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**Archaeometric Characterization of Roman Tile Fabrics
from the Sangro Valley, Italy**

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Submitted for Honors in Archaeological Studies at Oberlin College
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Abstract

In this paper, I use archaeometric methods to investigate the raw materials and manufacture of terracotta roof tiles from three Roman sites in the Sangro Valley, Abruzzo, Italy. Although fragmentary remains of the tegula and imbrex roof system are commonly uncovered at sites throughout the ancient world, these tiles are woefully understudied. Equally obscure are the workings of the economy of Samnium during and after its conquest by the Romans. As mass-produced industrial materials generally manufactured and used within a small radius, tiles may prove to be the ideal medium through which to explore the regional ceramic economy. This study applies ceramic petrography and x-ray fluorescence to tiles from the Sangro Valley Project's excavations at Monte Pallano, Acquachiarra, and San Giovanni, as well as to samples of local clays and regional coarsewares, in order to identify mineralogical and chemical patterns related to clay sourcing and tile production. These efforts cast doubt on the validity of current methods for identifying ceramic groups and creating fabric typologies, yet they simultaneously shed light on the nature of tile manufacturing in the ancient Sangro Valley, suggesting a pattern of decentralized production in a diffusely settled area. This, in turn, may prove significant for the archaeological interpretation of social and economic trends in the region.

Chapter 1: Background and Research Design

The Sangro Valley region of east central Italy is an ideal location to trace dynamics of social and economic change during and after the Roman conquest of Samnium. Recent archaeological work conducted by the Sangro Valley Project (SVP) has yielded a number of significant finds, contributing greatly to knowledge of the environmental and socioeconomic processes that have shaped human settlement in the region. Among the less-studied materials recovered by the SVP is an abundance of roof tile in a variety of coarse fabrics. Since these tiles were almost certainly made locally, they pose a unique opportunity to study ancient ceramic production on a small scale.

Matching tiles with clay sources may lead to an identification of manufacturing and distribution networks throughout the Sangro Valley, allowing archaeologists to trace the environmental and cultural factors at play as humans in the past made and used ceramics, and to observe how these behaviors changed over time. In order to do this work, it is first necessary to understand the composition of Sangro Valley tiles and how they relate to the raw materials available in the region. Archaeometry – the application of the physical sciences to archaeology – is an ideal way to approach these questions, offering objective, quantifiable, and multifaceted perspectives on ceramic composition.

In this study, petrographic thin sectioning and x-ray fluorescence spectrometry are applied to a selection of tiles, potsherds, and clays from the Sangro Valley in order to evaluate two tile fabric sequences and identify similarities between materials. Though the accuracy of the existing SVP tile fabric sequences was not validated, the results of these

analyses do provide a window into the diverse and complex compositions of these tiles. This, in turn, suggests a decentralized industry of non-specialist manufacturers responding to diffuse settlement and fluctuating demand: a significant insight into industry and population dynamics in the ancient Sangro Valley.

Geography of the Sangro Valley

To understand the archaeology of the Sangro Valley, it is first necessary to understand the geographic setting that has shaped human decisions about settlement, land use, and resource exploitation. Located in central Italy nearly due east of Rome, the Sangro River winds over 107 kilometers from the central Apennines to the Adriatic (Appendix A, maps 1 and 2). Along its course it passes through three geological zones. In the Upper Valley, the Sangro's headwaters cut a narrow bed through steep mountains. In the Middle Valley the river widens, flowing through a region defined by overlapping zones of hard limestone and soft, clayey marl. In the flood plain of the Lower Valley the Sangro passes through gentler topography with soft clays and sands before ultimately emptying into the Adriatic. The changing topography, variety of rocks and soils, and relative proximity to the mountains and the sea have influenced patterns of human settlement, agriculture, resource use, and trade and communication in this area for thousands of years.

From its inception the Sangro Valley Project has focused on the Middle Valley – more specifically, the region around Monte Pallano. Pallano is a major landform: it rests in the cradle of two river systems and marks a transition point between the Adriatic coast and the

mountainous interior. Rising 1,020 meters above sea level and crowned with an imposing limestone ridge, the mountain is an ideal location for fortification with an imposing view of the valley.¹ For these reasons, from the earliest known history of the region Monte Pallano has been a significant settlement site at the intersection of trade routes and cultures.

Settlement in the Sangro Valley²

Archaeological and historical summaries of the history of the Abruzzo region typically begin with the Iron Age of the 10th through 5th centuries B.C.E. At this time the Sangro Valley was a small part of a culturally homogeneous, though not politically unified, central Adriatic culture. The people who inhabited the region at the time left few written records and are primarily known through grave goods found in tombs such as those along the Via de Gasperi in the modern town of Tornareccio, on the slopes of Monte Pallano. Opulent jewelry, elaborate armor and weapons, and funerary statues such as the famed Capestrano Warrior attest to a rural population led by a warrior elite. More recent archaeological work has uncovered materials representing other social classes, particularly scatters of coarse pottery called *impasto*, which point to the locations of small farms dispersed throughout the landscape.

The fifth and fourth centuries saw significant social change in the central Adriatic as magistrate-led villages supplanted what had been prince-led clan societies – mirroring

¹ Susan Kane, Sam Carrier, Ed Bispham, Keith Swift, Eric DeSena, and Velicia Bergstrom, *Sangro Valley Project Field Manual 2011* (Sangro Valley Project, 2011), 11-12.

² Except where noted otherwise, the information in this and the following section is from the 2011 Sangro Valley Project field manual (ibid.), particularly the “Introduction to the Sangro Valley Project” (11-24).

similar social movements elsewhere in the classical world, which brought down hereditary elites in favor of civil administration. An increased focus on communal and civic identity led to the construction of major public sites, including sanctuaries and hill forts. A Hellenistic sanctuary atop Monte Pallano dates to this time, and it is possible that the megalithic walls crowning the mountain do as well, though they may be remnants of the earlier princely society. Appendix A, map 3 shows the distribution of cultural groups in the Abruzzo at this time and Monte Pallano's location at the intersection of three major territories.

Perhaps the most significant single date in the history of the Sangro Valley is 354 B.C.E. In that year the Romans first made contact with the inhabitants of the central Adriatic, who at this point had coalesced into a number of distinct groups, among them the Samnites. The pressures of Roman expansion into the region led to a long, protracted military struggle known as the Samnite Wars. Despite significant local resistance, the Romans ultimately prevailed: the first century B.C.E. saw the decline of the native Oscan language and greatly increased Roman cultural influence. From this point on, the history of Samnium was entwined with the increasingly imperial history of Rome. Samnium became a major region of livestock-raising and saw the growth of urban centers and villas as Roman rule expanded, then suffered the tolls of successive waves of invaders as the empire contracted and fell.

The broad outlines of the history of Samnium – and, by extension, the Sangro Valley – are sketched by Roman historians, who saw the region and its people from the perspective of invaders and outsiders. Their characterization of Samnium as a war-

mongering agricultural backwater has remained the dominant narrative for millennia. Only recently have scholars attempted a deeper understanding of the history of the area, drawing heavily on archaeological evidence in the absence of internal written records. Archaeological efforts such as the Sangro Valley Project have been critical in expanding the understanding of Samnite society in the context of Roman imperialism.

The Sangro Valley Project

The Sangro Valley Project (SVP) was established in 1994 with the goal of investigating historical dynamics of social change, settlement, and land use along the Sangro river system. The project hopes ultimately to provide a comprehensive picture of how interactions between humans and environment have transformed the regional landscape, from prehistoric times to the early modern period. This mission was very much influenced by the Biferno Valley Project, a ten-year survey in the Molise region of Italy that conducted a groundbreaking comprehensive archaeological investigation of a river system throughout time. With this model in mind Dr. John Lloyd of Oxford University led the first phase of the SVP, which consisted of five years of survey in the area surrounding Monte Pallano, as well as around Opi in the upper valley and Fara in the lower valley. The findings from Phase I, though preliminary, were instrumental in broadening the available information on regional history and indicating potential sites for future excavation. Appendix A, map 4 shows the results of survey around Monte Pallano, with major scatters of artifacts at Acquachiara and San Giovanni.

Following Lloyd's death, Drs. Ed Bispham of Oxford University and Susan Kane of Oberlin College initiated a second phase of fieldwork that ran from 1999 to 2010, excavating near the top of Monte Pallano and farther downslope at Acquachiara, and continuing to expand the project's base of survey data. In 2011 the project entered a third phase, commencing excavations in the community of San Giovanni and conducting intensive survey of wooded areas on Monte Pallano, which had previously been neglected.³

The sites excavated by the SVP thus far provide a reasonable cross-section of human activity in the Sangro Middle Valley from the Iron Age to the late Roman period. Work at Monte Pallano uncovered three stages of a sanctuary that was originally built in the late Hellenistic period and appears to have been rebuilt in the Augustan period and again in the second century C.E. This sanctuary is one of many significant archaeological sites on the mountain; others include a set of formidable megalithic walls dating to the Iron Age, and a major civic complex excavated by the Soprintendenza per I Beni Archeologici dell'Abruzzo. Taken together, these monuments suggest that Pallano was a strategic location for defense, religious activity, and civic administration for hundreds of years, throughout periods of significant cultural and political change. Moving down off the mountain and onto its slopes, successive excavations at Acquachiara offer insight into daily life and economic activity during these time periods, uncovering two agricultural processing areas dating to the archaic (ca. 6th century B.C.E.) and Roman imperial periods. Finally, while interpretation of the first season of excavation at San Giovanni has only just begun it is clear that the site dates to the late Roman period, and survey of the surrounding area retrieved early

³ For more on the development of survey during Phase III of the SVP, see James Countryman, *A Study of Agricultural Terracing at Monte Pallano, Abruzzo, Italy*, unpublished thesis, Oberlin College, 2012.

medieval architectural elements. Preliminary interpretation suggests that these materials may derive from a Roman villa complex, with possible later reuse as a site of Christian worship. The archaeological evidence from Monte Pallano, Acquachiarra, and San Giovanni thus offers a wide variety of perspectives from which to study public and private life in the Sangro Middle Valley over the course of a millennium.

Roof tile: an introduction

Among the material uncovered by the SVP is an abundance of roof tile, found in all phases of the project, during both survey and excavation. This comes as no surprise: tile was an essential architectural element in many ancient cultures and is one of the most common finds at archaeological sites throughout the Mediterranean.

The oldest known roof tiles were produced near Argos in 1800 B.C.E. or earlier.⁴ Widely used by the Greeks and Etruscans, it took longer for the Romans to adopt them, but by Livy's time residents of the city of Rome were receiving state-issued tiles to replace straw and wood shingles, which were substantial fire hazards for the growing urban population.⁵ In time, the Romans began to view tile as an expression of wealth: the 89 B.C.E. Charter of Tarentum established property qualifications for political office that were based on the number of tiles roofing one's home, and in 43 B.C.E., the Roman Senate introduced a war tax to be assessed per tile.⁶ As a ubiquitous construction material that could serve as a proxy for roof size and therefore for the size of a building, tile became shorthand for status.

⁴ Gerald Brodribb, *Roman Brick and Tile* (Wolfeboro, NH: Alan Sutton Publishing Inc., 1989), 5.

⁵ *Ibid.*, 6-7.

⁶ *Ibid.*, 7-8.

Roof tiles were designed to overlap and interlock securely to prevent rain from leaking through. The most common method of achieving this was the tegula and imbrex system, so effective that it is still found with some variation throughout the modern Mediterranean (Appendix B, figures 1 and 2). Tegulae are large, flat, rectangular tiles with raised rims, called flanges, running parallel to each other down the long sides. Cutaways, notches at the corners of the flanges, allowed tegulae to interlock when laid in columns along a roof. Over the gaps between tegula flanges were set imbrices, long tiles curved in the shape of an arch.⁷ Though they were designed as roofing material, the forms of tegulae and imbrices lent themselves well to other uses: tegulae were in some places commonly used to construct tombs, while imbrices might be turned into piping.⁸ In addition to this basic scheme, other tiles were crafted in specialized shapes: tegulae with holes cut out to provide ventilation or lighting, molded antefixes to add decorative elements to the edge of a roof, and tubular box tiles to conduct hot air through hypocaust heating systems.⁹ There is thus wide variation in tile form and use.

Tiles were generally made from terracotta, similar to the material used to make amphorae, dolia, and coarsewares; indeed, excavation at kiln sites makes it clear that tiles and coarse vessels were sometimes manufactured in the same place (Appendix B, figure 7).¹⁰ This clay was heavily tempered with material ranging from sand to grog (small

⁷ Peter Warry, *Tegulae: Manufacture, typology, and use in Roman Britain*, BAR British Series 417 (Oxford: Archaeopress, 2006), 93.

⁸ Örjan Wikander, *The Roof Tiles*, vol. 6 of *Acquarossa: Results of Excavations Conducted by the Swedish Institute of Classical Studies at Rome and the Soprintendenza alle Antichità dell'Etruria Meridionale* (Stockholm: Astrom Editions, 1986), 132.

⁹ Brodribb, *Roman Brick and Tile*, 19-21.

¹⁰ For example, excavations at Metaponto have uncovered a workshop with side by side kilns for tile and pottery: Joseph Carter, "Rural Architecture and Ceramic Industry at Metaponto, Italy, 350 – 50 B.C.," in *Roman Brick and Tile: Studies in Manufacture, Distribution, and Use in the Western Empire*, ed. Alan McWhirr, BAR International Series 68 (Oxford: B.A.R., 1979), 45-64.

fragments of fired clay), and typically fired at 600-800°C in an oxidizing environment that gave it a characteristic range of colors from beige to orange to red-brown.¹¹ The question of how raw clay was shaped into tile has been addressed in several previous studies,¹² and while some specific details are disputed (and likely varied between workshops), the general process is clear. To form imbrices, sheets of clay were draped over curved wooden formers and allowed to dry until leather-hard (Appendix B, figure 4). Tegulae were somewhat more difficult to shape. First slabs of clay were pressed into a rectangular mold, often with a thin layer of sand or gravel as a parting agent to prevent the clay from sticking to the bottom. Any excess that spilled over the sides was scraped away, and the profiles of flanges were either cut out with a tensioned wire or shaped by hand (Appendix B, figure 3). Upper and lower cutaways may have been scooped out with knife or wire, or formed by small block-like inserts in the mold. The flat surfaces were then smoothed with a wooden striker, and the tile was left to dry and harden before firing. This process led to considerable variation in the forms of flanges and cutaways ; it also left characteristic markings on the surfaces of the tile that persist after firing, making it easier to reconstruct manufacturing methods.

In addition to tool traces, tiles – primarily tegulae – sometimes bear other markings. Finger tracks are some of the most common. In some cases they seem to be unintentional: grip marks on a tile handled while the clay was still wet, or a long groove left along the base of the flange as it was being shaped (Appendix B, figure 5).¹³ Others were certainly left

¹¹ Chandra L. Reedy, *Thin-Section Petrography of Stone and Ceramic Cultural Materials* (London: Archetype Publications Ltd., 2008), 111-113, 224.

¹² To name a few, from which this description is taken: Warry, *Tegulae: Manufacture, typology and use in Roman Britain*; Wikander, *The Roof Tiles*, 104-108; Tony Rook, "Tiled Roofs", in *Roman Brick and Tile: Studies in Manufacture, Distribution, and Use in the Western Empire*, ed. Alan McWhirr, BAR International Series 68 (Oxford: B.A.R., 1979), 295-302.

¹³ Brodrigg, *Roman Brick and Tile*, 125.

deliberately: for example, the curved arcs termed “signatures” that appear on the lower edge of some tegulae (Appendix B, figure 2).¹⁴ Nonhuman animals also made marks on tegulae, walking across their flat upper surfaces as they were lying out to dry.¹⁵ More rarely, tiles may bear writing. Stamped labels were common on Roman British tiles, which were often produced by or for the military, identifying the legions to which they belonged (Appendix B, figure 6).¹⁶ On occasion tile-makers would leave graffiti on their work. A particularly poignant example comes from Piettrabondante, where a bilingual inscription (in Latin and Oscan, the language of the Samnites) accompanies the imprints of two small pairs of shoes:

Delftri, the slave of Herreneis Sattis, signed this with her foot.

Amica, the slave of Herreneis, signed this while we were laying the tile out to dry.¹⁷

Such markings permit a detailed exploration of the tools, personalities, and environments by which tiles were shaped.

While the fundamentals of tile formation and use are known, the social and economic aspects of tile manufacture and distribution have long gone unexplored. Little research has been done to determine who made tile, how specialized tile manufacture was, and whether it was a full-time occupation or intermittent, seasonal work. Nor is it known how tiles were commonly sold and distributed. Since tiles were large, heavy utilitarian items employed in massive quantities, it is generally understood that they must have been produced within a small radius of a building site; whether this meant an abundance of small, scattered tile workshops or traveling tile-makers who used local clays is unclear, and

¹⁴ Ibid., 99-100; Warry, *Tegulae: Manufacture, typology and use in Roman Britain*, 90.

¹⁵ Brodrigg, *Roman Brick and Tile*, 125-6.

¹⁶ Ibid., 117; Warry, *Tegulae: Manufacture, typology and use in Roman Britain*, 74-89.

¹⁷ Kane et al., *Sangro Valley Project Field Manual 2011*, 16.

may well have varied in different areas and time periods. Either way, the specifics of tile manufacture – where raw materials were obtained, how workshops were structured, and how products were distributed – present an opportunity to reconstruct aspects of ancient ceramic and construction economies on a regional scale.

Why an archaeometric analysis of tile?

Although it has the potential to answer significant archaeological questions, and despite – or perhaps because of – its abundance, classical archaeologists have paid little attention to roof tile. A few major studies have been conducted (most notably by Gerald Brodrigg in the 1970s and Peter Warry in the 2000s)¹⁸ in Roman Britain, where many unbroken tiles have been found and the widespread presence of stamps offers valuable clues about the who and where of tile production and distribution. By and large, however, most archaeological projects weigh tile in bulk and redeposit it in a trench or banish it to the depths of a storeroom without further study. This is true of the Sangro Valley Project, where seventeen seasons of survey and excavation have yielded over 5.5 tons of tile that has received little documentation or critical study.

The SVP tile assemblage presents a challenge even to an experienced ceramicist: a massive collection of fragments in very heterogeneous coarse fabrics. However, the potential benefits of studying them are great: these may be valuable artifacts to shed light on little-understood regional trends. Because roof tiles were produced and distributed on a relatively local scale, they offer unique insights into the ceramic economy of the Sangro

¹⁸ Brodrigg, *Roman Brick and Tile*; Warry, *Tegulae: Manufacture, typology and use in Roman Britain*.

Valley during a time of great change, as the area historically dominated by the Samnites became a part of the Roman Empire. It is significant that the Sangro Valley Project's tile assemblage draws from two private rural sites of different periods, as well as a larger public religious site, offering insights into a diverse range of human activities and socioeconomic contexts throughout time. The study of roof tile may thus be significant for understanding the internal dynamics of ancient communities in the Sangro Valley, and how they responded to new cultural and economic pressures by maintaining or altering traditional manufacturing processes, trade connections, and resource use.

To address these broad questions, it is first necessary to identify and characterize the major tile fabrics found in the Sangro Valley. This will make it possible to describe and compare assemblages from different sites, identify correlations between composition and morphology, compare tile fabrics with other regional ceramics, and investigate clay provenance. The detailed characterization of tile fabrics lays an essential foundation for exploring the organization of ceramic production in ancient communities. This study, therefore, has three goals:

1. To identify and characterize the major fabric types of tiles from the SVP's excavations at Monte Pallano, Acquachiara, and San Giovanni, based on inclusions and on clay matrix.
2. To test the ability of macroscopic examination to determine meaningful differences between tile fabrics.
3. To collect comparative data about samples of regional coarsewares and local clays in order to develop hypotheses about clay provenance and the relationships between

different regional ceramic industries.

The intended outcomes of this work are a definitive fabric sequence for the identification and description of tiles in the field, and a corpus of data that can be applied to questions of provenance, manufacture, and distribution in order to understand the exploitation of clay resources and the economy of tile in the area surrounding Monte Pallano during the Roman period.

The question of tile fabric is best addressed through the methods of archaeometry: the application of the physical sciences to archaeological materials. The influence of geology on archaeology in the early years of the discipline has led to abundant crossover between the two fields, and geological and chemical methods have long been essential techniques for the study of ancient materials – from petrographic studies of classical marbles in the nineteenth century, to modern use of neutron-activation analysis. Archaeometric methods have also become critical to provenance studies, which seek to identify distinct characteristics of ceramics and other materials that are specific to their origins.

In the context of this study, archaeometry offers an objective way of testing the validity of fabric sequences developed by macroscopic examination, providing quantitative insights into fine details of temper types and clay compositions that are not visible to archaeologists in the field. In addition, many archaeometric techniques of sampling and analysis may be applied easily to ancient tiles without doing undue harm. The fragmentary nature of the SVP tile assemblage is an obstacle to studies based on morphology, since no items are complete enough to ascertain their original shape and full dimensions, and most

lack features such as flanges and cutaways. However, almost all tile fragments are more than sufficiently large to be sampled for archaeometric study; and given tile's status as a coarse, utilitarian ware excavated in bulk, with low perceived value, the risk posed by destructive analytical methods is minimal. Once samples have been removed they may be analyzed with little or no preparation or treatment, depending on the technique selected, and the same samples may be subjected to multiple analyses and then retained for future study. Archaeometry is a relevant, useful, and practical framework for an investigation of ceramic fabrics, and well-suited to the SVP tile assemblage.

This study focuses specifically on the analytical potential of petrographic thin-sectioning and x-ray fluorescence, two archaeometric techniques that are widely used in archaeological ceramic studies. In petrographic thin-sectioning, a paper-thin slice of a ceramic sample is mounted on a slide and viewed with a polarizing microscope in order to characterize mineral inclusions and the surrounding clay mass. X-ray fluorescence, meanwhile, is a nondestructive method for quantifying major, minor, and some trace chemical constituents of a sample. These two methods are therefore complementary techniques that make it possible to study many different aspects of tile fabrics, supplementing the results of macroscopic examination with mineralogical and geochemical data. The following chapter will describe the scientific principles behind these techniques and the statistical methods necessary to interpret their output, and explain what the resulting data can reveal about tile in the ancient Sangro Middle Valley.

Chapter 2: Materials and Methods

Materials

Ceramic building material, or CBM, refers to all forms of tile and brick used as architectural elements in the ancient world. CBM for this study came from excavations at all three of the Sangro Valley Project's sites, as well as from survey and test pits on Monte Pallano during Phase I of the project. Altogether, 364 pieces have been individually documented, with 101 set aside for petrographic and/or chemical analysis. All CBM recovered has been fragmentary, and at all three sites the majority of pieces found were flat. These most likely come from broken tegulae, but may include some brick. A substantial minority of pieces were tegula flanges, with much scarcer amounts of imbrex and clearly identifiable brick.

Acquachiara

	Tegula	Imbrex	Brick	Flat	Grot	Total
Bulk weight (kg)	401.4	40.3	0.0	362.2	407.5	1211.4
Bulk count	572	265	0	911	NR	1748
% saved (by weight)	14.25	6.95	--	7.65	0.00	7.24
% saved (by count)	6.99	1.89	--	4.39	0.00	4.86
% documented (by weight)	14.25	6.95	--	7.65	0.00	7.24
% documented (by count)	6.99	1.89	--	4.39	0.00	4.86
% analyzed (by weight)	3.14	0.00	--	2.54	0.00	1.80
% analyzed (by count)	2.45	0.00	--	0.99	0.00	1.32

Table 1: CBM excavated at Acquachiara (2007, 2009)

Assemblage. The assemblage of CBM excavated at the Acquachiara site contained

entirely fragmentary roof tile, with no identifiable brick. In the field all tile was grouped by context, and pieces of imbrex, tegula, and flat tile were separated, counted, and weighed. Any pieces too badly broken to identify were set aside as grot; these were weighed but not counted. After bulk quantification, over 90% of the tile was reburied.

Study samples. Although most tile was redeposited, 85 fragments (constituting 7.24% of the total assemblage by weight and 4.86% by count) were saved for further study. These were a nonrandom sample selected to represent the diversity of forms and fabrics found throughout the trench. Each piece was then documented individually and a standard set of information was recorded, including weight and dimensions, color, tegula flange morphology, and distinctive surface features (see the forms reproduced in Appendix C). Based on the procedures of macroscopic analysis described below, a tentative clay fabric series (Appendix C) was developed and each tile was either assigned to one of nine fabric groups or, if they did not appear to fit into any of the fabric categories, set aside as indeterminate. Distinctive markings (such as finger or animal prints) and significant morphological features (such as tegula flanges and cutaways) were photographed.

Samples for analysis. Subsampling for petrographic and chemical analysis was done on the basis of fabric. From each fabric group two pieces were selected for sampling: one that was thought to be representative of the characteristics that defined that group, and one that was chosen randomly. In addition, all pieces that were marked as indeterminate were also sampled. Together these constituted 1.80% of the assemblage by weight (24.86% of the study samples) and 1.32% by count (27.16% of the study samples). Blocks measuring approximately 3x3x5 cm were removed and thin sections made, and all samples have been

both examined petrographically and analyzed via x-ray fluorescence.

Monte Pallano

	Tegula	Imbrex	Brick	Miscellaneous / Rubble	Flat	Total
Bulk weight (kg)	139.64	26.39	10.34	537.627	*	574.35
Bulk count	404	306	23	15981	*	16310
% saved (by weight)	NR	NR	NR	NR	NR	NR
% saved (by count)	NR	NR	NR	NR	NR	NR
% documented (by weight)	NR	0.00	0.00	***	NR	NR
% documented (by count)	2.97	0.00	0.00	***	[5]**	0.10
% analyzed (by weight)	NR	0.00	0.00	***	0.00	NR
% analyzed (by count)	1.24	0.00	0.00	***	0.00	0.03

Table 2: CBM found at Monte Pallano, SVP Phase I (1994-1998)

NR: Not recorded

* Flat tiles were not identified in the field; it is unclear whether they were counted as tegula or miscellaneous.

** Since the bulk weight and count of excavated flat fragments are not available, these numbers are raw counts rather than percentages.

*** All tile was classified as either flat, tegula, or imbrex before documentation and analysis.

	Tegula	Imbrex	Brick	Flat	Unclassified	Total
Bulk weight (kg)	2658.15	119.41	0.00	*	182.27	2777.56
Bulk count	5355	849	0	*	1834	6204
% saved (by weight)	NR	NR	--	NR	NR	NR
% saved (by count)	NR	NR	--	NR	NR	NR
% documented (by weight)	NR	NR	--	NR	***	NR
% documented (by count)	1.05	3.65	--	[102]**	***	3.05
% analyzed (by weight)	NR	NR	--	NR	***	NR
% analyzed (by count)	0.11	0.24	--	[28]**	***	0.58

Table 3: CBM excavated at Monte Pallano, SVP Phase II (1999-2005)

NR: Not recorded

* Flat tiles were grouped with tegula flanges in the field.

** Since the bulk weight and count of excavated flat fragments are not available, these numbers are raw counts rather than percentages.

*** All tile was classified as either flat, tegula, or imbrex before documentation and analysis.

Assemblage. As the tables above suggest, the CBM recovered from Monte Pallano is

both substantially more abundant and substantially more complex than that from

Acquachiara, perhaps reflecting the nature of the Monte Pallano site as a more densely

settled public area. The Monte Pallano tiles included in this study came from excavations at the start of Phase II of the Sangro Valley Project, as well as some specimens from survey and test pits during Phase I – over a decade of field work in all.¹⁹ Since methods for processing tile varied widely over this period, it is difficult to provide a comprehensive picture of the assemblage. The data given here should be understood as approximations, and it has been noted where missing records or reclassified material obstruct a full understanding of the data.

In general, tile found at Monte Pallano was separated by survey unit, test pit, or excavation context, and classified as either imbrex or tegula. There are two principle sources of confusion in this procedure: the treatment of flat tile, and the composition of unsorted tile. During Phase II, flat tiles were sorted with tegula flanges; this may have been the case in Phase I as well, or they may have been classified as miscellany instead. Bulk quantification records from both phases include categories for tile that was not sorted – a large quantity of “miscellaneous/rubble” from Phase I, and a smaller quantity of unclassified material from Phase II. It is unclear whether these categories are strictly grot, include flat tiles, or are catch-all classifications used when time did not permit adequate sorting in the field.

Once sorted, tiles were counted and weighed in bulk. In some cases only a 50% sample was weighed and counted; to produce the tables above these data were simply doubled to approximate the total. Additionally, in a small number of contexts (containing, by weight 3.23% of tegula, 9.00% of imbrex, and 1.12% of unclassified material) tile

¹⁹ These data are assembled from Louise Harrison's contribution to the Sangro Valley Project's 1998 Interim Report, which provided bulk quantification data for the four years that comprise Phase I, and records from the Sangro Valley Project's 1999-2005 database.

fragments were not counted, just weighed. No effort has been made to approximate the number of uncounted fragments based on weight. Thus, the tabulated data above are only approximate, and the counts given are certainly lower than the true total. After quantification, the overwhelming majority of the material was redeposited.

Study samples. It is unclear exactly how much tile from Monte Pallano was saved, but the quantity is estimated to be less than 5% of the material from Phase II, and less than 1% of that from Phase I. Due to the significant presence of decorative architectural terracottas in the Phase II excavations, from some contexts a substantial amount of tile was saved, including many small fragments. For this reason it was both impossible and undesirable to document each specimen, and so the only pieces studied individually were those that were well-preserved enough to yield at least one complete measurement, and were also sufficiently large to be sampled for physical analysis. These amounted to approximately 0.10% by count of the Phase I material, and approximately 3.05% by count of the Phase II material.

Initially, tiles from Monte Pallano were documented as those from Acquachiara had been, and a fabric series was developed (see Appendix C). Ultimately, though, the exigencies of time made it impossible to maintain this standard of documentation for every specimen. Many pieces were not documented in detail, but simply measured and assigned to a fabric group – hence the absence of weight-based percentages in the tables above. As at Acquachiara, distinctive markings and significant morphological features were photographed.

Samples for analysis. Tiles from Monte Pallano were sampled for further analysis

based on fabric group, following the same procedures applied to the assemblage from Acquachiara. All in all, 0.03% by count of the Phase I material (30% of the study samples) and 0.58% by count of the Phase II material (19.02% of the study samples) was sampled; these pieces have been examined petrographically and subjected to x-ray fluorescence.

San Giovanni

	Tegula	Imbrex	Brick	Flat	Grot	Total
Bulk weight (kg)	272.5	47.0	147.5	426.0	190.5	1083.5
Bulk count	568	299	371	1577	--	2815
% saved (by weight)	16.29	8.09	7.86	0.70	0.00	5.80
% saved (by count)	6.87	5.35	3.50	0.32	0.00	2.59
% documented (by weight)	11.45	3.19	4.81	0.70	0.00	3.95
% documented (by count)	2.99	1.34	2.43	0.32	0.00	1.24
% analyzed (by weight)	4.84	4.89	3.05	0.00	0.00	1.85
% analyzed (by count)	3.87	3.68	2.96	0.00	0.00	1.56

Table 4: CBM excavated at San Giovanni (2011)

Assemblage. Although the CBM excavated from San Giovanni is mainly fragments of imbrex and tegula, it also includes significant quantities of brick and of box tile. This immediately sets it apart from the assemblages found at Acquachiara and Monte Pallano, in which brick is very rare and box tile nonexistent. Pieces of brick could not always be distinguished from flat tegula fragments, as discussed above, but they could sometimes be identified by the presence of a finished corner without a flange or by distinctive finger traces running along the diagonal; other pieces were counted as brick simply because their thickness would be improbable for a tegula. The shapes of the largest fragments suggest that the original bricks were square, and one had a complete side of approximately 27 cm in length, indicating that these were likely *pedales* (ca. 280 x 280 mm).²⁰ The San Giovanni

²⁰ Brodribb, *Roman Brick and Tile*, 152.

excavations also yielded a few pieces of box tile, lending credence to the hypothesis that the structure at one point had a hypocaust heating system; these tiles were recorded as small finds and thus were not included in this study.

