boy, a dancing girl, and the Judgment of Paris. Chronologically, the next room included in this study is the House of the Sun-Dial, which dates to the third century A.D. The Dionysos and Ariadne mosaic, discovered in the House of the Sun-Dial, is located on the outskirts of Daphne. The next rooms included in this study are located at the Necropolis and Bath D, which date to the fourth century A.D. The Funerary Symposium mosaic and its two side panels, Agora and Eukarpia, were found in the Necropolis. The Hermes and the Infant Dionysos mosaic was found in Bath D at Antioch. The Ktisis mosaic was discovered in the fifth century A.D. House of Ge, which was located in Daphne. The Peacock mosaic and the Worcester Hunt mosaic date to the sixth century and were both discovered in Daphne. The Peacock mosaic was discovered in the House of the Bird Rinceau. The Worcester Hunt mosaic was discovered in the House of the Worcester Hunt.

Several colors of tesserae were sampled in this study (see Table 1). White samples were taken from each of the mosaics. Seven red samples, six white samples, one brown sample, and two black samples were taken from the Drinking Contest mosaic. Four red samples, four white samples, one black sample, and one brown sample were taken from the Aphrodite and Adonis mosaic. Three white samples, three red samples, and one black sample were taken from the Dionysos and Ariadne mosaic. One red sample and two white samples were taken from the Funerary Symposium mosaic. Two red samples and two white samples were taken from the Agora panel. Two red samples and two white samples were taken from the Eukarpia panel. Two white samples were taken from the Hermes and the Infant Dionysos mosaic. Two white samples, one red
sample, and one black sample were taken from the *Ktisis* mosaic. Two red samples and two white samples were taken from the *Worcester Hunt* mosaic and its border. One white sample was taken from the *Peacock* mosaic. Each of the mosaics is described in further detail below.

**Drinking Contest Mosaic**

The mosaic of the *Drinking Contest* of Herakles and Dionysos was discovered in the dining room of the Atrium House in Antioch (Figure 18). Stylistically it dates to the early second century A.D. and measures 1.84 x 1.86 m. The *Drinking Contest* mosaic is composed of marble, limestone, and glass tesserae. As mentioned above, this mosaic panel was part of a five-image *triclinium* that measured 7.20 x 4.80 m (Elderkin 1934). The *triclinium* was composed of five individual *emblemata* (Levi 1947: 15). The *Drinking Contest* mosaic would have been the first image seen upon entrance into the dining room. This mythological scene reveals the problems associated with challenging a god. Dionysos has obviously won the drinking contest, having finished his cup, while Herakles desperately tries to empty his cup, clenching on to the drapery for support as he haphazardly leans backwards. Kondoleon (2000: 170) describes the scene thus, “The composition captures the essence of the struggle between mortal and immortal, the elegant repose of the god and the unbalanced human.” The panel’s symmetry is complete with a female flute player behind Herakles; an Eros-type figure pointing out the obvious winner; and a Silenos with white hair, also celebrating Dionysos’ victory. The mosaicist accomplished an array of graded colors through the use of light and dark tesserae. The mosaic style of the five figures arranged from foreground to background, and the
shadows created by the drinking vessels and even musculature, suggest this mosaic is a copy of an earlier, lost painting (Kondoleon 2000: 170). The use of multiple borders surrounding the panel also conveys the effect of a framed painting.

*Aphrodite and Adonis Mosaic*

The mosaic of *Aphrodite and Adonis* was the third major panel in the Atrium House’s *triclinium* (Figure 19). Unlike the *Drinking Contest* mosaic, the *Aphrodite and Adonis* panel faced diners arrayed on their couches. Stylistically it also dates to the early second century A.D. The *Aphrodite and Adonis* mosaic is composed of marble,
limestone, and glass tesserae; it measures 1.60 x 1.90 m. The construction of a later wall destroyed the upper section of the mosaic. Initially, due to poor preservation, Campbell (1934) believed that the image of Aphrodite and Adonis actually represented Phaedra and Hippolytus, characters from another love story who often are posed in this manner. The panel depicts a female figure seated on a throne, with a nude male figure seated on her right. His spear and dog suggest the male figure is a heroic hunter type (Levi 1947: 25). Although Phaedra and Hippolytus often are depicted with a dog, they almost always are portrayed with the other major characters involved in their love triangle (Figure 20). Even though the image is badly destroyed, its size suggests that no other characters were included. On the other hand, Aphrodite and Adonis often are represented alone. Given

**Figure 19. Aphrodite and Adonis** mosaic (Kondoleon 2000: 175)
the individuals shown in the other panels in this house, the Aphrodite and Adonis combination fits the grouping better. The most intriguing aspect of the Atrium House mosaics is the central panel: where a mortal faces the trial of fate and the deities. Although the so-called Judgment of Paris (in the middle panel) is not included in this study, it depicts the mythological trial of Paris who was forced to judge a beauty contest between Hera, Athena, and Aphrodite. The painterly effects of the panels extend to the borders of the Judgment of Paris and the Aphrodite and Adonis panels.

Dionysos and Ariadne Mosaic

The mosaic panel of Dionysos and Ariadne was discovered on the outskirts of the suburb of Daphne in 1935 (Figure 21) and serves as an example of a mosaic that was
Figure 21. Dionysos and Ariadne mosaic (Photo Courtesy Worcester Art Museum)

salvaged during the 1930s project. The Dionysos and Ariadne mosaic dates to the third century A.D. (Jones 1981). Found in the House of the Sun-Dial, the mosaics in this house were mostly destroyed except for the surrounding panels (Stillwell 1938). The image of Dionysos and Ariadne existed in different mosaics around the area of Antioch and Daphne. This panel depicts the bust of a male and female. Both figures are crowned with wreaths of leaves. The male wears a white tunic with gray shading and wears a necklace. The female carries a spear and wears a dark brown tunic with dark red, gray, and white highlights. The panel is surrounded by geometric panels of triangles on the right and stars on the left (Stillwell 1938: 202). The main image that this panel surrounded was destroyed completely.

Funeral Symposium, Agora, and Eukarpia Mosaics

The Mnemosyne mosaic, or the Funerary Symposium, and its side panels Agora and Eukarpia, were discovered on the edge of Antioch’s city limits in the Necropolis, or cemetery (Figures 22 through 24). Each of the panel images is an emblema, which was
formed at a workshop and then set in place (Levi 1947: 295). The entire group dates to the fourth century A.D., measures 1.77 x 2.69 m, and is composed of limestone, marble, and glass tesserae. The central mosaic reveals a women’s funerary AlΩXIA, or banquet, most probably honoring a woman whose name, Mnemosyne, appears above a large cloth or textile pinned to the wall in the background (Kondoleon 2000: 121-122). In total, six women are attending Mnemosyne’s banquet: one sits on a low stool while holding a scroll, two recline on a curved couch, two are entering the room with wineskins as a probable offering, and another (a servant) has entered from the right with a jug and basin. The mosaic floor was discovered in a small chamber surrounded by tombs. Benches similar to the one depicted in the mosaic were uncovered in the excavation of this room, suggesting a connection between the scene and actual events. Alternatively, Kondoleon

Figure 22. Funerary Symposium mosaic (Kondoleon 2000: 121)
Figure 23. *Eukarpia* mosaic (Photo Courtesy Worcester Art Museum)

Figure 24. *Agora* mosaic (Photo Courtesy Worcester Art Museum)
(2000: 122) suggests that the room may have served as a meeting place for women in a funerary *collegium* and the inscription could also be translated as “memory.” To the left and right of the *Funerary Symposium* mosaic are two female personifications, one of *Agora* (the Marketplace) and the other of *Eukarpia* (Abundance) (Levi 1947: 296; Campbell 1988). Although this was the only pavement recovered in the cemeteries of Antioch, the funerary banquet was a common decoration for Roman tombs. The Roman funerary banquet was also an important ritual surrounding death.

*Hermes and the Infant Dionysos Mosaic*

The mosaic panel of *Hermes and the Infant Dionysos* was discovered on the eastern side of Room 3 in Bath D at Antioch (Figure 25). Stylistically this mosaic dates to the early fourth century A.D. (Campbell 1988). The surviving mosaic measures 2.25 x 3.25 m and is composed of marble, limestone, and glass tesserae. The original mosaic was more than 15 meters in length. A wide band of ornamental designs surrounds the rectangular panel depicting Hermes carrying the infant Dionysos to the nymphs (Campbell 1934). Hermes looks to his right, but moves to his left, suggesting he is running from something (Levi 1947: 286; Campbell 1988: 17). He wears only a cloak and has two wings projecting from both ankles. Dionysos has a “Christ-like” pose, balanced on Hermes’ right hand with a nimbus behind his head and a wreath in his hair. Dionysos is identified through an inscription above his head: ΔΙΟΝ[ΥΣΟΣ]. The rest of the surviving mosaic (not shown) was separated by a large gap. On the other side of the gap, another inscription, M, refers to the nymphs (i.e., [NY]Μ[ΦΑΙ]) to whom Hermes
Figure 25. *Hermes and the Infant Dionysos* mosaic (Photo Courtesy Worcester Art Museum)

carries the child (Campbell 1988). The fragmentary image shows a broken pillar with a leafless branch behind it, next to a wreathed female head.

