The Archaeology of Kitan/Liao Subaltern Unglazed Earthenware Ceramics:

Optical, Petrographic and Geochemical Approaches

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i. Abstract

There is a paucity of research on the subaltern population of the Liao Dynasty, and as a result of this, the archaeology of the Liao period has little firm control over the chronology and variation in non-elite material culture. In order to address this lacunae, this study applies pXRF and optical petrography to sample of 215 Liao period unglazed earthenware sherds from the Chifeng Region, Inner Mongolia, Peoples Republic of China. These analyses provide baseline information on the geochemical and mineralogical variation within these sherds, and strongly indicate that pXRF and optical petrography are suitably sensitive for the analysis of these materials. Furthermore, the results of this study are used to construct a series of methodological recommendations to aid further analyses. While several geochemical and petrographic groupings are identified, only two are deemed to securely have archaeological significance, due to issues of equifinality.

Il y a un manque de recherche sur la population subalterne de la dynastie des Liao. Par conséquent, l'archéologie de la période a peu de contrôle sur la chronologie et la variation de la culture matérielle non - élite. Afin de remédier cette insuffisance, cette étude applique pXRF et pétrographie optique à 215 tessons non-vitré de la région de Chifeng, en Mongolie intérieure, République populaire de Chine. Ces analyses fournissent des informations de base sur la variation géochimique et minéralogique de ces tessons, et indiquent que pXRF et pétrographie optique sont favorables pour l'analyse de ces matériaux. De plus, les résultats de cette étude compose une série de recommandations méthodologiques qui pourrait accélérer plusieurs analyses successives. Bien que plusieurs groupes géochimiques et pétrographiques sont identifiés, seulement deux sont considérés comme ayant une importance archéologique, à cause de équifinalité.

ii. Acknowledgements

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iii. Preface

All of the work presented here was produced as a part of the KLASH (Kitan Liao Archaeological Survey and History) project and was supported by funding from the Social Sciences and Humanities Research Council, the UK Arts and Humanities Research Council, Bruce and Barbara Trigger Award and the McGill Department of Anthropology. I was responsible for the concept formation, collection of geochemical and petrographic data and the analysis of that data. Assistance in the pulling of samples for analysis was provided by Gwen Bennett (McGill University) and Naomi Standen (University of Birmingham, UK). Assistance with washing of the samples in preparation for the geochemical analyses was provided by Jonathan Dugdale (University of Birmingham, UK) and Lance Pursey (University of Birmingham, UK), while assistance in preparing sherds for transport prior to thin section production was provided by Gwen Bennett, Naomi Standen and Joshua Wright (University of Aberdeen, UK). Assistance with operating the polarizing microscope was provided by J. Cui (Peking University) and Yu Yongbin (Peking University). Assistance in extracting quantitative information from geochemical spectra was provided by Bruce Kaiser (Bruker Elemental). Gwen Bennett provided a figure that was adapted and labelled here as Figure 5.4. Finally, Amanda Triassi and Frances Kozair assisted with the translation of the abstract from English to French