All CBM encountered during excavation was removed and grouped by context, then separated by type (tegula flange, imbrex, brick, or flat), weighed, and counted in the field. Fragments too small to be assigned to a type were set aside as grot; these were weighed only. The overwhelming majority of CBM was then redeposited, with samples removed for further study and analysis.

Samples for study. A small portion of the CBM excavated from San Giovanni (5.80% by weight, 2.59% by count) was retained for further study. Study samples were separated in the field in order to represent the range of clay fabrics (as assessed by macroscopic examination, described below) and tegula flange shapes found in the assemblage as a whole, or because they featured particularly unusual markings such as fingerprints or hoof marks, or because they offered a complete dimension for measurement. All study samples were brought back to the house for processing and documented as the study samples from Acquachiarra and Monte Pallano had been (see form in Appendix C). Those pieces that were selected for their morphology or markings (by weight, 3.95% of the total assemblage and 68.10% of the study samples; by count, 1.24% of the total assemblage and 47.88% of the study samples) were photographed and placed in storage.

Samples for analysis. A subset of the study samples (by weight, 1.85% of the total assemblage and 31.90% of the study samples; by count, 1.56% of the total assemblage and 60.23% of the study samples) were set aside as samples for petrographic and geochemical

analysis. These pieces bore no distinctive markings but were intended to represent the range of clay fabrics found at the site, as assessed by macroscopic examination, and were large enough to be subsampled. Basic macroscopic observations about inclusion types and percent coverage were entered into the database (see form in Appendix C), and ca. 3x3x5 cm samples of each piece were removed. These samples have been analyzed via x-ray fluorescence and are currently being prepared for thin-sectioning.

Sampling and representation

At all three sites, the statistical population of interest – all tile used at the site during ancient periods of settlement and use – was subsampled numerous times. The likely presence of post-depositional activity means that by the time archaeological work began, some of the original CBM had already been lost: for example, it may have been removed and carried away for use on later buildings. This, combined with incomplete excavation, means that the assemblage of tile recovered during archaeological work does not include all of the tile that was originally present, and is not necessarily representative of that whole; it is difficult to estimate what the original quantity of tile may have been. After excavation the surviving assemblage was sampled twice, first to remove material for study and then to identify a smaller quantity of tiles for analysis. As the tabulated summaries above show, these analytical samples only account for between 0.03% and 1.85% of the total tile found.

The strategies applied to draw samples for study and analysis are best described as purposive or judgmental: tiles were not selected randomly, but were chosen to provide

illustrative examples of the most common forms and fabrics present, as well as any rare or unusual features. For archaeological work, this has its advantages: it ensures that all significant types are represented in the collection of study materials, and that the objects with the greatest potential to yield new information are saved. However, it also places logistical limitations on the inferences that can be drawn. Because the samples were not random, the resulting body of material is not statistically representative of the original population or the archaeological assemblage.²¹ It is thus meaningless to state that based on these study samples a certain tegula flange shape is more common than another, or to discuss the relative prevalence of different fabrics by context.

The non-representative nature of this collection places a significant restriction on the data obtained from these tiles. Of course, there is still much to learn even from a non-random sample, and for the purposes of this study, the benefits of a purposive sample were thought to outweigh the limitations. Significant logistical factors that prevent rigorous random sampling: the SVP's work has yielded over 5.5 tons of CBM, and the project simply does not have the staff resources, storage space, or shipping capacity to study a random sample that is large enough to be representative with a sufficiently low margin of error. Moreover, the goals of this study are to identify and characterize the fabrics found at each site and compare them to local clay sources, not to produce a quantitative summary of the amounts of each fabric. Therefore, it is more important to ensure that the sample includes at least one specimen of each fabric than to produce a representative sample from each site

²¹ For a full discussion of issues related to purposive sampling versus random sampling in archaeology and archaeometry, see Clive Orton, *Sampling in Archaeology*, Cambridge Manuals in Archaeology (Cambridge: Cambridge University Press, 2000), 1-3; and Byron Kratochvil, "Sampling and sample preservation for trace element analysis", in *Sample Preparation for Trace Element Analysis*, ed. Zoltan Mster and Ralph E. Sturgeon (Boston: Elsevier, 2003).

and context. Purposive sampling ensures that particularly rare fabrics that may not be included in an insufficiently large random sample are selected for study, even at risk of over-representation – and indeed, sometimes the most unusual specimens contain more valuable archaeological information than the most abundant ones. It was therefore deemed both logistically necessary and advantageous to use purposive sampling techniques, even at risk of producing a non-representative sample.

Methods

The past few decades have seen a great proliferation of techniques for the archaeometric analysis of ceramics and other materials. Methods for this study were selected to provide complementary perspectives on different aspects of tile composition, within the budget and time-frame of the study. Concerns such as minimum sample size and sample destruction were also taken into account. Following macroscopic examination in the field to develop a preliminary fabric series, samples were subjected to petrographic thin-sectioning to identify their major mineral constituents, and x-ray fluorescence to obtain semi-quantitative measurements of the concentrations of five trace elements: Rb, Sr, Y, Zr, and Nb. The combination of these two methods allows for in-depth consideration of two different perspectives on tile composition, reflecting diverse aspects of manufacture and use.

Macroscopic analysis

In macroscopic fabric analysis, ceramic materials are examined at a fresh break in order to determine characteristics of the clay matrix and inclusions. This work is usually done by eye, but sometimes with minimal magnification, such as a hand lens. Most studies of the composition and provenance of archaeological ceramics begin with macroscopic analysis since it can be performed in the field quickly and easily, with very little equipment and minimal specialized training; with relatively little effort sherds or fragments can be separated into groups and a preliminary fabric series devised, as was done with the tiles from Acquachiara and Monte Pallano. This analysis was based on the following attributes:

Color. The color of fired ceramics is due to the behavior of certain elements and inclusions – primarily iron and organic material – under specific firing conditions. Organic material customarily gives clay a dark gray color, while different forms of iron may appear as rust-red or very dark brown. When clay is fired in an atmosphere rich in free oxygen the carbon in organic inclusions is oxidized, as are iron compounds, imparting a red or yellow color to the finished product. Under oxygen-poor conditions these components are reduced rather than oxidized, and the resulting ceramic is dark brown or black. Ceramics may also show layers of alternating colors, an effect of impartial oxidation.²² Colors can be described in a standardized way with the use of Munsell charts, which assign codes to colors based on their hue (the wavelength of light producing that shade), value (how light or dark the shade

²² Prudence Rice, *Pottery Analysis: A Sourcebook* (Chicago: University of Chicago Press, 1987), 333-5; Clive Orton, Paul Tyers, and Alan Vince, *Pottery in Archaeology*, Cambridge Manuals in Archaeology (Cambridge: Cambridge University Press, 1993), 68-9.

is), and chroma (degree of saturation).²³ At Acquachiara and Monte Pallano, tiles fell into three major color groups: 7.5 YR 8/3, 10 YR 7/3, and 5.6 YR 7/6, 7/4, and 7/3. Though Munsell charts were not available to document the bricks and tiles from San Giovanni, they appear to fall into these color ranges as well.

Hardness and feel. The feel of a ceramic, determined by rubbing the thumb across a fresh break, describes how smooth, rough, or powdery a fabric is.²⁴ Hardness describes the ability of a material to resist abrasion; greater hardness may indicate a higher firing temperature or a more reducing atmosphere during firing. It is measured in a standardized way using the Mohs scale, in which minerals of known hardness are drawn across a piece of ceramic to see whether they can scratch the surface. Though this ordinarily requires a binocular microscope and a set of standard minerals, other items of known hardness, such as a fingernail, a copper wire, and a steel blade can also be used.²⁵ In documenting tiles from the SVP, those abraded by a fingernail were described as “soft”, with hardness below 2 on the Mohs scale. Those abraded by a copper coin were “moderately soft” (between 2 and 3.5), and by a steel knife, “moderately hard” (between 3.5 and 6; tiles that could not be abraded by a steel knife were “hard” (above 6). Orton, Tyers, and Vince note that hardness is rarely a defining feature of ceramic fabrics,²⁶ and this is certainly true of the SVP tiles: nearly all were moderately hard.

Inclusions. The term “inclusions” refers to all visible particles and features in a ceramic fabric that are larger than clay minerals (that is, greater than two micrometers in

²³ Rice, *Pottery Analysis: A Sourcebook*, 339-341.

²⁴ Orton, Tyers, and Vince, *Pottery in Archaeology*, 70.

²⁵ Rice, *Pottery Analysis: A Sourcebook*, 353-6; Orton, Tyers, and Vince, *Pottery in Archaeology*, 69.

²⁶ *Ibid.*

diameter). This includes voids, as well as grains naturally present in the clay and materials added by humans as temper – which frequently cannot be distinguished from each other.²⁷ Though many inclusions are too small to see, those that are visible to the naked eye or under a hand lens may be characterized by properties such as frequency, sorting, color, and size.²⁸ In recording tiles from the Sangro Valley Project, frequency and sorting were classified by reference to standardized charts,²⁹ and size range was given by specifying the diameters (or longest dimensions) of the largest and smallest visible inclusions, to the nearest tenth of a millimeter. Most often specific inclusions were distinguished based on their color, but particularly distinctive minerals (such as mica and carbonates) were identified by name where possible.

The SVP tile fabric sequences are based on the texture of the clay matrix and the density, sorting, and color of inclusions. It was hypothesized that these variables relate to tile-makers' choices and actions in selecting a clay source and altering the raw clay during production (for example, levigating and tempering). Color and hardness – the most striking observable features of fired clay – were not treated as significant characteristics in developing the fabric sequences, since they reveal more about firing environment than clay provenance. Within each sequence, fabrics were defined as narrowly as possible, with the goal of attaining maximum analytical precision: it is easier to combine similar fabrics than to split a fabric grouping that has been found to be too broad.

The Acquachiara fabric sequence (Appendix C) contains nine types distinguished by

²⁷ Ibid., 70-1.

²⁸ Ibid., 139.

²⁹ For frequency: Munsell Color Company, *Munsell Soil Color Charts* (New Windsor, NY: Munsell Color, 2000). For sorting: Orton, Tyers, and Vince, *Pottery in Archaeology*, 239.

the inclusions that they contain, and primarily by variations in the amounts of iron oxide and calcareous material. The Monte Pallano fabric sequence (Appendix C) was developed differently; it contains eleven distinct fabrics, grouped into three broad families. Groups B and C are characterized by the presence and absence, respectively, of calcareous material, and contain subgroups that resemble Acquachiara fabrics 1 through 4. Group A contains fabrics with a wide variety of extremely dense, gritty inclusions, markedly different from the material found at Acquachiara. Also different from Acquachiara is the presence of mica in many fabrics, especially B2. No fabric sequence has been developed for the tiles from San Giovanni.

Though macroscopic analysis is fundamental to the processing of archaeological ceramics, there remains some question as to how meaningful the results are. As the use of archaeometric methods increases, the results sometimes contradict the patterns observed in visual examination. This problem has been noted before in the archaeological literature -- as Örjan Wikander wrote in his technical study of tiles from Acquarossa:

Tiles whose fabrics appear almost identical to the eye may prove totally unrelated in technical examinations, while fragments which seem to differ considerably in clay, temper, and firing may in fact belong to the same tile. It is, thus, my belief that few reliable conclusions can be drawn from visual inspections alone.³⁰

For this reason, macroscopic fabric analysis is increasingly being performed not as a stand-alone technique, but as a preliminary tool for the initial separation of fabrics, with results to be evaluated by other techniques.

³⁰ Wikander, *The Roof Tiles*, 100.

Ceramic petrography

Petrographic thin-sectioning capitalizes on the optical properties of polarized light in order to describe the clay matrix of a ceramic sample and to identify the inclusions present. In the 1940s, Anna Shepard's groundbreaking work on pottery from New Mexico demonstrated that petrographic techniques from geology could be applied to ceramics to separate wares and to trace trade routes. Due in large part to her work, petrography has become a basic element of ceramic technical studies.³¹ Since it provides a comprehensive view of a sample under magnification and may yield quantitative data about percent density and size distribution, it is a powerful tool to support or undermine observations made macroscopically. It can thus lead to more accurate and scientifically rigorous characterization of fabrics.

Though thin-sectioning cannot be performed in the field, the necessary equipment and facilities can be found at nearly any geology laboratory, making the technique widely accessible to archaeologists. To prepare a sample for examination, a piece of ceramic is impregnated with epoxy, mounted on a glass slide, and then cut and ground down to a thickness of 30 μm .³² The resulting thin section is viewed with a petrographic microscope, which produces transmitted polarized light – that is to say, waves of light travel through one or more polarizing films that filter them based on their directions of vibration, and this light is passed through the specimen rather than shined on it.³³

³¹ Sarah E. Peterson and Philip P. Betancourt, *Thin-Section Petrography of Ceramic Materials*, INSTAP Archaeological Excavation Manual 2 (Philadelphia, PA: INSTAP Academic Press, 2009), 3-4.

³² James B. Stoltman, "The Role of Petrography in the Study of Archaeological Ceramics", in *Earth Sciences and Archaeology*, ed. Paul Goldberg, Vance T. Holliday, and C. Reid Ferring (New York: Kluwer Academic / Plenum Publishers, 2001), 298-299.

³³ *Ibid.*

As light moves through a thin section, its interaction with the crystal structures of inclusions creates predictable optical effects that make it possible to identify specific minerals. These properties include degree of transparency and relief; display of interference colors, which appear due to retardation of light passing through a crystal; and changes in appearance when rotated, which indicate the symmetry of the crystal.³⁴ Because clay particles are below 2 μm in diameter, they cannot be resolved with a petrographic microscope and will appear as an undifferentiated mass, but it is possible to note the color of the clay matrix; its texture may be described using terminology borrowed from soil micromorphology.³⁵ Thin sections also show pores and voids in the fabric, which may result from a number of well-documented manufacturing practices.³⁶ Any and all of these features may be useful in differentiating ceramic wares.

Thin sections may be documented and interpreted qualitatively or quantitatively. The goals of qualitative examinations are to characterize the clay matrix and to identify inclusions that are 2 μm in diameter and larger.³⁷ As in macroscopic analysis, the degree of sorting and rounding of major categories of inclusions can be assessed by comparison with standard charts. In some archaeological scenarios, these observations alone may be sufficient to separate groups of archaeological significance: for example, Anna Shepard's groundbreaking petrographic work on ceramics from the La Plata Valley showed that culinary and non-culinary wares had qualitatively different types of temper.³⁸ In theory, it is

³⁴ Rice, *Pottery Analysis: A Sourcebook*, 376-9. A comprehensive explanation of these phenomena can be found in William D. Nesse, *Introduction to Mineralogy* (New York: Oxford University Press, 2000).

³⁵ Stoltman, "The Role of Petrography in the Study of Archaeological Ceramics", 299; Reedy, *Thin-Section Petrography of Stone and Ceramic Cultural Materials*, 175-6.

³⁶ Peterson and Betancourt, *Thin-Section Petrography of Ceramic Materials*, 13-14; Reedy, *Thin-Section Petrography of Stone and Ceramic Cultural Materials*, 173-4.

³⁷ Stoltman, "The Role of Petrography in the Study of Archaeological Ceramics", 301.

³⁸ *Ibid.*, 309-311.

also possible to use qualitative thin section data to match ceramics to raw clays, though this is much more complex: it assumes that the analyst is able to distinguish tempering material from inclusions naturally present in the clay, which is rarely the case. Sometimes it is clear that a material has been added by humans, as when grog (fragments of pre-fired clay), shell, or volcanic ash appear in a specimen. Other inclusions, particularly sand-sized grains, are much harder to classify, requiring detailed knowledge of local clay resources.³⁹ For this reason, it is substantially easier to identify fabric groups qualitatively than to match ceramics with clays.

When qualitative observations alone are insufficient to answer archaeological questions, thin sections may also be documented quantitatively in order to determine the size range and area occupied by different types of inclusions. At the simplest level, percent density may be estimated visually, though the accuracy of this technique is generally mediocre: one study suggests that these estimates have a 10% margin of error.⁴⁰ More reliable figures can be obtained through point counting, in which a band or grid is superimposed over a thin section and all inclusions that fall within the band or on grid points are counted and measured to provide estimates of grain frequency and distribution. Selecting an appropriate counting method introduces complex sampling issues,⁴¹ and the technique can be extremely time-consuming, since a representative view of a single thin section necessitates individual examination of up to 400 grains.⁴² Yet this method often yields results where simple qualitative analysis is insufficient: one study was able to

³⁹ Ibid., 301; Reedy, *Thin-Section Petrography of Stone and Ceramic Cultural Materials*, 129-132.

⁴⁰ Stoltman, "The Role of Petrography in the Study of Archaeological Ceramics", 125; Reedy, *Thin-Section Petrography of Stone and Ceramic Cultural Materials*, 305-6.

⁴¹ For a thorough discussion, see Reedy, *Thin-Section Petrography of Stone and Ceramic Cultural Materials*, 125-6, or Orton, *Sampling in Archaeology*, 177-191.

⁴² Reedy, *Thin-Section Petrography of Stone and Ceramic Cultural Materials*, 125.

separate Romano-British tiles from different kiln sites based on the distribution of quartz grain sizes obtained through point-counting.⁴³

Tile thin sections from the Sangro Valley Project were analyzed by a combination of qualitative and quantitative methods. By and large, data collection followed the suggestions given by Freestone as minimum standards for documentation:

(1) a list of all nonplastic inclusions present above trace level, with relative abundance; (2) total concentration of nonplastic inclusions even if only in subjective terms (such as 'abundant' and 'rare'); (3) degree of sorting of the nonplastic inclusions, and any indication of the presence of a bimodal distribution; (4) the 'typical' grain size and grain size range; (5) an estimate of roundness; and (6) color of the clay matrix and whether or not it is birefringent.⁴⁴

Each thin section was documented on a form replicated in Appendix D. Major categories of inclusions were identified as feldspar, grog, carbonate, mica, quartz, rock, ferrous grains, or heavy minerals. Within each of these categories, percent density was estimated, size range measured, and degree of sorting, roundness, and sphericity recorded by reference to standard charts. Inclusions present in smaller quantities were noted as "<5%" or "scarce" and described as fully as possible. In addition, the color and birefringence of the clay mass and the characteristics of voids were noted. The resulting data were compiled in a spreadsheet; a condensed version is in Appendix D.

X-ray fluorescence

X-ray fluorescence (XRF) is a technique for bulk chemical analysis that provides the

⁴³ Timothy Darvill, "A Petrological Study of LHS and TPF Stamped Tiles from the Cotswold Region", in *Roman Brick and Tile: Studies in Manufacture, Distribution, and Use in the Western Empire*, ed. Alan McWhirr, BAR International Series 68 (Oxford: B.A.R., 1979), 309-332.

⁴⁴ Reedy, *Thin-Section Petrography of Stone and Ceramic Cultural Materials*, 132.

composition of major, minor, and trace elements, based on the characteristic energies that they emit when bombarded with radiation. XRF is favored among archaeologists for many reasons: the instruments are relatively easily for non-specialists to operate, analyses can be completed in a matter of minutes with minimal sample preparation, and the advent of portable XRF spectrometers means that the technique can be performed non-destructively in the field, making it an ideal method to apply to archaeological materials.

In an XRF instrument, electrons are accelerated through a cathode ray tube to collide with a target made of rhodium, releasing a beam of photons directed at the material being analyzed.⁴⁵ One of those photons may strike an electron located in one of the atoms in the sample, transferring its energy to the electron. The excited electron is then ejected from the atom, creating a vacancy in one of the atom's electron shells. When this happens an electron from a higher energy level in the same atom will descend to fill the space, releasing excess energy.⁴⁶ This process of electron excitation and transition is known as *fluorescence*, and it produces secondary radiation that travels back to the XRF instrument in the form of a photon. The energy of the resulting photon depends on the difference in energy between the two electron shells; in the $K\alpha$ transition, which is most common and most intense, an electron falls from the L shell (the second-lowest energy level) to the K shell (the lowest energy level, closest to the nucleus).⁴⁷ Because the energy difference between electron shells is specific to each element, the intensity of photons with different energies can be

⁴⁵ Ron Jenkins, *X-Ray Fluorescence Spectrometry*, 2nd ed., vol. 152 in *Chemical Analysis: A Series of Monographs on Analytical Chemistry and its Applications*, ed. J. D. Winefordner (New York: John Wiley and Sons, Inc., 1999), 4.

⁴⁶ *Ibid.*, 1-3; M. Steven Shackley, "An Introduction to X-Ray Fluorescence (XRF) Analysis in Archaeology," in *X-Ray Fluorescence Spectrometry (XRF) in Geoarchaeology*, ed. M. Steven Shackley (Springer, 2011), chap. 2, doi 10.1007/978-1-4419-6886-9_1.

⁴⁷ Shackley, "An Introduction to X-Ray Fluorescence (XRF) Analysis in Archaeology."

used to determine the concentrations of different elements.⁴⁸ This is the fundamental mechanism of XRF: stimulating the emission of *characteristic radiation* in order to determine the chemical composition of a sample.

In addition to the photons released by atoms of each element as they fluoresce, XRF also produces background, or *continuous radiation*, the broad band of energy released by x-rays that pass through the sample and decelerate without striking a photon.⁴⁹ The XRF spectrum also includes peaks due to elastic and inelastic scattering of x-ray photons within the sample.⁵⁰ To minimize background, filters may be installed to absorb source x-rays within the region of interest. For example, a “green filter”, composed of layers of 0.006” of copper, 0.001” of titanium, and 0.012” of aluminum, filters all radiation above 17.5 KeV, ensuring that all peaks that appear in that range are due to the fluorescence of the sample.⁵¹ It is also possible to apply a vacuum to the interior of the instrument in order to remove air, which can interfere with the detection of elements with low atomic number (below Ti) by absorbing the low-energy fluorescence that they produce.⁵² Both of these adjustments help to clarify the resulting data.

XRF data are presented as spectra, with peaks representing the intensity of fluorescence at various energy levels. Qualitative analysis of which elements are present can be performed by reading the wavelengths that correspond to major peaks in the spectrum, while quantitative analysis of elemental concentrations can be calculated based

⁴⁸ Ibid.; Jenkins, *X-Ray Fluorescence Spectrometry*, 5-7.

⁴⁹ Jenkins, *X-Ray Fluorescence Spectrometry*, 3-4.

⁵⁰ Ibid., 12.

⁵¹ Shackley, “An Introduction to X-Ray Fluorescence (XRF) Analysis in Archaeology”; Bruce Kaiser, “pXRF for Cultural Heritage”, workshop at the Fiske Center for Archaeological Research, University of Massachusetts – Boston (March 7-8, 2011).

⁵² Shackley, “An Introduction to X-Ray Fluorescence (XRF) Analysis in Archaeology.”

on the size of the area under each peak.⁵³ Quantitative results may be affected by the size, shape, and density of the specimen, and they require that an instrument be calibrated with a series of check samples of known concentration.⁵⁴ As an intermediary form of data interpretation, semi-quantitative analysis can compare the relative concentrations of elements in the same study, but does not produce absolute concentrations that can be compared to other materials.⁵⁵

XRF is able to detect about 80 elements with atomic numbers above 12 (magnesium). This means that the technique is useless for organic materials, since it cannot detect carbon, oxygen, or hydrogen, but is well-suited to ceramics, which are composed primarily of silicon, aluminum, calcium, iron, and potassium, with minor and trace amounts of other, heavier elements.⁵⁶ Sensitivity and detection limit vary based on instrument, sample, and element, but in general, XRF can detect concentrations as low as one part per million.⁵⁷ It is, therefore, a valuable technique for archaeologists to obtain comprehensive, quantitative data about major, minor, and trace elements found in the clay matrix and inclusions of ceramic materials.

There is some question among archaeologists over which elements are most suited to analysis. It is known geologically that some elements are more stable than others and post-depositional environment can alter the composition of geological materials. These phenomena are well-documented in clays over periods of thousands or millions of years,⁵⁸

⁵³ Rice, *Pottery Analysis: A Sourcebook*, 393.

⁵⁴ *Ibid.*, 394; Kaiser, "pXRF for Cultural Heritage."

⁵⁵ Kaiser, "pXRF for Cultural Heritage."

⁵⁶ Rice, *Pottery Analysis: A Sourcebook*, 391, 394.

⁵⁷ S. J. B. Reed, *Electron Microprobe Analysis and Scanning Electron Microscopy in Geology* (Cambridge: Cambridge University Press, 1996), 4-6.

⁵⁸ B. Velde, *Introduction to Clay Minerals: Chemistry, Origins, Uses, and Environmental Significance* (New York: Chapman and Hall, 1992), 146-163.

but are also seen – though less well-studied – in fired archaeological ceramics over shorter time periods, so that materials that have been deposited for two millennia will not necessarily have the same composition upon excavation as they did when they were first formed and used.⁵⁹ These diagenetic changes are particularly troublesome in porous, low-fired wares, since groundwater can easily seep through pores, dissolving some minerals and depositing others.⁶⁰ For example, minerals of the carbonate family (which includes limestone) are very water-soluble; from examination of SVP tiles in thin section it is clear that secondary carbonates have formed in some pores, thus altering the chemical composition that will be seen via XRF. On the other hand, elements such as zirconium, yttrium, and niobium are less likely to be deposited or leached during burial, and may therefore be more suitable indicators of provenance.⁶¹ The question of elemental stability is critical for archaeologists to consider in collecting and interpreting data about elemental composition.

While most XRF spectrometers are large, stationary machines the size of a lab bench, the past decade has seen increased interest in portable XRF (pXRF). pXRF devices are hand-held, rugged, and intended to be used with minimal sample treatment. This technology is new, and questions remain about how it compares to stationary instrumentation. One source suggests that pXRF spectrometers are capable of analyzing an area ca. 25 millimeters in diameter and 0.1 to 1 millimeters deep, but have slightly higher detection limits than stationary XRF – which is to say, the sample must contain a greater

⁵⁹ Orton, Tyers, and Vince, *Pottery in Archaeology*, 147.

⁶⁰ Norman Herz and Ervan G. Garrison, *Geological Methods for Archaeology* (New York: Oxford University Press, 1998), 268-269.

⁶¹ Kaiser, “pXRF for Cultural Heritage.”

concentration of a given element before the instrument is able to detect its presence.⁶² More recent comparative studies confirm this, finding that while data from pXRF and stationary XRF instruments are generally comparable, pXRF had somewhat higher error, higher background, and higher detection limits.⁶³ Nevertheless, pXRF holds two significant advantages for archaeologists. Because the instruments are portable, they may be used to collect elemental data *in situ* or in locations that lack access to a fully-equipped laboratory. In addition, although traditional XRF requires samples to be powdered and in some cases compressed into pellets, pXRF requires no sample preparation beyond cleaning the surface, meaning that valuable archaeological materials need not be destroyed in the process of analysis.⁶⁴ Primarily for these reasons, this study was conducted using a Bruker Tracer III-V+ pXRF spectrometer.

Materials for this study were subjected to two different XRF analyses. In the initial run, the instrument was set up with a vacuum applied and no filter installed, and materials were analyzed for 300 seconds with a voltage of 40.00 kV and a current of 23.00 μ A. These settings, dubbed “lab rat mode”, provide an overall summary of all detectable elements in the sample.⁶⁵ Following this, the vacuum was removed and a green filter installed, and materials were analyzed a second time for 600 seconds with a voltage of 40.00 kV and a current of 23.00 μ A. These settings were specifically chosen to provide optimal accuracy for measurement of rubidium, strontium, yttrium, zirconium, and niobium, five trace elements

⁶² Philip J. Potts and Philip Robinson, “Sample preparation of geological samples, soils, and sediments,” in *Sample Preparation for Trace Element Analysis*, ed. Zoltan Mester and Ralph E. Sturgeon (Boston: Elsevier, 2003), 730-732.

⁶³ Shackley, “An Introduction to X-ray Fluorescence (XRF) Analysis in Archaeology.”

⁶⁴ Potts and Robinson, “Sample preparation of geological samples, soils, and sediments,” 730-734.

⁶⁵ Kaiser, “pXRF for Cultural Heritage.”

commonly used in studies of the provenance of archaeological ceramics.⁶⁶ On most samples, only a single spot was analyzed. However, on one sample (tile 28, from Acquachiarra) three different spots were analyzed in order to establish the internal variability of the material, and ten runs of a single spot on tile 52 (from Acquachiarra) were done in order to establish the precision of the technique.

Once XRF data had been collected, semi-quantitative interpretation was deemed preferable to qualitative or quantitative techniques for several reasons. Since the lab rat analyses indicated that all samples contained the same elements, a qualitative study of the results would clearly be inappropriate. Quantitative interpretation holds many advantages, most notably ensuring that data can be compared directly to other studies performed with different equipment or even different techniques entirely. However, this requires instrumental calibration, and in the case of pXRF there is considerable disagreement as to how that should be done: some, most notably instrument manufacturers, hold that the spectrometers' factory settings (based on a technique called fundamental parameters calibration) are sufficient for the instruments to produce calibrated results out of the box,⁶⁷ while many archaeologists question whether accurate quantitative data can be obtained without empirical calibration based on check samples of known composition.⁶⁸

In light of this ongoing debate and the absence of appropriate standards for calibration, semi-quantitative analysis was selected as a technique that would allow for direct comparison of materials within this study, and limited comparison with other materials, provided they were analyzed under the same instrumental settings. To perform

⁶⁶ Ibid.

⁶⁷ Ibid.

⁶⁸ Shackley, "An Introduction to X-ray Fluorescence (XRF) Analysis in Archaeology."

this analysis, all data were normalized to the Compton peak, a feature that appears in every XRF spectrum. The Compton peak is formed by photons scattered inelastically by the rhodium target within the instrument, and is proportional to the mass of a sample; thus, normalizing to this peak adjusts spectra to account for differences in individual samples' sizes and densities.⁶⁹ The resulting data are presented as counts – the number of detected photons with energy levels characteristic of a certain element – rather than as percentages or parts per million, so although it is not possible to determine the absolute concentration of an element from this type of analysis, it is possible to compare the relative amounts of a given element, or the ratios of two elements, between samples.

⁶⁹ Ibid.; Lesley Frame, e-mail message to author, October 31, 2011.

Chapter 3: Results

As explained in the previous chapter, analytical techniques were selected in order to provide complementary views of different aspects of ceramic composition. Tiles from Monte Pallano and Acquachiarra were examined in thin section and major classes of inclusions were documented qualitatively, while x-ray fluorescence produced semi-quantitative data about the chemical composition of tiles and bricks from Monte Pallano, Acquachiarra, and San Giovanni. In addition, XRF readings for tiles from all three sites were compared with readings from sherds of coarsewares from Monte Pallano and the Via de Gasperi tombs, and samples of local clays, in order to clarify the relationships between local clays and ceramics and to identify similarities between them. This chapter presents a description of the results, and condensed data and statistical summaries; the complete raw data and plots are available on an accompanying disc.