*Ktisis Mosaic*

The mosaic image of *Ktisis* was discovered in Room 4 of the House of Ge in the suburb of Daphne in 1936 (Figure 26). Dating to the fifth century A.D., the House of Ge contained a collection of female images representing abstract ideas such as life, earth,
spring, and winter. The mosaicists of Antioch often created female personifications of concepts such as KTICIC (Foundation) or ΓΗ (Earth) or BIOC (Life) (Kondoleon 2000: 65). Fifth century floors frequently used medallions with a bust image, like that of Ktisis, surrounded by an octagon or a star-pattern (Morey 1938). The inscription divided in two parts by the female bust is KTICIC. Ktisis has a crown of large round, red and green jewels separated by a vertical series of two pearls (Levi 1947: 347). The woman’s hair is pulled back into a loose mass at the nape of the neck. The figure has earrings with a triangular shape hanging from thick gold hoops. Ktisis wears a violet tunic with a red mantel thrown over her shoulders (Levi 1947: 347). The bust is enclosed in a golden

*Figure 26. Ktisis mosaic (Kondoleon 2000: 67)*
octagon. The square panel that surrounds the bust of Ktisis contains a multi-colored continuous pattern of diamonds tangent on the corners and enclosing four-pointed stars. A border with large birds and flowers surrounds the entire panel (Levi 1947: 347).

Worcester Hunt Mosaic

The Worcester Hunt mosaic was discovered in Daphne at the House of the Worcester Hunt (Figure 27). Stylistically the Hunt mosaic dates to the sixth century A.D. and measures 6.26 x 7.11 m. The Hunt mosaic is composed of both marble and limestone tesserae. One of the largest floors from Antioch, the Worcester Hunt mosaic portrays various hunting scenes. The complex scene shows hunters on foot and horseback using sword, spear, or bow and arrow to hunt lions, tigers, deer, antelope, rabbits, a wolf, a panther, and a bear with great success, except for one hunter who is saved by the spear of a horseman after being attacked by a lion (Morey 1938; Levi 1947). A company of animals in various poses flanks the central hunter. This central figure calls the viewer’s attention because he is larger than the other hunters depicted in the scene. Morey (1938: 41) compared this image to the hunter image depicted on third century A.D. sarcophagi of western Asia Minor and suggested a Persian influence on the pavement makers. Morey (1938) noted the attention to detail given to the animals, as well as the lack of detail given to the hunters, and suggested that Persian taste was responsible for the design. Although all of the figures reveal action, the animals are the only figures with musculature. Morey argues that a more traditional Greek design would have depicted the opposite: detailed human figures and vague animal figures; however,
the detailed depicted are complex. Furthermore, the design reflects Hellenistic emblemata styles of carpet or tapestry (Kondoleon 2000: 158.

Peacock Mosaic

The Peacock mosaic was discovered in the House of the Bird Rinceau at Daphne (Figure 28). Stylistically it dates to the sixth century A.D. The Peacock mosaic measures 1.17 x 3.81 m, but is part of a much larger floor, measuring 65 m². A computer
regeneration of the complete *Peacock* mosaic floor, which was divided among sponsoring institutions, is shown in Figure 29 (Kondoleon 2000). The mosaic is composed of marble and limestone tesserae. The image shows a grape vine scroll, entwined with birds and

![Figure 28. Peacock mosaic detail (Kondoleon 2000: 209)](image)

![Figure 29. Peacock mosaic floor completed through computer regeneration, colored sections still exist (Kondoleon 2000: 209)](image)
animals, growing from an urn in each corner. The vines give the impression of a fluttering ribbon (Levi 1947; Kondoleon 2000). The fragment included in this study shows two peacocks surrounding a basket of grapes. These two birds are the only peacocks in the entire floor, suggesting an intentional importance. Although the Romans viewed peacocks as linked to immortality and eternal life, the motif can also be viewed as Christian, or Early Byzantine. Paired peacocks, inhabited vines, grapes, or wine vessels were popular in early Christian art showing the beauty of God’s creation (Kondoleon 2000: 209).

A review of the physical and artistic context of the mosaic tesserae included in this analysis provides important background information that may aid in the final conclusions about the source of the tesserae material. The mosaics included in this study exemplify a range of images from multiple time periods from Roman Antioch.
Chapter Four: Scientific Analysis of Marble

Scientific analysis of archaeological materials began as early as the Italian Renaissance and escalated into the period of scientific discovery known as the Enlightenment. In 1798, for example, Martin Klaproth analyzed the chemical composition of Roman glass and bronze mirrors. Michael Faraday (1791-1867) and Humphrey Davy (1778-1829) were involved in early analytical work on chemical analyses of “Egyptian blue” (i.e. faience) and an opaque red vitreous material (Henderson 2000: 8).

The scientific analysis of archaeological stone has mostly focused on obsidian, chert, flint, and marble. Most often stone material has been analyzed through mineralogy, microscopic structure, texture, and inclusions like fossils. These characteristics, while aiding in analysis of the environment of the rock structure, have helped deduce the provenance of the materials (Henderson 2000: 297).

Archaeologists needed a more exact method for describing the various types of ancient marble (Coleman and Walker 1979: 107). For the purpose of the thesis, only scientific techniques relevant to marble analysis are discussed here. Most scientific analysis of archaeological stone from the Roman period has occurred on marble, which was widely used and traded. Historically, the three main goals of Greek and Roman
marble analysis since the Renaissance have been to ascertain: 1) provenance, 2) correct association of separated fragments, and 3) authenticity (Herz 1990: 101).

**Marble Identification Techniques**

A plethora of physical, chemical, isotopic, and trace-element analysis techniques has arisen and proven successful in the past two decades including: thin-section petrology (Bergamini and Fiori 1999; Polikreti and Maniatis 2002), cathodoluminescence (CL) (Moens 1992; Blanc 1995), X-ray diffraction (XRD) (Lloyd 1988; Herrmann 1990), electron paramagnetic resonance (Attanasio and Platania 2000; Polikreti and Maniatis 2002), instrumental neutron activation analysis (Grimanis and Vassilaki-Grimani 1988; Rapp 1998), and stable isotope ratio analysis (SIRA) (Craig and Craig 1972; Herz 1990; Gorgoni et al. 2002). Although each technique has advantages and disadvantages, the ultimate analytical program may involve a combination of techniques. Several techniques have proven more successful when paired with an additional test, such as combining spectrometry and neutron activation analysis, because different techniques measure different elements. Archaeologists have used many techniques for marble source determination.

**Visual Marble Identification**

Visual identification of stone can provide basic descriptive analysis of an object including geological typology. More detailed analysis of marble artifacts through visual identification of color has been used for nearly a century (Moltesen et al. 1992); however, this method creates problems for perception and description. Although some
archaeologists rely solely on visual identification, the problems of communicating the perception of color force most archaeologists to seek out other forms of analysis. Although some marble has distinct colors, many marble quarries produce pure white marble, making visual source identification difficult. In addition, homogeneity of color is not guaranteed. Color charts often are used as a guide, but color is only one attribute associated with marble. Many archaeologists acknowledge the difficulty of visual analysis and have re-evaluated previously grouped materials. In the past, subjective aesthetic conclusions about a stone’s source were drawn and objects were given place names as adjectives. Obviously, many controversies, which remain unresolved, arose, and the literature is plagued with contradictory descriptions of the same pieces (Herz 1990: 101).

*Thin-section Petrology*

Another technique used to source marble is thin-section petrology, or petrofabrics. Using a mounted section of the study material under an optical light microscope, thin-section petrology examines a representative section of the material for arrangement of inclusions, along with their size, shape, frequency, and composition (Henderson 2000: 12). The sections are c. 30 µm in thickness, allowing polarized light to pass through the materials and highlight irregularities and variation in color, which can then be used to identify the source of the material. An auxiliary lens and various comparative thin-sections (quartz, gypsum, mica, etc.) help identify crystal minerals and their orientations. This technique is one of the less expensive ways of examining marble; however, many inexperienced researchers mistake normal variations for something more extraordinary.
While thin-section petrology is a quantitative analytical technique, this technique is destructive, requiring a large sample of the material, and is not very informative by itself for marble sourcing (Polikreti and Maniatis 2002: 1). One way to eliminate subjective conclusions is to base analysis entirely on more scientific, objective data. To avoid subjectivity as a result of inexperience, thin-section petrology was not used in the examination of the Antioch tesserae samples.

_Cathodoluminescence (CL)_

Cathodoluminescence microscopy (CL) was first used to source marble successfully in 1987 by Danielle Decrouez and Vincent Barbin (Moens 1992). An electron beam bombards the mineral mounted on a thin-section, here calcite (CaCO₃) and dolomite (CaMg(CO₃)₂) marble types, to reveal different colors (Barbin et al. 1992; 1999). Impurities and lattice defects affect the luminescence image. The visible colors, variations of blue and orange, are associated with a white marble’s source. Each cathodomicrofacies generally characterizes a given area (Barbin et al. 1992; 1999). Barbin et al. (1992) were able to discriminate differences between marble from quarries at Penteli, Dokimeion, Naxos, Thasos, Paros, Pteleos, Candoglia, Lasa, Crevola, Villete, and Doliana. In 1995, Blanc published an experimental use of CL attached to a spectrometer, which used a compressed powder sample, approximately 3 mg, mixed with graphite and coated with carbon or gold-palladium. A spectrum of white marble displays two bands of energy, a variation attributable to manganese. Blanc (1995) suggested that the use of CL as an accessory to stable isotopes, which is discussed below, is especially valuable for provenance of white marble. This method is not widely used alone. Again,
CL can be subjective because of variances in color identification; therefore, CL was not used in the analysis of Antioch mosaic tesserae.