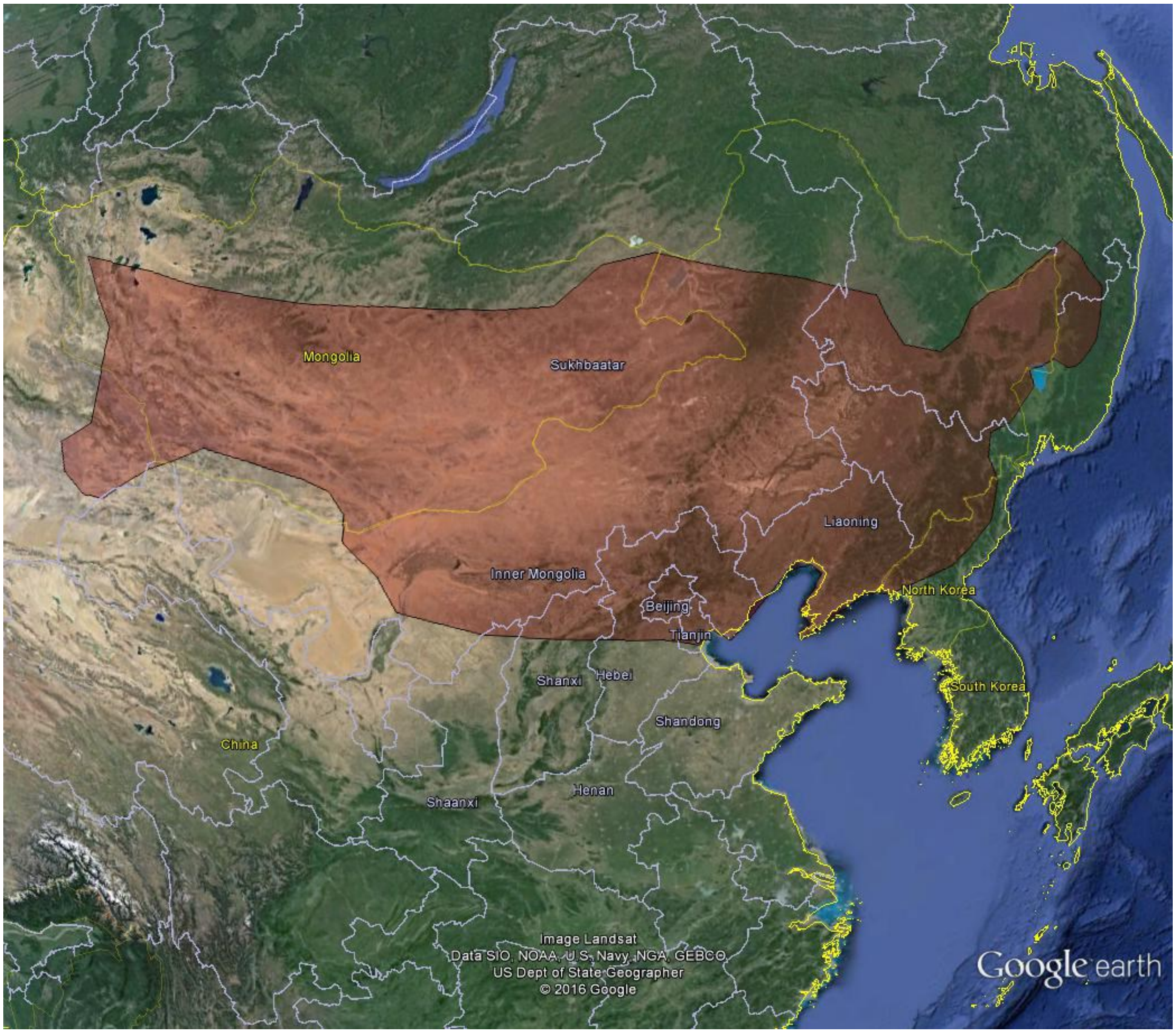
Contents

1. Introduction

There is a serious problem in Chinese archaeology relating to the representation of subaltern and pastoral communities as valid topics of archaeological research. The reasons for this lie with several historical contingencies concerning archaeology in China as well as some general features of the archaeological record in China - among them: the long standing perceptions of nomadic pastoralists as a static population experiencing no historical development (Lattimore 1938), historic and modern perceptions of nomadic pastoralists as barbarians (Bennett and Standen 2011; Standen 2011); the historical orientation of Chinese archaeology (Falkenhausen 1993); the ubiquity and high visibility of elite material culture/sites in China (Bennett and Standen 2011) and the relative difficulty of archaeologically investigating rural or pastoral populations compared to sedentary and urban populations (C. Chang and Koster 1986). All these contingencies have combined to create the current severe underrepresentation of both nomadic pastoral and non-elite communities in published scholarly work on Chinese archaeology. For the archaeology of the Liao Dynasty (907-1125 CE) this is doubly so. As an empire founded by 'barbarian' Kitan[1] nomadic pastoralists and geographically centred outside what is considered, at least in traditional Chinese archaeology, to be China proper (See Figure 2.1) as well as located conceptually outside the traditional line of political descent of the Chinese state; the Liao Dynasty has received very little scholarly attention.

[1] Also known as the Khitan or Qidan.

Figure 2.1



Approximate Extent of the Kitan Empire (image from Google Earth). Borders are approximated from Wittfogel and Feng (1949:pp753-754).

The lack of published archaeological studies of the Liao period as well as the lack of archaeological studies of 'Chinese' subaltern populations[2] intersects to form a confluence of underrepresentation with regard to the archaeology of Liao subaltern communities. This topic has received almost no scholarly attention whatsoever until very recently and obviously represents a glaring lacunae in our basic understanding of the Liao state. The Liao state was an extremely large, long lasting political entity that at its time dominated the regional politics of East Asia, and even continues to be of some influence in that

[2] Subaltern is used here in the wider Gramscian (Gramsci 1971; Louai 2012) sense (as opposed to specifically referencing the work of the Subaltern Studies Group or South Asia) In that it is used to denote the non-elite population of the Liao Empire that is not participating in the elite political and, more importantly with regards to ceramics, economic mechanisms of Liao Imperial rule.

Cathay or Kitai (a word that ultimately derives from Great Khitan one of the names of the Liao state), survives today as the word for China in many Balto-Slavic languages (Franke and Twitchett 1994). As such, it seems reasonable to be surprised that there is such a large gap in our basic knowledge of this period and a small step to realise that this gap demands serious attention.

The most efficient means to archaeologically examine Liao subaltern populations at this time would seem to be analyses of regional political economies as the primary proxy evidence, since this is the most ubiquitous category of material culture found in Liao sites- unglazed non-elite utilitarian earthenware ceramics. Ceramic materials tend to have high information content with regards to relations of production as well as interaction networks. In other regions, precisely these feature of non-elite ceramics have been used to access information on power relationships and the lives of subaltern populations (Flexner 2012, 2014, Pezzarossi 2014, Orser 2010, Hauser 2008).