Petrographic thin sectioning

Description of thin sections

The tables in Appendix D present condensed versions of the petrographic data from Acquachiarra and Monte Pallano. These tables show the densities of each category of inclusions, as well as the color of the clay matrix and the frequency of voids. (Complete tables that include roundness, sphericity, size range, and sorting for each category of

inclusions are available on disc.) Thin sections are organized by the fabric group to which they were assigned. In order of frequency, the most common inclusions noted in thin sections are:

Quartz. Quartz is found in every tile sample from Monte Pallano and from Acquachiara, generally in large quantities; more often than not it is the most abundant inclusion in a given sample. Quartz is the primary component of sand, which may be naturally associated with clays or added deliberately as temper; either way, its presence in ceramics decreases shrinkage and drying time, increases plasticity, and improves thermal shock resistance.⁷⁰ Unfortunately, there is no straightforward way to distinguish natural quartz from temper. A common theory is that more angular quartz is more likely to have been crushed and added deliberately by humans, but this is inconclusive evidence for tempering, since primary clays often contain angular inclusions.⁷¹ More promising is a study of Italian Bronze Age ceramics that found that a bimodal size distribution was characteristic of tempered clays, while untempered clays showed a unimodal distribution.⁷²

Quartz was found in similar levels in tiles from Monte Pallano and Acquachiara, but while quartz in Monte Pallano tiles frequently showed significant size variation with a bimodal distribution and high angularity, quartz in Acquachiara tiles was better sorted, with less size variation, and generally followed a unimodal distribution. It seems reasonable to hypothesize that the clays used to make tile for the Monte Pallano site were tempered with quartz sand, while those used at Acquachiara contained quartz from a

⁷⁰ Rice, *Pottery Analysis: A Sourcebook*, 75; Reedy, *Thin-Section Petrography of Stone and Ceramic Cultural Materials*, 137-8.

⁷¹ Reedy, *Thin-Section Petrography of Stone and Ceramic Cultural Materials*, 131.

⁷² Ibid.

different source.

Ferrous grains. Small grains of iron-rich material were found in consistent quantities in nearly every sample analyzed. Iron oxides are commonly found as a component of sand and present no significant benefit in fired ceramics, so it is likely that these originated as a natural component of the clay from which the tiles were made, or were included incidentally in the process of adding sand as quartz temper.⁷³

Mica. Mica was found in just under 75% of samples from Acquachiara, and just under 90% of samples from Monte Pallano, with remarkable uniformity: tiles generally contain up to 5% mica, almost always muscovite, with occasional biotite. Mica is commonly found in sands, and may appear in large quantities in primary clays.⁷⁴ For example, it is a major component of the multicolor clay found in the area around Monte Pallano, as discussed below.

Carbonates. Forms of carbonate commonly found in ceramics include lime, calcite, shell, and bone.⁷⁵ Carbonates were a major constituent of roughly one-third of the tiles analyzed from both Acquachiara and Monte Pallano, and were generally well-sorted and well-rounded, with density ranging from 5% to 15%. A few thin sections included microfossils, likely due to the marine origin of many clays in the Sangro Valley; as Reedy notes, these are “sensitive paleoenvironment indicators” and have been used successfully in provenance studies of Aegean ceramics.⁷⁶ However, most of the carbonate noted in thin sections was likely limestone (CaCO₃), which is prevalent in the regional geology of the

⁷³ Ibid., 138.

⁷⁴ Ibid., 138, 148.

⁷⁵ Rice, *Pottery Analysis: A Sourcebook*, 97-8.

⁷⁶ Reedy, *Thin-Section Analysis of Stone and Ceramic Cultural Materials*, 142.

Sangro Valley. In areas with calcareous geology it is common for clays to be composed of 6% carbonates or more;⁷⁷ as noted below, the two clays most common in the area surrounding Monte Pallano are both rich in carbonate.

As inclusions in ceramics, carbonates increase porosity, which would be undesirable in roof tiles meant to weather the elements.⁷⁸ In addition, when fired above 600 degrees Celsius, their decomposition can lead to “lime popping” or “lime blowing”, which causes cracking and spalling in ceramics.⁷⁹ For this reason, combined with the prevalence of carbonates in Sangro Valley clays, it is likely that most of the carbonate noted in thin sections is naturally occurring rather than temper, and it is also possible that clays were processed to remove some carbonates before they were worked.

In addition, many thin sections show rims of carbonate associated with voids in the fabric. This phenomenon was noted, to varying degrees, in 61.5% of tile thin sections from Monte Pallano and 73.9% of thin sections from Acquachiara. Since carbonates are highly water-soluble, it is common in regions with calcareous geology for carbonates to dissolve in water and then precipitate out of solution as they pass through pores in buried ceramics, accumulating over time. It is thus reasonable to conclude that these carbonates are secondary, incorporated into the tile fabric after firing, and their presence is an indication of post-depositional change that affects both the mineralogical and chemical composition of these tiles.

Grog and rock. By definition, grog is always anthropogenic; it appears as fragments

⁷⁷ Ibid., 141.

⁷⁸ Ibid., 131, 224.

⁷⁹ Ibid., 142; Rice, *Pottery Analysis: A Sourcebook*, 97-8.

of crushed sherds or deliberately-fired balls.⁸⁰ Rock, meanwhile, can be naturally occurring or added temper, and is a component of many sands.⁸¹ Since grog and argillaceous rock often appear similar in thin section,⁸² it can be difficult to distinguish them, which affected interpretation of thin sections from the Sangro Valley. By best judgment, grog appeared in 28.2% of thin sections from Monte Pallano and 56.5% from Acquachiara, while rock appeared in 48.7% of thin sections from Monte Pallano and 36% from Acquachiara. In each tile concentrations of grog and lithics seemed to vary inversely – that is, tiles that contained more grog had lower amounts of rock, and vice versa – and since both materials have similar net effects on the fired ceramic, the change in frequency from Monte Pallano to Acquachiara may reflect a change in manufacturing preferences over time. Within each thin section the densities of grog and rock ranged from 20% to scarce, with a wide variety of different types of grog and lithics appearing, as noted in the data tables.

Minor constituents. In addition to these major constituents, some minerals commonly appeared in thin sections in quantities below 5%. Feldspars – particularly plagioclase ($\text{NaAlSi}_3\text{O}_8$ - $\text{CaAl}_2\text{Si}_2\text{O}_8$), but occasionally orthoclase (KAlSi_3O_8) as well – appear in scarce quantities in 41% of thin sections from Monte Pallano and 43.5% of thin sections from Acquachiara. When added as temper, feldspars act as a flux to promote vitrification and increase the strength of the fired ceramic; this is because they have a relatively low melting point, around 1100 degrees Celsius.⁸³ However, since these tiles were fired at relatively low temperatures and show no signs of vitrification, and since feldspars are not a

⁸⁰ Reedy, *Thin-Section Analysis of Stone and Ceramic Cultural Materials*, 146.

⁸¹ *Ibid.*, 133.

⁸² *Ibid.*, 147.

⁸³ Rice, *Pottery Analysis: A Sourcebook*, 75, 97.

major constituent of tile fabrics, it is much more likely that these minerals are naturally occurring in the source clays. This would be consistent with what is known about clays from the area around Monte Pallano, as discussed below. A small selection of thin sections also contain scarce quantities of unidentified heavy minerals, which are also likely naturally occurring. These do not appear with enough frequency or regularity to draw inferences from them.

The characteristics of the clay matrices observed in thin section varied widely. Several distinctive colors and color combinations were noted – though as explained above, the color of fired ceramics is largely a function of firing conditions and cannot necessarily be read as an indicator of clay type or provenance. Some tiles were observed to have consistent streaks or patches of different colors within their clay matrix, which may indicate that they were produced by mixing two different pastes; this, in turn, may seriously impede the ability to trace tiles to their clay source. Clay matrices also included abundant voids; this is common for terracotta tiles and other coarse ceramics. While the shapes of voids were irregular, covering substantial size ranges, many tiles showed distinctive large, narrow, elongate voids. These were likely formed by the release of gases during firing.⁸⁴ Finally, it is significant that voids, streaks of color, and micas often all show distinctive horizontal alignment parallel to the base of the tile. This suggests that vertical pressure was applied while the clay was still wet, supporting the idea that tiles were shaped by stacking and compressing layers of clay within a frame.

⁸⁴ Reedy, *Thin-Section Analysis of Stone and Ceramic Cultural Materials*, 111-113.

Discussion

By and large, the suite of mineral inclusions found in tiles from the Sangro Valley is not distinctive; it is a basic assortment of minerals found in most clays and sediments, with no unusual constituents that may “fingerprint” a particular geographic location or clay source. Given the geology of the Adriatic coast, these inclusions could have been found nearly anywhere in the Sangro Valley. Despite this, in the tiles from Monte Pallano and Acquachiarra these minerals combine in diverse and complex ways: simply considering the presence or absence of different inclusions, there are twenty-four different combinations of inclusions found in sixty-four tiles from two sites. The generic nature of the inclusions, paired with the multiplicity of ways in which they combine, makes it extremely difficult to interpret the potential array of tile fabrics.

For the results of thin-sectioning to validate the fabric groups developed macroscopically, they must show more variation between fabrics than within them. Most data collection was not quantitative, and where numbers were collected, the sample sizes from each fabric were simply too small for any kind of statistical analysis. Nevertheless, from the data tables alone it is apparent that the composition varies widely both within and between fabric groups, to an extent that the boundaries between fabric groups cannot be said to be meaningful. Tiles that bear a strong resemblance to each other by eye alone are clearly different when viewed in thin section, and tiles that do look similar petrographically had not been assigned to the same fabric group macroscopically. All of this casts doubt on the viability of separating fabric groups in the field.

Thin section data also point to the existence of manufacturing practices that will make it more difficult to match tiles to clay sources. Tiles were made from tempered clay: this is clear because they contain grog, which would never be found naturally in a clay outcrop. While the inclusions of carbonates, feldspar, and heavy minerals are almost certainly features of the original clay source, other materials, such as quartz, mica, and lithics, may or may not be added temper. Since temper affects the petrographic and chemical composition of ceramics, it is necessary to be able to distinguish the temper from the original composition of the paste. It is also necessary to compensate for the effects of clay mixing and post-depositional change (such as the appearance of secondary carbonates), both of which can be extremely difficult to identify. Human handling and changes during use and burial alter the composition of fired ceramics so that they are less similar to the clays from which they were made, and this poses a substantial obstacle to archaeometric studies. The petrographic data thus provide many more questions than answers.

X-ray fluorescence

Estimating precision and variance

In analyzing the data set generated by x-ray fluorescence analysis of tiles from the Sangro Valley Project, the most fundamental question to address is whether differences in elemental composition correspond to the division of tiles into fabric groups – that is, can

XRF confirm the accuracy of the Acquachiara and Monte Pallano fabric series, and do these groups represent meaningful differences between tiles on a chemical level? Before that question can be considered, however, it is necessary to determine how reliable the data are, and which elements will be most useful for analysis. Table 1 below summarizes the results of ten consecutive analyses of a single spot using instrument settings optimized for detection of Rb, Sr, Y, Zr, and Nb, as described in Chapter 2. With perfect accuracy, the coefficient of variation⁸⁵ for each element would be 0%; these data show coefficients of variation varying from 3.91% to 7.54%, with highest precision in detecting Zr and lowest in detecting Y. Table 2 below summarizes the results of analyses of three different spots on the same sample, using the same instrument settings, in order to estimate how much elemental concentrations vary within different regions of a single tile. Y shows the most variation and Nb the least, with coefficients of variation from 1.72% to 7.41%. These figures suggest that pXRF has moderate precision when applied to samples of Sangro Valley tile, and they give an approximate idea of the internal variability of SVP tiles. A strong analysis of XRF data will give most weight to those elements that can be measured most precisely and vary least throughout a sample, when these two factors are considered together, it appears that in this case Nb and Zr are the most reliable elements for study and Y the least, with Rb and Sr falling in between.

⁸⁵ The coefficient of variation, which expresses the standard deviation as a percentage of the mean, may be interpreted similarly to the relative standard deviation.

Element	Mean net counts	Standard deviation (counts)	Coefficient of variation (%)
Rb	2597	150	5.78
Sr	14161	578	4.08
Y	1101	83	7.54
Zr	6522	255	3.91
Nb	416	22	5.29

Table 5: Approximating the precision of pXRF: ten assays of a single spot

Element	Mean net counts	Standard deviation (counts)	Coefficient of variation (%)
Rb	2833	114	4.02
Sr	12491	754	6.04
Y	1160	86	7.41
Zr	7381	299	4.05
Nb	524	9	1.72

Table 6: Approximating sample variability: assays of three spots on the same sample

Analysis of a single variable

Data were first analyzed by examining the distribution of single variables through box plots. To form a box plot, data are plotted along an axis and a box is drawn around the middle 50%, with “tails” enclosing the highest and lowest 25% of the points. Subcategories of a data set may be compared visually by plotting each individually and placing the boxes side by side. For tiles from Acquachiara and Monte Pallano, parallel box plots were formed to examine the distribution of amounts of Rb, Sr, Y, Zr, and Nb in samples, subdivided by the

fabric group to which each tile had been assigned macroscopically. The number of plots is too great to include in a print appendix, so an incomplete but particularly illustrative array of diagrams is presented in Appendix E; the complete analyses are available on disc.

For tiles from Acquachiara, the box plots show little clear separation between fabric groups (Appendix E, plots 1-3.) Group 8 is an exception: its low concentrations of Rb, Sr, Y, and Zr easily distinguish it from almost all other groups in those plots. Groups 1 and 4 also stand out due to their low concentrations of Sr, Zr, and Nb, and in the plots of Nb, group 2 – which has relatively high amounts -- is distinct from group 5, which falls much lower. Most other groups show substantial overlap, and concrete conclusions are difficult to draw due to the small number of samples in some groups⁸⁶ and the wide spread of data in others (for example, the amount of Rb in samples of group 9, which varies from 837 counts to 3425 counts).

For tiles from Monte Pallano, parallel box plots based on fabric groups showed no significant differences between groups A, B, and C, so additional plots were generated to determine the separability of the subgroups within each fabric (Appendix E, plots 4-6). In group A, all four subgroups showed substantial amounts of overlap in their concentrations of Y, Zr and Nb, but in the box plots of Rb subgroups A1 and A4 can be separated clearly, and groups A2, A3, and A4 can all be distinguished from each other based on the amounts of Sr they contain. Two samples that were tentatively placed in group A but were not assigned to subgroups consistently fall within the range of values observed in A1. Within group B, subgroup B2 consistently has lower amounts of each element than subgroup B1, though

⁸⁶ In drawing comparisons with box plots, sample sizes of $n > 5$ are desirable; the Acquachiara tile samples do not satisfy this criterion, so the resulting box plots should be interpreted with caution. (Personal communication with Jeffrey Witmer, April 2012.)

only in the cases of Zr and Nb is the difference great enough to separate them entirely. The third subgroup, which has the most members, overlaps with many other groups. An additional sample, placed in group B but not assigned to a subgroup, shows values consistently in the range for group B1. Finally, subgroups C2 and C3 consistently overlap and in the case of Nb are nearly identical, but subgroup C1 shows markedly higher amounts of most elements, especially Rb and Zr. A sample tentatively assigned to group C2 is set apart from the other members of that group by its lower Sr content and higher levels of Nb.

Perhaps the most interesting data are associated with a sample that could not be assigned a fabric macroscopically: it shows concentrations of Rb, Y, Zr, and Nb that are significantly higher than any of the identified fabric groups. This tile was selected for analysis because it did not appear to belong to any of the identified fabric groups, and when observed in thin section it was noted to contain significant quantities of heavy minerals, which explains the outlying XRF readings: transition elements (such as Zr and Nb) and rare earth elements (such as Y) are particularly common in heavy minerals.⁸⁷

In addition to examining the distribution of individual elements within and between fabric groups, box plots were also constructed for the samples from Acquachiarra, Monte Pallano, and San Giovanni in order to see if tiles could be separated based on type or context. On first examination these plots show no significant difference between tegula flanges, flat pieces, imbrices, and brick, though in some of the plots from San Giovanni the mean values for imbrices are notably higher than for tegula flanges or bricks (Appendix E, plot 7). The two contexts that yielded tile at San Giovanni are not separable in any box plots,

⁸⁷ M. J. Blackman, "The Effect of Human Size Sorting on the Mineralogy and Chemistry of Ceramic Clays," in *Chemical Characterization of Ceramic Pastes in Archaeology*, ed. Hector Neff (Madison, WI: Prehistory Press, 1992), 121-2.

and the Acquachiara tiles likewise show few differences between contexts, except that 10200 can be separated from 10203, 10204, and 10210 by its lower amounts of Rb and higher amounts of Nb (Appendix E, plot 8). The plots from Monte Pallano are difficult to interpret due to the sheer number of contexts involved, but considering only those contexts excavated during Phase II of the SVP and omitting test pits yields few results: context 7007 is distinguished by its low concentrations of Rb and Sr, and 7012 by a low amount of Zr, but there are no recurring patterns. It thus appears that neither tile types nor contexts can be separated geochemically based on a single variable alone.

A technique called one-way analysis of variance (ANOVA) may be applied to determine quantitatively whether there are statistically significant differences between any of these groupings. ANOVA compares the variation within multiple groups to the variation between them, in order to test the null hypothesis that all of the group means are equal; a p value of less than 0.05 indicates that at least two means differ to a statistically significant degree. If the null hypothesis is rejected, additional statistical tests can indicate which pairs of means differ from each other. However, this procedure is only valid when all of the groups being analyzed must have normal distributions and equal variances.⁸⁸ Because many of the fabric groups and contexts in question have very small sample sizes, it is not possible to assess whether the distribution is normal. However, since the different tile types, the two contexts from San Giovanni, and the major fabric groups from Monte Pallano contain more data, ANOVA can be used to compare these groupings provided they pass a test of equal variance.

For all groupings with $n \geq 5$, Bartlett's test was used to evaluate whether variances

⁸⁸ Stephen Shennan, *Quantifying Archaeology*, 2nd ed. (Edinburgh: Edinburgh University Press, 1997).

were equal,⁸⁹ and ANOVA was performed on those that passed the test. The tiles from Monte Pallano and Acquachiara showed no significant differences in the amount of any element based on tile type (Appendix E, tables 1 and 2), nor were there significant differences between the major fabric groups from Monte Pallano (Appendix E, table 3). The CBM from San Giovanni did show statistically significant differences based on tile type: imbrices are separated clearly from brick by their concentration of Rb, while imbrices, tegulae, and bricks can all be distinguished from each other based on their concentration of Y (Appendix E, table 4). For both of these elements the highest amounts are found in imbrex and the lowest in brick, with tegula in between. Since these samples have not yet been examined in thin section it is difficult to speculate about why this may be, but it is likely due to the fact that imbrex fabrics generally have fewer inclusions than brick. Rb, at least, is found in greater concentrations in clays than in inclusions: Rb⁺ often appears in clay structures as a substitute for K⁺.⁹⁰ Therefore, lower concentrations of temper in imbrices would lead to higher relative amounts of Rb. The concentration of Y may also be affected for similar reasons. The fact that this phenomenon only appears in tiles from San Giovanni is due to the limitations of the available data set: no imbrices from Acquachiara were sampled for analysis, and the number of imbrex samples from Monte Pallano was too low to include them in the ANOVA. Additional analyses with larger sample sizes, from all three sites, would be necessary in order to determine whether this is a significant trend.

These results of the ANOVA are consistent with what is visually apparent from the box plots. It is clear that differences in the distribution of single elements are not related to

⁸⁹ Levene's test is often preferred to Bartlett's test (personal communication with Jeffrey Witmer, April 2012), but for this data set yields the same results.

⁹⁰ Blackman, "The Effect of Human Size Sorting on the Mineralogy and Chemistry of Ceramic Clays," 118.

context, though they may have some relationship with tile type; the ranges of elemental concentrations found in each fabric group generally overlap, regardless of which element is being plotted. Though some fabric groups appear to be separable from each other, it is difficult to tell whether they are truly separable due to the small number of samples in each group. Higher-order statistical techniques, manipulating two or more elements, are necessary to explore these distinctions.

Bivariate analysis

While box plots provide a visual representation of the distribution of a single element, bivariate plots – in which two different elements are placed along the x and y axes of a graph, and points representing samples are placed according to their amounts of each of the two elements – make it possible to identify patterns based on the covariation of pairs of elements. It is probably not a coincidence that the elements most useful for separating fabric groups in box plots were Zr, Nb, and Sr, and to a lesser extent Rb; these are the elements that could be measured with the greatest precision and showed the least variation within a single sample. Meanwhile, Y, which had substantially lower precision and large intra-sample variation, proved poor at distinguishing fabrics, but did prove useful in separating the three types of CBM from San Giovanni. For this reason, all five elements were used in generating bivariate plots.

For each site's tile samples, bivariate plots were made using each possible paired combination of Rb, Sr, Y, Zr, and Nb. Points were color-coded based on the type, context, and

– in the case of Acquachiarra and Monte Pallano – fabric group to which the sample belonged. For the tiles from San Giovanni, it is instantly clear that none of the plots can separate tiles completely based on context or type – not even those based on Rb or Y, the elements that were best able to distinguish different tile types in box plots (Appendix E, plots 9 and 10). The plots from Acquachiarra and Monte Pallano were considerably more difficult to interpret, since some used nearly a dozen different colors to identify different categories. Some trends do emerge. For example, among the Acquachiarra tiles group 4, which stood out in the box plots due to its low concentrations of Sr, Zr, and Nb, is likewise set apart in these graphs – as is group 8, though some points from group 1 often come quite close (Appendix, E, plot 11). At the same time, some patterns apparent in the box plots are obscured in bivariate plots. The distinction between groups 2 and 5 is apparent in the plots of Nb vs. Rb or Sr (Appendix E, plot 11), but invisible in most others, and the separation of context 10200 from contexts 10203, 10204, and 10210 is likewise difficult to see.

The plots from Monte Pallano reveal much the same results. No patterning is evident by tile type or by major fabric group. The plots based on context are difficult to read because of the sheer number of contexts involved, but cursory examination shows no clear separation. By and large, then, bivariate plots reinforce the trends observed in the box plots: most fabric groups, tile types, and contexts fall into the same general range of values and overlap too strongly to be separated. In fact, when the observed differences between groups hinge on a single variable, plots against a second variable appear to minimize or erase the observed distinctions.

Multivariate analysis

It is also possible to apply multivariate techniques that group samples based on their amounts of all five elements, searching for higher-order patterning. The simplest of these is cluster analysis, a technique that groups data points based on their closeness to one another in order to produce a dendrogram with branches representing the level of similarity between different samples.⁹¹ There are three main subtypes of cluster analysis. *Agglomerative* methods begin by considering each point individually and group the most similar, while *divisive* methods initially group all points together and separate those that are most different from each other.⁹² *Partitionist* methods divide points into a desired number of groups: for example, if a study is attempting to separate ceramics that are known to come from three different sources, a partitionist analysis may be used to form exactly three clusters.⁹³ Within each of these main types of analysis, multiple algorithms have been developed. Data from the SVP tile assemblage were analyzed using Ward's method, an agglomerative method with an algorithm that emphasizes homogeneity within clusters by minimizing the *error sum of squares* – that is, the squared distance between each individual point in a cluster and that cluster's mean.⁹⁴ This is one of the most common methods of cluster analysis applied to archaeometric data.⁹⁵

Clusters of data concerning CBM from Acquachiara, Monte Pallano, and San Giovanni

⁹¹ Ibid., 235.

⁹² Ibid., 235-6, 245.

⁹³ Ibid., 249-250.

⁹⁴ Ibid., 241.

⁹⁵ Ibid. For a recent example of a study applying this technique to CBM, see Shawn Graham, *Ex Figlinis: The Network Dynamics of the Tiber Valley Brick Industry in the Hinterland of Rome*, <http://electricarchaeologist.files.wordpress.com/2010/02/bar-version-s-graham.doc>.

were clustered and the clusters labeled based on tile type, context, and fabric. Particularly illustrative clusters are presented in Appendix E; the complete array of plots is available on disc. Clustering tiles from Acquachiara by context suggests a distinction between tiles from context 10204 and the other contexts at that site: certain clusters consist entirely of tiles from 10204 and 10025, which overlaps with 10204 (Appendix E, plot 12). The same plot relabeled by fabric shows two main groups (Appendix E, plot 13). One contains all samples of fabrics 1, 4, 5, and 8, which were noted earlier to have in common low concentrations of Sr and Zr; the other contains all samples of fabrics 2 and 3. Fabrics 6, 7, and 9 do not fall cleanly into either of these groups, though two samples from fabric 9 form a cluster by themselves. The tiles from Monte Pallano show fewer patterns, but the unusual composition of sample 64 – which could not be assigned to a fabric group and was already distinguished in box plots and bivariate plots by its high concentrations of Rb, Y, Zr, and Nb – is clear: in the analyses of tegulae from Monte Pallano it falls in a cluster by itself (Appendix E, plot 14). Finally, the clusters of material from San Giovanni reveal little, but do suggest a weak separation between imbrices and other types of CBM (Appendix E, plot 15), as was observed in the box plots of Rb and Y for that site.

Significantly, many of the patterns observed in these clusters disappear when more data are added. For example, in analyzing the data from Monte Pallano the profoundly unusual nature of sample 64, which is evident in box plots, bivariate plots, and cluster analyses of tegulae alone, disappears when flat pieces and imbrices are added to the data set: it no longer falls in a cluster by itself. This may indicate that the technique is effectively overwhelmed by too many data, or that in some cases the patterns being identified are

weak, coincidental distinctions rather than meaningful trends. Is it possible to know, for example, whether the separability of Acquachiara context 10204 is statistically and archaeologically significant, rather than just a fluke of this particular analysis? Would applying another clustering algorithm – say, a divisive method rather than an agglomerative one – produce similar results? If not, which clusters, if any, are valid?

This question calls attention to one of the main drawbacks of cluster analysis: it does not provide a quantitative way to assess the validity of the resulting clusters. The problem is articulated well by Read, who writes:

Cluster procedures do not 'work' in general. This is not to say that there are no cases where the results are valid; rather, there are no statistical means to assess whether or not the results are correct, just a partial, or even incorrect delineation of structure for the data being explored.⁹⁶

Archaeologists have favored cluster analysis because its statistical methodology is similar to the reasoning that we use in classifying and categorizing: the concept of placing each item with its most similar neighbor until groups emerge is intuitive and familiar.⁹⁷ Yet the varied methods for assessing similarity and difference mathematically are, at their core, nearly as subjective as a ceramicist's decision that a set of sherds may be separated into a certain number of fabrics. Another ceramicist may examine the same materials and place them in entirely separate groups, and neither conclusion is necessarily more legitimate than the other; they are simply based on different criteria. The same is true of statistical clusters, and the results of an algorithm that groups tiles from one context apart from others may be an idiosyncrasy of a particular clustering technique just as much as it is a reflection of a true compositional difference.

⁹⁶ Cited in Shennan, *Quantifying Archaeology*, 254.

⁹⁷ *Ibid.*, 235.

Other multivariate techniques – used alongside or instead of cluster analysis – can sometimes provide better perspective on a data set. One useful method is discriminant analysis, which seeks to identify the variables that most effectively separate predefined groups. While cluster analysis is an exploratory technique that uses levels of similarity and difference to identify potential groupings, discriminant analysis presupposes that samples can be assigned accurately to one of a number of known groups, then tries to find data patterns that correspond to group membership. For example, discriminant analysis may be used to search for geochemical trends that underlie the separation of tiles into fabric groups. Discriminant analysis may also be used to support or invalidate the results of a cluster analysis, by treating each cluster as a group and searching for the combinations of variables that drive the clustering process.⁹⁸

The statistical theory behind discriminant analysis is much more complex than cluster analysis, and its potential applications to the SVP tile data are numerous. In order to assess whether this technique may be useful, two preliminary analyses were run: one to see how well tile fabrics from Monte Pallano could be discriminated, and one to assess the validity of the clustering of fabrics from Acquachiara. As with cluster analysis, there are multiple algorithms available for discriminant analysis; the method used here was Fischer's linear discriminant analysis, which is the most commonly-applied in archaeology. This does not require that data be normally distributed, but does require that the number of observations analyzed (n) be at least three times greater than the number of variables being used in the analysis (p), and that the variances of the groups be equal.⁹⁹ In this case,

⁹⁸ M. J. Baxter, *Exploratory Multivariate Analysis in Archaeology* (Edinburgh: Edinburgh University Press, 1994), 204-6.

⁹⁹ *Ibid.*, 200.

an analysis that includes all five elements necessitates at least fifteen observations, for which the data are more than sufficient.

An initial discriminant analysis was performed to test the degree of discrimination between fabric families A, B, and C in the Monte Pallano tile fabric series (Appendix E, plot 16). (It was impossible to evaluate the discrimination of fabrics from Acquachiara, or of the Monte Pallano fabric subgroups, because the presence of categories with only one sample violates the equal variance condition.) This analysis searches for the set of equations that provide the clearest distinctions between fabric families in order to find the best possible rules for assigning samples to groups. While there are many ways to assess the success of a discriminant analysis, the simplest is to look at the percentage of samples that would be classified in the wrong group, according to the rules derived in the analysis. In this case, exactly 50% of the samples were misclassified. Simple logic shows that this result is little better than randomly assigning tiles to fabrics. If, instead of being classified according to these discrimination rules, all tiles were simply assigned to group A (the largest group), which contains 38.2% of the samples, 61.8% would be misclassified. Since discriminant analysis shows no significant improvement over random classification, it is reasonable to conclude that no real patterning underlies these groups – the same result noted, with less quantitative rigor, in the cluster analysis.

A second test sought to support or invalidate what appear to be patterns in the cluster analysis of tile fabrics from Acquachiara (Appendix E, plot 17). In that analysis, fabrics seemed to cluster into three groups: two neatly separating fabrics 1, 4, 5, and 8 from fabrics 2 and 3, with a third group containing two samples of fabric 9. Discriminant analysis

was intended to identify rules of discrimination that separate these three clusters. The results show that only one sample was misclassified. This is substantially better than the results that would be obtained from a random classification rule: for example, if all samples were randomly assigned to the largest cluster, 47.8% would be misclassified. The results of cluster analysis seem to be borne out by discriminant analysis. However, Baxter cautions that in testing clusters via discriminant analysis, a negative result is more meaningful than a positive one: the possibility remains that both techniques are simply registering the same “arbitrary but sensible partitions” of the data, rather than meaningful patterning.¹⁰⁰ The discriminant analysis therefore cannot provide absolute confirmation that the clusters are identifying true differences, but it does lend support to that conclusion.

An abundance of other strategies exist for expressing the strength of discrimination quantitatively. For example, since the inclusion of a sample in an analysis will influence the discriminant rules that are derived for the classification of that sample, one may avoid circular statistics by cross-validating analyses: splitting a data set in half to generate discriminant equations, then applying the same equations to the other half of the samples to determine what percentage are misclassified.¹⁰¹ It is also valuable to consider figures such as $P(g/D)$, the probability that a sample with a given discriminant score will fall into a given group; Baxter suggests that $P(g/D)$ values of 0.95 or higher lend strong support to provenance studies.¹⁰² In their statistical complexity these strategies go beyond the range of what may be accomplished in this study. Nevertheless, it is apparent that discriminant analysis is a useful – though not infallible – tool for checking the validity of fabric series and

¹⁰⁰ Ibid., 205.

¹⁰¹ Ibid., 201-2.

¹⁰² Ibid., 203-4.

clusters, even when used in the most simplistic ways possible.

Comparanda: Ceramics

In addition to samples of CBM from Acquachiara, Monte Pallano, and San Giovanni, x-ray fluorescence was also applied to a selection of other ceramics representing ancient and modern wares, local and imported, all collected in the region surrounding Monte Pallano. Some of these had already been examined by petrographic methods; in this study they were subject to XRF to see if elemental composition can be a reliable guide in distinguishing different wares and sites in the Sangro Valley.