**X-ray Diffraction**

X-ray diffraction (XRD) spectrometry is a non-destructive spectrometric analytical technique (Lloyd 1988). This technique can be used to identify crystalline materials, such as calcite or dolomite, or to determine the degree of crystallinity (Henderson 2000: 10). The determination of marble’s crystallinity provides valuable information for the sourcing process. For example, if a white marble sample is composed of dolomitic marble, then the object’s source is most probably Thasos, a quarry with a high dolomitic content. X-ray diffraction involves the emission of radiation wavelengths at the crystalline material (Herrmann 1990). The wavelengths bounce off the crystalline structure in spectra unique to the sample material. The spectra have independent peak intensities represented graphically by height. Although XRD requires that the sample be in powder form, thus destroying the original structure, the size of the sample required is relatively small, and the chemical composition of the sample is not altered in the analysis. The sample can be re-used for another method or for a second analysis by XRD.

Although little analysis has been done on exactly how small a sample can be, the author experimented with the sample size of a known calcitic and a known dolomitic marble sample to determine the reliability of small sample sizes. It was determined that a sample size as small as 2.6 mg would produce reliable results. X-ray diffraction is a valuable technique for the analysis of mosaic tesserae, since it only requires a small sample size.
and provides valuable source information. Most of the samples were large enough to be analyzed by XRD.

*Electron Paramagnetic Resonance*

Electron paramagnetic resonance spectroscopy (EPR), or electron spin resonance (ESR), has been used for analyzing unpaired electrons in a molecule. Unpaired electrons can aid in the determination of the age or the provenance of an object (Lambert 1997: 264). For the past 15 years, EPR spectra have been collected for different types of white marble from around the Eastern Mediterranean (Polikreti and Maniatis 2002). Several different uses of this method of analysis have occurred. Polikreti and Maniatis (2002), in addition to several other archaeologists, used 10 parameters in order to discriminate between quarries, such as those at Penteli, Naxos, Hymettus, and Prokonnesos, with some degree of overlap between Paros and Prokonnesos and Paros and Hymettus. Other quarries that have been identified through EPR include Seravezza and three quarries from Carrara. Researchers have compared different pairs of combinations of the parameters in order to ascertain a provenance. In addition, Polikreti and Maniatis used maximum grain size, measured with a stereomicroscope. Electron paramagnetic resonance characterizes marble by its impurities, manganese (Mn$^{2+}$) or Iron (Fe$^{3+}$). Manganese is diluted into the lattices of calcite or dolomite, which are the main constituents of marble (Attanasio and Platania 2000). This constant irregularity allows for measuring of a selected spectral feature of the impurity from both archaeological samples and from known quarry samples. Electron paramagnetic resonance was not used in this analysis, because a
relatively large-sized sample is required to perform this analysis and little is known about
the proportions of various impurities of colored marble.

**Instrumental Neutron Activation Analysis**

Instrumental neutron activation analysis (INAA) is one of the most sensitive and
accurate techniques available for the determination of a large number of trace elements in
different materials (Grimanis and Vassilaki-Grimani 1988; Mello et al. 1988). Many
chemical elements can be distinguished at the low parts-per-million level and some at the
parts-per-billion range (Rapp 1998: 148). The powdered sample (50 mg for metals, 200
mg for silicates) is placed in a capsule, which is irradiated in an atomic pile for a defined
period of time (Rapp 1998). Decay of the elements begins counting first the short-lived
elements, followed by the long-lived elements. The results, a spectrum of wavelength
against peak intensity, are displayed graphically (Henderson 2000). Luedtke (1978)
discovered that if chert types were formed close in time and space they shared similar
proportions of trace elements, as determined by INAA. Eventually, she was able to
differentiate between three sources of chert in the North American midwest.

Instrumental neutron activation analysis has now been used for multielemental analysis
of marble specimens for provenance studies; however, trace element composition of
marbles is highly variable. Further analysis for rare earth elements (REE) is necessary.
Rare earth elements are distributed more evenly in marbles than many other trace
elements (Grimanis and Vassilaki-Grimani 1988: 275); however, for marble, INAA has
limited capabilities in quarry discrimination and is rarely used alone (Polikreti and
Maniatis 2002: 1). Mello et al. (1988) showed that INAA could identify the marble
quarries of Paros, Aphrodisias, Marmara, Naxos, Penteli, Carrara, and Denizli; however, the quarries could only be determined through paired analysis. Instrumental neutron activation analysis requires a large sample size and has not been used on colored marble; therefore, it was not included in this analysis.

*Stable Isotope Ratio Analysis*

Stable isotope ratio analysis (SIRA) is another technique that is useful for the analysis of small samples. Isotopic analyses of marble have enabled archaeologists to reconstruct correctly marble artifacts and to determine the provenance of marble artifacts. Stable isotope ratio analysis uses mass spectrometry to determine ratios of certain elements. Harmon Craig and Valerie Craig developed a method in the early 1970s to test the isotopic composition of marble pieces (Craig and Craig 1972). Craig and Craig examined carbon and oxygen values, which are major components of calcite or calcium carbonate (CaCO₃) that largely makes up marble, in order to compare the results. Elements differ by the number of protons in their nuclei. Many elements also have multiple isotopes that occur in nature. Oxygen and carbon exist in nature in several isotopic forms, all of which are stable except for carbon-14. With six protons and six neutrons, carbon is a stable isotope, with an atomic number of 12. Carbon also exists with extra neutrons. Carbon-13 has one extra neutron and is stable. Carbon-14 has two extra neutrons and is not stable. Oxygen’s main form occurs in nature as oxygen-16. Other forms of oxygen are oxygen-17 and oxygen-18. While Carbon-14 is unstable and therefore radioactive, none of the oxygen isotopes are unstable.
Proportions of various isotopes can differ from place to place due to variations in formation of the material. Marble is derived from limestone, which is a sedimentary rock created from cementation of shells and other sea life. The differences in limestone formation are the foundation for variation among marbles. Variation in the three formation factors – heat, pressure, and fluid activity – also leads to variation in isotopic values. The processes involved in isotopic composition can be described as follows: 1) mode of origin, 2) isotopic composition of water, 3) temperature of the metamorphism that converted the limestone into marble, and 4) later weathering history (Herz 1990: 105; Herz and Dean 1986; Gorgoni et al. 2002). Atmospheric, geological, or biological processes (wind, water, and metabolism) can move substances containing lighter isotopes faster than those with heavier isotopes. Water is the source of oxygen and carbon dioxide is the source of carbon in the raw materials that comprise rocks and stones. Local conditions can affect the isotopic values. When geological formation is complete, the isotopic proportions are sealed in place like a fingerprint of the source (Lambert 1997: 5).

Craig and Craig (1972: 401) believed that the ratio of $^{13}$C/$^{12}$C and $^{18}$O/$^{16}$O in Greek marbles provided the best chance for unique characterization by locality. Their 1972 study collected samples from four major quarries – Paros, Penteli, Hymettos, and Naxos – which were used by the ancient Greeks. Craig and Craig (1972) also suggested that the trace elements, strontium (Sr) and magnesium (Mg), could be used to analyze further a marble source. The isotope results are given as deviation ($\delta$) values in relation to the isotopic standard reference material of a natural limestone, Pee Dee Belemnitella (PDB), in parts per mil (‰):

$$\delta (‰) = [(R/R^\prime) - 1] \times 1000$$
where R is the ratio $^{13}\text{C}/^{12}\text{C}$ and $^{18}\text{O}/^{16}\text{O}$ and $R^+$ is the ratio in the PDB standard (Craig and Craig 1972; Herz 1987). This technique provides a precision of ± 0.05 per mil (Craig and Craig 1972: 402). The results were then plotted on a $\delta^{18}\text{O} - \delta^{13}\text{C}$ diagram. The results showed that Pentelic and Naxian marbles were much lower in $^{18}\text{O}$ than Parian and Hymettian marbles, probably due to interactions with meteoric water at elevated temperatures. The Pentelic marbles were also higher in $^{13}\text{C}$ than most of the marbles studied (Craig and Craig 1972: 402). Craig and Craig (1972) suggested that the isotopic method for provenancing Greek marbles would be the most useful, especially if combined with other techniques.

Norman Herz believes that, at present, SIRA is the most powerful analytical technique available for sourcing marble, stating that one of the main advantages is the small size of the sample required, only about 10 mg or less (Herz 1990: 103). This small sample size is beneficial when analyzing art work and archaeological artifacts. The technique developed by Craig and Craig has enabled archaeological works of art to be attributed to specific quarries; however, “scientific contributions to archaeology often follow an uneven path of evolution” (Lambert 1997: 7). The limitations of this technique were immediately obvious as the database of comparative samples began to grow. Craig and Craig examined only the four most prominent Greek sources, and their separation in a plot was simple and easily distinguished the sources. Herz (1992), Matthews et al. (1992), and Moens et al. (1992) published databases created by sampling additional quarries. More sources were sampled and added to Craig and Craig’s original diagram (Figure 30), creating a much more complex picture (Figure 31) that has multiple problems. Up to six sources are possible for certain isotopic signatures. Several of the
tested quarries have isotopic signatures that overlap with multiple other sources. In addition, isotopic variation within a single quarry can be large.