However, due to the fact that the previous elite-focused archaeologies of the Liao period have also tended to be subordinate to historical questions, and as such have used historical rather than archaeological dating criteria, we have very little chronological control (both relative and absolute) over the vast majority of the ceramics produced during the Liao period. Notable exceptions are elite glazed stoneware and porcelains, which have been the primary focus of most previous archaeological studies of Liao ceramics (Bennett 2015; Bennett and Standen 2011). As a result of this lack of chronological control, ceramics referred to in the literature as “Liao” can potentially represent material produced over a 1300 year time span, from the Xiongnu period to the Mongol Empire period (Bennett and Standen 2011). This 1300 year stretch of time in NE China and Mongolia contains various polities with radically different political orders and large changes in both subsistence practices and social conditions. As such, in order to ask any fundamental questions regarding Liao subaltern political economies we first need a reliable ceramic chronology, which in turn requires solid information on Liao ceramics- both in terms of their technological characteristics, and the time periods at which different varieties of ceramic materials were produced. This has been one of the stated aims of the Kitan Liao Archaeological Survey and History Project (KLASH) (Bennett and Standen 2011) of which the research presented here is a small part.

This study is an effort to take the first steps in obtaining such information, specifically basic geochemical and mineralogical information, which could in the near future lead to the creation of ceramic typologies or chronologies. A chronology of unglazed utilitarian ceramics would allow non-elite sites and material culture to be dated, something not presently possible without using the few surviving corroborating historical texts from this period or associations with material culture from elite burials. In order to begin achieving this goal, the present study incorporates basic petrographic and geochemical (pXRF) observations of a group of surface collected ceramics, referred to in local archaeological nomenclature as "Liao"[3], from sites with a definite Liao component located in the Chifeng region, Inner Mongolia, Peoples Republic of China (hereafter referred to as the PRC). These sites were surface collected as part of two large regional survey projects: the Chifeng Collaborative International Archaeological Research Project (hereafter referred to as CCIARP) (Chifeng International Collaborative Archaeological Research 2011) and KLASH project The CICARP sites run the gamut from small rural collection units located in the region between the Liao Central and Supreme Capitals to urban environs like the market town of Songshanzhou, while the KLASH material consists of a single collection from and the walled city site of Enzhou, a historically recorded resettlement location for forcibly relocated subaltern populations (Bennett 2015).

The basic observations of the ceramics from these Liao period sites are used to examine the variation present within the material labelled as "Liao" and to attempt to group these ceramics by their geochemical or mineralogical content. While these groupings do not necessarily relate to the locus at which the ceramic materials were produced, or in fact the time period at which the materials were produced (although in some cases these groupings certainly may be related to these factors), they do provide some indication as to the validity[4] of these techniques for characterizing Liao unglazed ceramics and provide for the identification of several recommendations as to the optimal methodology that could be used in the future to access information on the chronology and provenience of Liao unglazed ceramics. This analysis also provides the necessary data to identify contingent aspects of Liao unglazed ceramic materials that provide opportunities for the application of techniques not used in this study, to further address questions of time and source. The collection of such baseline data, information on the applicability of pXRF and petrography to Liao unglazed ceramics, and methodological recommendations for the optimal use of these techniques has the ability to provide a foundation for future studies of Liao unglazed ceramics, both within the Chifeng region, and the rest of the insular Kitan Empire.

[3] But not necessarily all belonging to the Liao dynastic polity as the archaeological designation of Liao encompasses a much longer time period than just the Liao Dynastic period.
[4] Here used after Frahm and Doonan (2013) to mean the ability of a technique to answer archaeologically relevant questions.

2. Review of the Literature

2.1 The Liao Dynasty

It would first seem prudent to introduce the Liao Dynasty[5] (also known as the Liao Empire, Kitan Empire or Great Khitan) as, despite its historical prominence in East Asia, it is not well known outside of China. The Liao Dynasty was a large pastoral nomadic empire that formed in 907CE from several smaller pastoral polities (sometimes referred to as "tribes", however, this is largely inaccurate (Sneath 2007)), known collectively as the Kitan which occupied the region of the Eastern Mongolian Steppe and the Manchurian plain, particularly the grasslands in the vicinity of the Liao and Shiliamurun River valleys. The Empire at its height would have stretched from what is today the Russian Far East Maritime Province (Primorsky Krai) to the Altai Mountains between Mongolia and Kazakhstan and it would have occupied most of Northern China as well as parts of Siberia, Mongolia and North Korea, a territorial area (conservatively) around half the size the Roman Empire at its height (117AD). A map of the approximate extent of the Liao Dynasty at its height is provided in Figure 2.1[6]. The area occupied by the Liao Dynasty is ecologically diverse, ranging from the extremely arid Gobi Desert and semi-arid steppe surrounding it, the temperate steppe of northern Mongolia and North Eastern China, the temperate forests and taiga of Southern Siberia and the Russian Maritime Province, to the intensely fertile loess plateau east of the loop of the Yellow River around the modern day city of Datong (which was the Liao Western Capital).