Material	Context(s)	Number of samples
amphora	MP 8003, 8005, 8011	8
black gloss	MP 8011	3
buffware	MP 8005, 8011	9
coarseware	MP 8003, 8005, 8011	13
coarseware	Via de Gasperi tombs	9
dolium	MP 8003	1
dolphin tile	MP	2
imbrex	modern	2

Table 2: Other ceramic materials analyzed

Since it is known that at some sites tile was produced alongside utilitarian vessels,¹⁰³ sherds of amphora and coarseware from Monte Pallano were selected to see if there is any similarity between these wares. Black gloss and buffware from Monte Pallano were also

¹⁰³ For example, at Metaponto, as discussed in Chapter 1.

studied in order to determine if there is a substantial difference between coarse and fine pottery from that site, and coarseware from Iron Age tombs along the Via de Gasperi in Tornareccio was analyzed to test the ability to differentiate coarse ceramics from different sites surrounding Monte Pallano. Finally, two small pieces of the famed Monte Pallano dolphin tiles were analyzed, making it possible to compare decorative architectural terracottas with more utilitarian building materials from the same building. Two fragments of late nineteenth-century imbrex, collected from a collapsed shepherd's hut near the Parco Nazionale della Majella (approximately 35 kilometers from Monte Pallano) act as a control, providing a sample of modern roof tile that was undoubtedly not made with clays from the Sangro Middle Valley.

While the plots of CBM showed little or no separation based on type, context, or fabric, the pottery samples are clearly differentiable. In box plots comparing sherds separated by type, amphora, black gloss, and buffware generally show similar elemental compositions, but coarseware and dolium are quickly set apart by higher amounts of Rb, Y, Zr, and Nb, and lower amounts of Sr (Appendix E, plot 18). An ANOVA confirms that coarseware is significantly different from amphora and buffware in its concentrations of Rb and Zr (Appendix E, table 5). (Black gloss and dolium were omitted from the analysis due to inadequate sample size, while the distributions of Sr, Y, and Nb did not pass an equal variance test.) Meanwhile, when ANOVA is applied to all ceramic materials, amphora and buffware differ significantly from CBM and coarseware in their concentration of Rb (Appendix E, table 6). Even on the basis of a single variable there is a strong separation between amphora and buffware, coarseware, and CBM.

This impression of separability is supported by the results of bivariate and multivariate analysis. In bivariate plots – particularly those with Sr on one axis (Appendix E, plot 19) – coarsewares from both Monte Pallano and the Via de Gasperi tombs consistently fall in the same region, almost entirely distinct from other types of pottery; when all pottery samples are clustered together, amphora, buffware, and black gloss split almost perfectly from coarseware and dolium (Appendix E, plot 20). When tiles are added to the diagram, there is imperfect but nevertheless clear separation between pottery and CBM. (The complete dendrogram is too large to print in an appendix, but is available on disc.) Discriminant analysis shows that when CBM, coarseware, and amphora/buffware are analyzed as three separate groups, 13 samples (8.90% of the total) are misclassified (Appendix E, plot 21). This is imperfect, but it is significantly better than the result that would be produced if a random classification rule were applied, and therefore suggests patterning.

Perhaps the most telling results come when all tiles from Acquachiara are considered alongside the sherds of coarseware from the Via de Gasperi tombs and two samples of early modern imbrex. All of these materials come from different sites and were made hundreds, if not thousands, of years apart. Yet when analyzed – in box plots, bivariate plots, and cluster analyses (Appendix E, plot 22) – there is consistently no distinction between the modern imbrex and the ancient CBM, while the coarsewares are separated from both ancient and modern tile. The potential for XRF to discriminate between different materials appears to depend on the coarseness of the ceramic rather than on any other factor: data concerning tiles made two millennia and 35 kilometers apart but with similar

ratios of clay to inclusions are not separable by any statistical technique, but the difference between coarseware and CBM of any provenance is easily apparent.

Comparanda: Clays

While the primary purpose of this study is to characterize – and, if possible, distinguish between – ceramic tile fabrics found in the Sangro Valley, a subsidiary goal is to explore the possibility of matching ceramic groups to specific clay sources. To that end, seven clay samples were analyzed as comparanda: four drawn from the immediate vicinity of Monte Pallano, and three from farther afield (Table 2). All are marine clays of varying ages, characteristic of the geology of the Adriatic coast; their locations are plotted in Appendix A, maps 5 and 6.¹⁰⁴

Sample No.	Location	Type	Year collected
1	Chieti	--	2006
2	Casoli	--	2006
3	Casoli	--	2006
4	Outside Atessa	multicolor	2011
5	Outside Atessa	multicolor	2011
6	Outside Atessa	Gray-blue	2011
7	Outside Tornareccio	Gray-blue	2011

Table 7: Clay samples analyzed.

The Abruzzo region has high levels of geological activity, which make for a complicated landscape. Clays are often found in thin lenses with diverse composition, and

¹⁰⁴ Personal communication with Keith Swift, February 2012, and Anna Pia Apilongo, July 2011.

there is no guarantee that clays that are exposed today would have been accessible in ancient times. Nevertheless, it is possible to identify two major types of clays currently dominating the landscape around Monte Pallano. Modern potters in the area still use these clays, and because they are found in large, deep beds, it is likely that they were available to Samnite and Roman crafters as well.¹⁰⁵

Of these two clay types, the best-studied is identified in geological literature as *argilla varicolore*, or multicolor clay. As its name suggests, this clay is identified by mixed layers in vivid colors. A 1996 mineralogical analysis of a sample from Pennadomo, about 15 km from Monte Pallano, revealed a composition of 81% phyllosilicates (smectites, kaolinite, chlorite, and mica), 15% calcite, and smaller quantities of quartz and potassium feldspar. The second clay is *argilla grigio-azzurra*, a gray-blue clay that is composed primarily of illite and smectites and also contains abundant quantities of carbonate. Both clays are found in abundance along the road that leads from Tornareccio to Atessa, where two samples of multicolor clay and one sample of gray-blue clay were collected during the 2011 field season; a second sample of gray-blue clay was collected just east of Tornareccio.¹⁰⁶

Additional analyses were performed on three clay samples collected farther from Tornareccio in 2006. Two were collected near Casoli, about 15 to 20 km northwest of Monte Pallano, where a substantial clay bed underlies much of the land between the Sangro river and the modern community of Guardiagrele.¹⁰⁷ The third is from about 55 km north of Monte Pallano, and was sampled from a large clay bed at the base of the slope leading up to the modern town of Chieti; though exposed in ancient times, this clay is now largely

¹⁰⁵ Personal communication with Keith Swift and Anna Pia Apilongo, July 2011.

¹⁰⁶ Personal communication with Anna Pia Apilongo, July 2011.

¹⁰⁷ Personal communication with Keith Swift, February 2012.

covered by a layer of sand.¹⁰⁸ Since it is unlikely that materials were transported this far in order to produce utilitarian materials such as roof tile, these samples act as controls to test ability to separate different clays from disparate locations.

There is little previous research available to shed light on critical aspects of these clays, such as their composition, the extent of the beds they are found in, and their homogeneity. If nothing else, the seven samples included in this study offer a small window into the many types of clays found in the Sangro Valley and in the Abruzzo more broadly, and thus form a reasonable starting point for exploring the natural resources available for ceramic production in the region.

At the time of XRF analysis, the clay samples were dry but had not been fired. This presented some difficulty, as the chunks of clay were irregularly shaped and did not have perfectly flat surfaces, which would have been optimal. In order to estimate deviation due to sample shape and inhomogeneity three subsamples of each clay were analyzed, under the same instrument settings applied to ceramics. For each clay the average number of counts for each element, standard deviation, and coefficient of variation are presented in Appendix E, table 8. The coefficients of variation varied widely from one clay to another: the lowest observed was 1.39% and the highest 21.08%. While clay 1 and clay 6 consistently had very high coefficients of variation and clay 7 very low, the remainder were almost always between 4% and 8%, within the same range as the ceramic samples (see Tables 1 and 2 in this chapter). It is impossible to say whether this variation is due to differences in the quality of the sample or the internal variability of the clay.

The resulting data were analyzed in light of two questions: first, whether the

¹⁰⁸ Ibid.

different clays analyzed could be clearly separated, and second, whether or not specific clays bear the same chemical signatures as any ceramic groups.

To assess whether there is a clear separation between different clays, statistical analysis was conducted in the same way as for ceramics, beginning with examination of single variables and proceeding to bivariate and multivariate analyses. Box plots show that the multicolor and blue-gray clays always overlap in their elemental concentrations, but are distinguished from the clays from Chieti and Casoli by their low concentrations of Sr and high concentrations of Nb (Appendix E, plots 23 and 24). Bivariate plots, too, show that while the two varieties of clay surrounding Tornareccio cannot be separated, there is a strong distinction between local and non-local clays, particularly in plots involving Nb, Rb, and/or Y (Appendix E, plot 25). When clustering algorithms are applied there is decent but incomplete separation between clays from Chieti, Casoli, and Tornareccio (Appendix E, plot 26), and discriminant analysis comparing the two clays from Casoli, two from Tornareccio, and one from Chieti misclassified only three samples (14.3%) (Appendix E, plot 27). This is substantially better than the result that would be obtained by a random classification rule: for example, if all samples were arbitrarily assumed to be specimens of multicolor clay, 71.4% would be misclassified. Most significantly, subsequent discriminant analyses comparing non-local clays (from Chieti and Casoli) to local clays (multicolor and gray-blue) found complete discrimination between these two groups (Appendix E, plot 28), and an analysis of the discrimination between multicolor and gray-blue clays likewise found that all samples could be assigned perfectly. Despite the wide range of elemental values for at least some clays, it does appear that the two varieties of clay local to Tornareccio bear

chemical signatures that are distinct from each other and from nonlocal clays.

Because the various ceramic groups are much less separable, as determined above, it is impossible to match specific ceramic groups definitely to specific clays. However, some broad comparisons may be made, and the results are surprising. Appendix E, plot 29 presents a bivariate plot of Nb vs. Sr, comparing pottery (coarseware and finer wares) and CBM with local and nonlocal clays. Local clays consistently have values in the same region as pottery, and nonlocal clays fall in the same region as CBM, with almost complete separation between them. The same pattern is seen in plots of many other element pairs. Discriminant analysis provides a more sophisticated way to evaluate whether there is a true correlation here. Fischer's linear discriminant analysis was used to derive discrimination equations for local and nonlocal clays, with perfect separability (Appendix E, plot 28). The same equations were then applied the data concerning pottery and CBM that were analyzed above, classifying samples as “predicted local” or “predicted nonlocal”. The results are presented in a mosaic plot (Appendix E, plot 30) and contingency table (Appendix E, table 7): 86.8% of CBM was predicted to be nonlocal, while 93.2% of pottery was classified as local. Applying a chi-squared test to the contingency table yields a p value below 0.0001 – in other words, these data have strong statistical significance and the correlation is highly unlikely to be a coincidence.

These findings, if they are valid, run directly contrary to what would be expected: namely, that large utilitarian ceramic pieces such as roof tile would be produced with local clays and would not be transported far, while potters producing finer wares are likely to be more discerning in their choice of raw materials and to trade their products over a wider

area. Potential explanations and their implications will be explored in the following chapter.

Chapter 4: Conclusions

In developing this study, it was hoped that archaeometric analyses of roof tile would both validate the Sangro Valley Project's tile fabric series and identify potential similarities between tiles, coarsewares, and local clays. These are necessary steps in order to explore the provenance and distribution of tile – which in turn has important ramifications for understanding diachronic patterns of resource use, production, and settlement in the Sangro Valley. While preliminary inferences can be drawn from this study, in many ways the data pose more questions than they answer, and it is clear that additional inquiry will be necessary in order to truly understand ancient ceramic economies in the Abruzzo. This chapter will evaluate the successes and limitations of this study and present potential directions for future research.

Evaluation of research objectives

As explained in Chapter I, this study had three principle research objectives. The first two were to identify and characterize the major fabric types of tiles from the SVP's excavations, and to test the ability of macroscopic examination to determine meaningful differences between tile fabrics. To that end, fabric sequences were developed for tiles from Monte Pallano and Acquachiara, based predominantly on paste texture and inclusions. It was hypothesized that these characteristics would represent different choices made by different tile-makers when selecting raw materials and processing clays during production.

If this were the case, each unique fabric would represent a group of tiles that were made from the same clay and/or produced by the same manufacturer.

In order to test this hypothesis, it was first necessary to be certain that the fabric groupings, which had been developed macroscopically in the field, were in fact based on meaningful and measurable differences in composition. Petrographic thin-sectioning and x-ray fluorescence were selected as archaeometric techniques that could provide insight into the mineralogical and chemical makeup of tile samples as a check on the accuracy of the hypothesized fabric sequence. Unfortunately, neither method indicated any strong distinction between fabrics as identified.

A qualitative examination of tile thin sections from Monte Pallano and Acquachiara indicated substantial variation in mineralogy. While it was not possible to do a rigorous statistical analysis of such qualitative data, it was readily apparent that the variation within fabric groups was equal to or greater than the variation between them, and some samples that looked remarkably similar in thin section had been assigned to different fabric groups. Both of these observations suggest that any differences between fabric groups are not consistently reflected in their mineralogy.

X-ray fluorescence assays of tiles from Monte Pallano, Acquachiara, and San Giovanni presented abundant semi-quantitative data about the abundance of five trace elements, which were evaluated by a variety of statistical methods. No analysis showed discrimination between the fabric groupings from Monte Pallano. For tiles from Acquachiara, XRF data consistently suggested groups that were broader than those identified in the original fabric series: fabrics 1, 4, 5, and 8 all clustered together and

separated easily from 2 and 3, with 6, 7, and 9 split between the two clusters. As noted in Chapter II, the fabrics were intentionally defined narrowly on the grounds that it would be easier to combine overly narrow groups than to separate overly broad ones. In that respect these results appear promising. However, a preliminary examination of the macroscopic observations that form the basis of the fabric series does not reveal any characteristics that may be influencing this separation, raising questions as to whether it reflects a genuine pattern or a false correlation in the data.

From these analyses, it appears that the tile fabrics based on macroscopic observation do not represent meaningful differences in composition on a mineralogical or chemical level. Based on XRF data it may be possible to separate tiles from Acquachiara into two or three fabric groups that are based on, but broader than, those in the original fabric series; however, further study is necessary in order to assess the validity of these groupings.

The third objective of this study was to collect comparative data about samples of regional coarsewares and local clays in order to develop hypotheses about clay provenance and the relationships between different regional ceramic industries. It is known that in some areas tile was manufactured alongside coarse pottery,¹⁰⁹ and it is possible that workers who made multiple kinds of ceramics within the same workshop would use the same clays. Therefore, it was hypothesized that measurable similarities between materials may indicate connections between the production of tiles and other ceramics in the ancient Sangro Valley. In addition, it was hoped that characteristics shared between fabric groups and raw clays might be used to link certain fabrics with their sources. Since archaeometric

¹⁰⁹ For example, at Metaponto, as discussed in Chapter I.

analyses did not validate the separation of tiles into fabrics this was not possible, but these analyses do offer some clues about the relationships between tiles, pottery, and clays.

Pottery and clays were not viewed in thin section, but petrographic examination of tiles from Monte Pallano and Acquachiara revealed that the most common inclusions in tiles are quartz, iron oxides, mica, and carbonates. This is a fairly generic suite of minerals commonly found in sands and clays in sedimentary environments; there are no unusual inclusions or combinations of inclusions that may “fingerprint” a specific geographic region or clay source. It seems highly unlikely that tiles could be matched with clays on the basis of petrography.

The x-ray fluorescence findings are more intriguing. As discussed in Chapter III, the data appear to show a clear separation between amphora and buffware, coarse pottery, and ceramic building material. The latter group includes all bricks and tiles from Monte Pallano, Acquachiara, and San Giovanni, as well as two samples of modern imbrex from a different region, which were sampled as controls. The fact that the two control imbrices consistently clustered with other forms of CBM is telling, since these materials were made two millennia and thirty-five kilometers apart and were almost certainly not made from the same clays, nor subjected to the same post-depositional alterations.

This observation suggests that the primary factor influencing XRF readings of these materials is the density of inclusions, which affects the chemical composition of ceramics by effectively diluting, to varying degrees, the concentrations of elements found in the clay paste.¹¹⁰ A piece of tile and a ceramic vessel may be made from the same clay, but if one is

¹¹⁰ A similar “diluting” effect has been noted in other archaeometric studies, though its implications have not been thoroughly explored. For example, Blackman notes that increased quantities of carbonate and quartz inclusions tends to decrease the concentrations of transition and rare earth elements: “The Effect of

tempered with large quantities of quartz sand and the other is left unprocessed, they will have different elemental concentrations and thus yield different XRF readings. On the other hand, ceramics that are undeniably made from different clays may appear similar because they have a similar ratio of inclusions to paste. This has significant implications for the interpretation of XRF data of ceramics: it indicates that XRF readings may not be reflective of provenance at all.

In addition to showing a clear separation between different ceramic wares, the XRF data also draw an effective distinction between local and non-local clays. Most surprisingly, as noted in Chapter III, it appears that the composition of CBM correlates overwhelmingly with non-local clays and pottery correlates with local clays. This unexpected result may be understood by looking to archaeology, geology, or methodology.

An archaeological explanation would posit that the pottery used at Monte Pallano and deposited at the Via de Gasperi tombs was made locally. Meanwhile, roofs at Monte Pallano, Acquachiarra, and San Giovanni were tiled with tegulae and imbrices made from non-local clays or imported from as far afield as Chieti, 55 km away. The XRF readings thus reflect similarities between ceramic materials and the clays from which they were made. Perhaps Sangro Valley potters and tile-makers selected different clays based on the type of material that they were making, in ways that remained remarkably consistent over the better part of a millennium; or consumers obtained different types of ceramics from different places, reflecting distinctions of cost or quality. It is tempting to accept this result and declare that XRF is a successful indicator of ceramic provenance, and therefore a meaningful key to human behavior. However, this also introduces several new problems.

Human Size Sorting on the Mineralogy and Chemistry of Ceramic Clays," 121.

The idea that this correlation between ceramics and clays reflects provenance flies in the face of a common archaeological assumption: tiles are produced and consumed within a small radius because they are bulky, utilitarian goods, while pottery (especially finer pottery, such as black gloss) is transported over greater distances because it is a more valuable prestige good. To assume that this correlation is a result of ceramic provenance makes it necessary to explain why the merits of using non-local clays to produce CBM would outweigh the logistical difficulties of distributing these materials. It also raises the question of why this pattern would hold true for both coarseware from Iron Age tombs (along the Via de Gasperi) and tiles from a late Roman building (in San Giovanni) – materials spanning nearly a thousand years that included great social and economic change. Is it possible that the Roman conquest truly had no effect on the sourcing, production, and distribution of ceramics within Samnium?

It is also possible that the observed similarities are due not to human behavior – the choice to use certain clays in making certain wares – but to the geological processes that influenced the clays being studied. As noted in Chapter III, altering the ratio of temper to paste in a ceramic will increase the concentration of some elements and decrease the concentration of others, depending on whether they are more abundant in inclusions or in clay minerals. The same principle likely applies to raw clays. Pollard and Heron note that as secondary clays are transported the inclusions that they contain are sorted by size, with larger inclusions being deposited before smaller ones.¹¹¹ It is possible that the transportation of sediments throughout the Adriatic plain led to clay beds with a variety of depositional histories, which had differential effects on the composition of clays throughout

¹¹¹ A. M. Pollard and Carl Heron, “The Geochemistry of Clays and Provenance of Ceramics,” 125.

the Sangro Valley. This may lead to differing ratios of inclusions to paste, and therefore differing concentrations of trace elements, that happen to mimic the effects of levigating and tempering in ceramic production.

It is instructive to consider specific mineralogical differences that may influence elemental composition. In examining the XRF readings, CBM and non-local clays are distinguished from pottery and local clays by elevated concentrations of Sr and Rb and diminished concentrations of Nb (among other less significant factors). Since the Sr^{2+} cation can substitute for Ca^{2+} in many mineral structures, its abundance may indicate varying compositions of carbonates or plagioclase feldspar, both of which are rich in calcium.¹¹² The concentration of Rb may also be related to the quantity of potassium feldspar inclusions, since Rb^+ can substitute for K^+ , as noted in Chapter III.¹¹³ It is logical that coarse terracottas would contain greater amounts of these elements than pottery, which would be processed to remove inclusions and produce a finer paste. If the clays sampled from the upper valley happen to contain greater quantities of carbonates and feldspars than the clays sampled from the middle valley, this would explain why certain ceramics may appear similar to certain clays, although they are not made from them, in ways that show patterning related to the geography and geology of the valley.

This hypothesis is perhaps the most likely explanation for this result, but it is difficult to support or disprove without greater knowledge of the composition and depositional history of Sangro Valley clays. In order to shed light on this issue, subsequent studies may focus on x-ray diffraction of clay samples, which will provide greater insight

¹¹² Personal communication with Zeb Page, April 2012.

¹¹³ Examining the covariation of Sr to Ca and Rb to K would be one way to verify that this is, in fact, the case in the materials being studied.

into the mineral contexts in which trace elements are found.

Finally, it is possible that there is a methodological explanation for this result: for example, systematic issues with sampling that would affect the local and non-local clays in different ways. Samples of local clays were collected in the summer of 2011, while the Casoli and Chieti clays had been in storage since the summer of 2006. This led to noticeable differences in moisture, texture, and density, which may have impacted XRF readings for these two groups of clays. It is also necessary to consider the inherent problems in comparing raw clay to ceramics, which are discussed much more thoroughly below. These factors make it difficult to state definitively that there is an association between clays and ceramics even when they have similar chemical signatures. There may in fact be significant differences between pottery and CBM, and between local and non-local clays, but the appearance of correlation between these groups may simply be a coincidence rather than an archaeologically meaningful observation.

Although this result is intriguing, it is necessary – as Orton points out – to be mindful of Twyman's law: “any figure that looks interesting or different is probably wrong.”¹¹⁴ Given the limitations discussed above and in the following section, it would certainly be a mistake to assume that the apparent correlation between clays and ceramics is a meaningful reflection of provenance, which would raise many provocative archaeological concerns. It is impossible to settle on an explanation without much more thorough consideration of clays in the Sangro Valley, including possible resampling and reanalysis.

¹¹⁴ Orton, *Sampling in Archaeology*.

Limitations

In interpreting the results of this study, it is important to consider the limitations that may lead to inaccurate or misleading data. These include limitations introduced by materials, sampling, and methods.

Limitations of material. Although this study includes a chemical comparison of raw clay and fired ceramics, the natural variability of clays, human behavior in manufacturing ceramics, and post-depositional change all make this comparison a difficult one to draw. This is the bane of many archaeological provenance studies; some of the principle considerations are discussed in Chapters II and III.

The natural variability of clays is a significant obstacle in tracing ceramics back to their source.¹¹⁵ Though the degree differs for each clay bed and each region, trace elements generally show greater variability than mineral constituents; for this reason, petrographic analyses are often more reliable indicators of provenance than chemical tests.¹¹⁶ Once clay has been selected, human decisions to blend different materials, remove natural inclusions, or add temper further alter its composition. The relevance of these issues to the Sangro Valley tile assemblage is discussed in Chapter III: the difficulty of distinguishing between temper and natural inclusions impedes efforts to determine what variation is due to clay sources and what is anthropogenic, and the practice of clay mixing – suggested by streaks of different colors through the matrix of many tiles – likewise makes it difficult to identify similarities between tiles and clays. Finally, fine layers of secondary carbonate noted in

¹¹⁵ A. M. Pollard and Carl Heron, "The Geochemistry of Clays and Provenance of Ceramics," in *Archaeological Chemistry*, ed. A. M. Pollard and Carl Heron (London: Royal Society of Chemistry, 2008).

¹¹⁶ Rice, *Pottery Analysis: A Sourcebook*, 418-419.

many tile thin sections indicates that post-depositional alteration has affected mineralogical and chemical composition. The nature of elemental changes in buried ceramics is not well-understood, but porous, low-fired wares such as roof tile are particularly vulnerable;¹¹⁷ several recent studies have indicated that these alterations are difficult to predict and detect and can have a severe impact on compositional analysis.¹¹⁸

All of these factors may obscure connections between fired ceramics and the raw clays from which they were made, or create an illusion of false similarity between unrelated materials. For this reason, it is generally taken as axiomatic that provenance studies should not be founded on a comparison of clays to ceramics: as Herz and Garrison write,

under no circumstances can the chemistry of raw clay be compared to that of a finished pot. To demonstrate the provenance of the clay in the pot, the steps taken by the potter in making the pot must be followed: the clay must be purified and fired under analogous conditions.¹¹⁹

When those steps and conditions are not well-understood, and no ceramics of known provenance are available for comparison, tracing ceramics to source becomes extremely difficult. For this reason, data obtained by comparing raw clays with fired ceramics should be interpreted with great caution, if it is appropriate to compare these materials at all.

Limitations of sampling. The sampling issues discussed in Chapter II pose many challenges in data interpretation. Small sample sizes from each fabric group obstruct rigorous statistical comparisons between them, as noted repeatedly in the analysis of XRF

¹¹⁷ Herz and Garrison, *Geological Methods for Archaeology*, 269.

¹¹⁸ For more thorough discussion of the nature of post-depositional alteration and the problems it poses for provenance studies, see A. Schwedt, H. Mommsen, and N. Zacharias, "Post-depositional Elemental Alterations in Pottery: Neutron Activation Analyses of Surface and Core Samples," *Archaeometry* 46, no. 1 (2004): 85-101; and A. Schwedt, H. Mommsen, N. Zacharias, and J. Buxeda i Garrigós, "Analcime Crystallization and Compositional Profiles – Comparing Approaches to Detect Post-depositional Alterations in Archaeological Pottery," *Archaeometry* 48, no. 2 (2006): 237-251.

¹¹⁹ Herz and Garrison, *Geological Methods for Archaeology*, 269.

data in Chapter III: often the number of pieces analyzed simply is not large enough to draw meaningful conclusions. Additionally, the results yielded during analysis may have been affected by the condition of samples. In particular, clay samples were collected and stored under varying conditions over five years of field work. At the time of analysis some were dry and crumbly, while others were wet and malleable. Inconsistent sample condition and preparation may alter chemical composition and/or affect XRF readings, especially when looking at highly mobile trace elements.

Limitations of methods. Any archaeometric study is limited by the inherent constraints of the methods selected, the specific characteristics of the instruments on hand, and the skill of the analysts involved. Tile fabrics are extremely complex, and the interpretation of ceramic thin sections is difficult. It is possible that quantitative analysis, such as point counting, would have revealed patterns that were not observable when looking at thin sections qualitatively; it is also possible that a more experienced analyst would have noted subtler distinctions between samples. X-ray fluorescence also raises methodological concerns of precision and accuracy. As noted in Chapter II, portable XRF devices are not generally as precise or accurate as tabletop XRF instruments. Tests to determine the precision of the Bruker Tracer III-V+ on Sangro Valley Project tiles (Chapter III) indicate that precision varies widely from element to element and from sample to sample. This is a matter of concern for the comparison of trace element data, since by their nature these are present in very small quantities. Although the instrument was factory-calibrated, no standards or check samples were analyzed, leaving its accuracy in question. This lack of certainty about precision and accuracy does not entirely preclude use of these

data – they still yield useful results and may inform future work – but it does complicate data interpretation and obstruct efforts to compare these results to other studies.

Further Conclusions

While many of this study's findings with respect to its research goals are inconclusive, there remains the undeniable fact that tiles excavated by the Sangro Valley Project do show profound variability in composition, even beyond what is apparent to the naked eye. Can these data yield any additional information about the nature of these differences, and their archaeological significance?

First of all, this study does not implicate any other factors that may correspond to mineralogical or chemical differences between tiles. As demonstrated in Chapter III, tile compositions show no trends based on context. Within the San Giovanni assemblage – the only site for which tegulae, imbrices, and bricks were analyzed – certain elements did show statistically significant differences based on CBM type. This may indicate variance in the manufacturing practices used to make different types of tiles: it was noted above that XRF readings appear to correlate with the inclusion density of a piece of ceramic, and so it is possible that tile-makers preferred to make imbrices from clays with fewer larger inclusions, since these tiles are generally thinner and require less bulk. However, the absence of imbrices in the samples from Monte Pallano and Acquachiara makes it difficult to test this hypothesis, and since these differences do not appear in multivariate analyses, their validity is questionable: it may be that adding additional data in multivariate analysis masks true patterning, as discussed in Chapter III, or the initial appearance of a trend may

be a fluke of the data. Further investigation is required to determine whether differing clay preparation for different types of CBM does in fact lead to measurable differences in fabric.

More promising is the simple fact of the sheer diversity of tile fabrics analyzed, which may itself offer hints about the structure of tile manufacturing in the Sangro Valley. Producing ceramic building material does not necessitate great care: tiles are large, bulky slabs of clay with utilitarian forms. Since they will be placed high on a roof, far from human scrutiny, there is no aesthetic imperative to produce carefully controlled fabrics. Considered in this light, it is tempting to assume that the reason that tiles display such a wide range of pastes and inclusions is because there is no need to go to great effort over the material; tiles need not be carefully processed to meet a standard of uniformity in order to be functional.

At the same time, it is clear that the materials that went into roof tiles were not random, arbitrary, or uncontrolled; examination of tiles in thin section indicates that tile-makers made deliberate choices to process raw clays and form fabrics in certain ways. The presence of grog, which cannot be found in natural clay outcrops but must be added by humans, means that tiles were certainly tempered. Moreover, tiles from Monte Pallano are tempered differently than those from Acquachiara: they generally contain different shapes and size distributions of quartz and different ratios of grog to rock, as noted in Chapter III. This suggests that workability, shrinkage, and cracking were issues to which tile-makers were attuned, and actively worked to control. Evidence of clay mixing also contributes to the impression that tile-makers were concerned about the fabrics of their tiles: they were aware of the properties of different clays and went to some effort to get the material right. And yet they did so in widely variant, nonstandard ways.

The fact that the composition of tiles was deliberately controlled by tile-makers indicates some concern for the qualities of the final products. At the same time, the fact that fabrics don't appear to have been treated in systematic ways suggests that the industry of tile-making was generally decentralized. This interpretation is perhaps supported by Rice's proposal that "product uniformity co-varies with the numbers of producers within a community."¹²⁰ In other words, the profound lack of uniformity among Sangro Valley tiles would seem to indicate a large number of tile-makers. The fact that these manufacturers are all working in a relatively small area, in what appears to be an uncoordinated way, also suggests a decentralized and unspecialized model of tile production.¹²¹

In areas that were rural in ancient times, the remains of tile kilns are often found alongside other industries, such as ironworking and pottery production.¹²² It is likely that at these sites, tile production was pursued seasonally or on an as-needed basis by workers who spent the bulk of their time producing other things. By contrast, uniform tile fabrics with low variation have been noted in areas where tile production was much more systematized and centrally controlled. For example, in Roman Britain, much CBM was produced under a system of rigid military supervision; Peacock's petrographic studies of these materials identified two easily separable fabrics.¹²³ Two other studies – one from Roman Britain, the other from Hellenistic Gordion in Turkey – have found that in regions where CBM was made by traveling bands of tile-makers, archaeometric analysis shows

¹²⁰ Cited in Reedy, *Thin-Section Petrography of Stone and Ceramic Cultural Materials*, 159.

¹²¹ Stoltman, "The Role of Petrography in the Study of Archaeological Ceramics", 312.