Many archaeologists argue that since carbon and oxygen SIRA alone fails to identify the provenance in many cases, then it should be replaced with another technique (Polikreti and Maniatis 2002: 2). Although SIRA does not always determine a single source for every marble artifact sampled, to date it is still the most accurate and widely available method. The addition of historical information and non-scientific data can help differentiate between sources. In addition, other scientific techniques can be used. Two other measurable isotopes exist in marble. The isotopes of strontium and electron spin resonance of a particular form of manganese have been used, independently, to separate successfully some of the overlapping results. In addition, the proportions of a variety of elements, including chromium and antimony, have been used in a similar manner to

![Figure 30. Original $\delta^{13}C$ and $\delta^{18}O$ variations (Craig and Craig 1972: 401)
Figure 31. The updated graph with additional white marble samples (after Herz 1987).
separate overlapping results (Lambert 1997: 8). As for isotopic variation within a quarry, not all quarries exhibit a large disparity. Carrara, a white marble source in Italy, shows a small variation of less than 0.5 ‰ for $\delta^{13}C$ and less than 2 ‰ for $\delta^{18}O$ within an outcrop (Herz 1987). Herz (1992) has collected databases for isotopic values from multiple quarries from periods ranging from the Early Bronze Age to the Classical era. The application of the databases to further archaeological questions has led to improvements of the analysis process (Gorgoni et al. 2002: 116). Isotopic values of colored marble have been collected from several quarries; however, colored marble quarries have not received the same analytical attention that white marble has. Although several studies have focused on *rosso antico*, a red marble (Lazzarini 1990; Gorgoni et al. 2002), no substantial colored marble database exists. Further description of analytical techniques and their application are discussed in the next section.

**Applications of Marble Provenance Techniques**

G. Richard Lepsius (1890) published the first systematic description of major marble quarries exploited during Classical times. Limited to physical characteristics, Lepsius’ descriptions became and remain “archaeological gospel” (Herz 1990: 101). Some of his descriptions are as follows: “Pentelic was a medium-grained, weakly foliated, sometimes micaceous marble; Hymettian was fine-grained and bluish; Parian medium- to coarse-grained, pure white, and translucent; and Naxian or merely “island” was a coarse-grained, white marble (Lepsius 1890:13-22; 77-85).” Today, multiple analytical techniques are used to derive information from artifacts and sources. In the analysis of marble, thin-section analysis involves tedious microscopic study and produces
very detailed results; however, a database of comparative analyses of known sources does not exist, and a large sample is needed for this technique. While elemental analysis also provides detailed information, trace elements can vary by factors of over a hundred within the same quarry due to localized interactions with inclusions and surrounding rocks (Craig and Craig 1972; Herz 1990). Recently, the use of multivariate statistical treatment of elemental data has provided a means for partly overcoming the variability in the composition of the material. Discriminant analysis, scatter plots, and ellipses of the results of NAA and SIRA have been used to improve source determination (Matthews et al. 1995).

A provenance study using SIRA was performed on a marble bust housed at Harvard’s Fogg Art Museum. The bust was said to be a representation of Antonia Minor (accession number 1972.306), the daughter of Mark Antony and the mother of Germanicus and Claudius (Erhart 1978). The bust is composed of five separate parts: the head, the lower portion of hair, and three bust pieces. Several scholars question whether or not these multiple pieces actually belonged to the same bust (Lambert 1997: 4). While the bust’s history can be traced back to the seventeenth century as a part of the collection of Wilton House in England, its prior history is unknown (Erhart 1978: 195). Herz (1990) analyzed all of the pieces of the Antonia bust by examining the carbon-13 and oxygen-18 values of the marble. “In both Greek and Roman antiquity all marble portraits of important persons were made of Parian marble” (Herz 1990: 105). The final conclusion was that only the head proved to be authentic, made of Parian marble. The lower hair-piece and one of the pieces of the bust were of Carrara marble, a source in Italy. The other two fragments were also made from Parian marble, but their isotopic
signatures were clearly different from the head. The results suggest that throughout its history, the Antonia bust was reconstructed multiple times with pieces of marble from different sources (see also Lambert 1997: 4-5).

**Combination Analysis**

Most archaeologists agree that a combination approach to the provenance of artifactual marble produces the best results (Moens *et al.* 1988; Herz 1990; van der Merwe *et al.* 1995; Attanasio and Platania 2000; Gorgoni *et al.* 2002). Henderson (2000: 12) suggests that thin-section petrology and XRD spectrometry provides the best analytical combination, producing crystal identification and distribution through the material. Herz (1990: 108) often uses a combination of SIRA and XRD, as he did for the allegedly ancient Greek kouros from the J. Paul Getty Museum in Malibu. Art historians are highly skeptical about the authenticity of this piece, because this kouros is stylistically unique from most, and only 12 complete kouroi are known worldwide. If authentic, the kouros stylistically would date to c. 530 B.C. Stable isotope ratio analysis results showed: $\delta^{18}$O = -2.37 ‰; $\delta^{13}$C = +2.88 ‰ (Herz 1990: 108). These results, when compared to the database, suggest the following quarries as possible sources: Denizli, Doliana, Marmara, Mylasa, and Thasos-Akropolis. X-ray diffraction results show a composition of 88 percent dolomite and 12 percent calcite. Through the process of elimination, only Denizli, Marmara, and Thasos-Akropolis contain dolomitic marble. Comparison of trace-element data eliminated Denizli. Dolomitic content determined by Cordishchi through EPR eliminates Marmara (Herz 1990: 108). Since Thasos is composed of almost 100 percent dolomite and Marmara is composed of only 57 percent
dolomite, discriminant function analysis suggests that the kouroi, with 0.9 probability, was composed of Thasian marble. Historical evidence concurs with the results, because Thasos-Akropolis has the oldest quarries of Thasos, which also produced kouroi during the seventh and sixth centuries B.C. Thus the results of this analysis, even though they do not conclusively prove the Getty kouro to be authentic, revealed that a combination of multiple scientific and archaeological techniques is required if we are to succeed in determination of marble sources (Herz 1990: 108).

Several archaeologists have developed what they view as the correct methodology for analysis of archaeological marble. Many heated debates have arisen during ancient marble conferences, like the Association for the Study of Marble and Other Stones used In Antiquity (ASMOSIA), about the benefits and failings of the various techniques used to analyze marble. An example of a different technique used to acquire the same goal, provenance determination, came from a personal communication with Yannis Maniatis on October 9, 2003. He believes the best method includes the following series of steps: 1) a chip must be removed from the object in question, 2) the microstructures of the sample must be examined, 3) the grain size range must be determined, 4) the texture must be described, 5) the sample should then be ground for EPR spectroscopy of Mn$^{2+}$ and Fe$^{3+}$ impurities in the marble, and 6) SIRA of carbon and oxygen should be performed. The results of the EPR are quantitative, and do not destroy the material. Maniatis (2003) believes that carbon and oxygen isotopic analysis is a blind test, which might produce results unrepresentative of the provenance area. While the results might be unrepresentative, this is true for any technique and, furthermore, the chance of obtaining an unrepresentative sample is proportionally relative to the size of an object.
Attanasio and Platania (2000) recently have realized the importance of combination analysis. While they recognized the combination of INAA and carbon and oxygen SIRA to determine the provenance of marble, they used EPR spectroscopy, primarily focusing on the spectral features of the Mn$^{2+}$ impurity. With either analytical technique, they emphasized the importance of petrographic and art historical information. For identification of joining fragments, Attanasio and Platania suggest that while $^{13}$C and $^{18}$O isotopes have correctly identified joining fragments, SIRA results are extremely uncertain. They suggest that quarry variability is substantial enough to make incorrect associations (Attanasio and Platania 2000: 322).

Matthews (1988) recognized that variability must be relatively small over distances up to about one meter, but stated that fragment association is still possible, with some caution, and easily done with isotopic analysis. Matthews (1988) tested the variability of large sculptures of different marble types by taking samples from more than one place. The variability in one mausoleum frieze was shown to have up to 1.1 ‰ range of variation in $\delta^{18}$O (Matthews 1988: 344). This variability was assumed to be a result of weathering. Matthews (1988) suggests that discarding a greater amount of surface drillings produces a more reliable result. He concludes that multiple samplings of large objects should be taken in order to assess adequately an object’s isotopic values (Matthews 1988: 345).

For attribution of marble sculptures housed in the Boston Museum of Fine Arts and the Sackler Museum, van der Merwe et al. (1995) compared isotopic results collected from the sculptures to that of the quarry database produced by Herz (1992), Matthews et al. (1992), and Moens et al. (1992). The results show that only two of the 83 sculptures
analyzed could be attributed unequivocally to a single quarry (van der Merwe et al. 1995: 188). But many of the overlapping results were resolved when additional information such as grain size, mineralogy, color, and historical data were taken into account.

Moens et al. (1988; 1992) favored an approach that combines thin-section petrology, carbon and oxygen SIRA, and trace-element analysis, using INAA, AAS, and CL. In a study published in 1992, Moens et al. reported the results of analysis of 129 white marble artifacts. A core sample (diameter = 15 mm; length $\geq$ 50 mm) was extracted from half of the artifacts, chips were taken from about 10 percent of the artifacts, and powdered samples were taken from the remaining ones (Moens et al. 1992: 248). The core samples, which were taken from less visible areas of the sculpture during restoration, allowed for all three methods of analysis to occur. Isotopic and petrographic analysis (including CL) only occurred on the samples where chips were removed due to the size required for petrographic analysis. The powdered samples only received isotopic analysis. This combination of techniques proved highly successful. Of the 129 samples tested, 118 received attribution to a single quarry source (Moens et al. 1992: 249). For the artifacts that could not be attributed, half were powdered samples, limiting analysis to SIRA. The different analytical methods yielded contradictory information for the rest of the unattributable artifacts, suggesting a quarry not in the database, which contains 14 different quarries (Moens et al. 1992: 249).