[5] With regards to the terminology used here: The Kitan Empire, Liao Empire and Liao Dynasty are used interchangeably to refer to the state whose leader Abaoji declared himself emperor in 907CE and which was conquered by the Jurchen who formed the Jin Dynasty in 1125CE. The "Liao period" is used here to refer to the Imperial period between these dates; 907-1125CE. "Kitan" is used here to refer to the pastoral population from which the aristocracy of the Liao Dynasty formed but that existed prior to its formation and also after its fall. "Liao" on the other hand refers to the entire population of the Liao Dynasty, including both the Kitan population and the numerous other agricultural and non-Kitan pastoral populations that made up the majority of the Kitan population.

[6] Figures are labelled with section number first and then figure number, as such Figure 1 in Section 2 is referred to as Figure 2.1.

Figure 2.1

Map of the Approximate Extent of the Kitan Empire (image from Google Earth); ~2.657 million km^2 (calculated from the polygon). Borders are approximated from Wittfogel and Feng (1949: pp753-754).

Liao Language and sources

The Liao period is a historic period, as there are several textual sources for the geopolitical events of this period. Primary among these is the *Liao Shi*, the official imperial history of the Liao Dynasty commissioned by the Mongol Yuan Dynasty (1271-1368 CE). The only English translation and extensive analysis of this text is Karl August Wittfogel and Feng Jiasheng's (1949) "History of Chinese Society: Liao, 907-1125"[7]. Other textual sources for the Liao are mostly from the Northern Song dynasty (960-1279 CE), the contemporary political power controlling Southern China and those parts of Northern China not controlled by the Kitan, or their tributary state the Western Xia (1038-1227 CE). Notable among these are the *Qidan Guo Zhi* and the *Zizhi Tongjian* (Standen 2007a). There are several issues, however, with these textual sources; they are not contemporary accounts but have been complied or rewritten at a later date, or alternatively have been lost and partially reconstructed at a later date. Additionally, none of the available sources are direct Liao accounts, as all primary Kitan histories have been lost completely. They are rather accounts from later pastoral nomadic dynasties (this is the case for the *Liao Shi*) looking for a line of political succession to legitimate their rule, or the Song Dynasty, which had a consistently antagonistic relationship with the Liao (Standen 2011). The resulting situation is that, for the most part,

[7] Which forms the basis for much of the information in this short introduction to the pre-dynastic Kitan and Liao Dynasty

these sources are primarily interested in the Liao elite or Liao foreign relations with the Song and, as such, provide little direct insight into the non-elite population of the Empire (Bennett 2015; Bennett and Standen 2011). The *Liao Shi* is the only available historical source with substantial material relating to the subaltern population of the Liao and even here it is mostly concerned with the economic and agricultural history of the Empire and not the lived experience of the non-elite segments of the population.

Apart from the large historical accounts from this period, there are also numerous Kitan texts that have survived in the form of stelae, inscriptions on artefacts, rock art, tomb murals or funerary inscriptions. These could potentially contribute to a fuller picture of Liao society; however, the Kitan scripts (two writing systems were used during the Liao period: the Kitan large script and Kitan small script) are not yet completely deciphered, and as such, these texts currently have limited utility (Bennett and Standen 2011; Liu 2014; Janhunen 2003; Kane 2008). Furthermore, as Kitan is a language without an extant speech community and its orthography is logographic, full decipherment will be at best extremely difficult, and perhaps impossible (Liu 2014; Kane 2008). Interestingly, because so little of Kitan has been deciphered, its linguistic affinity is unknown, although likely contenders include the Turkic, Mongolic, Tungusic or Para-Mongolic language families (Liu 2014; Janhunen 2003; Kara 1986).

Origins of the Liao Dynasty

The origins of the populations that would later refer to themselves as the Kitan are for the most part unclear. There seems however to be a consensus in the literature that they are likely politically descended from the Yuwen Xianbei, one of the offshoots of the large pastoral nomadic Xianbei empire, present on the North Asian steppe until the mid-fourth century CE (Franke and Twitchett 1994; Xu 2005). Historical accounts (specifically the *Wei Shi*) indicate that at around 345CE the Murong Xianbei (another offshoot of the Xianbei) defeated the Yuwen Xianbei which split into several smaller groups. One of these begins to be called the Kitan, although whether it is actually a separate polity or just one part of the Kumo Xi (another successor group to the Yuwen Xianbei) is difficult to discern and the sources of this period appear contradictory (Franke and Twitchett 1994). More certain is that when the Kumo Xi were militarily defeated by the Tuoba Wei (yet another Xianbei successor polity), the Kitan split from the Kumo Xi and formed their own polity in the vicinity of the *Xilamulun* (or the *Xar Moron* in Mongolian) and Liao River valleys in Northeastern China (Franke and Twitchett 1994; Xu 2005). At this point it is not known exactly what being Kitan denotes, it could be an ethnonym or a simply the name of a semi-permanent political grouping (Franke and Twitchett 1994).