¹²² Ironworking: David R. Rudling, Caroline Cartwright, Giles Swift, Sally Foster, John Shepherd, Pat Hinton, and Fred Tebbutt, "The Excavation of a Roman Tillery on Great Cansiron Farm, Hartfield, East Sussex," *Britannia* 17 (1986): 191-230. Pottery production: Carter, "Rural Architecture and Ceramic Industry at Metaponto, Italy, 350 – 50 B.C."

¹²³ D. P. S. Peacock, "Bricks and Tiles of the Classis Britannica: Petrology and Origin," *Britannia* 8 (1977): 235-248.

relatively few tile fabrics with no statistically significant similarities to other regional ceramics, pointing to the specialization and isolation of the tile industry.¹²⁴

The tile fabrics found in the Sangro Valley are what one would expect of an area that is not densely settled and does not experience constant construction, resulting in low demand for building materials: assemblages with a wide range of unstandardized materials, likely made by non-specialists who also produced other wares during times when there was no call for tile. If this is the case, tile fabrics offer profound insight not only into the economy of ceramic production in the ancient Sangro Valley, but also into broader patterns of settlement and land use.

Directions for Future Research

The principle research aim of this study was to determine whether macroscopically observable differences in tile fabrics correspond with mineralogical or chemical distinctions that may be useful in tracing these materials to source. The ultimate null result has significant implications for future archaeological work on Sangro Valley tiles; a 2001 study similarly met with little success.¹²⁵ These findings indicate that trying to separate tile fabrics in the field is unlikely to be productive, because their macroscopic characteristics do not correspond to meaningful mineralogical or chemical differences. Even if it were possible to identify such differences, we simply lack the capacity to match them with clay

¹²⁴ Roman Britain: Darvill, "A Petrological Study of LHS and TPF Stamped Tiles from the Cotswold Region." Gordion: Robert C. Henrickson and M. James Blackman, "Hellenistic Production of Terra Cotta Roof Tiles Among the Ceramic Industries at Gordion," *Oxford Journal of Archaeology* 18, no. 3 (1999): 307-236.

¹²⁵ Elizabeth Spalding, *Ceramic Analysis and Catalogue of Roof Tile: Monte Pallano, Italy*, unpublished thesis draft, Oberlin College, 2001.

sources due to problems of local geology – namely, scarce information about complex and turbid clays set in rapidly changing terrain. It is significant that past archaeometric studies of CBM provenance have been successful in areas that have relatively straightforward geology and few, clearly differentiated tile and brick fabrics – for example, Roman Britain. Unfortunately, the Sangro Valley has neither.

In this light, what can usefully be done with tile encountered during excavation and survey? The unfortunate answer seems to be, not very much. Two successive archaeometric studies of Sangro Valley tiles have yielded little, and demonstrated that it may well be impossible to develop a useful fabric series for these materials; additional analyses may not merit the necessary outlay of resources in terms of equipment, funding, and labor. At the same time, studies of tile forms have not succeeded in producing new and meaningful information,¹²⁶ and since no complete tiles have been recovered from any of the Sangro Valley Project's sites, it is at present impossible to do a comprehensive morphological study along the lines of Warry's work in Roman Britain.¹²⁷ Even saving tile for future examination is logistically fraught, considering the weight and bulk of these materials. Though it is hard to admit, there simply may not be that much information available in tile. Future excavations would be wise to focus on bulk quantification in the field, note any unusual markings that may offer clues about production or environment, and avoid more intensive efforts.

That said, this study did yield some curious results that may merit additional investigation: XRF data were effective in discriminating between broad classes of ceramics

¹²⁶ Eli Goldberg, *Tiles and Tribulations: Report on Summer Research with the Sangro Valley Project*, unpublished research report, Sangro Valley Project, August 2010.

¹²⁷ *Tegulae: Manufacture, typology, and use in Roman Britain*, 2006.

and, potentially, correlating them with local and non-local clays. If this discrimination is valid, it suggests that XRF may actually be of some utility in tracing provenance and developing a comprehensive picture of ancient ceramic production. Given the limitations discussed above, however, it is impossible to say whether these observations represent genuine patterns of archaeological significance or are tainted by methodological issues. If further work is to be done in this area to confirm or reject these results, methodological considerations will be key. These include increasing sample sizes and ensuring that collection and preparation of clay samples is uniform. X-ray diffraction may prove a key technique to provide a mineralogical context for trace element concentrations.

Other major concerns, such as identifying and compensating for manufacturing practices and diagenetic changes that cause fired ceramics to deviate from their source clays, border on impossible to address without significant advances in the field of archaeometry. Ultimately the discovery of a kiln site, or of wasters that can be associated definitively with a clay source or production site, may prove to be a critical smoking gun so that fired ceramics of unknown provenance can be compared with fired ceramics of known provenance, rather than with raw clays. By addressing the methodological limitations of this study it may yet be possible to illuminate the relationships between these materials for a deeper understanding of ancient ceramic economies in the Sangro Valley.

Works Cited

- Baxter, M. J. *Exploratory Multivariate Analysis in Archaeology*. Edinburgh: Edinburgh University Press, 1994.
- Bell, Tyler, Ed Bispham, Tony Brown, Neil Christie, Chris Day, Ralph Fyfe, Louise Harrison, Jodi Humphrey, John Lloyd, Gary Lock, Alison MacDonald, and Andrew Wilson. *Interim Report: the 1998 season*. Sangro Valley Project. Accessed March 25, 2012. <http://www.arch.ox.ac.uk/files/Research%20Projects/Sangro/1998%20report.pdf>.
- Bishop, Ronald L., Robert L. Rands, and George R. Holley. "Ceramic Compositional Analysis in Archaeological Perspective." *Advances in Archaeological Method and Theory*, vol. 5. Springer, 1982. <http://www.jstor.org/stable/20210058>
- Blackman, M. J. "The Effect of Human Size Sorting on the Mineralogy and Chemistry of Ceramic Clays." In *Chemical Characterization of Ceramic Pastes in Archaeology*, edited by Hector Neff. Madison, WI: Prehistory Press, 1992.
- Brodribb, Gerald. *Roman Brick and Tile*. Wolfeboro, NH: Alan Sutton Publishing Inc., 1989.
- Carter, Joseph. "Rural Architecture and Ceramic Industry at Metaponto, Italy, 350 – 50 B.C." In *Roman Brick and Tile: Studies in Manufacture, Distribution, and Use in the Western Empire*, edited by Alan McWhirr. BAR International Series 68. Oxford: B.A.R., 1979.
- Countryman, James. *A Study of Agricultural Terracing at Monte Pallano, Abruzzo, Italy*. Unpublished thesis, Oberlin College, 2012.
- Darvill, Timothy. "A Petrological Study of LHS and TPF Stamped Tiles from the Cotswold Region." In *Roman Brick and Tile: Studies in Manufacture, Distribution, and Use in the Western Empire*, edited by Alan McWhirr. BAR International Series 68. Oxford: B.A.R., 1979.
- Gerster, Lorenzo. *Architektonische Skizzen eines Archäologen: Zeichnungen von Alban Gerster-Giambonini Aus Den Jahren 1918 Bis 1934*. Zürich: Tontafelverlag, 1994.
- Goldberg, Eli. *Tiles and Tribulations: Report on Summer Research with the Sangro Valley Project*. Unpublished research report, Sangro Valley Project, August 2010.
- Graham, Shawn. *Ex Figlinis: The Network Dynamics of the Tiber Valley Brick Industry in the Hinterland of Rome*. Accessed July 2011. <http://electricarchaeologist.files.wordpress.com/2010/02/bar-version-s-graham.doc>

- Henrickson, Robert C., and M. James Blackman. "Hellenistic Production of Terra Cotta Roof Tiles Among the Ceramic Industries at Gordion." *Oxford Journal of Archaeology* 18, no. 3 (1999): 307-326.
- Herz, Norman, and Ervan G. Garrison. *Geological Methods for Archaeology*. New York: Oxford University Press, 1998.
- Jenkins, Ron. *X-Ray Fluorescence Spectrometry*. 2nd ed. Vol. 152 of *Chemical Analysis: A Series of Monographs on Analytical Chemistry and its Applications*, edited by J. D. Winefordner. New York: John Wiley and Sons, Inc., 1999.
- Kane, Susan, Sam Carrier, Ed Bispham, Keith Swift, Eric DeSena, and Velicia Bergstrom. *Sangro Valley Project Field Manual 2011*. Sangro Valley Project, 2011.
- Kaiser, Bruce. "pXRF for Cultural Heritage." Workshop at the Fiske Center for Archaeological Research, University of Massachusetts – Boston. March 7-8, 2011.
- Kratochvil, Byron. "Sampling and sample preservation for trace element analysis." In *Sample Preparation for Trace Element Analysis*, edited by Zoltan Mester and Ralph E. Sturgeon. Boston: Elsevier, 2003.
- Munsell Color. *Munsell Soil Color Charts*. New Windsor, NY: Munsell Color, 2000.
- Nesse, William D. *Introduction to Mineralogy*. New York: Oxford University Press, 2000.
- Orton, Clive. *Sampling in Archaeology*. Cambridge Manuals in Archaeology. Cambridge: Cambridge University Press, 2000.
- Orton, Clive, Paul Tyers, and Alan Vince. *Pottery in Archaeology*. Cambridge Manuals in Archaeology. Cambridge: Cambridge University Press, 1993.
- Peacock, D. P. S. "Bricks and Tiles of the Classis Britannica: Petrology and Origin." *Britannia* 8 (1977): 235-248.
- Peterson, Sarah E., and Philip P. Betancourt. *Thin-Section Petrography of Ceramic Materials*. INSTAP Archaeological Excavation Manual 2. Philadelphia, PA: INSTAP Academic Press, 2009.
- Pollard, A. M., and Carl Heron. "The Geochemistry of Clays and Provenance of Ceramics." In *Archaeological Chemistry*, edited by A. M. Pollard and Carl Heron. London: Royal Society of Chemistry, 2008.
- Potts, Philip J., and Philip Robinson. "Sample preparation of geological samples, soils, and sediments." In *Sample Preparation for Trace Element Analysis*, edited by Zoltan

- Mester and Ralph E. Sturgeon. Boston: Elsevier, 2003.
- Reed, S. J. B. *Electron Microprobe Analysis and Scanning Electron Microscopy in Geology*. Cambridge: Cambridge University Press, 1996.
- Reedy, Chandra L. *Thin-Section Petrography of Stone and Ceramic Cultural Materials*. London: Archetype Publications Ltd., 2008.
- Rice, Prudence. *Pottery Analysis: A Sourcebook*. Chicago: University of Chicago Press, 1987.
- Rook, Tony. "Tiled Roofs." In *Roman Brick and Tile: Studies in Manufacture, Distribution, and Use in the Western Empire*, edited by Alan McWhirr. BAR International Series 68. Oxford: B.A.R., 1979.
- Rudling, David R., Caroline Cartwright, Giles Swift, Sally Foster, John Shepherd, Pat Hinton, and Fred Tebbutt. "The Excavation of a Roman Tillery on Great Cansiron Farm, Hartfield, East Sussex." *Britannia* 17 (1986): 191-230.
- Schwedt, A., H. Mommsen, and N. Zacharias. "Post-depositional Elemental Alterations in Pottery: Neutron Activation Analyses of Surface and Core Samples." *Archaeometry* 46, no. 1 (2004): 85-101.
- Schwedt, A., H. Mommsen, N. Zacharias, and J. Buxeda i Garrigós. "Analcime Crystallization and Compositional Profiles – Comparing Approaches to Detect Post-depositional Alterations in Archaeological Pottery." *Archaeometry* 48, no. 2 (2006): 237-251.
- Shackley, M. Steven. "An Introduction to X-ray Fluorescence (XRF) Analysis in Archaeology." In *X-Ray Fluorescence Spectrometry (XRF) in Geoarchaeology*, edited by M. Steven Shackley. Springer, 2011. doi 10.1007/978-1-4419-6886-9_1.
- Shelton, China P. *Food, Economy, and Identity in the Sangro River Valley, Abruzzo, Italy, 650 B.C. – A.D. 150*. Unpublished dissertation, Boston University, 2009.
- Shennan, Stephen. *Quantifying Archaeology*. 2nd ed. Edinburgh: Edinburgh University Press, 1997.
- Spalding, Elizabeth. *Ceramic Analysis and Catalogue of Roof Tile: Monte Pallano, Italy*. Unpublished thesis draft, Oberlin College, 2001.
- Stoltman, James B. "The Role of Petrography in the Study of Archaeological Ceramics." In *Earth Sciences and Archaeology*, edited by Paul Goldberg, Vance T. Holliday, and C. Reid Ferring. New York: Kluwer Academic / Plenum Publishers, 2001.
- Velde, B. *Introduction to Clay Minerals: Chemistry, Origins, Uses, and Environmental*

Significance. New York: Chapman and Hall, 1992.

Warry, Peter. *Tegulae: Manufacture, typology, and use in Roman Britain*. BAR British Series 417. Oxford: Archaeopress, 2006.

Wikander, Örjan. *The Roof Tiles*. Vol. 6 of *Acquarossa: Results of Excavations Conducted by the Swedish Institute of Classical Studies at Rome and the Soprintendenza alle Antichità dell'Etruria Meridionale*. Stockholm: Astrom Editions, 1986.

I affirm that I have adhered to the Honor Code on this assignment.

Acknowledgments

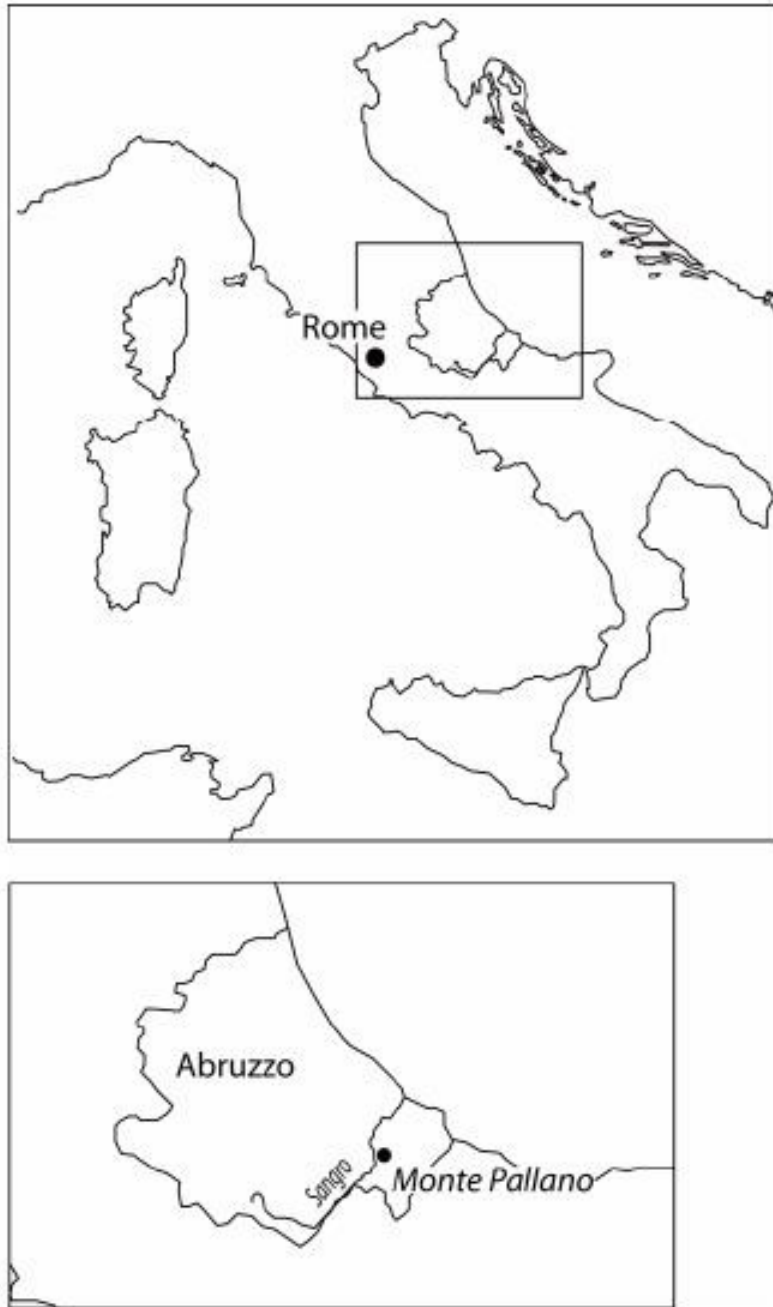
This research would not have been possible without the logistical support of the Sangro Valley Project, the Soprintendenza per i Beni Archeologici dell'Abruzzo, and Bruker Elemental. Generous financial assistance was provided by the Oberlin College Classics Department, the Jerome Davis Fund, and the Office of Undergraduate Research.

I am grateful to a large cast of people, including:

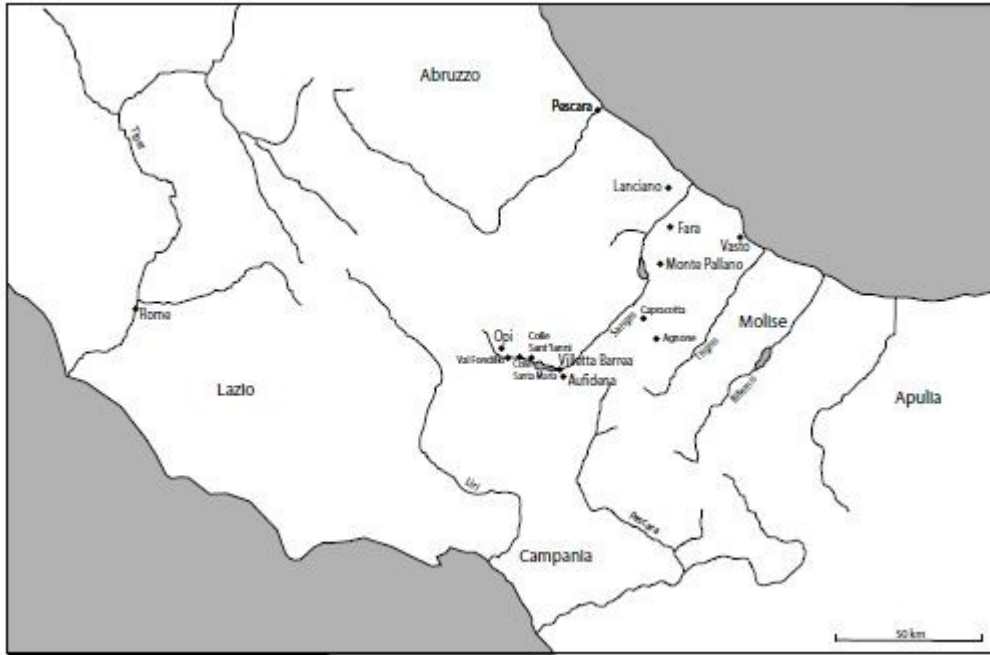
- The staff, students, and local friends of the Sangro Valley Project – particularly Keith Swift, Archer Martin, Raffaele Palma, and Hillary Conley, for their ceramic expertise; Alexis Christensen, for enabling my tile habit in the field; Anna Pia Apilongo, for guiding me patiently to local clays; Amerigo Lemme, for destroying his rotary saw blades on tile samples; and Sam Carrier and Chris Motz, for ensuring a steady flow of data at all times.
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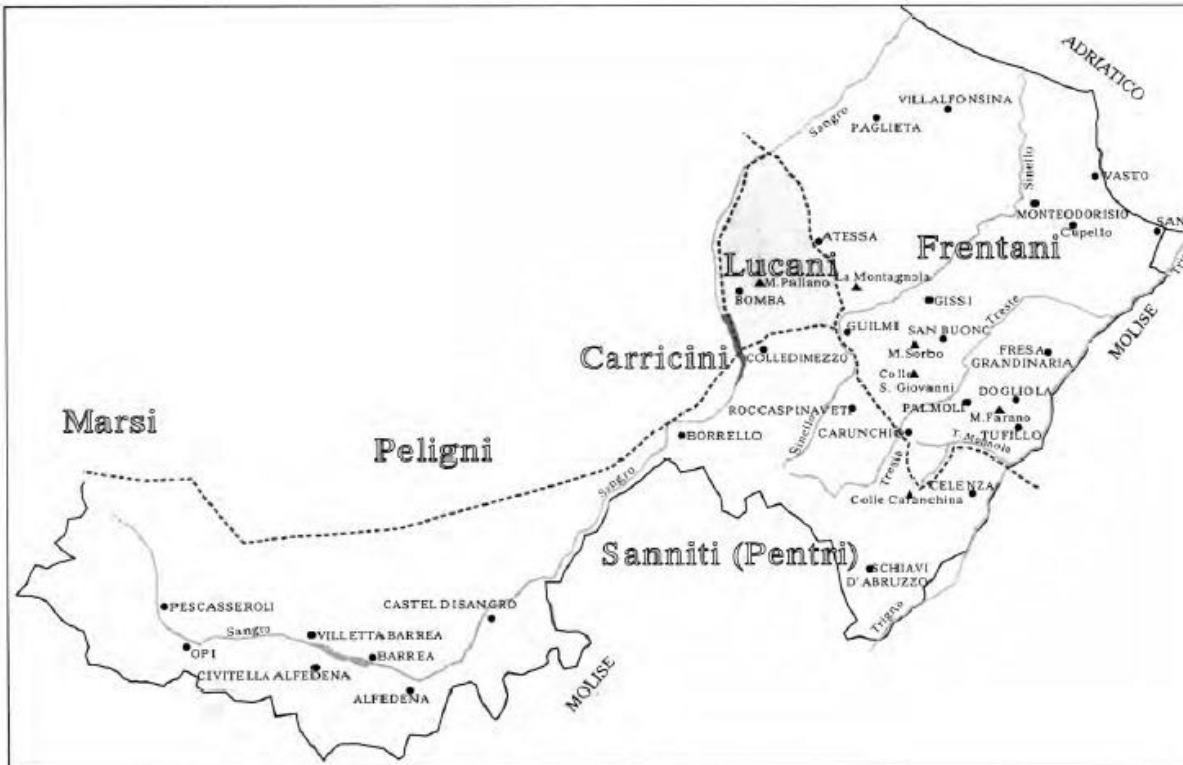
Appendix A: Maps



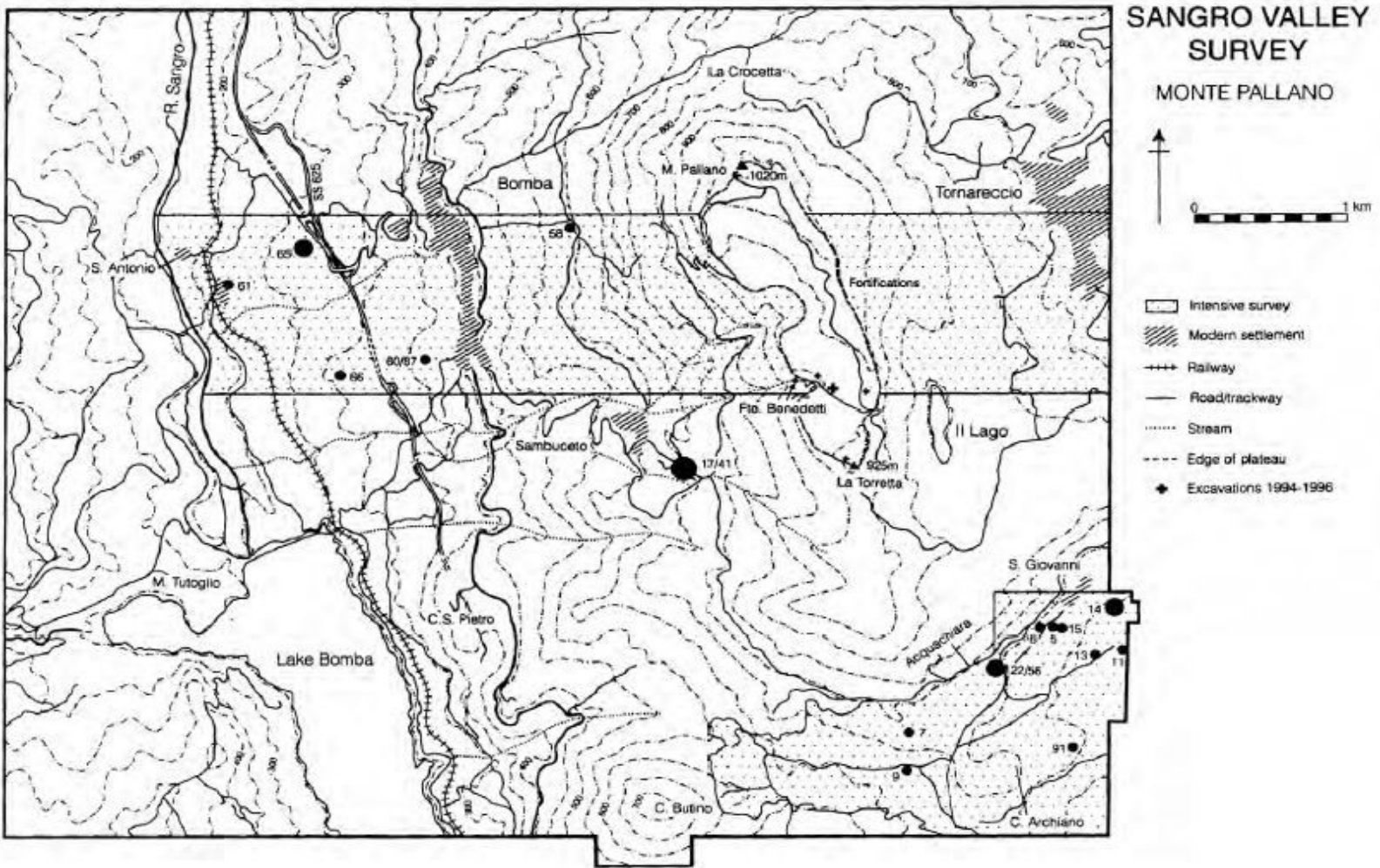
Map 1: The Sangro Valley is located in the southern part of the Abruzzo region, on the Adriatic coast of central Italy. (From Shelton, Food, Economy, and Identity in the Sangro Valley.)



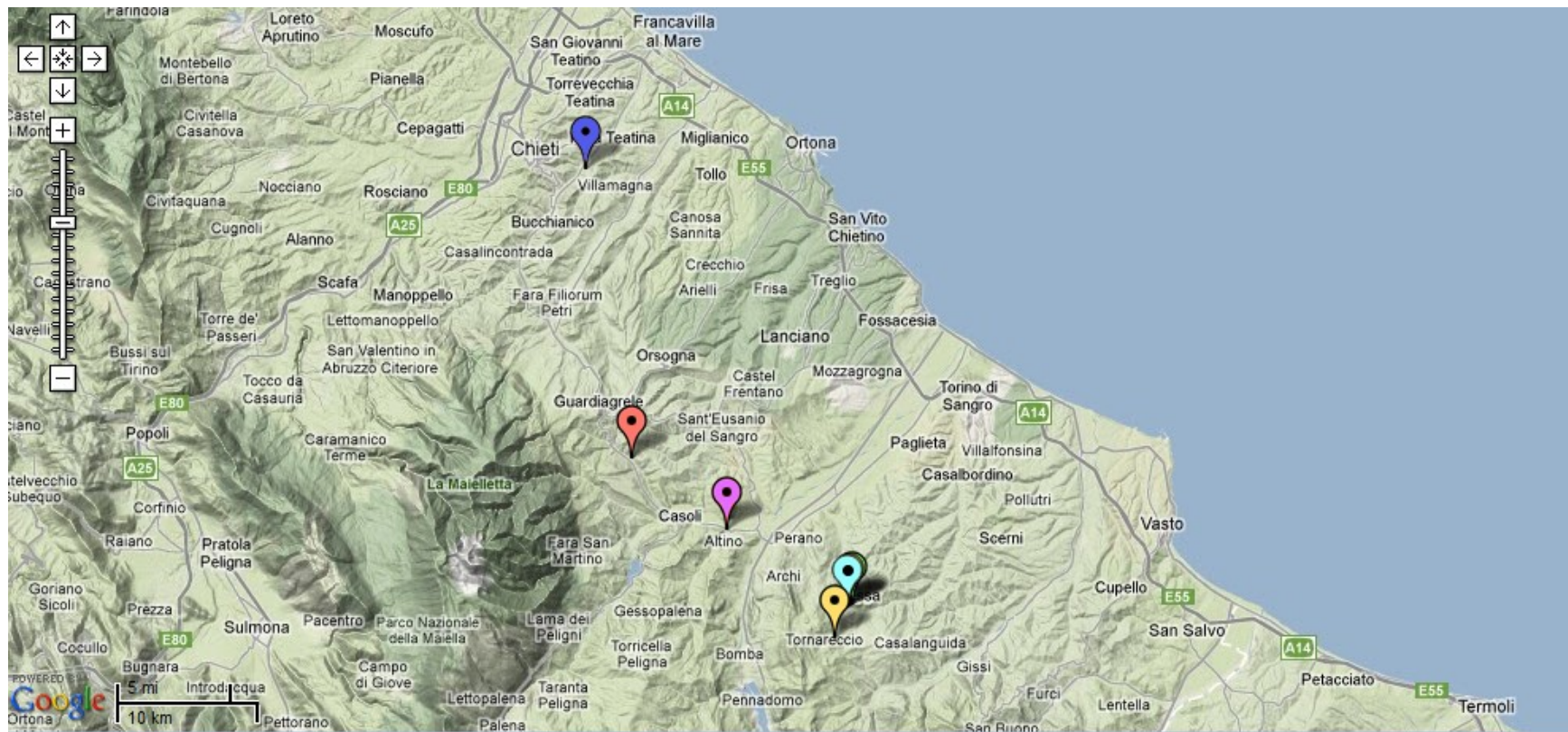
Map 2: Central Italy: the Sangro Valley and parallel river valleys. (From Shelton, Food, Economy, and identity in the Sangro Valley.)



Map 3: Ancient inhabitants of the Abruzzo region. Monte Pallano falls at the intersection of the territories of three groups: the Carricini, Lucani, and Frentani. (From the Sangro Valley Project Field Manual.)