Until this combination approach, Archaic Naxian sculptures only received stylistic analysis (Kokkorou-Alevras et al. 1995: 95). Using a combination of EPR and INAA, the authors attempted to determine the provenance of the sculptures. Maximum grain size was determined from small fragments removed from the sculpture with a
chisel. Drilling was not used because, according to Kokkorou-Alevras et al. (1995), it alters the EPR spectrum. Using the following characteristics in EPR (Kokkorou-Alevras et al. 1995: 96):

the Mn$^{2+}$ ions and the peaks with g-values equal to 14.25, 4.70, 4.32, 2.0044, 2.0037, 2.0056, 2.0020, and 2.0000

and the following elements in INAA (Kokkorou-Alevras et al. 1995: 96):

Na, K, Sc, Fe, Co, Zn, As, Br, Sr, La, Ce, Nd, Sm, Eu, Tb, Yb, Hf, Th, U, and the ratio Eu/Ce

the authors were able to associate or unassociate the sculptures with specific marble quarries. Sixteen of the 27 sculptures that were analyzed were actually from Paros; only five of the sculptures were from Naxos. This analysis even allowed for differentiation between the two marble sources on the island of Naxos.

**Mosaic Analysis**

Two factors must be considered when studying mosaic supply sources: 1) the availability of materials near the site and 2) the possibility of the use of recovery materials, or secondary waste materials from larger works. The mosaicist often used architectural marble debris (Bergamini and Fiori 1999). At Antioch, limestone and basalt were available as building materials. The majority of mosaics at Antioch are composed of a combination of limestone, marble, and glass tesserae. While limestone was most likely obtained from the local quarry and glass was most likely produced on site at the mosaic workshops, marble was not available from a nearby source.
Capedri et al. (2001) analyzed mosaics from the rooms of the Domus dei Coiedii at Suasa (Ancona, Italy) that dated archaeologically and stylistically between the end of the first century B.C. to the beginning of the first century A.D. and the second century A.D. to the first half of the third century A.D. Most of the floors were covered in mosaics. Some of the mosaics were destroyed when Suasa was sacked and others were damaged by drainage. The mosaics are composed mostly of stone, with a few glass tesserae. The older tesserae were less than 1 cm², while the tesserae from the second period were larger than 1 cm². Capedri et al. (2001: 10) used a combination of petrofabric analysis and SIRA analysis to examine 81 tesserae, and determined that the opus tessellatum sections were made of mostly local stones, which belonged to the Umbro-Marchigiana Sedimentary Sequence. The white to pinkish and reddish tesserae were mostly limestone from the ‘Scaglia Rosata’ Formation. The dark to black tesserae were composed of non-fossiliferous marls and marly clay, which probably derive from the local ‘Marne a Fucoidi’ Formation. The stones from the opus sectile sections, mosaics formed of geometric designs, were composed of sedimentary stone, magmatic stone, and marble. The sedimentary stones were limestone, which belong to the ‘Rosso Ammonitico,’ and occurred in the Umbro-Marchigiana Sedimentary Succession, black marls and marly clays similar to the stones in the opus tessellatum sections, and onyx marble. The magmatic stones were prophyrites and gabbros. The marble stones were composed of several white marbles from Marmara and Carrara and colored marbles including: marmo cipollino (green), rosso antico (wine red), pavonazzetto (white with purple veining), portasanta (pink), giallo antico (white or pink and yellow), bigio antico
(dark gray with white and gray veins), *lapis taenarius* (dark gray), and *brecce coralline* (white set in reddish cement) (Capedri *et al.* 2001: 7).

**Things to Consider and Commentary on the Techniques**

Attempts to source marble require proper sampling of both geological and artifactual materials. Weathering, ground water, and carbon dioxide can cause variations in physical composition, including isotopic, crystalline, and elemental characteristics. Additional variation can occur within a single quarry as a result of formation processes. All of these factors combined suggest the need for continued sampling and statistical treatment of the existing results.

Some archaeologists have argued that when provenance questions arise, the focus is on two or three quarries (Polikreti and Maniatis 2002); however, this focus adds an assumption into the analysis, which may prove false. It is important to include all quarries that might be involved rather than pick and choose a few to study, because trade routes have not been established definitively.

In addition to including all possible marble sources, we must consider the sources of other stone as well. Stable isotope ratio analysis results do not differentiate between marble and limestone. One problem is that isotopic compositions of marble often overlap with those of limestone, marble's protolith (Gorgoni *et al.* 2002: 121). Wenner *et al.* (1988: 325) suggest that the geological factors, such as metamorphism, that control variability of isotopic values in marble, also control variability in limestone. This, of course, means that any analytical technique designed to study the characteristic signatures of marble (trace element, spectra, or isotopic values) will not help differentiate between
marble and limestone. Wenner and Herz (1992: 199) also point out that while no
database for the provenance of Classical limestones exists, this is probably a result of the
use of local limestone. Local stone resources, if available, would have been cheaper to
use; however, commerce in certain limestones existed during Greek and Roman times.
“Both Pliny and Theophrastus praised the ‘poros’ limestone of Greece as being lighter
than, but as attractive as, the famous lycnites marble of Paros” (Wenner and Herz 1992:
199). Corinth and Neapolis were both known for limestone exportation by ship during
Classical and Byzantine times. Wenner and Herz (1992) began the assembly of a
database of isotopic signatures of limestone sources in Classical Greece by focusing on
Corinth and Neapolis. Figure 32 shows the range in isotopic values of limestones, while
Figure 33 compares the results of Wenner and Herz’s study of the Neapolis and Corinth
limestone quarries to a few of the near-by marble quarries. Wenner and Herz (1992: 199)
suggest that further isotopic, megascopic, and microscopic analysis should occur in order
to understand better the extent of limestone exportation.

Weathering is another explanation for contradictory information. Tykot et al.
(1999) show that weathering has a significant impact on isotopic signatures by using the
combination of SIRA, XRD, grain-size determination, and archaeological data to provide
minimally destructive provenance information. X-ray diffraction requires only a few
milligrams of marble powder, and since XRD does not alter the sample, SIRA can re-use
the same sample. Because of the size of the sample, a highly weathered sample can
produce unusual results. Weathered marble surfaces are likely to have an altered
crystalline structure and altered isotopic values (Tykot et al. 1999). Understanding the
formation of isotopic values and crystalline structures can explain this phenomenon.
Figure 32. Comparison of the isotopic compositions of ancient marble quarries in the eastern Mediterranean with limestones (Wenner et al. 1988: 326)

Remembering that water affects the oxygen isotope values and that carbon dioxide affects the carbon values, ground and meteoric water and atmospheric carbon dioxide exposure can lower isotopic signatures and recrystallize dolomite and calcite on marble surfaces; thus, a weathered marble sample requires cleaning prior to analysis (Tykot et al. 1999). The results of this study revealed that even small cracks or fissures can expose marble surfaces to weathering, and to be safe, even “clean” marble should be treated prior to
Figure 33. Comparison of isotopic signatures of Classical marble sources and limestone from Neapolis and Corinth (Wenner and Herz 1992: 202)

sample collection. The results of the work by Tykot et al. (1999) reveal that a minimum of 1-2 mm of marble must be discarded prior to collection of an XRD and SIRA sample from a weathered marble object. Stable isotope ratio analysis and XRD were selected for this analysis because both techniques are minimally destructive, require small sample sizes, and have proven a successful combination in previous provenance determination studies.
Chapter Five: Analysis and Results

The primary research objective of this study is source determination. The secondary objective is to evaluate the source of the mosaic tesserae in relation to the distance the material traveled and the image created by individual stones. Positive results might reveal 1) preferred sources for tesserae, 2) trade routes of specialized stone, 3) chronological changes in preference and 4) workshop preference of stone material. Provenance determination can provide clues to help understand the meaning of the mosaic images and the possible trade routes that existed during the Roman period. X-ray diffraction (XRD) and stable isotope ratio analysis (SIRA) were selected for the determination of the provenance for 55 marble mosaic tesserae from Antioch-on-the-Orontes. Both techniques are minimally destructive and have been proven to be part of a successful combination method for determining the provenance of marble. The surface samples were collected by the Worcester Art Museum conservator at the time, Lawrence Becker, and sent for analysis in plastic containers. The 55 samples include 22 red, 26 white, 4 black, and 2 brown tesserae and come from 10 mosaic floor images from 7 different rooms (see Table 1 for details).

This analysis attempted to source mosaic tesserae with minimally destructive techniques of XRD and SIRA. In this study of tesserae fragments from Antioch mosaic floors, a combination analysis was applied. The samples were collected by chipping
away at individual tesserae for samples of an appropriate size for SIRA and XRD analysis. First, the samples were described by color, weighed, and powdered for analysis. X-ray diffraction was used to determine the crystalline composition of the sample, focusing on dolomite or calcite. Then, carbon and oxygen SIRA was performed on the same samples used in XRD. Comparative analysis of the samples’ $\delta^{13}C$ and $\delta^{18}O$ isotopic values to the isotopic values for quarries that have been previously published occurred. The results were not definitive, but were informative. The isotopic databases that have been published, or made available, are limited to mostly white marble quarries. “No technique applied alone can resolve all of the provenance questions, especially if there is no archaeological or art historical information available to restrict the number of quarries and confine the problem” (Polikreti and Maniatis 2002: 1). Discussion, comparative analysis, and further explanations of results are provided in Chapter Six.