Regardless of what this term denotes, the political entity known as the Kitan persists as a small scale nomadic pastoral political group centered on the Liao River valley, and for the next several hundred years submits to the authority of surrounding pastoral and sedentary empires including the Türk and Uighur empires centered on the Mongolian Steppe, the Koguryŏ state of the Korean Peninsula and the Sui and Tang Dynasties centred on the North China plain (Franke and Twitchett 1994; Xu 2005). The approximately 500 year pre-dynastic period of the Kitan ends in the late ninth and early tenth century CE with the collapse of the Uighur Empire, the fragmentation of the Tang Dynasty, and the uniting of the various Kitan groups under the central leadership of Abaoji (primarily through the murder of his political rivals at a feast (Wittfogel and Feng 1949)). This ultimately leads to the Kitan consolidating their power on the Manchurian steppe and emerging from the ninth century as the paramount military power in NE Asia (Franke and Twitchett 1994; Standen 2007a; Karl August Wittfogel and Feng 1949) as well as the most convincing successor to the Tang Dynasty (although traditional Chinese historiography views the Northern Song Dynasty as the rightful successor to the Tang Dynasty despite the 50 year gap between these entities) (Standen 2007a). Figure 2.2 provides a chronology of the polities located in North Asia prior to, during, and immediately after the Liao period.

Table 2.2 Chronology of NE Asia

Mongolia/Manchuria	North China	Central Plains
Xiongnu	Han Dynasty (202-220)	
	Three Kingdoms (220-265)	
	Sixteen kingdoms (304-439)	
Xianbei	Northern and Southern Dynasties (420 -589)	
	Sui Dynasty (591-618)	
Kitan	Tang Dynasty (618-907)	
		Five Dynasties (907-960)
Liao (907-1125)		Northern Song Dynasty (960-1126)
Jurchen	Jin (115-1234)	
Mongol	Yuan (1260-1368)	

Adapted from Bennett and Standen (2011:Figure 8.1)

Liao Foreign Relations

During the early part of the Liao period, the Kitan state, now under the sole leadership of Abaoji (who declared himself an Emperor in 916CE and adopted the Chinese style dynastic title of Liao) and his descendants, began a series of conquests of surrounding polities, including settled agricultural polities on the North China and Manchurian plain (including many formerly Tang prefectures), as well as pastoral, semi-sedentary horticulturalist and sedentary hunter-gatherer societies in the Mongolian steppe and forested areas bordering the Manchurian plain (including the Jurchen who would in 1125CE rise up and conquer the Liao to form the Jin Dynasty). The most prominent of these, at least as far as the *Liao Shi* is concerned, is the 926CE conquest of the Bohai State located in the eastern part of the Manchurian plain region in the vicinity of modern day eastern Liaoning, Jilin and Heilongjiang as well as parts of North Korea (DPRK) and the Russian Maritime Province (Primorsky Krai Province). The Kitan at first administered the Bohai territory as a tributary state, Dongdan, but later annexed it to form the eastern administrative territory of the Empire (Franke and Twitchett 1994; Wittfogel and Feng 1949). The conquest of Bohai and the seizure of the formely Tang Youzhou prefecture along the southern border of the Liao (which would later be consolidated through the construction of the Liao Southern Capital at modern day Beijing) involved the forcible relocation of sizeable agrarian populations and craft specialists into the center of the Liao Empire to, not only provide a base of taxation, but also to weaken conquered regions and hedge against regional uprisings (Franke and Twitchett 1994; Wittfogel and Feng 1949). These relocated populations and conquered populations would come to form the majority of the populace of the Liao Empire with the Kitan forming a distinct minority.

The topic of Liao foreign relations is certainly the best documented aspect of the Liao Empire and primarily concerns its interactions with large neighbouring states (Franke and Twitchett 1994). Foremost among these is the Song Dynasty, in control of parts of Northern China and almost all of southern China[8]. The relationship between these two states in the latter half of the tenth century was antagonistic for the most part. However, in 1005CE the conflict between these states was resolved with the signing of the treaty of *Shanyuan* which produced a lasting peace until the end of Liao rule in 1125CE; a full century of peace. This treaty, although technically between equals (the emperors of the Song and Liao symbolically becoming brothers), required the Song to pay a yearly “contribution to military expenses” to the Liao in the form of three tons of silver and 200,000 bolts of silk (Franke and Twitchett 1994:109). This payment, although seemingly large, was not a major issue for the extremely affluent Song state (Franke and Twitchett 1994).