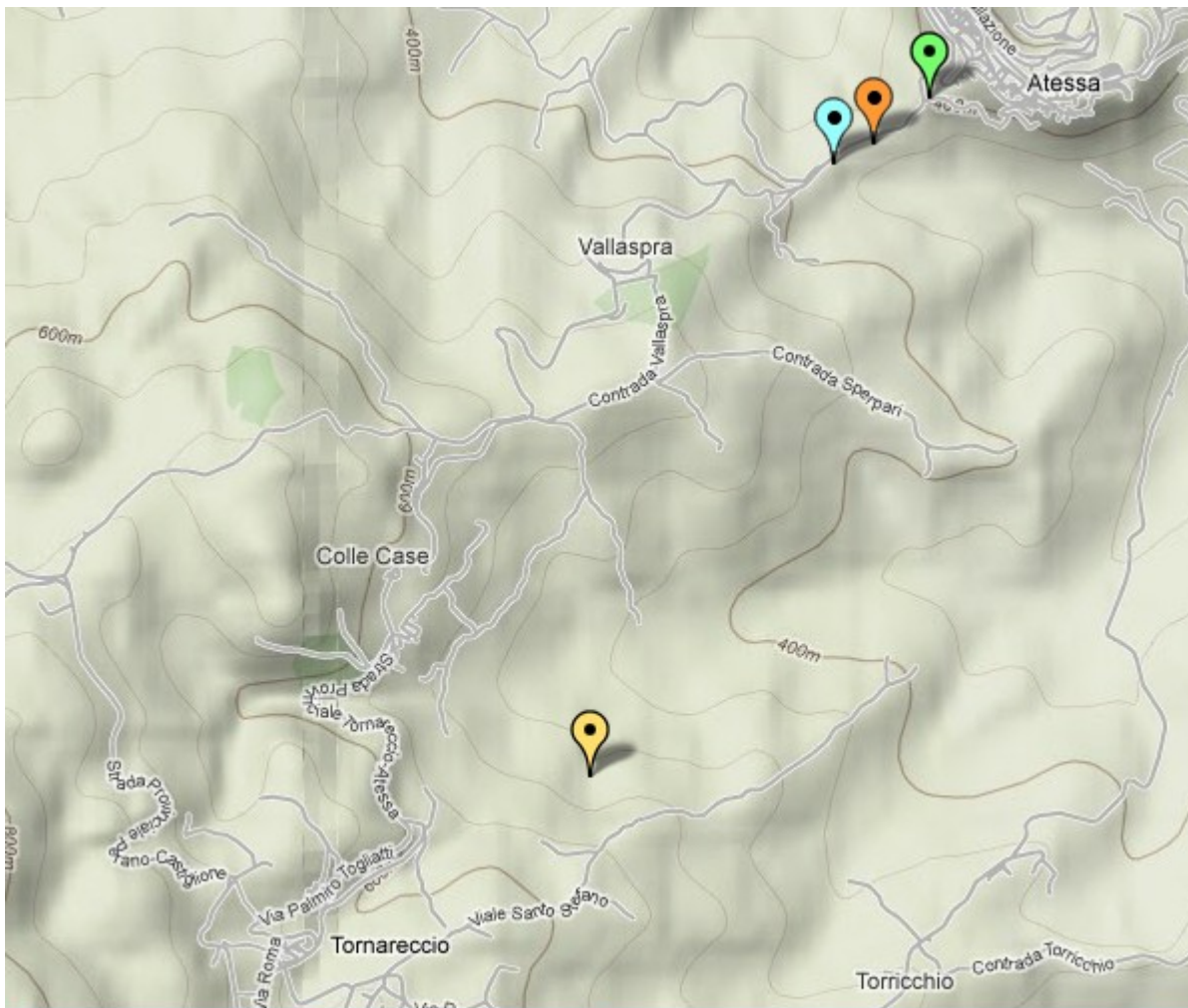


Map 4: Survey data from Phase I of the Sangro Valley Project, showing the summit of Monte Pallano and major scatters at Acquachiara and San Giovanni (lower right). (From the Sangro Valley Project Field Manual.)



● Clay sample 1 ("Chieti")
 ● Clay sample 2 ("Casoli")
 ● Clay sample 3 ("Casoli")
 ● Clay sample 4 (multicolor)
 ● Clay sample 5 (multicolor)
 ● Clay sample 6 (gray-blue)
 ● Clay sample 7 (gray-blue)

Map 5: Locations of clay samples in the Abruzzo. (Map generated by the author with assistance from Keith Swift.)



📍 Clay sample 4 (multicolor)
 📍 Clay sample 5 (multicolor)
 📍 Clay sample 6 (gray-blue)
 📍 Clay sample 7 (gray-blue)

Map 6: Close-up: locations of clay samples between Tornareccio and Atessa. (Map generated by the author.)

Appendix B: Images

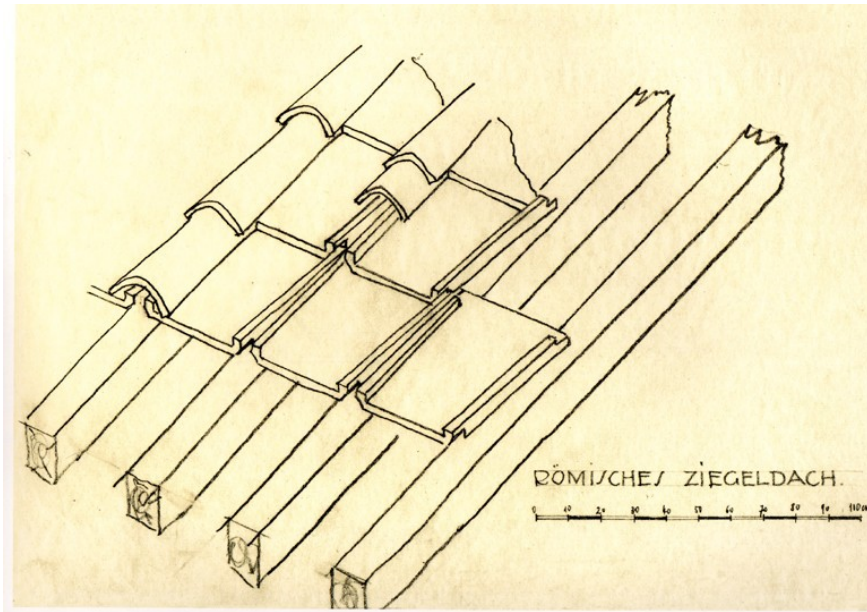


Figure 1: Tegulae and imbrices laid out in columns on a roof. (From Gerster, *Architektonische Skizzen eines Archäologen.*)



Figure 2: A small segment of reconstructed roof at the National Museum of Scotland, with two signatures on the right-hand tegula. (Photograph by the author.)



Plate 2.40: Loading clay into three-sided Mould C



Plate 2.41: Peeling clay off mould after wiring



Plate 2.42: Surface left after wiring

Figure 3: A modern experiment in tile molding. (From Warry, Tegulae.)



Figure 4: A modern tile-maker laying out imbrices to dry. (From Brodrigg, Roman Brick and Tile.)



Figure 5: Finger traces along the flange of a tegula. (Photograph by the author.)



other unstamped tegulae from Chester that have Group C cutaways, so it seems certain that *Legio XX* or its contractors were still producing tegulae into the third century.



Plate 5.7: *Legio XX Antoniniana* dies RIB 2463.51/52/N

Figure 6: A selection of military stamps from Romano-British tegulae. (From Warry, *Tegulae*.)



Figure 7: Twin kilns at Metaponto: the smaller (in the foreground) was used to fire pottery, while the larger (in the background) was used for tile. (From Carter, "Rural Architecture and Ceramic Industry at Metaponto.")

Appendix C: Macroscopic Fabric Analysis

Recording Form for Tiles from Monte Pallano and Acquachiara (2010)

FABRIC RECORDING FORM

Type: tegula imbrex other: _____

Site and context: _____

Item I.D.: _____

Drawing numbers: _____

Photo numbers: _____

Weight: _____ kg

PROPERTIES

Hardness: surface: soft moderately soft moderately hard hard
core: soft moderately soft moderately hard hard

Munsell color: surface: _____
core: _____

Feel: gritty rough smooth soapy powdery

Marks/decoration: surface treatment writing stamps
 finger print finger trace animal print plant imprint
 sand/gravel ridges striations folding knife/tool marks
 other: _____

Description: _____

INCLUSIONS

Frequency: 1% 2% 3% 5% 10% 15% 20% _____ %

Sorting: very poor poor fair good very good

Size range: _____ – _____ mm

Notes: _____

FABRIC:

Recorder initials: _____ Date: _____

Acquachiara Fabric Series (2010)

Group 1

Texture: Fine-grained and relatively smooth (for tile...)

Hardness: Soft to moderately soft

Color: Intense pink (2.5YR 6/6, 5YR 6/6-7/4)

Inclusions: Few (<3%). Primarily small voids with a bit of crumbly swirled/streaked calcareous material. Some pieces have no inclusions at all. Some pieces have light orange and white streaks.

Group 2

Texture: Fine-grained and relatively smooth (for tile...)

Hardness: Soft to moderately soft

Color: Intense pink (Munsell 2.5YR 6/6, 5YR 6/6)

Inclusions: About 10% density, fair to poor sorting. Smaller inclusions are primarily calcareous; larger ones are cream, red, and gray. Occasional large voids.

Group 3

Texture: Slightly rough

Hardness: Moderately soft

Color: Pale pink (Munsell 5YR 7/3)

Inclusions: Rare (<3%), well-sorted, and small; almost exclusively voids and small, light pink / tan / cream-colored particles. A few quite faint orange and white streaks.

Group 4

Texture: Slightly rough

Hardness: Moderately soft

Color: Tan (Munsell 10YR 7/2-3, 7.5YR 7/2). Even throughout.

Inclusions: Few (ca. 5%), sorted fairly to well. Primarily small voids and small dark particles, with a scarce few larger gray or creamy pieces. Nothing larger than ca. 2.5 mm in diameter.

Group 5

Texture: Slightly rough

Hardness: Moderately hard

Color: Inconsistent. One piece is pale pink with a slightly darker core; another is tan with a dark outer layer, presumably reduced.

Inclusions: High percentage (ca. 15-20%) of poorly-sorted inclusions. Some small voids and black and white particles; larger inclusions are primarily calcareous, with some extremely large chunks of ferrous rock.

Group 6

Texture: Quite rough and gritty

Hardness: Moderately hard

Color: Strong yellow/beige (Munsell 2.5Y 8/2), even throughout

Inclusions: High percentage (ca. 20%) of ill-sorted inclusions. Most are small, dark grains; also larger chunks of white material and some irregular voids.

Group 7

Texture: Slightly rough

Hardness: Moderately hard

Color: Pale pink or tan, margins are generally less oxidized (?)

Inclusions: Wide variety of white, cream, red, and gray inclusions; about 10-15% density, with fair to good sorting.

Group 8

Texture: Fine-grained and relatively smooth (for tile...)

Hardness: Moderately soft

Color: Intense pink (Munsell 2.5YR 6/6, 5YR 6/6)

Inclusions: 5-10% density with good sorting; primarily small, prominent calcareous spheres, with some voids.

Group 9

Texture: Slightly rough

Hardness: Moderately hard

Color: Yellowish light brown (Munsell 2.5Y 8/3)

Inclusions: Density ca. 15%, fair to good sorting. Abundant small voids and small, dark particles; larger particles are white, gray, and tan.

Monte Pallano Fabric Series (2010)

Family A: Characterized by small to mid-sized, extremely dense inclusions with a rough, gritty feel. Subgroups are based on dominant inclusion and sorting.

- *Subgroup 1.* Poorly sorted and not quite as dense as the other subgroups. Most visible inclusions are calcareous; diverse range of other inclusions in light and dark gray, red, pink, tan, and possibly a bit of grog and mica.
- *Subgroup 2.* A coarse, dense mixture of mid-sized to large gray, beige, and dark brown inclusions. Similar to ACQ 6.
- *Subgroup 3.* Extremely well-sorted mixture of small white and light gray grains. A little bit of sparkling material (mica?) is also visible.
- *Subgroup 4.* Exclusively small white grains. Often an intense, dark pink. Resembles ACQ 8, but grains are smaller and more dense, and have a distinct gritty feel.

Family B: Pinkish color, smooth to slightly rough. Most dominant inclusions are calcareous, with little other material.

- *Subgroup 1.* Corresponds to ACQ 1 and 2. Characterized by light to intense pink color, smooth to slightly rough. Many pieces have a powdery, chalky feel. Few or no visible inclusions. Inclusions are most commonly crumbles or streaks of calcareous material, with sparse small dark grains, and some small round and lens-shaped voids. Some pieces have a few larger gray grains and grog (ACQ 2).
- *Subgroup 2.* Smooth to slightly rough. Color is most often a pale pink/tan, though some pieces are a more intense pink. 5-10% density of small, well-sorted inclusions: an even mix of dark grains, small white/cream grains, and sparkling flakes (mica?).
- *Subgroup 3.* Corresponds to ACQ 3. Pale pink, slightly rough, sharp angular break. Few or no visible inclusions, almost entirely calcareous, with some mid-sized irregular voids. One piece has a visible chunk of shell.

Family C: Tannish color, slightly rough. Dominant inclusions are mid-sized, browns and grays. Calcareous material, if present, is scarce and small.


- *Subgroup 1.* Corresponds to ACQ 4. Slightly rough, color is generally beige/tan. Small roundish voids, a few dark brown and gray inclusions, some lighter tan/cream inclusions that may be small pieces of grog.

- *Subgroup 2.* Slightly rough, color is generally beige/tan. Most prominent inclusions are mid-sized, reddish-brown, and slightly angular; other visible inclusions are dark grains and mid-sized spherical voids. Small amounts of calcareous material, mica, and quartz are visible.
- *Subgroup 3.* Slightly rough, creamy color. Few visible inclusions; some mid-sized light gray, tan, and reddish inclusions, nothing smaller than ca. 1.5 mm. Looks like a diluted version of the other two subgroups.

Databae Forms for Bricks and Tiles from San Giovanni (2011)

Register		Sample ID: TILE.78		Tile Record		Bulk Tile	
Site: SG	Season: 2011	Trench: T.1000	Context:	Tile Type: Tegula Flange	Photographed	Analysis Performed:	
					Sampled		
Weight: <input type="text"/> kg	Flange Type: <input type="text"/>		Flange Width: <input type="text"/> Height: <input type="text"/>		Upper Cutaway Length: <input type="text"/>	Lower Cutaway Depth: <input type="text"/> Height: <input type="text"/> Length: <input type="text"/>	
Thickness: <input type="text"/> cm							
Properties:				Inclusions:			
Margin: <input type="text"/>				Frequency: <input type="radio"/> 1% <input type="radio"/> 5% <input type="radio"/> 20%			
Core: <input type="text"/>				<input type="radio"/> 2% <input type="radio"/> 10% <input type="radio"/> Other: <input type="text"/>			
Feel: <input type="radio"/> Gritty <input type="radio"/> Rough <input type="radio"/> Smooth <input type="radio"/> Soapy <input type="radio"/> Powdery				<input type="radio"/> 3% <input type="radio"/> 15%			
Marks / Decoration:				Sorting: <input type="text"/>			
<input type="checkbox"/> Surface treatment				Size Range: <input type="text"/> to <input type="text"/> mm			
<input type="checkbox"/> Writing				Notes: <input type="text"/>			
<input type="checkbox"/> Stamps				Fabric: <input type="text"/>			
<input type="checkbox"/> Other: <input type="text"/>				State of Recording: <input type="text"/>			
Description: <input type="text"/>				Crate Number: <input type="text"/>			
				Created By: Date: 7-Apr-2012 17:20:35			
				Modified By: <input type="text"/> Date: 7-Apr-2012 17:21:06			

Register		Sample ID: TILE.78		Tile Record		Bulk Tile	
Site: SG	Season: 2011	Trench: T.1000	Context:	Tile Type: Flat	Photographed	Analysis Performed:	
					Sampled		
Weight: <input type="text"/> kg							
Thickness: <input type="text"/> cm							
Properties:				Inclusions:			
Margin: <input type="text"/>				Frequency: <input type="radio"/> 1% <input type="radio"/> 5% <input type="radio"/> 20%			
Core: <input type="text"/>				<input type="radio"/> 2% <input type="radio"/> 10% <input type="radio"/> Other: <input type="text"/>			
Feel: <input type="radio"/> Gritty <input type="radio"/> Rough <input type="radio"/> Smooth <input type="radio"/> Soapy <input type="radio"/> Powdery				<input type="radio"/> 3% <input type="radio"/> 15%			
Marks / Decoration:				Sorting: <input type="text"/>			
<input type="checkbox"/> Surface treatment				Size Range: <input type="text"/> to <input type="text"/> mm			
<input type="checkbox"/> Writing				Notes: <input type="text"/>			
<input type="checkbox"/> Stamps				Fabric: <input type="text"/>			
<input type="checkbox"/> Other: <input type="text"/>				State of Recording: <input type="text"/>			
Description: <input type="text"/>				Crate Number: <input type="text"/>			
				Created By: Date: 7-Apr-2012 17:20:35			
				Modified By: <input type="text"/> Date: 7-Apr-2012 17:22:29			

[Register](#)  **Sample ID: TILE.78** **Tile Record** [Bulk Tile](#)

Site: Season: Trench: Context: [▶](#)

Tile Type: **Brick** Photographed Analysis Performed: Sampled

Weight: kg
 Thickness: cm


Properties: Margin:
 Core:
 Feel: Gritty Rough Smooth Soapy Powdery

Inclusions: Frequency: 1% 5% 20%
 2% 10% Other:
 3% 15%
 Sorting:
 Size Range: to mm
 Notes:

Marks / Decoration: Surface treatment Finger print Plant imprint Striations
 Writing Finger trace Sand / Gravel Folding
 Stamps Animal print Ridges Knife / Tool marks
 Other: **Fabric:**

Description:

State of Recording: [▶](#)
 Created By: [REDACTED] Date: 7-Apr-2012 17:20:35
 Modified By: Date: 7-Apr-2012 17:23:38

[Register](#)  **Sample ID: TILE.78** **Tile Record** [Bulk Tile](#)

Site: Season: Trench: Context: [▶](#)

Tile Type: **Imbrex** Photographed Analysis Performed: Sampled

Weight: kg
 Thickness: cm
 Width (Top): cm
 Width (Bottom): cm

Properties: Margin:
 Core:
 Feel: Gritty Rough Smooth Soapy Powdery

Inclusions: Frequency: 1% 5% 20%
 2% 10% Other:
 3% 15%
 Sorting:
 Size Range: to mm
 Notes:

Marks / Decoration: Surface treatment Finger print Plant imprint Striations
 Writing Finger trace Sand / Gravel Folding
 Stamps Animal print Ridges Knife / Tool marks
 Other: **Fabric:**

Description:

State of Recording: [▶](#)
 Created By: [REDACTED] Date: 7-Apr-2012 17:20:35
 Modified By: Date: 7-Apr-2012 17:23:11

Appendix D: Petrographic Thin-Sectioning

Recording Form for Thin Sections (2011)

THIN SECTION RECORDING FORM

Sample number: _____ Item I.D.: _____ Date: _____

CLAY MATRIX

Color: _____

Birefringence: _____

MAJOR INCLUSIONS

	% Density	Roundness	Sphericity	Size range (µm)	Sorting
feldspar	<input type="checkbox"/> 5% <input type="checkbox"/> 10% <input type="checkbox"/> 15% <input type="checkbox"/> 20% <input type="checkbox"/> 30% <input type="checkbox"/> >30%	<input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5 <input type="checkbox"/> 6	<input type="checkbox"/> low <input type="checkbox"/> high		<input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
grog	<input type="checkbox"/> 5% <input type="checkbox"/> 10% <input type="checkbox"/> 15% <input type="checkbox"/> 20% <input type="checkbox"/> 30% <input type="checkbox"/> >30%	<input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5 <input type="checkbox"/> 6	<input type="checkbox"/> low <input type="checkbox"/> high		<input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
carbonate	<input type="checkbox"/> 5% <input type="checkbox"/> 10% <input type="checkbox"/> 15% <input type="checkbox"/> 20% <input type="checkbox"/> 30% <input type="checkbox"/> >30%	<input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5 <input type="checkbox"/> 6	<input type="checkbox"/> low <input type="checkbox"/> high		<input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
mica	<input type="checkbox"/> 5% <input type="checkbox"/> 10% <input type="checkbox"/> 15% <input type="checkbox"/> 20% <input type="checkbox"/> 30% <input type="checkbox"/> >30%	<input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5 <input type="checkbox"/> 6	<input type="checkbox"/> low <input type="checkbox"/> high		<input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
quartz	<input type="checkbox"/> 5% <input type="checkbox"/> 10% <input type="checkbox"/> 15% <input type="checkbox"/> 20% <input type="checkbox"/> 30% <input type="checkbox"/> >30%	<input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5 <input type="checkbox"/> 6	<input type="checkbox"/> low <input type="checkbox"/> high		<input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5
rock	<input type="checkbox"/> 5% <input type="checkbox"/> 10% <input type="checkbox"/> 15% <input type="checkbox"/> 20% <input type="checkbox"/> 30% <input type="checkbox"/> >30%	<input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5 <input type="checkbox"/> 6	<input type="checkbox"/> low <input type="checkbox"/> high		<input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5

MINOR INCLUSIONS

Identify where possible; otherwise, describe color, relief, cleavage and twinning, birefringence, and shape. Provide abundance and size range.

Notes: _____

VOIDS:

Percent density: <5% 5% 10% 15% 20% 30% >30%

Sorting: very poor poor fair good very good

Size range: _____ – _____ µm

Shape and alignment: _____

Monte Pallano Thin Section Data – Condensed

Sample No.	Context	Fabric	Matrix	Feldspar	Grog	Carbonate	Mica	Quartz	Rock	Ferrous Grains	Voids	Secondary carb.?	Heavy min.?
64	7015	?	dark brown	scarce (plagioclase)	-	-	5% (muscovite)	10%	abundant (quartz- and mica-rich, some carbonate)	-	5 – 10%	no	yes (abundant)
32	5013	A (random)	orange-green with red patches	-	10% (some red-brown; some green-gray and quartz)	-	5% (muscovite)	15%	-	10%	5%	no	no
51	8105	A (random)	light brown	-	<5% (dark red, quartz-rich)	-	5% (muscovite)	10%	scarce (quartz- and carbonate-rich)	5 – 10%	5%	yes	no
31	6045 (1P9)	A?	light brown	scarce (plagioclase)	scarce (similar to matrix)	<5%	5% (muscovite)	5%	-	5 – 10%	5%	yes	no
58	7004	A1 (random)	brown	scarce (plagioclase)	-	-	5%	15%	5 – 10% (two types: one rounded and porous, one with fine quartz crystals)	-	5%	no	no

Sample No.	Context	Fabric	Matrix	Feldspar	Grog	Carbonate	Mica	Quartz	Rock	Ferrous Grains	Voids	Secondarily carb.?	Heavy min.?
60	6034 (TP9)	A1 (random)	orange-brown	-	5% (multiple distinct types)	<5%	<5% (muscovite)	5%	scarce (carbonate- and quartz-rich, some heavy minerals)	5%	5%	yes	no
16	7005	A1 (representative)	tan and gray-green	scarce (plagioclase)	-	-	5% (mostly muscovite, some biotite)	10%	scarce (quartz-rich)	10%	5 - 10%	yes	no
42	8206	A2 (random)	orange-brown	-	-	15% (some fossils)	5%	5 - 10%	-	5 - 10%	5%	no	no
55	6000 (TP9)	A2 (random)	gray-green	10% (orthoclase and plagioclase)	-	-	-	5%	scarce (quartz-rich)	5%	5%	yes	yes (abundant)
17	7010	A2 (representative)	tan and gray-green	scarce (plagioclase)	15%	-	scarce (muscovite)	10 - 15%	10% (quartz-rich)	10%	ca. 10%	no	no
5	7012	A3 (random)	orange-red	-	-	10% (including fossil)	-	15%	-	5 - 10%	5%	no	no
35	7010	A3 (random)	orange-tan and gray	-	-	10 - 15%	5% (mostly muscovite)	5%	<5% (quartz-rich)	5%	10%	yes	no
18	7012	A3 (representative)	orange-tan and gray	scarce (plagioclase)	-	10 - 15%	5% (muscovite)	10%	-	10%	5%	no	no
30	6042 (TP9)	A4 (random)	orange-brown	-	scarce (contains carbonate, quartz, and mica)	10%	<5% (muscovite)	15%	-	5 - 10%	10%	yes	no

Sample No.	Context	Fabric	Matrix	Feldspar	Grog	Carbonate	Mica	Quartz	Rock	Ferrous Grains	Voids	Secondary carb.?	Heavy min.?
36	7004	A4 (random)	brown with orange streaks	-	-	-	5% (muscovite)	10%	<5% (quartz-rich)	5%	<5%	yes	no
19	7009	A4 (representative)	red, mottled gray	scarce (orthoclase and plagioclase)	-	-	5% (mostly muscovite, some biotite)	20%	-	10%	5%	yes	no
38	8xxx	B (random)	orange with red streaks	-	scarce	scarce	5% (muscovite)	5%	scarce (quartz-rich)	5%	5%	no	no
39	5018	B (random)	gray-green	-	<5% (similar to matrix)	-	-	10%	5% (quartz-rich, some plagioclase feldspar)	5 - 10%	5%	yes	no
54	5101	B1 (random)	orange with red streaks	-	-	<5% (some fossils)	5% (muscovite)	10%	<5% (quartz- and carbonate-rich, some mica)	5%	5%	yes	no
59	7015	B1 (random)	orange-brown	-	-	-	<5% (muscovite)	10%	-	5%	5%	yes	yes (scarce)
20	7011	B1 (representative)	orange-tan and gray with red streaks	scarce (plagioclase)	-	10%	5% (mostly muscovite, some biotite)	10%	scarce (quartz-rich)	5%	5%	yes	no
34	7010	B2 (random)	orange-green with red patches	-	-	-	5 - 10% (mostly muscovite, some biotite)	15 - 20%	-	5%	5 - 10%	yes	no
40	6032 (TP9)	B2 (random)	orange	-	5% (similar to matrix, quartz- and mica-rich)	scarce	5% (muscovite)	10%	-	5 - 10%	5%	yes	no

Sample No.	Context	Fabric	Matrix	Feldspar	Grog	Carbonate	Mica	Quartz	Rock	Ferrous Grains	Voids	Secondarily carb.?	Heavy min.?
21	7004	B2 (representative)	tan and brown	scarce (plagioclase)	-	5%	5 - 10% (mostly muscovite)	10 - 15%	scarce (ferrous, with quartz and carbonate)	5%	10%	yes	no
7	7015	B3 (random)	tan with dark clouds	-	-	5% (including fossil)	5% (mostly biotite, some muscovite)	20%	-	10%	5%	no	yes (scarce)
33	5100	B3 (random)	orange-green with red patches	-	-	-	5% (mostly muscovite, some biotite)	10 - 15%	-	10%	5%	yes	no
62	7007	B3 (random)	orange-brown with red streaks	scarce (plagioclase)	-	scarce	<5% (muscovite)	20%	-	5%	5%	no	no
22	7015	B3 (representative)	tan and gray-green	-	-	-	5% (muscovite and biotite)	5%	-	5 - 10%	5%	yes	no
56	8104	C (random)	brown	scarce (orthoclase)	-	10%	5% (muscovite)	10%	-	5%	5%	yes	yes (scarce)
61	6032 (TP9)	C? (random)	gray-green	-	-	-	5%	10%	scarce (porous)	5 - 10%	5%	no	no
37	7013	C1 (random)	gray-green	-	scarce (similar to matrix, contains carbonate and quartz)	-	<5% (muscovite)	5%	<5% (carbonate-rich, some quartz)	-	5 - 10%	yes	no
41	5101	C1 (random)	orange-gray	<5% (orthoclase and plagioclase)	-	-	5% (muscovite)	10%	-	5%	5%	yes	yes (scarce)
23	7004	C1 (representative)	olive green	-	-	-	-	5%	-	5 - 10%	5%	yes	no

Sample No.	Context	Fabric	Matrix	Feldspar	Grog	Carbonate	Mica	Quartz	Rock	Ferrous Grains	Voids	Secondarily carb.?	Heavy min.?
6	7012	C2 (random)	olive-brown and orange	5% (orthoclase, plagioclase, and microcline)	5% (red matrix, quartz-rich)	-	5% (muscovite)	15%	-	10%	5%	no	no
46	8702	C2 (random)	gray-brown	-	-	-	5%	10%	<5% (quartz- and carbonate-rich)	5%	5%	yes	no
24	7011	C2 (representative)	tan and gray-green	-	-	-	<5% (muscovite)	10%	5% (quartz-rich)	5 - 10%	5%	no	no
57	6034 (TP 9)	C2? (random)	gray-brown	scarce (orthoclase and plagioclase)	-	-	5% (muscovite)	10%	5% (quartz-rich, some heavy minerals)	5%	5%	no	no
63	6xxx	C3 (random)	light brown	-	-	10%	5% (muscovite and biotite)	10 - 15%	-	5%	5%	yes	no
25	7007	C3 (representative)	tan and gray-green	scarce (plagioclase)	-	-	5% (muscovite)	10%	-	10%	5%	no	no

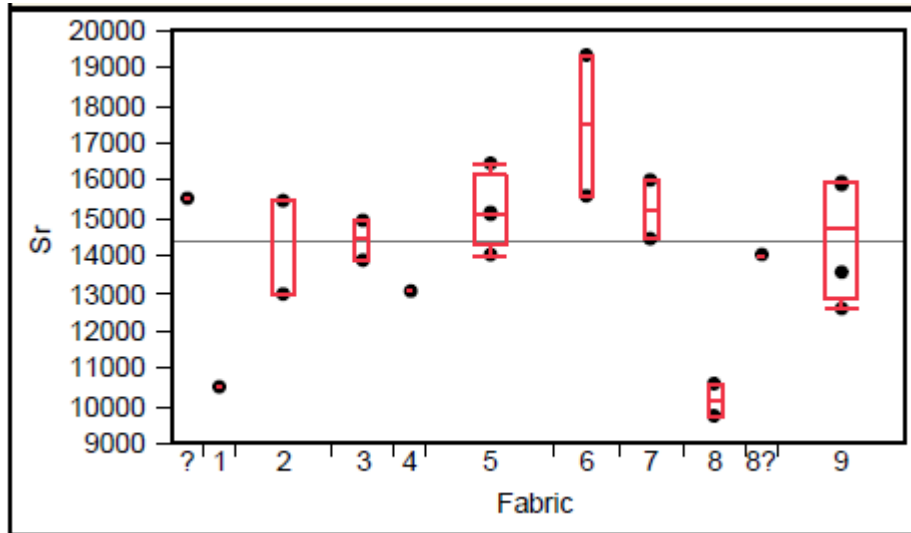
Acquachiara Thin Section Data - Condensed													
Sample No.	Context	Fabric	Matrix	Feldspar	Grog	Carbonate	Mica	Quartz	Rock	Ferrous Grains	Voids		Heavy min.?
											Density	Secondary carb.?	
26	1003	?	olive green with red streaks	-	scarce, red	10%	5% (mostly muscovite, a little biotite)	5%	-	10%	5%	yes	no
27	10203	?	tan, mottled gray	-	scarce	-	<5% (muscovite)	10%	scarce (quartz)	5%	5%	yes	no
28	10210	?	tan and gray	scarce (plagioclase)	<5% (red dish matrix quartz with some carbonate and mica)	scarce (large chunks)	-	5 - 10%	-	5%	5%	yes	no
47	10204	?	orange with red flecks	-	-	-	5%	5%	<5% (quartz with some mica)	-	5%	yes	no
52	10204	?	red-orange and tan	-	5% (light brown and gray brown, tempered with quartz and ferrous grains)	-	5% (muscovite)	10%	-	10%	5%	yes	no
48	10025	1 (random)	red and orange/tan	-	20% (red, tempered with quartz and mica)	scarce	5-10%	5-10%	-	5%	5%	no	yes

Sample No.	Context	Fabric	Matrix	Feldspar	Grog	Carbonate	Mica	Quartz	Rock	Ferrous Grains	Voids		Heavy min.?
											Density	Secondary carb.?	
10	10204	1 (representative)	orange-brown and gray	scarce (plagioclase)	<5% (very red, tempered with quartz, mica, and Fe)	-	5% (muscovite and biotite)	10%	-	10%		no	no
50	10204	2 (random)	orange-brown	scarce (plagioclase)	-	-	10%	10%	scarce	10%	<5%	no	no
11	10204	2 (representative)	red and orange/tan	-	scarce (red, tempered with quartz and mica)	-	5%	10%	-	10%	5%	yes	no
49	10025	3 (random)	gray-green with red streaks	-	-	-	<5% (muscovite)	10%	-	5%	5%	yes	no
12	10204	3 (representative)	gray-green with red flecks	scarce (orthoclase and plagioclase)	-	10%	<5% (muscovite)	15%	-	15%	5-10%	yes	no
3	10200	4 (random)	olive brown	-	scarce	-	-	5-10%	-	10%	10%	no	no
13	10204	4 (representative)	-	scarce (orthoclase and plagioclase)	-	-	5% (muscovite)	10%	-	-	5 - 10%	yes	no
29	10210	5 (random)	tan, gray-green clouds	-	<5% (gray-green with traces of carbonate)	10	-	10%	5%	5%	5%	yes	yes