X-ray diffraction uses x-rays to determine the primary mineral in an object. For marble objects, XRD can differentiate between dolomitic and calcitic marbles. Since several sources can be eliminated if we know the marble is dolomite, this is an easy way to determine what analytical technique should follow diffraction analysis. Because the ultimate question of XRD is to determine the primary component of marble, dolomite or calcite, a shortened wavelength spectrum from 27 to 32 was selected to reduce analysis time. A calcitic sample would reflect the x-rays off the sample at around 29.4° and a dolomitic sample would reflect the x-rays at around 30.8°. Some samples did not reflect the x-rays between these ranges suggesting one of to things. One possible explanation is that the sample is not primarily composed of either dolomite or calcite. Another possible explanation for no reflection in this range is that the sample is not large enough.
Stable isotope ratio analysis uses the individual isotopic proportions of carbon and oxygen that are sealed in during geological formation to fingerprint the source. The powdered sample, 100 µg, was separated for the SIRA on a Finnigan MAT Delta Plus XL mass spectrometer equipped with a Kiel III individual acid bath carbonate system. Isotopic values can also help eliminate several sources when trying to provenance an artifact. A combination of multiple provenance techniques helps archaeologists reconstruct the variables that Romans considered when they collected marble for different uses. These variables include color, grain size, or size of marble that can be extracted. Based on the resulting database collected during analysis by several archaeologists including Norman Herz, Carlo Gorgoni, and Lorenzo Lazzarini, possible sources for several mosaic samples were determined. Some marble sources have multiple quarries, which have very different isotopic values. Paros, a small Cycladic Island, has three different marble quarries which were exploited (van der Merwe et al. 1995; Gorgoni et al. 2002). Sometimes this offers additional information about an artifact. Carrara, a marble source in Northern Italy, has one large quarry, but different sections were exploited during different cultural periods (Herz 1987). The Classical period exploited one section of Carrara, while the Renaissance period exploited a different section (Herz 1987: 39). We know our samples are authentic Classical artifacts, and not replications, because they compare to the same isotopic values as the Classical section of the quarry in the database. This kind of information allows us to know how far marble traveled via artisans or tradesmen.

The mosaics, which currently are housed at the Worcester Art Museum (with the exception of the lower half of the Aphrodite and Adonis mosaic image, which is housed...
at the Wellesley College Museum), represent a broad time range, from the first century A.D. to sixth century A.D. Even with the specific question about image meaning, the results of XRD and SIRA may reveal even more important information about the relationships that exist between the samples and the possible sources. Provenance of this material might reveal source preferences, preferences over time, information about trade of specialized stone, and workshop preference of stone material.

The results of the XRD and SIRA are shown in Table 2. The XRD results reveal that all of the dolomitic samples are red. The rest of the tesserae are composed of mostly calcitic materials (Figure 34). Fifty-one of the 55 samples were large enough to run XRD analysis. The four samples too small for XRD analysis to occur were two red samples, one white sample, and one brown sample from the Aphrodite and Adonis mosaic panel. Of the 51 samples run, only one sample returned an indeterminate result and one black sample was determined not to be marble. Of the 49 other samples, 11 were dolomitic and 38 were calcitic. All of the dolomitic results were from red tesserae, including six samples from the Drinking Contest mosaic, one sample from the Ktisis mosaic, and three samples from Dionysos and Ariadne mosaic. Nine of the 22 red samples were calcitic, 24 of the white samples were calcitic, both of the brown samples were calcitic, and four of the five black samples were calcitic.

Although most of the mosaic samples appear to cluster in value with the other samples from the same mosaics, their sources cannot necessarily be connected to values existing in the white marble database. The Drinking Contest mosaic has the most variability in isotopic values, suggesting multiple sources were used. Although the results are not definitive, other tests can be run to eliminate some of the remaining
Table 2. Antioch Mosaic SIRA and XRD Results

<table>
<thead>
<tr>
<th>USF#</th>
<th>Mosaic Name</th>
<th>Color</th>
<th>XRD Result</th>
<th>$d_{13}C$ PDB</th>
<th>$d_{18}O$ PDB</th>
</tr>
</thead>
<tbody>
<tr>
<td>6115</td>
<td>Worcester Hunt Mosaic</td>
<td>white</td>
<td>calcite</td>
<td>-5.4</td>
<td>-5.5</td>
</tr>
<tr>
<td>6116</td>
<td>Worcester Hunt Mosaic</td>
<td>red</td>
<td>calcite</td>
<td>-7.0</td>
<td>-6.8</td>
</tr>
<tr>
<td>6117</td>
<td>Worcester Hunt Mosaic East Border</td>
<td>white</td>
<td>calcite</td>
<td>-3.8</td>
<td>-5.2</td>
</tr>
<tr>
<td>6118</td>
<td>Worcester Hunt Mosaic East Border</td>
<td>red</td>
<td>calcite</td>
<td>-3.0</td>
<td>-4.6</td>
</tr>
<tr>
<td>6119</td>
<td>Agora, Border</td>
<td>white</td>
<td>calcite</td>
<td>-3.1</td>
<td>-5.2</td>
</tr>
<tr>
<td>6120</td>
<td>Agora, Emblema</td>
<td>white</td>
<td>calcite</td>
<td>-4.0</td>
<td>-5.4</td>
</tr>
<tr>
<td>6121</td>
<td>Agora, Emblema</td>
<td>red</td>
<td>calcite</td>
<td>-5.0</td>
<td>-5.2</td>
</tr>
<tr>
<td>6122</td>
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Possibilities. Those marble artifacts with overlapping carbon and oxygen values can be further analyzed through quantitative analyses or by other techniques including scanning electron microscope (SEM), CL, EPR, and strontium isotope analysis. These analytical techniques used in combination with SIRA can provide an attribution to a more specific source. Figure 34 highlights the differences in isotopic values of the calcitic and dolomitic samples. The dolomitic samples have higher $\delta^{13}O$ values. Two clusters of dolomitic samples are apparent. One cluster of six samples, 6139, 6140, 6141, 6631, 6632, and 6638, suggests the samples match a single source. Three of those samples come from the Drinking Contest mosaic and three come from the Dionysos and Ariadne mosaic, which are part of the triclinium pavement in the Atrium House. Another cluster
Figure 34. SIRA results with calcitic samples labeled with squares and dolomitic samples labeled with diamonds

of dolomitic samples, whose values have a greater spread, suggest a single source for the following samples: two from the Drinking Contest mosaic (6137, 6142) and one from the Ktisis mosaic (6626). Two major clusters of calcitic samples are evident. One is composed of one red (6612), one white (6619), three black (6610, 6620, 6634), and two brown (6609, 6621) samples which come from the Aphrodite and Adonis, Drinking Contest, and Dionysos and Ariadne mosaics. This group has higher $\delta^{13}$C values than the second cluster. The second cluster is composed of nine red samples (6116, 6118, 6121, 6122, 6125, 6126, 6129, 6613, 6614) and twenty-three white samples (6115, 6117, 6119, 6120, 6123, 6124, 6127, 6128, 6130, 6131, 6132, 6134, 6135, 6166, 6167, 6622, 6623, 6624, 6625, 6628, 6629, 6630, 6635), which include samples from each of the mosaics.
tested in this study. Within the second cluster there are few secondary clusters that reveal pertinent information. With slightly higher $\delta^{13}C$, a small cluster of white calcitic samples (6130, 6131, 6132, 6134, 6135, 6625, and 6624) shows very similar isotopic values. These seven samples come from two mosaics, the Drinking Contest and Ktisis.

The SIRA results are presented in Figures 34 through 36 and reveal a range of carbon and oxygen values: for $\delta^{13}C = -7.1 \text{‰}$ to $1.3 \text{‰}$ and for $\delta^{18}O = -6.9 \text{‰}$ to $2.8 \text{‰}$. Figure 35 shows the isotopic values of each of the samples included in this study with each of the houses represented by differing colors. In Figure 35, the isotopic values are labeled according to the USF laboratory number as shown on Table 1 and Table 2. Figure 36 shows the distribution of the isotopic values of each the different colored samples. SPSS exploratory data analysis was used to create boxplots revealing the range of carbon and oxygen isotopic values (Figure 37). The boxplots reveals that the greatest range of isotopic values exists within the Drinking Contest (range of $\delta^{13}C = 7.5 \text{‰}$; range of $\delta^{18}O = 9.9 \text{‰}$) and Dionysos and Ariadne (range of $\delta^{13}C = 6.4 \text{‰}$; range of $\delta^{18}O = 9.0 \text{‰}$). The next largest range of values exists in the Aphrodite and Adonis (range of $\delta^{13}C = 4.2 \text{‰}$; range of $\delta^{18}O = 7.5 \text{‰}$) and the Ktisis (range of $\delta^{13}C = 3.9 \text{‰}$; range of $\delta^{18}O = 4.9 \text{‰}$). Further investigation of the exploratory data analysis reveal that both the oxygen and carbon values for the Dionysos and Ariadne mosaic are bimodal (modes for $\delta^{13}C = -5.3 \text{‰}$ and -.3 ‰; modes for $\delta^{18}O = -5.3 \text{‰}$ and 2.8 ‰) in distribution suggesting two sources of material used. One black sample, now believed to be limestone, produced the unexpected results of $\delta^{13}C: -18.3 \text{‰}$ and $\delta^{18}O: -25.4 \text{‰}$. This extremely low value suggests that the sample is not marble and was not included in the exploratory data
Figure 35. SIRA of mosaics color-coded by house
Figure 36. SIRA of mosaics grouped by color.
Figure 37. Boxplots showing the range of carbon and oxygen isotope values
analysis. Although the results fail to match up with the Classical white marble database, the results form patterns that suggest similar sources and accurate results. The results will be further discussed in groups by color since previous studies have focused on color as an identification technique.
Chapter Six: Discussion