[8] Not to diminish the significant relationships that the Liao had with the Kŏryeo and Silla Kingdoms on the Korean Peninsula and the Tangut Western Xia Dynasty in control of much of the western part of North China. However, these relationships represent a very specialized area of study not suitable for coverage here.

Liao Urbanism and Population

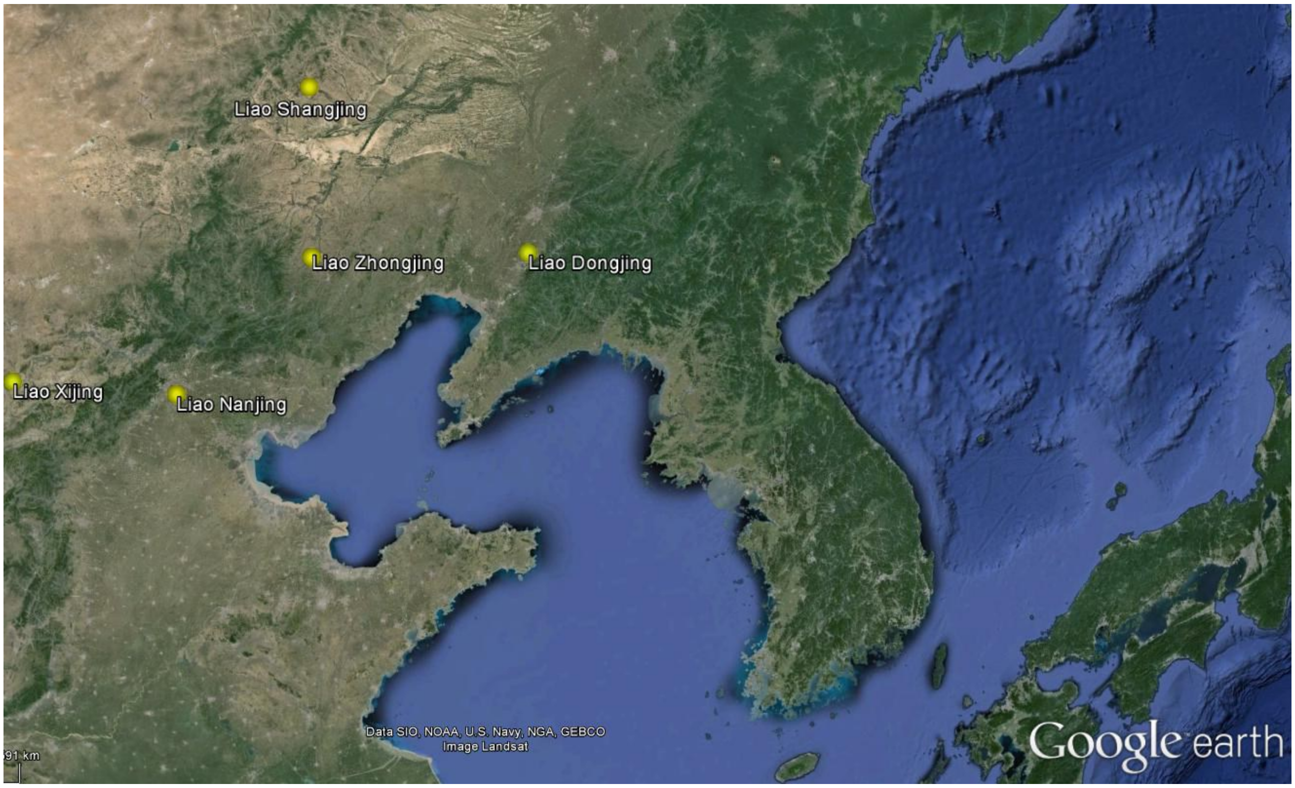
During the period of the Liao conquests of northeastern Asia, the population of the Empire grew substantially. The primary population estimate provided by Wittfogel and Feng (1949) conservatively places the population of the empire (at approximately around ~1125CE) at around 3,800,000 (based on what textual records are available and comparisons to Tang Dynasty populations). The vast majority of the Liao State was not composed of Kitan pastoralists, but rather settled agricultural populations (some of which were likely Kitan (Wittfogel and Feng 1949)). Many of these agriculturalists were forcibly relocated from the territory of Youzhou prefecture, and the Bohai state after its fall to the Liao or captured in raids on the North China plain, while others were likely refugees from surrounding states (Bennett 2015; Franke and Twitchett 1994; Wittfogel and Feng 1949). These populations were relocated to provide the area in the center of the Empire with a population of artisans and farmers that could be reliably taxed to provide agricultural surplus or to occupy outlying military settlements on the steppe (Wittfogel and Feng 1949). The assertion that the relocation of agriculturalists during the Kitan period provided a sustained increase in agricultural activity in the region of the Supreme and Central capitals is borne out in the palynological and soil charcoal record in this region, which shows a dramatic increase in agricultural activity and concurrent deforestation, starting during the early Liao period (Li, et al. 2006; Makohonienko, et al. 2004).