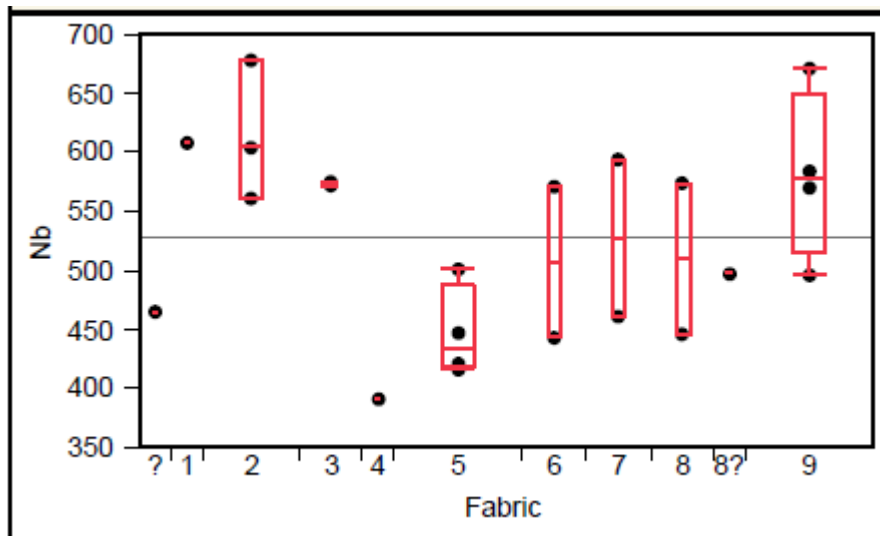
Sample No.	Context	Fabric	Matrix	Feldspar	Grog	Carbonate	Mica	Quartz	Rock	Ferrous Grains	Voids		Heavy min.?
											Density	Secondary carb.?	
14	10203	5 (representative)	gray-brown	5% (orthoclase and plagioclase)	10 - 15% (widely varied: tan or red clay. most with few inclusions. some with much quartz)	5%	-	20%	-	-	5%	yes	no
43	10204	5 (representative)	light brown	<5% (plagioclase)	-	-	-	10%	5% (multiple kinds, red-rimmed with quartz or carbonate)	5%	10%	yes	no
15	1005	7 (random)	gray and tan, single red patch	-	-	10%	5% (muscovite)	5%	-	5%	5-10%	yes	no
53	10025	7 (representative)	orange-brown	-	-	-	5%	10%	scarce	5-10%	5%	yes	no
45	10025	5 (random)	orange-brown	-	<5% (orange-brown matrix, quartz and mica)	5%	5%	15%	scarce (aggregates of carbonate, quartz, and ferrous grains)	10%	5%	yes	no
9	10025	3 (representative)	olive brown	scarce (orthoclase and plagioclase)	5% (contains quartz and mica)	5%	5% (muscovite)	15%	-	5 - 10%	5 - 10%	no	no

Sample No.	Context	Fabric	Matrix	Feldspar	Grog	Carbonate	Mica	Quartz	Rock	Ferrous Grains	Voids		Heavy min.?
											Density	Secondary carb.?	
2	10025	9 (representative)	olive green	-	scarce (dark red, quartz)	-	-	10%	scarce (quartz)	5%	<5%	no	no
8	10200	9 (representative)	olive-gray with orange	scarce (orthoclase and plagioclase)	-	-	5%	15%	-	5-10%	5%	yes	no
44	10025	9 (representative)	brown	scarce (plagioclase and microcline)	-	10%	scarce (muscovite)	10%	>5%	15%	5%	yes	no

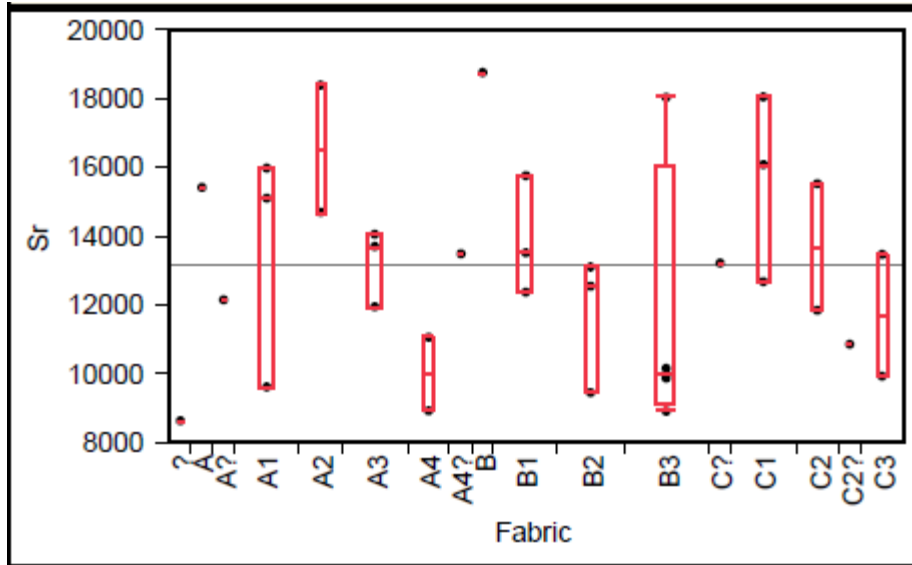
Appendix E: Analyses of X-ray Fluorescence Data



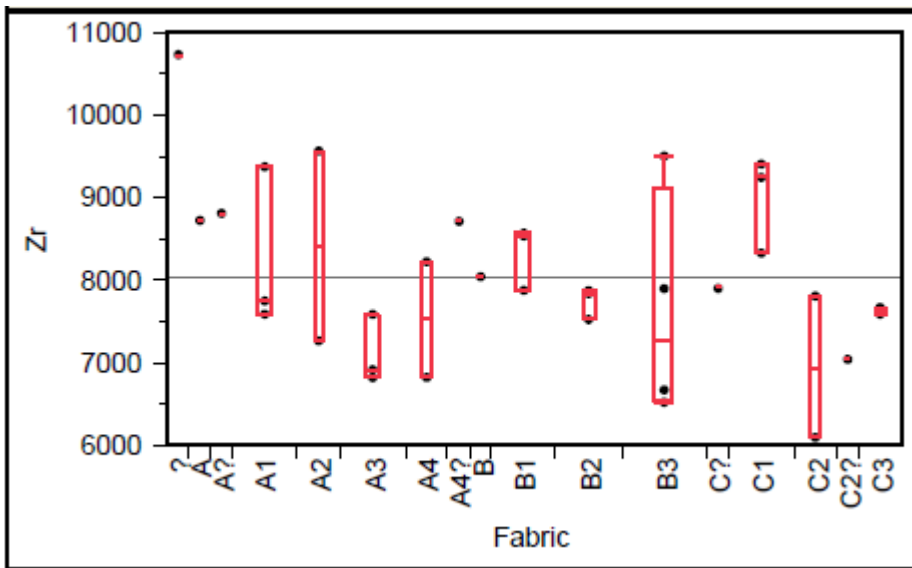
Plot 1: One-way analysis of counts of Sr in Acquachiara tiles, by fabric.



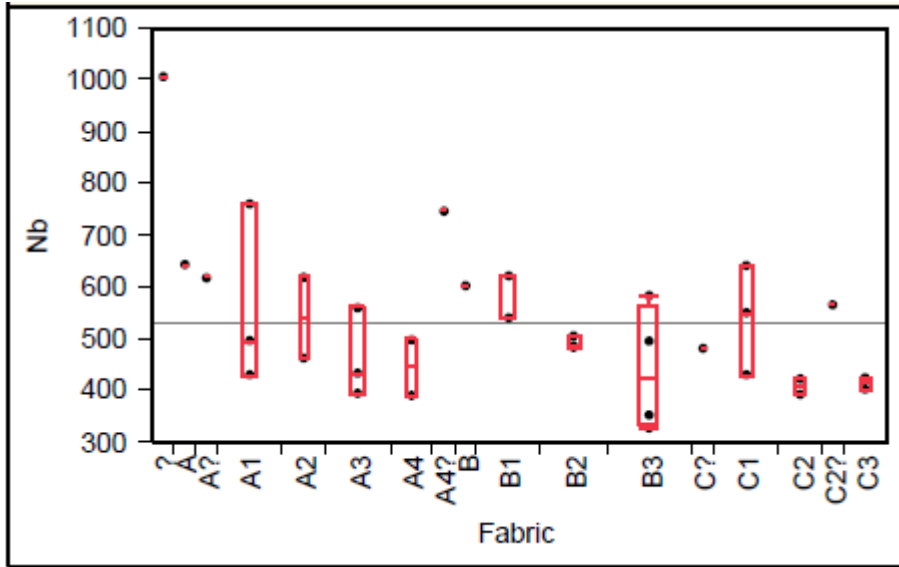
Plot 2: One-way analysis of counts of Nb in Acquachiara tiles, by fabric.



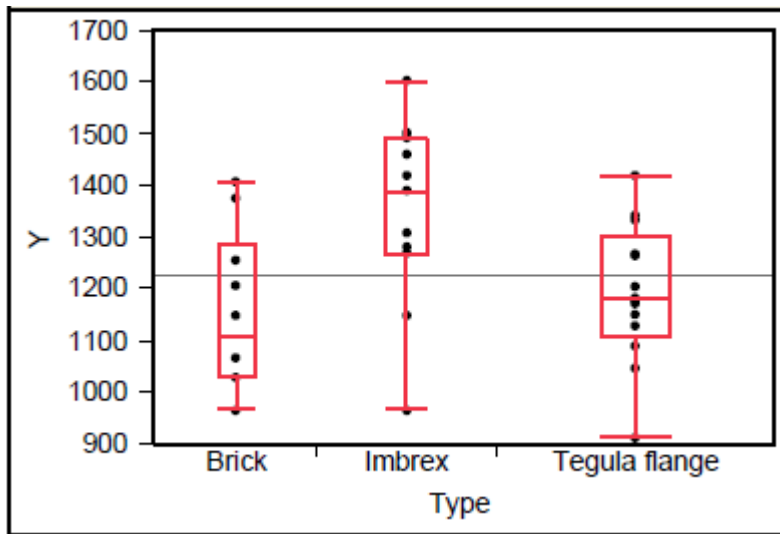
Plot 3: One-way analysis of counts of Sr in Monte Pallano tiles, by fabric subtype.



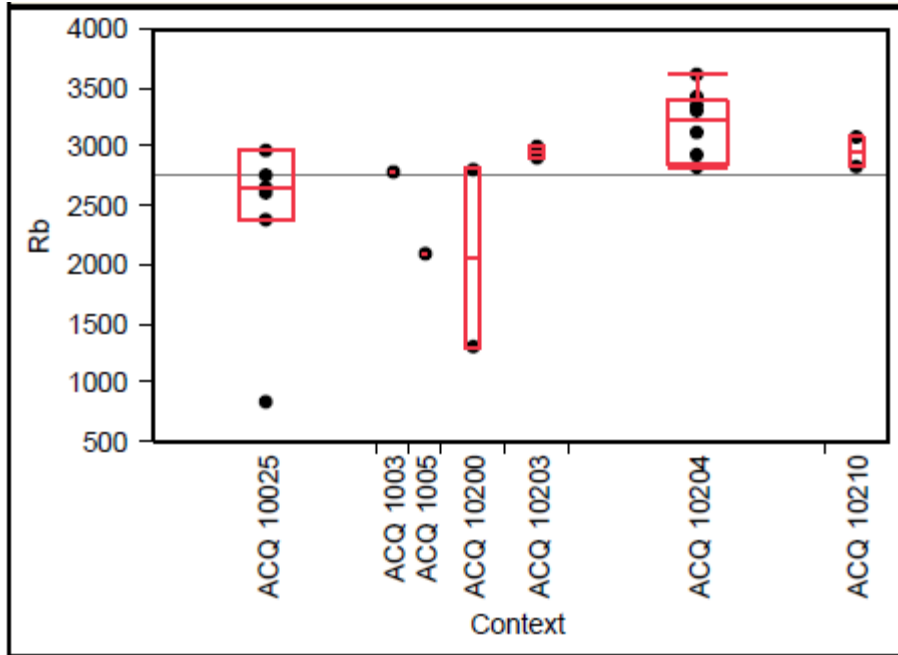
Plot 4: One-way analysis of counts of Zr in Monte Pallano tiles, by fabric subtype.



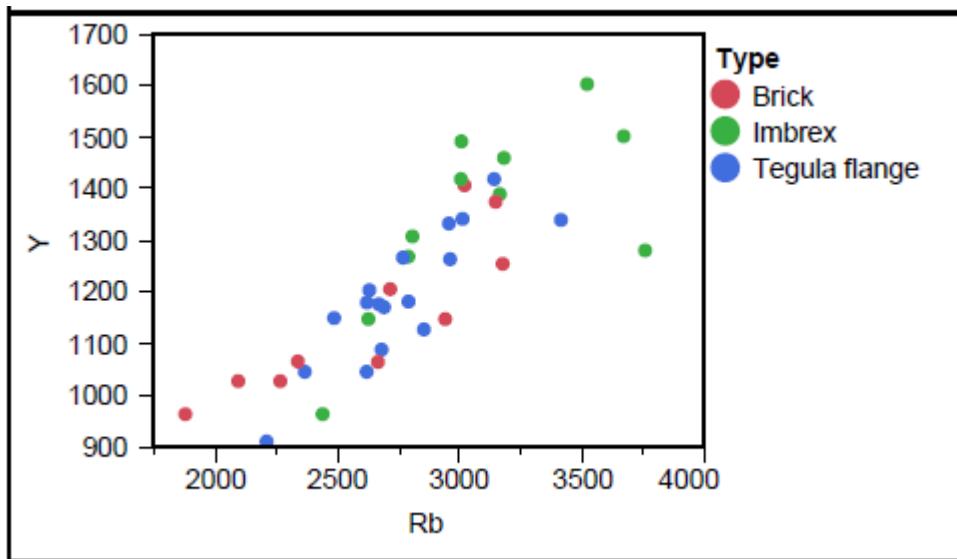
Plot 5: One-way analysis of counts of Nb in Monte Pallano tiles, by fabric subtype.



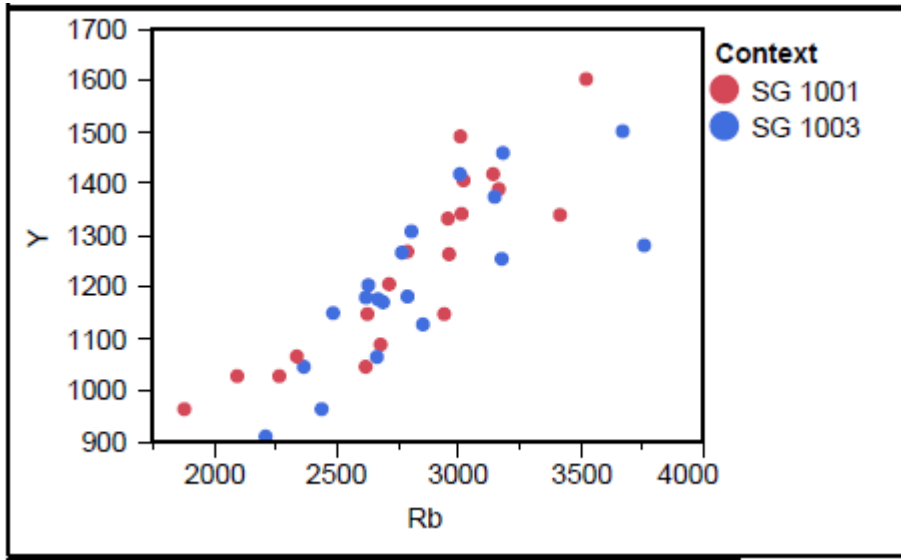
Plot 6: One-way analysis of counts of Y in San Giovanni CBM, by type.



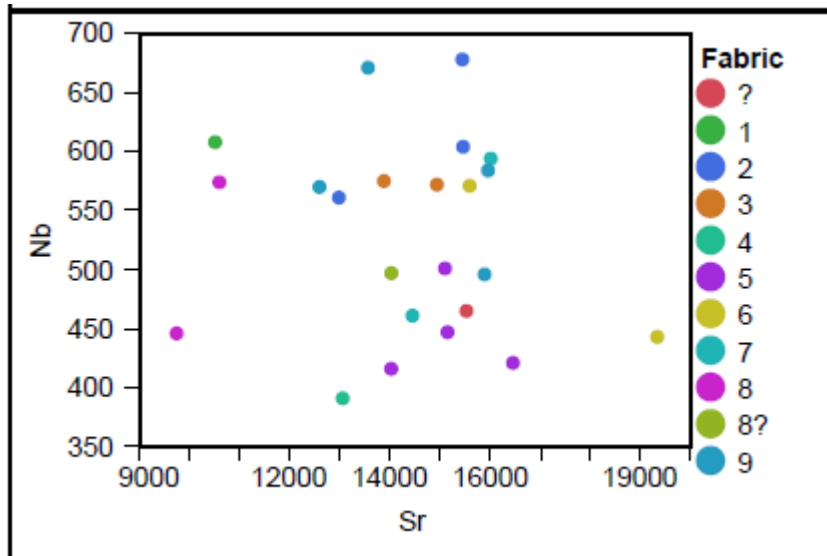
Plot 7: One-way analysis of counts of Rb in Acquachiara tiles, by context.



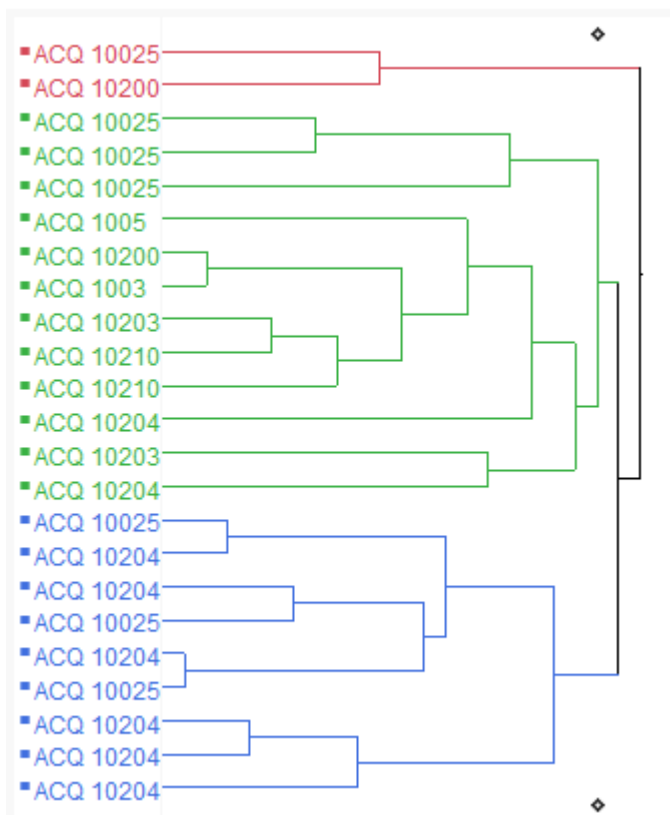
Plot 8: Bivariate analysis of counts of Y vs. counts of Rb in San Giovanni CBM, by type.



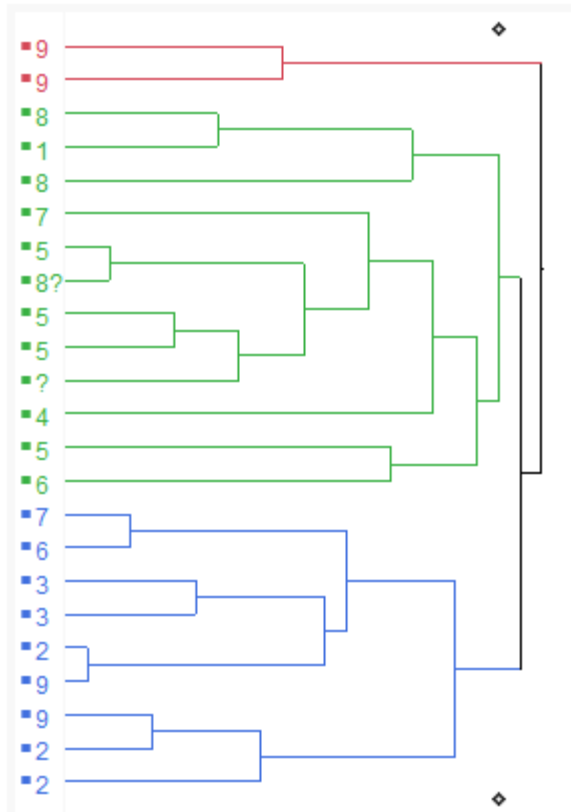
Plot 9: Bivariate analysis of counts of Y vs. counts of Rb in San Giovanni CBM, by context.



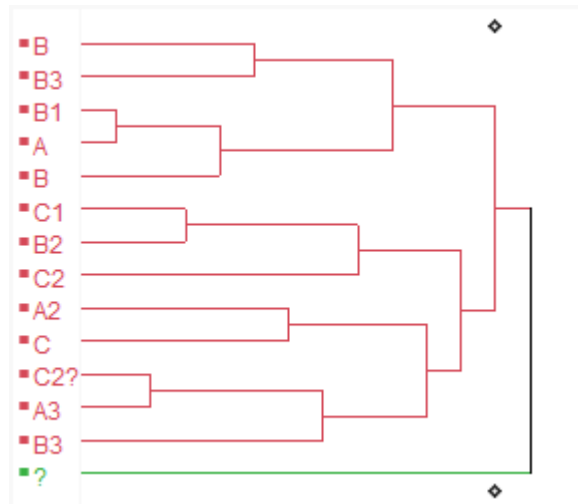
Plot 10: Bivariate analysis of counts of Nb vs. counts of Sr in Acquachiarra tiles, by fabric.



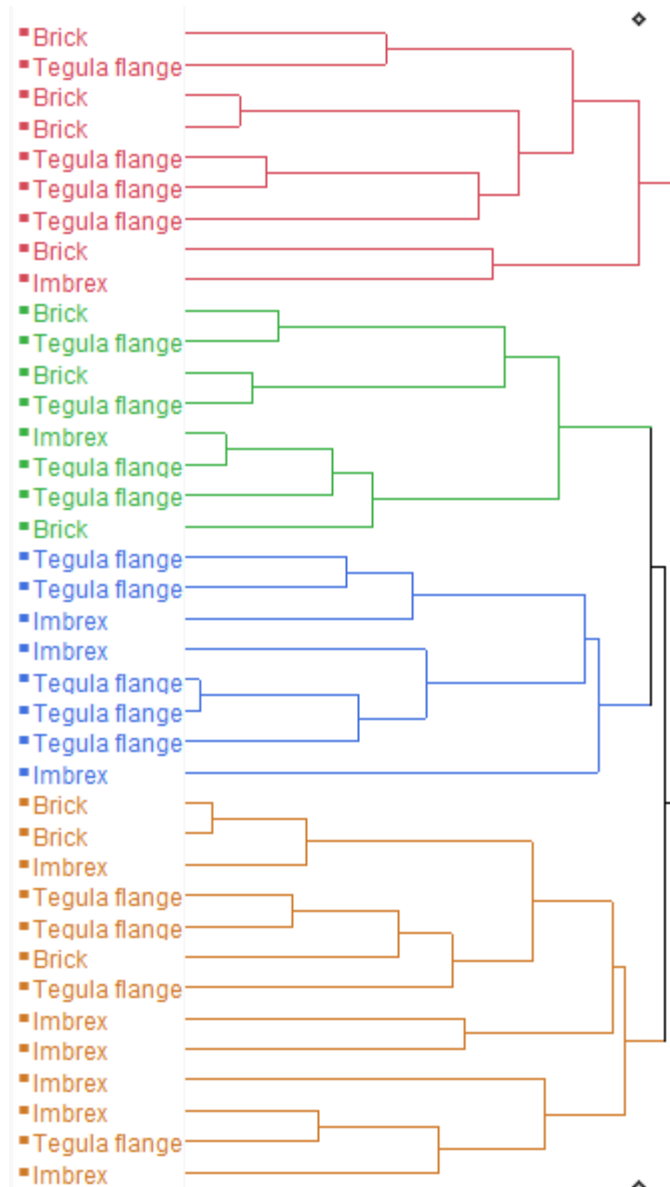
Plot 11: Dendrogram of tiles from Acquachiara, labeled by context.



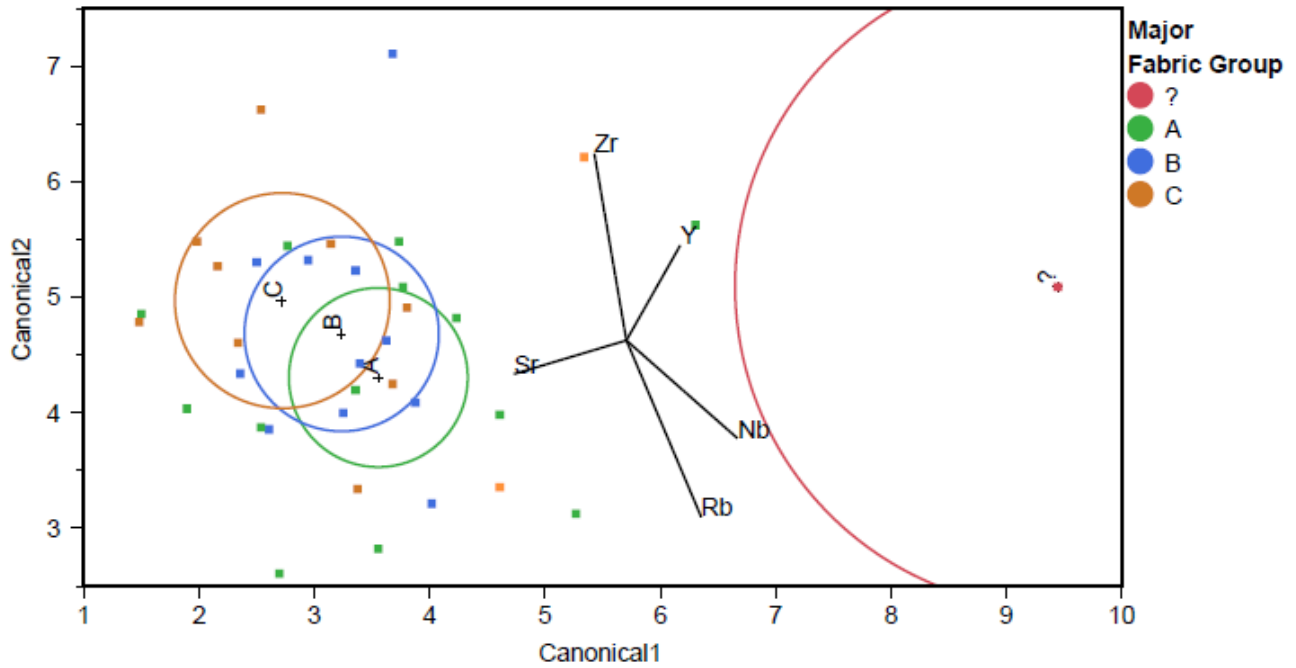
Plot 12: Dendrogram of tiles from Acquachiara, labeled by fabric.



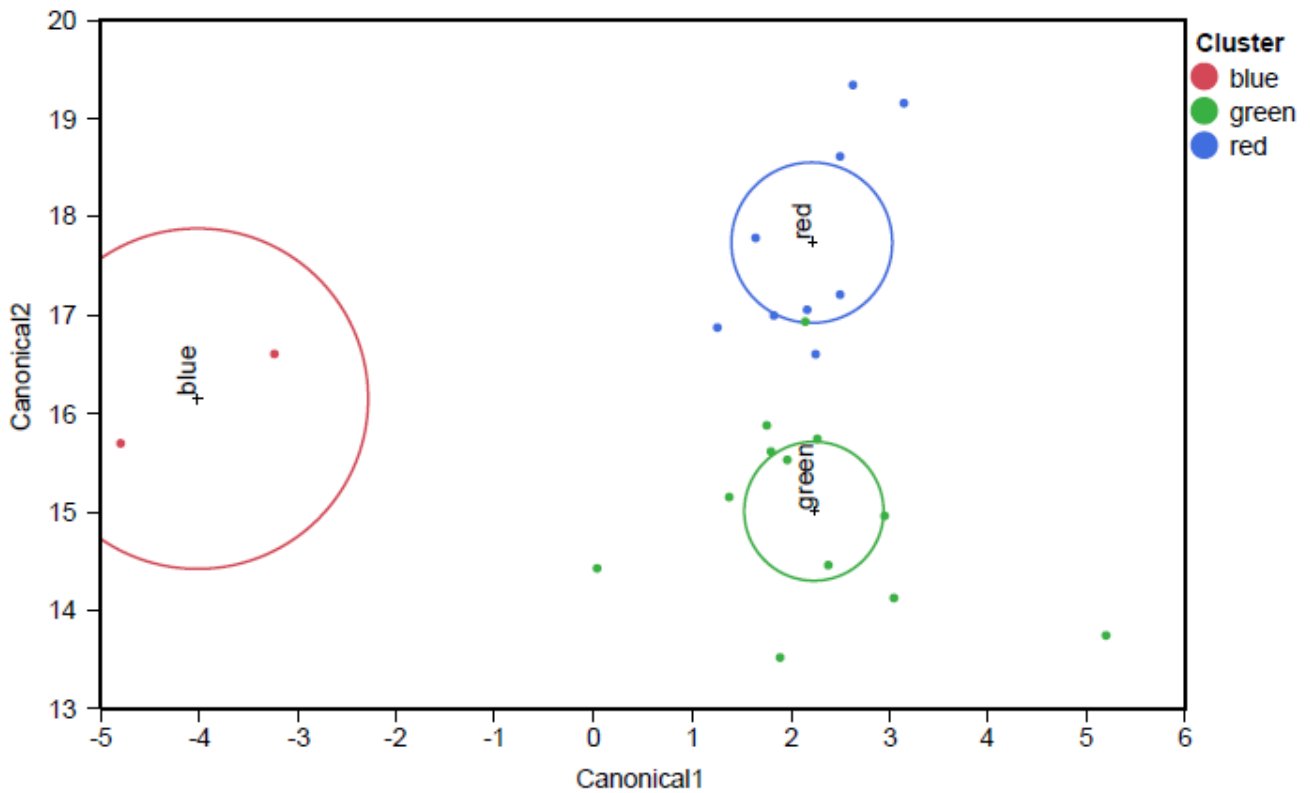
Plot 13: Dendrogram of tegulae from Monte Pallano, labeled by fabric.