By far, white marble has received the most attention (in the literature) for source determination. Pure white marble was the preferred marble type for both Greek and Roman sculptures (Herz 1987: 35; Rapp 1998: 140). This is not necessarily true for mosaics. Using the stable isotope ratio analysis (SIRA) results from the mosaic samples, comparisons with the white marble database can aid in the provenance determination of the mosaic samples. Figures 38 through 45 compare the mosaic results with the published source fields for the white marble database of stable isotopes for each of the major quarries as shown in Gorgoni et al. (2002). Doted lines show the SIRA results of artifacts tested in the analysis that Gorgoni et al. (2002) performed. The dashed lines show the SIRA results of the quarries tested and the circles with white interiors show the previous analysis performed by Moens et al. (1992). The gray areas show the differences between the Gorgoni et al. (2002) data and the Moens et al. (1992) data. The idea behind using these diagrams is to provide pictorial correlations between the mosaic results and the known databases. The actual databases have not been provided to the author; therefore, statistical assessment of the samples cannot occur. Using a visual comparison, the majority of the results, with a few exceptions, fall outside of the most commonly used white marble quarries. Those exceptions include samples from each of the color groups.
Figure 38. Aphrodisias white marble database compared to mosaic samples (after Gorgoni et al. 2002)

Figure 39. Carrara white marble database compared to mosaic samples (after Gorgoni et al. 2002)
**Figure 40.** Dokimeion white marble database compared to mosaic samples (after Gorgoni et al. 2002)

**Figure 41.** Naxos white marble database compared to mosaic samples (after Gorgoni et al. 2002)
Figure 42. Paros white marble database compared to mosaic samples (after Gorgoni et al. 2002)

Figure 43. Penteli white marble database compared to mosaic samples (after Gorgoni et al. 2002)
Figure 44. Prokonnesos white marble database compared to mosaic samples (after Gorgoni et al. 2002)

Figure 45. Thasos white marble database compared to mosaic samples (after Gorgoni et al. 2002)
Examining the eight most commonly used white marble quarry values provides some clues as to the source of the mosaic samples.

**Possible Sources**

Two brown samples (6609, 6621), one white sample (6619), one red sample (6136), and one black sample (6620) overlap with the isotopic ellipses of the Aphrodisias quarry. Two additional black samples (6610, 6634) match the results of the Aphrodisias quarry. These samples come from the *Drinking Contest* and the *Aphrodite and Adonis* mosaics, which were found in the same house, and from the *Dionysos and Ariadne* mosaic. These mosaics all date between the second and third century A.D. With the exception of sample 6612, these seven samples form one of the four clusters in the data. It is also important to note that the quarry of Aphrodisias produced black and white colored marbles (Anderson 1989: 65). One brown samples (6609) falls just outside of the statistical ellipse of the Carrara quarry; however, the Carrara quarry does not compare with isotopic signatures of any other samples in this study. One brown (6609), one black (6634), and one red sample (6612) match the isotopic ellipse of the Dokimeion quarry. A second black sample (6610) falls just outside the isotopic ellipse for the Dokimeion quarry. Dokimeion marble, also known as *pavonazzetto*, exists in two forms: a fine-grained all white marble and a yellow-white with gray to red to violet veining (Anderson 1989: 93). Three of the samples that match the Dokimeion quarry falls within the known *pavonazzetto* color variation: the red sample (6612) from the *Aphrodite and Adonis* mosaic and the black samples (6634) from the *Dionysos and Ariadne* mosaic and (6610) from the *Drinking Contest* mosaic. One brown sample (6609) also falls within the Naxos
quarry isotopic ellipse. Both brown samples (6609, 6621) and one red sample (6138) overlap the Paros quarry isotopic ellipse. Probably, the white sample (6619) also falls within to isotopic signatures of the Paros quarry. The brown sample (6609) also falls within the Prokonnesos quarry. None of the samples fall within the ellipses for the Penteli and Thasos. Although several of the mosaic results match the isotopic values of multiple white marble quarries, the comparisons are just a starting point for the ultimate source assignment for the mosaic samples. One must also keep in mind that colored marble might have a different isotopic value than white marble from the same source location (Gorgoni 1992). In addition, colored marble or colored limestone might match isotopic signatures from different locations. Although the isotopic values did not provide ultimate source determination for all samples, a few explanations for the results can be given. One explanation for the results not being definitive is that not enough isotopic values have been collected from colored marble sources. Another explanation is that the samples might not be marble, but rather limestone. The analytical techniques used in this study do not differentiate between marble and limestone, which are both calcareous materials, suggesting further testing is needed to draw conclusive results.

Only 9 of the 55 samples correspond with values on the white marble databases shown. While further scientific techniques are available for determining the source of the materials used in mosaics at Antioch, they cannot be used here, because multiple samples cannot be extracted from the materials in question. The size of the original artifacts, the individual tesserae, does not allow every type of analysis to occur. Bergamini and Fiori (1999: 200) also noted that the size of mosaic pieces do not enable multiple analytical techniques to be used. The limited number of samples that can be taken without
destroying the mosaic itself and the limited funding available to run further scientific
techniques hinder further analysis.

Previous studies of source determination for mosaics have shown that the
majority of tested tesserae are not actually marble, but rather limestone. Petrographic
analysis and chemical analysis of the opus tessellatum sections of the Domus dei Coiedii
mosaic at Roman Suasa in Ancona, Italy, revealed that most tesserae were made from
colored limestones or marls and marly clays (Capedri et al. 2001: 12). Another study
using petrographic analysis alone reached the same conclusions. A survey of mosaic
tesserae from different centuries and various geographic localities revealed that 85
percent of the 100 tesserae sampled were made of calcareous sedimentary limestones,
and only 15 percent of the tesserae were made of marble and magmatic and detritic rocks
(Bergamini and Fiori 1999: 200). This might explain the inability to connect the mosaic
tesserae results with any known white marble quarries.

The study by Capedri et al. (2001) on mosaics from the rooms of the Domus dei
Coiedii at Suasa also included an examination of samples taken from sections of opus
sectile fragments, or mosaics made of geometric patterns. The stones used in these
sections were composed of several different lithologies including metamorphic,
sedimentary, and magmatic. The metamorphic stones included white and colored marble.
The white marbles were Prokonnesian marble and Carrara marble (Capedri et al. 2001).
Several colored marble mosaic tesserae were also tested, including cipollino verde,
pavonazzetto, lapis taenarius, giallo antico, portasanta, rosso antico, and brecce
coralline. Figure 46 shows the isotopic signatures for each of the above-mentioned
marbles. The graphic results do not suggest a connection with any of the mosaic samples
Figure 46. Isotopic signatures for various colored marble from opus sectile mosaics (Capedri et al. 2001: 14-21)

indicating that none of the marble types included in the analysis performed by Capedri et al. (2001) exist in the tesserae sampled in this analysis. In addition to the metamorphic stones, Capedri et al. (2001) also examined the sedimentary and magmatic stones. The sedimentary stones included reddish limestones, dark gray to black marls, and onyx marble (alabaster). The magmatic stones included green porphyrites and medium-grained gabbros. No SIRA was performed on these particular samples in the study by Capedri et al. (2001).

The ultimate determination of provenance for the mosaic samples must come from the isotopic ratios, which are more typical of limestone than of marble. If the samples are marble, they do not match anything in the known marble database. Herz
(1992: 188) noticed a similar trend in one of his many studies and determined that in all probability the samples he tested were local limestone. A reexamination of the limestone plot from Chapter Four provides some clues as to possible answers for the results obtained from the mosaic samples (Figure 47). A dashed rectangular box is drawn over the area in which most marble isotopic signatures fall. The majority of the mosaic samples fall in the ranges of the average freshwater limestones and the common marine limestones.

Although the comparative analysis fails to identify the sources of a large number of the mosaic samples, many observations can be made about the isotopic results. When compared to the limestone quarries published in Wenner et al. (1988), other sources can be determined (Figure 47). The isotopic values for the white and red tesserae tested from the Necropolis, including the Funerary Symposium (6127, 6128, 6129), Eukarpia (6123, 6124, 6125, 6126), and Agora (6119, 6120, 6121, 6122) mosaic pavements, reveal a clustering that suggests a similar source for all of the samples. The Necropolis tesserae are probably all freshwater or marine limestones, since they compare to the isotopic fields published by Wenner et al. (1988). The samples taken from the Atrium House, including the Drinking Contest (6130, 6131, 6132, 6133, 6134, 6135, 6136, 6138, 6139, 6140, 6141, 6609, 6610, and 6611) and the Aphrodite and Adonis (6612, 6613, 6614, 6616, 6617, 6618, 6619, 6620, and 6621) mosaic pavements, also appear to cluster together. These samples include red and white tesserae and appear to compare to isotopic ratios of the marine limestones. Another clustering comes from three red samples from the Dionysos and Ariadne mosaic pavements (6631, 6632, and 6633) and three of the red samples from the Drinking Contest mosaic (6139, 6140, and 6141). According to the
comparison figure these samples can be called deep limestones. The red and white 
*Worcester Hunt* mosaic samples 6115 and 6116 overlap the isotopic ellipses of 
freshwater limestones and the *Worcester Hunt* mosaic samples 6117 and 6118 overlap the 
isotopic ellipses of marine limestones. The white samples from the *Hermes and the 
Infant Dionysos* mosaic (6622, 6623) match the isotopic ellipses of freshwater 
limestones. Two white samples from the *Ktisis* mosaic (6624, 6625) and one black 
sample from the *Dionysos and Ariadne* mosaic (6634) fall within the isotopic values of 
marine limestones. Most of the mosaics sampled in this study fall within one of the 
categories set up by Wenner *et al.* (1988). One red sample from the *Drinking Contest* 
mosaic (6138) matches the values of “ooze,” a deep-sea sediment composed of shells of 
marine animals and plants (Monroe and Wicander 1997: 616). Only six of the mosaic 
samples do not overlap with anything on the limestone isotopic scatterplot, including two 
red *Drinking Contest* samples (6137, 6142), one red *Ktisis* sample (6626), one white 
*Drinking Contest* sample (6133), one red *Aphrodite and Adonis* sample (6615), and one 
black *Ktisis* sample (6627). Although many samples match the isotopic ellipses for 
limestone, it does not mean that all the samples are limestone or another sedimentary 
rock. The similar values simply highlight that the possibility exists that the materials 
sampled are not marble. With this possibility, the limestone in the Antioch region should 
be tested and compared with the SIRA results provided in this thesis.