A system of five capitals administered these agricultural and pastoral populations.[9] The first to be built in 918CE was the Liao Supreme Capital (Shangjing), which was located in modern day Balinzuoqi Banner in Inner Mongolia. The second, built in 928 CE, was the Eastern Capital (Dongjing), constructed immediately after the Bohai conquests in the territory of the former Bohai Kingdom at modern day Liaoyang in Liaoning Province. After the conquest of parts of the previously Tang-controlled Sixteen Prefectures (now northern Hebei), another capital was built in 938 CE at the former capital of the Yan State. Known as the Liao Southern Capital (Nanjing), it would later become the capital of modern China, Beijing. Following the treaty of Shanyuan, the Liao Middle Capital (Zhongjing) was built in 1007 CE immediately to the south of the Supreme Capital at modern day Ningcheng in the Chifeng Region of Inner Mongolia (the materials analysed in this study are all drawn from the regions surrounding this city and the Supreme Captial). The Western Capital (Xijing) was the last to be built in 1044 CE at the former

[9] A system adopted from the Bohai state

capital of the Northern Wei, which is the modern city of Datong in Shanxi province. Figure 2.3 Shows the Locations of the Liao Capitals.

Figure 2.3



Locations of the Liao Capitals (Image from Google Earth)

2.2 Traditional Approaches to Liao Historiography

The Liao Empire's unopposed dominance of North Asia at the beginning of the tenth century as well as its equal status with the Song Dynasty, dictated by the treaty of Shanyuan, contribute to the Liao's unique position in Chinese historiography, where it is seen as an embarrassing period of foreign dominance of China (Standen 2011). Traditionally the Liao are referred to (along with the Jurchen Jin, Mongol Yuan and Tangut Xixia Dynasties) as a conquest dynasty or "Alien" regime (Franke and Twitchett 1994). A result of viewing the Liao as alien to China has been, at least traditionally, to present these polities as a barbarian "tribe" locked in combat with the "civilized" Song state (Standen 2011). A consequence of this is that the Liao are little studied outside of their antagonistic relationship with the Song (Franke and Twitchett 1994:672; Standen 2011). This has further served to downplay their immense geopolitical significance to the point that, in some cases, their dominance over most of North Asia has simply been ignored (Standen 2011). This attitude has not been restricted to the literature in

Chinese; Twitchett and Franke note that “The early Western historians of China paid almost no attention to the Liao.” (1994:669). This lack of attention continues today and is readily visible in the pedagogical texts used in university introductory courses to Chinese or East Asian history. These textbooks, despite being written by reputable scholars of Chinese history[10], have been known to downplay or skip the Liao entirely and tend also to provide maps with unusual and often inaccurate representations of the extent of the Liao Empire in comparison to the Song (See Figure 2.4). One popular text from the 1990s afforded the Liao only a single paragraph, referring to it as a barbarian “mini-empire” territorially depicted on a map at far from its full size, while providing the Song a full chapter (the text being refered to is Murphey 1997).

Positioning the Liao in Chinese history is complicated by the politically charged nationalist histories of China endorsed by the Chinese government, which have traditionally sought to demonstrate a national unity and highlight the influence of the “Chinese”[11] Central Plains polities on the non-Chinese nomadic pastoral populations, although recently these narratives have been shifting (Standen and Bennett 2014). These nationalist narratives have issues reconciling the assumed supremacy of the ‘civilized’ Central Plains with the supreme dominance of the Liao in the early 10th century, and as such, the Liao are often seen as an “…embarrassing contradiction to the orthodox interpretation…” (Standen 2011; Standen and Bennett 2014:158). Several scholars (Standen 2011, 2013; Standen and Bennett 2014) have noted that the primary means to reconcile the Liao with these narratives have been to refer to their sinicization; the process by which the influence of their Chinese subjects ‘civilized’ the Kitan aristocracy through the adoption of Confucian values (Standen 2013). However, as Standen (2013) has noted, this ignores the converse; that the Kitan also strongly influenced both their ‘civilized’ subjects and the surrounding ‘civilized’ polities.

2.3 Summary of the Present State of Kitan/Liao Literature

Historical Contingencies

The embarrassing and difficult position of the Liao in traditional narratives has doubtlessly contributed to the current paucity of publications in western languages about them (Franke and Twitchett 1994; Standen 2011). The non-archaeological studies that have been published, and that focus on the Liao themselves (rather than Liao Song relations), tend to represent only the elite portion of Liao society,

[10] Or perhaps because they are written by scholars of Chinese, as opposed to North Asian, history

[11] considered so as they are directly in the line of political succession that leads to the PRC, despite the relatively recent origins of China and the concept of a Han ethnicity (Chin 2012; Standen 1997)

likely due to the lack of textual sources that deal with subaltern populations in any detail. Topics that have seen some interest in the historical fields include the examination system (Wittfogel 1947), border-crossers (Standen 2007b)[12], princesses and aristocratic women (Johnson 2015) and the history of the naming of the Liao Dynasty (Kane 2013). The biological anthropology of the Liao and Kitan aristocracy has also received some attention, particularly with regard to using genetics to identify Kitan origins and modern day descendants (Yue, et al. 2006). While some of this literature is relatively old, elite bias is still very much an issue. For example, a recent special addition of the Journal of Song-Yuan Studies[13] titled "Evolving Approaches to the Study of the Liao" contains papers almost exclusively focused on elites (see (Hansen and Louis 2013)).