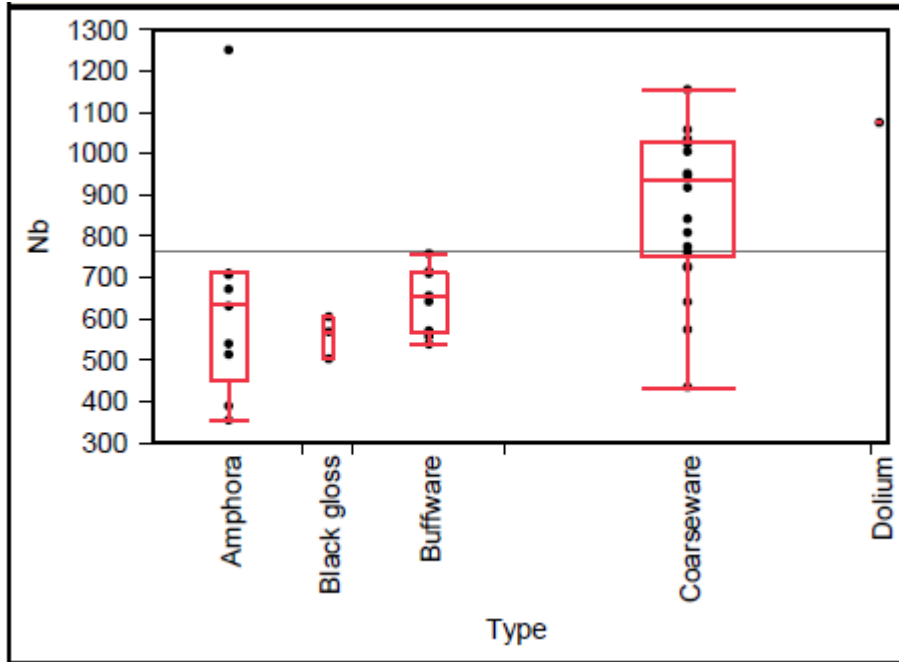
Plot 14: Dendrogram of CBM from San Giovanni, labeled by type.



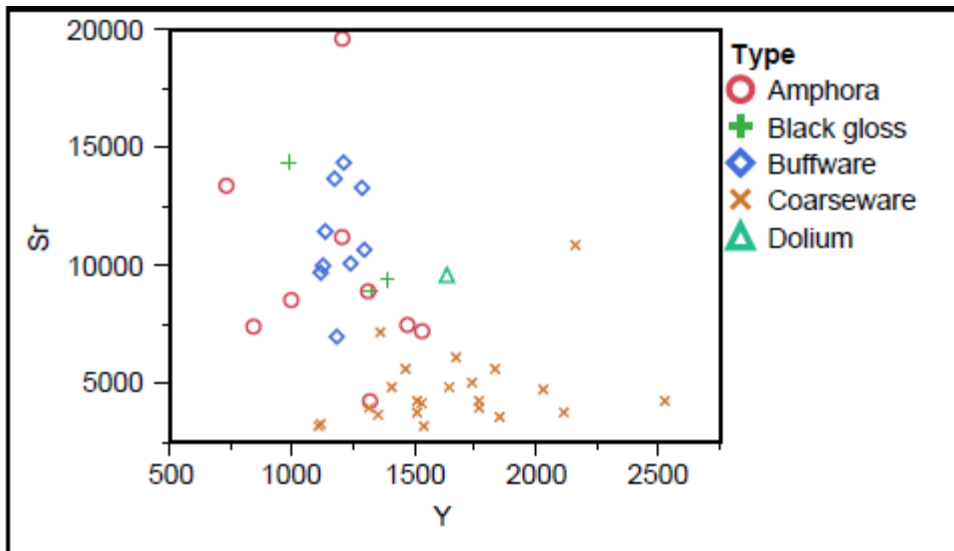
Plot 15: Canonical plot for discriminant analysis of tiles from Monte Pallano, by major fabric group. 17 tiles (50%) were misclassified.



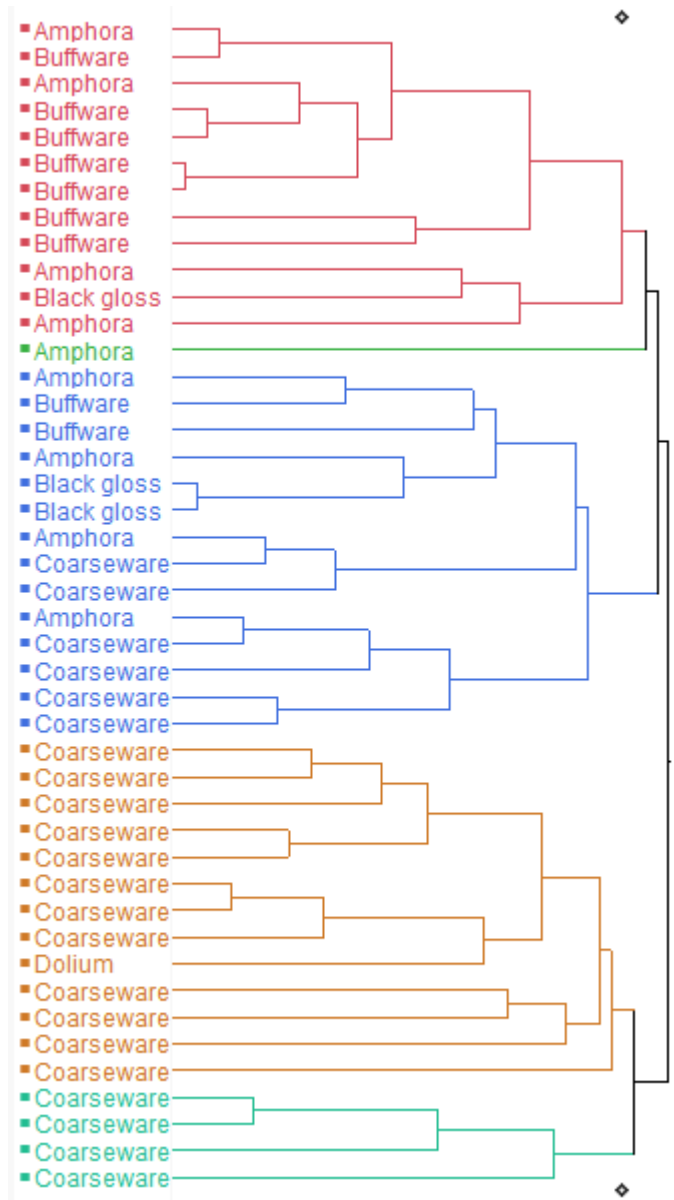
Plot 16: Canonical plot of discriminant analysis of tiles from Acquachiara, by assigned cluster. 1 tile (4.384%) was misclassified.



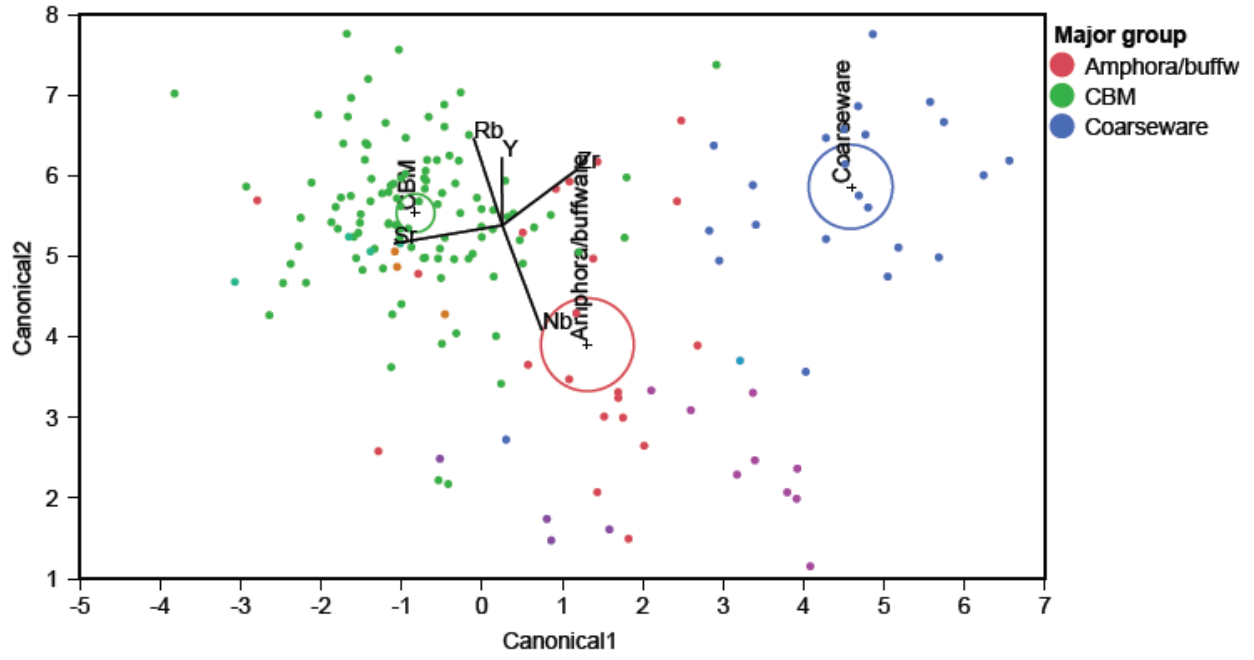
Plot 17: One-way analysis of counts of Nb in pottery samples, by type.



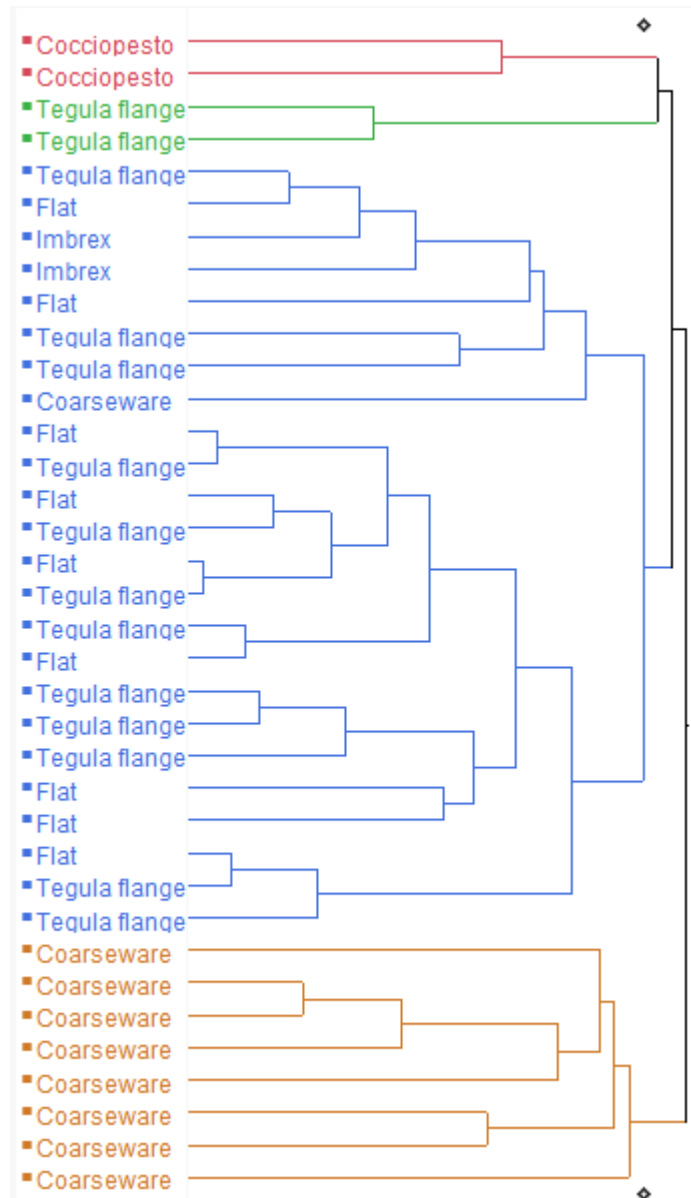
Plot 18: Bivariate plot of counts of Sr vs. counts of Y for pottery, by type.



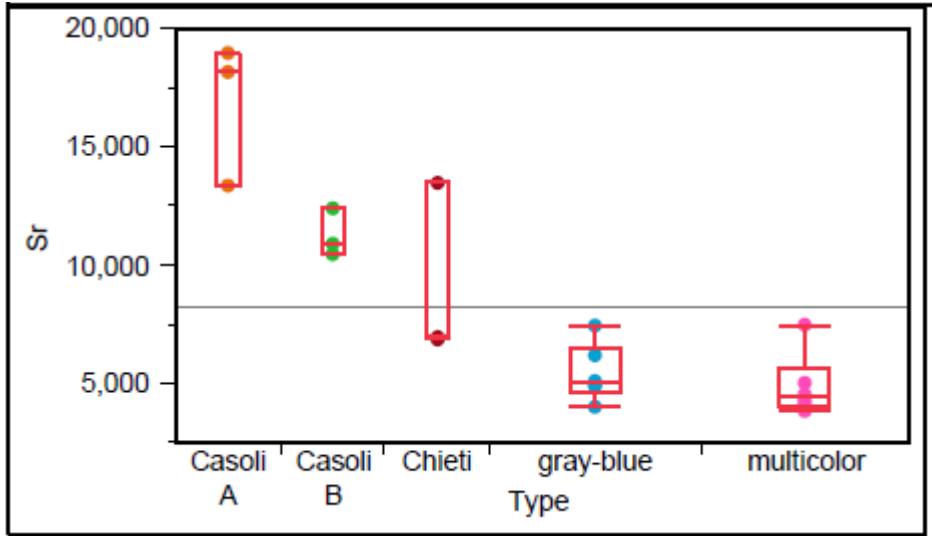
Plot 19: Dendrogram of pottery, by type.



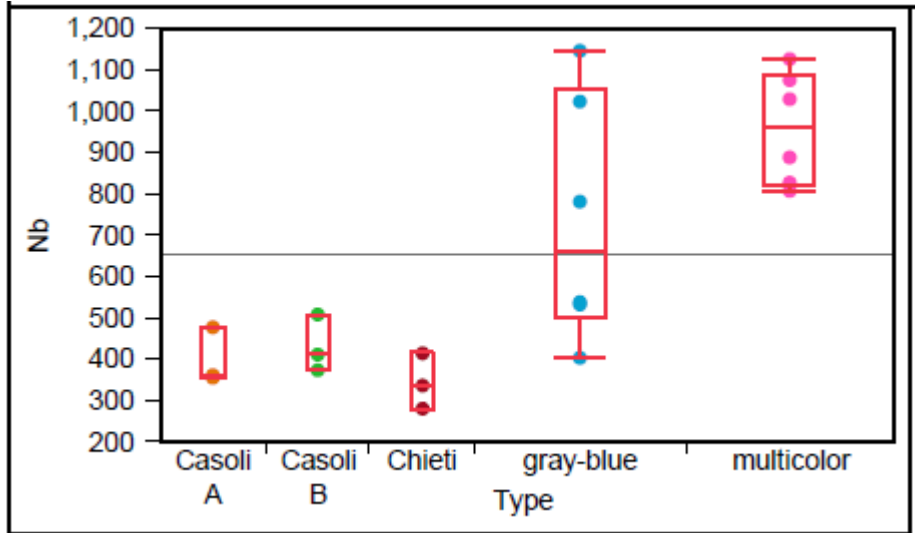
Plot 20: Canonical plot for discriminant analysis of amphora/buffware, CBM, and coarseware. 13 samples (8.90%) were misclassified.



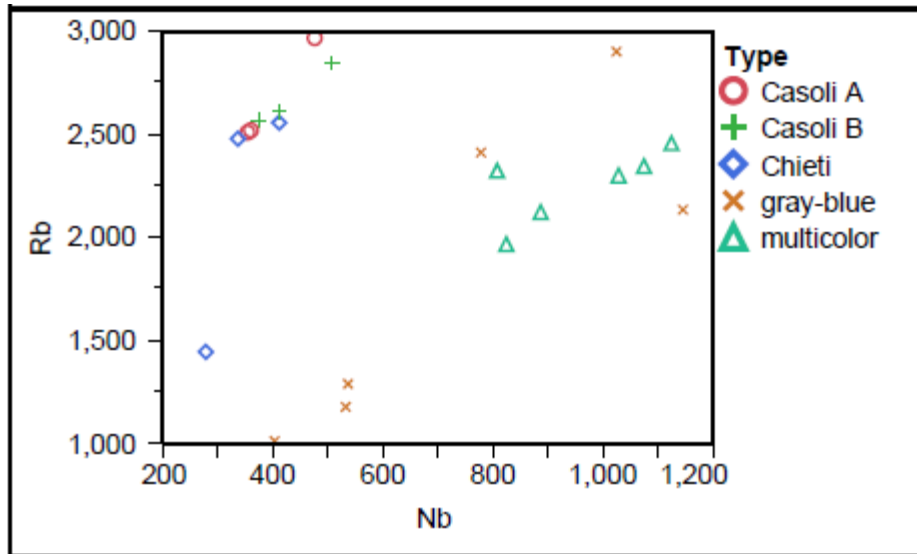
Plot 21: Dendrogram of tiles from Acquachiara, modern imbrices, and coarseware from the Via de Gasperi tombs, labeled by type.



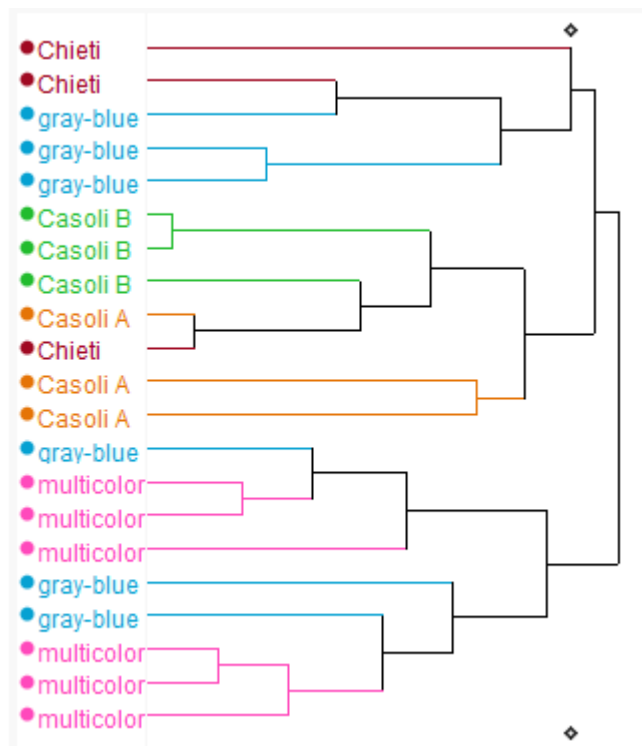
Plot 22: One-way analysis of counts of Sr in clays, by type.



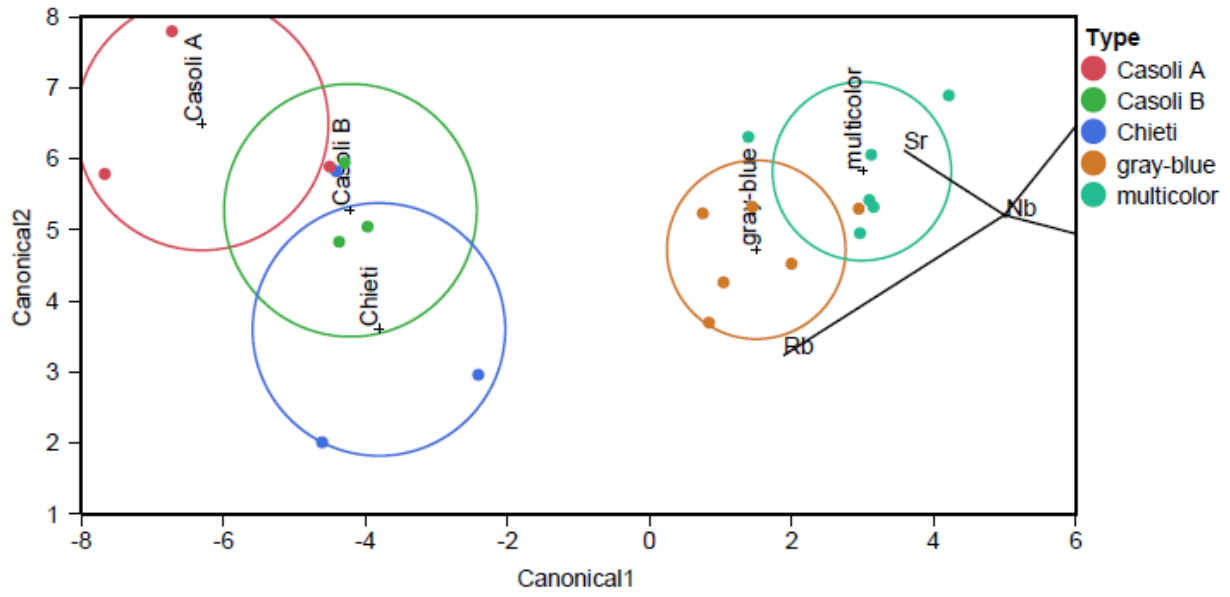
Plot 23: One-way analysis of counts of Nb in clays, by type.



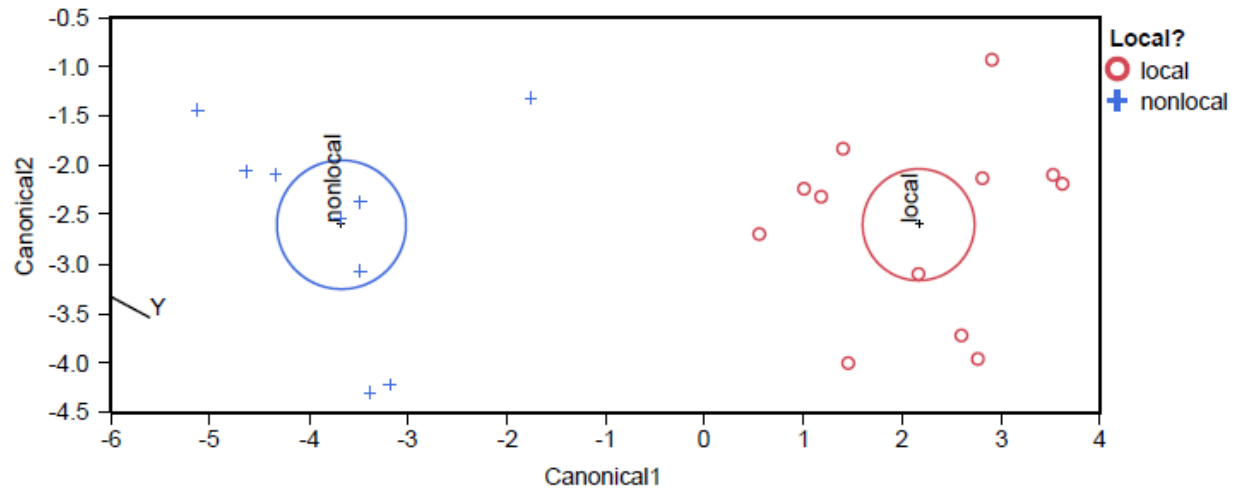
Plot 24: Bivariate analysis of counts of Rb vs. counts of Nb in clays, by type.



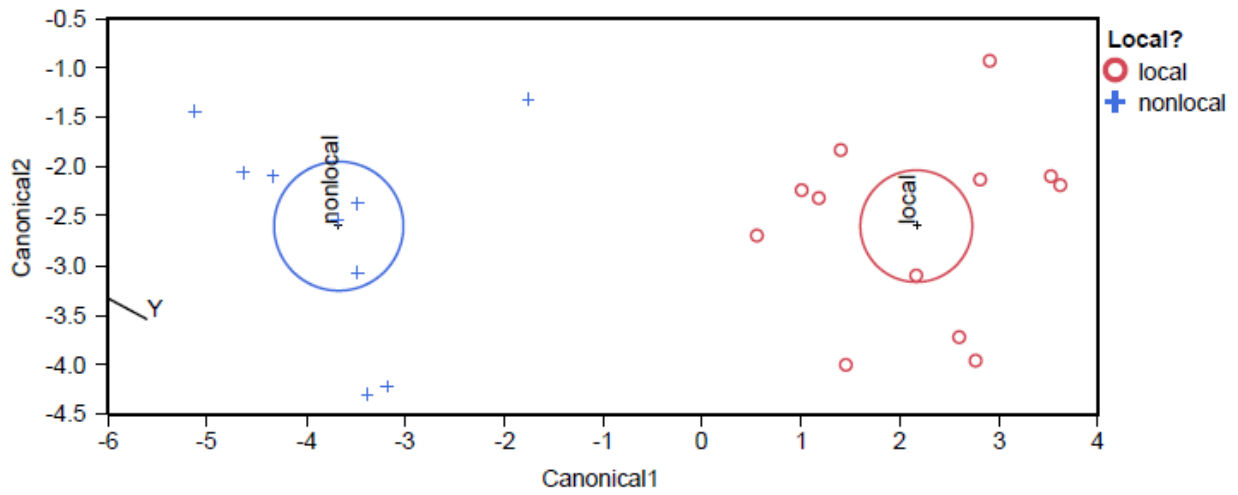
Plot 25: Dendrogram of clays, by type.



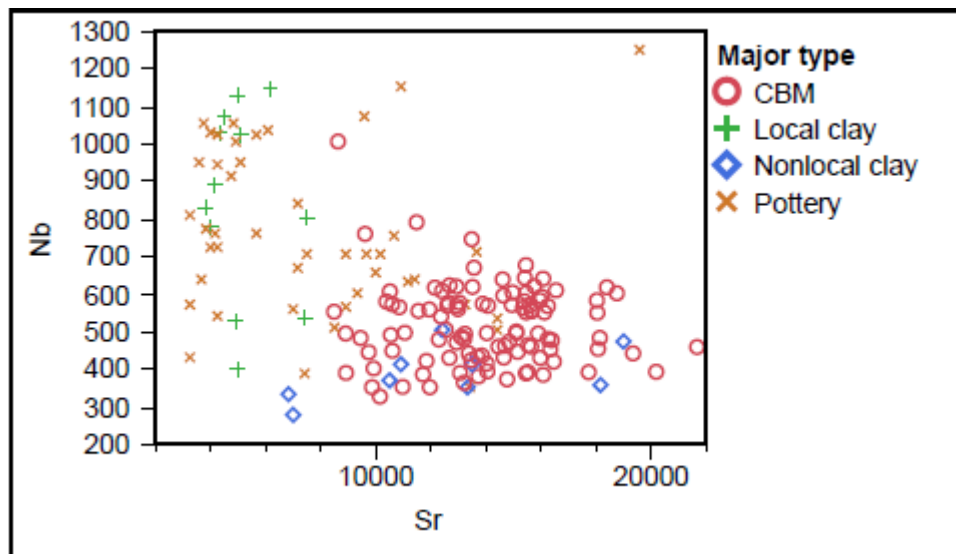
Plot 26: Canonical plot for discriminant analysis of clays, by type. 3 samples were misclassified (14.3%).



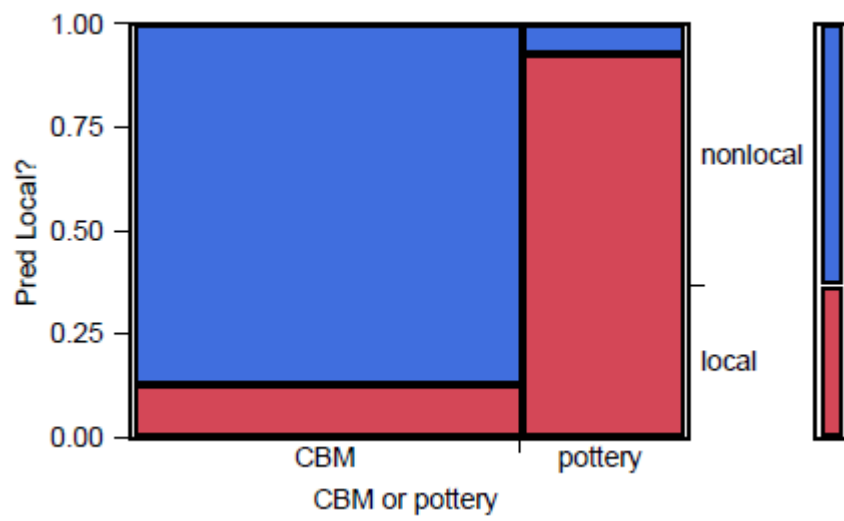
Plot 27: Canonical plot for discriminant analysis of clays, by location. 0 samples were misclassified.



Plot 28: Canonical plot for discriminant analysis of clays, by location. 0 samples were misclassified.



Plot 29: Bivariate analysis of counts of Nb vs. counts of Sr for major categories of ceramics and clays, by type.



Plot 30: Mosaic plot showing the percentage of CBM vs. pottery predicted to align with nonlocal vs. local clays.

Element	Bartlett's Test: p value	ANOVA: F value
Rb	0.0204	--
Sr	0.4161	0.7506
Y	0.0481	--
Zr	0.9811	0.5842
Nb	0.4725	0.9951

Table 1: ANOVA of flat tiles (n = 9) and tegulae (n = 14) from Acquachiara: summary.

Element	Bartlett's Test: p value	ANOVA: F value
Rb	0.6732	0.1942
Sr	0.4701	0.5795
Y	0.7201	0.6422
Zr	0.8404	0.6770
Nb	0.0778	0.6539

Table 2: ANOVA of flat tiles (n = 21) and tegulae (n = 10) from Monte Pallano: summary.

Element	Bartlett's Test: p value	ANOVA: F value
Rb	0.5879	0.2536
Sr	0.6622	0.8910
Y	0.1296	0.5530
Zr	0.8309	0.9423
Nb	0.5094	0.4081

Table 3: ANOVA of tiles of in major fabric groups A (n = 13), B (n = 11), and C (n = 9) from Monte Pallano: summary.

Element	Bartlett's Test: p value	ANOVA: F value
Rb	0.2335	0.0211
Sr	0.0732	0.9655
Y	0.4904	0.0107
Zr	0.6175	0.1151
Nb	0.7929	0.5067

Table 4: ANOVA of bricks (n = 10), imbrices (n = 11), and tegulae (n = 17) from San Giovanni: summary.

Element	Bartlett's Test: p value	ANOVA: F value
Rb	0.0831	0.0010
Sr	0.0003	--
Y	0.0003	<0.0001
Zr	0.1280	0.0030
Nb	0.0101	--

Table 5: ANOVA of amphora (n = 9), buffware (n = 9), and coarseware (n = 22) sherds: summary.

Element	Bartlett's Test: p value	ANOVA: F value
Rb	0.1020	<0.0001
Sr	0.0081	--
Y	<0.0001	--
Zr	<0.0001	--
Nb	<0.0001	--

Table 6: ANOVA of amphora and buffware (n = 18), CBM (n = 106), and coarseware (n = 22): summary.

		Predicted Origin		
Count		Local	Nonlocal	
Total %	Col %			
Row %				
Ceramic type	CBM	14	19	106
		9.33	61.33	70.67
		25.45	96.84	
		13.21	86.79	
Pottery	41	3	44	
	27.33	2.00	29.33	
	74.55	3.16		
	93.18	6.82		
		55	95	150
		36.67	63.33	

Table 7: Contingency table showing the percentages of CBM vs. pottery predicted to align with nonlocal vs. local clays.

Clay sample	Mean net counts	Standard deviation	Coefficient of variation (%)
1	503	90	17.89
2	629	44	7.00
3	554	50	9.03
4	470	29	6.17
5	506	32	6.32
6	491	64	13.03
7	400	11	2.75
1	702	148	21.08
2	894	61	6.82
3	759	46	6.06
4	651	38	5.84
5	666	44	6.61
6	651	109	16.74
7	535	12	2.24
1	718	141	19.64
2	871	38	4.36
3	771	34	4.41
4	715	53	7.41
5	768	40	5.21
6	724	99	13.67
7	570	19	3.33
1	949	155	16.33
2	1109	100	9.02
3	1050	43	4.10
4	1026	57	5.56
5	1112	58	5.22
6	1073	89	8.29
7	866	12	1.39
1	740	128	17.30
2	857	96	11.20
3	819	20	2.44
4	833	63	7.56
5	878	41	4.67
6	847	43	5.08
7	721	11	1.53

Table 8: Elemental compositions of clay samples from the Sangro Valley.