If the samples are not limestone, then another explanation for unusual isotopic 
results may be weathering. Several researchers have described unexpected isotopic ratios 
as possibly relating to weathering. The research studies by both van der Merwe *et al.* 
(1995) and Margolis and Showers (1988) tested surface and subsurface isotopic ratios
Figure 47. Comparison of the mosaic isotopic values with the isotopic values of limestone quarries in the eastern Mediterranean (after Wenner et al. 1988: 326.)
and compared the results. van der Merwe et al. (1995: 194) revealed that the oxygen isotopic ratios in weathered surfaces of dolomitic marble can deplete 1-2 ‰. Margolis and Showers (1988; 1990) also reported negative shifts in carbon isotopes of up to 13 ‰ and in oxygen isotopes of up to 3.2 ‰ in marble sculptures. Both studies reveal that weathering can have an effect, usually a negative shift, on the stable isotopic ratios. Since the majority of SIRA results for the mosaic samples are more negative than what would be expected if the samples were marble, the SIRA results may be indicative of weathering. Both carbon and oxygen isotopic values of groundwater tend to be more negative than those of marble, and could possibly be the cause of the isotopic values of the mosaic samples. It is important to note the exact nature of the samples accepted. Although the samples were solid, they were too tiny to remove a part of the surface; and therefore, eliminate the possibility of weathering. As with collections of sculptures, the mosaics sampled here had been cleaned thoroughly by museum curators, greatly reducing the probability of weathered surfaces. While it is possible that the isotopic values obtained in this study are the result of weathered surfaces, it is unlikely given that no weathering was evident. Also if the isotopic values were the result weathering, then the isotopic values would be scattered and would not cluster as they seem to do.

Clearly, a single method of analysis is not particularly effective in determining the sources of colored mosaic tesserae. The combination of carbon and oxygen SIRA with the identification of dolomitic marble through XRD did not prove as successful in this study as it has in previous white marble studies. Additional analysis with techniques such as SEM, CL, EPR, and trace element analysis could provide further answers. These methods are highly dependent on the extent of sampling allowed by museum curators.
Typically, chips and cores necessary for petrographic and elemental analysis are not easily obtainable unless the samples are undergoing massive restoration procedures (van der Merwe 1995: 195). In addition, the collection of a non-white marble database would significantly aid future research on colored mosaic tesserae.

This discussion focused on identifying possible quarry sources for the Antioch mosaic tesserae. The values for some samples tested in this analysis were similar to the white marble database but other samples have very different values. In addition, some samples overlap with isotopic values to sedimentary rocks, such as limestone.
Chapter Seven: Conclusions

Since the isotopic values for the samples presented in this study show considerable overlap, it is clear that visual, historical, and archaeological information regarding the mosaics and the samples are vitally important. Visual analysis of each sample – the presence of streaks and inclusions, the grain size, and color – aids in the final conclusions about possible sources. Fifty-five mosaic tesserae from ten Antiochene mosaics were analyzed with XRD and SIRA. It was thought that SIRA combined with XRD would provide the information necessary to answer the research questions. The quantitative data obtained from carbon and oxygen SIRA in this study provide the archaeological community with the beginnings of an artifact database for both mosaics and colored marble.

Findings for Research Goals and Objectives

The research goals this study hopes to address focused on 1) using XRD and SIRA to determine the source of the materials used in mosaic tesserae from Antioch; 2) comparing results for similarity; 3) determining the temporal or spatial relationship between the source and the importance of the image created; and 4) determining if a correlation exists between the importance of the materials used with the distance that the material traveled.
The research questions for this study focused on two main objectives. The results of provenance determination could reveal meaning behind the mosaic images and could reveal new trade routes in the Mediterranean. These questions will remain unanswered, since the provenance of most of the mosaic tesserae was not determined. Although this study did not answer all of the proposed research questions, it does show the importance of integrating multiple techniques for provenance determination studies. The results obtained in this study revealed important information that adds to existing marble databases and provides a basis for further investigation of colored marble artifacts.

The results of the SIRA and XRD analysis showed that the materials used for mosaic tesserae come from a variety of sources. Although no definitive sources were found, several possibilities exist. Fifty-one of the samples were large enough to run XRD. One returned an indeterminate result, one sample was determined not to be marble, 11 samples were determined to be dolomite, and 38 were determined to be calcite. The results of the comparative SIRA showed a large degree of overlap. While Aphrodisias was determined to be a possible source for the following samples: 6609, 6610, 6612, 6619, 6136, 6620, and 6634, Carrara was also identified as a possible source for sample 6609, Dokimeion as a possible source for 6609, 6634, 6610 and 6612, Naxos as a possible source for sample 6609, the Paros quarry as a possible source for 6609, 6619, 6621, and 6138, and Prokonnesos as a possible source of 6609. The results of the SIRA present multiple sources for several of the tesserae (i.e. 6609), and failed to identify sources for many of the tesserae. Several explanations can be given for these results. First, it is important to note the possibility that the samples are not marble, but rather limestone. One way of addressing this possibility would be to perform SIRA on the local
limestones around the Antioch region. Second, the SIRA values were more negative than expected if the results were marble suggesting the possibility of weathering. Sample size makes this possible explanation more difficult to address.

The second research goal examined which samples share similar results. The results described in Chapter Five were compared and revealed several clusters that suggest similar sources. Four clusters were evident when the samples were graphed on a scatterplot: two dolomitic clusters and two calcitic clusters. The first dolomitic cluster includes three samples from the Drinking Contest mosaic and three from the Dionysos and Ariadne mosaic which have matching isotopic values. The second dolomitic cluster includes three samples: one from the Ktisis mosaic and two from the Drinking Contest mosaic. The first calcitic cluster includes six samples from the Aphrodite and Adonis, the Drinking Contest, and the Dionysos and Ariadne mosaics. The second calcitic cluster includes 33 samples from each of the mosaics included in this study.

The third research goal focused on determining the temporal or spatial relationship between the source and the importance of the image created. This question cannot be answered without further testing, because sources were not determined for enough of the samples to derive any relationship between the source and the importance of an image. Testing of additional samples from specific portions of images, testing of additional colored marble sources, and the inclusion of additional scientific and analytical techniques would help answer this research question.

The fourth goal was to determine if a correlation existed between the importance of the materials used and the distance that the material traveled. Again, this question cannot yet be answered as the definitive source of each of the mosaic tesserae has not
been determined. One possible explanation for the results suggests that limestone was used rather than marble. This suggests that mosaicists were utilizing cheaper and more readily available resources for mosaics. It is important to note that the mosaic tesserae that have similar values to the known marble sources are from the second and third centuries, the earliest centuries sampled here, and that none of the mosaic tesserae from the fourth through sixth centuries had similar isotopic values with the known marble database. This variance in isotope values is supported by the range displays in the boxplots in Figure 37. Not all of the samples from the second and third centuries are similar to the known marble sources, possibly suggesting a transitional period where mosaicists used both limestone and marble resources. A complete picture of the correlation cannot be drawn between the importance of the materials and the distance that the material traveled without further testing.

Although some of the research goals were not attained in this study, answers are ultimately attainable through further analysis. Even though the source has not been determined for all of the samples tested, the spatial relationship between the sample values and other values on the isotopic database helps in understanding the relationship between the mosaic images. Several clusters of values suggest common sources. Although the sources temporarily remain unknown, further analysis can build on the data provided here.

**Limitations of This Study**

Several limitations to this study exist. First, with samples that are smaller than 2.0 cm², size limits the number of analytical techniques that can be applied to any one
tessera. Characterization and classification of stone materials used in mosaics is a tedious and difficult task. For this reason, mosaic analyses require scientific techniques with a high degree of accuracy for small sample sizes. These techniques often are more expensive and limit the amount of analysis that can occur. The second limitation to this analysis is money. Availability of finances proved to be a deciding factor in the amount of analysis that occurred in this project. The third limitation to this analysis is the complete absence of an existing database for colored marble. The lack of a colored marble database made it impossible to compare the results of this study with known colored marble quarries.

**Future Research**

Future work on mosaic tesserae analysis should begin with further analysis of colored marble sources. The existing SIRA databases focus primarily on white marble. The construction of a colored marble database would enable archaeologists not only to source mosaic tesserae, but also colored sculptures, architectural elements, and inlays. In addition, future analysis of mosaic tesserae should include more than just SIRA and XRD analysis. Strontium isotope analysis, thin section petrography, SEM, or CL would enhance the analysis of mosaic tesserae and provide additional information when two techniques return conflicting results. These additional tests add to the cost of analysis; however, they also aid in the final source determination process.

Archaeologists have studied interregional contact through trade routes within the Mediterranean Sea for many decades. This study provides further evidence of trade networks and suggests that trade was not just for essential materials, like metals, or food,
like bulk shipments of grain. The materials used for mosaic tesserae suggest that trade also occurred for decorative materials, such as mosaic floors. This thesis has addressed the history and methods of ancient marble extraction techniques, the archaeology of the Antioch region, the scientific methods of XRD and SIRA, and a discussion of the results of the analysis of the mosaic tesserae sampled. This study provides the archaeological community with the basis for a database of colored marble quarries and artifacts. The information provided here adds to the growing body of knowledge about the Late Roman and Early Byzantine world.
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