This basis towards elite centered research topics is also shared by the archaeology of the Liao period, despite archaeology not suffering the same paucity of evidence for subaltern populations that history does. Bennett and Standen provide an insightful explanation for why this might be: "… the archaeology of China's historical period … has been largely text-driven, with concomitant reinforcement of the texts' emphases on sharp cultural distinctions and elites" (2011:86). The subservience of Chinese archaeology to textual resources has been widely commented on in the archaeological literature (Chang 1981; Falkenhausen 1993), and several scholars have commented on the "danger" inherent to archaeology driven by historical aims, in that "Not only does it steer the archaeological sample toward conformity with tradition by telling archaeologists where to look; it also tells us what to see." (Bagley in Falkenhausen 1993:7). The result of this[14] by all accounts is: a lack of attention to the archaeology of non-elite populations, no matter what period or area they are from (Bennett and Standen 2011; Falkenhausen 1993), a lack of attention to aspects of subsistence and production (Chang 1981) as well as a generally descriptive style of object-focused archaeology being practised (Falkenhausen 1993). Specifically with regard to pastoral populations, like the Liao, there is also the additional difficulty of archaeologically investigating nomadic pastoral communities which may also contribute to the paucity of literature. This difficulty is the result of pastoral nomadic populations leaving a relatively ephemeral archaeological signature on the landscape compared to sedentary agricultural populations. Pastoral sites

[12] It should be noted that Standen also discusses non-elite crossings, but her focus is on the literate border crossers who possess a richer historical record

[13] Although the Liao are an earlier state than the Song they are often subsumed under them or ignored (Standen and Bennett 2014)

[14] Along with the Marxist-Leninist orientation of Chinese Archaeology in the PRC (Falkenhausen 1993)

tend to be un-stratified and are often sparsely distributed across the landscape (Chang and Koster 1986).

The effect of Chinese archaeology's historical contingencies (as well as the difficulty of investigating pastoral nomadic populations) upon our the basic knowledge of the Liao has manifested in some specific aspects of the period being very well understood, while other aspects have received little to no attention. Highly visible elite material culture such as tombs and tomb paintings (Johnson 1983; Laing 1994; Rorex 1984; Shen 2005; Steinhardt 1998), elite material culture such as glazed elite ceramics and metallurgy (Lu 2008; Mok 1985; Park, et al. 2008; Shanguo 2002; Watson 1984; Louis 2003), monumental architecture (Kuhn 2000; Steinhardt 1994, 1997) and capital city building (Lin 2010, 2011, 2012) have been thoroughly investigated. On the other hand we have a poor understanding of utilitarian materials, very little knowledge of Liao non-elite habitation or burial sites and perhaps most grave of all, a poor overall control and understanding of the chronology for the Liao period, and as of yet no accurate chronology of unglazed ceramics (Bennett and Standen 2011). This poor archaeological understanding is also true of the Western Liao (Qarakhanid or Kara Khitai) period[15] in Central Asia (Biran 2001).

CICARP and KLASH

The state of Liao archaeology in China, however, is rapidly changing. The nationalist paradigms in PRC museums have been transformed recently, and regional traditions are receiving much more attention independent of the central plains (Standen and Bennett 2014). Large survey projects such as the recently completed CICARP (Chifeng International Collaborative Archaeological Research 2011) have involved the surface collecting and mapping of Liao sites, including small-scale non-elite habitation sites. This project (which collected the majority of the materials analysed in this study) performed a large scale systematic pedestrian survey over a 1,234 km^2 area of the Chifeng region in Inner Mongolia, PRC (the Chifeng region is shown in Figure 2.4 while Liao sites found in the CICARP survey area are shown in Figure 2.5). In the course of this survey sites of all time periods from the Early Neolithic to the Ming Dynasty were mapped[16] and any artefactual material present on the surface of these sites was collected (for more details on the CICARP survey see (Chifeng International Collaborative Archaeological Research

[15] The Western Liao was a state formed by segments of the Liao aristocracy that fled west to Central Asia after the fall of the Liao Dynasty to the Jurchen Jin Dynasty. It represents the last independent Kitan polity prior to the Mongol expansions.
[16] Although material from post-Han to the Ming Dynasty were labelled as Liao

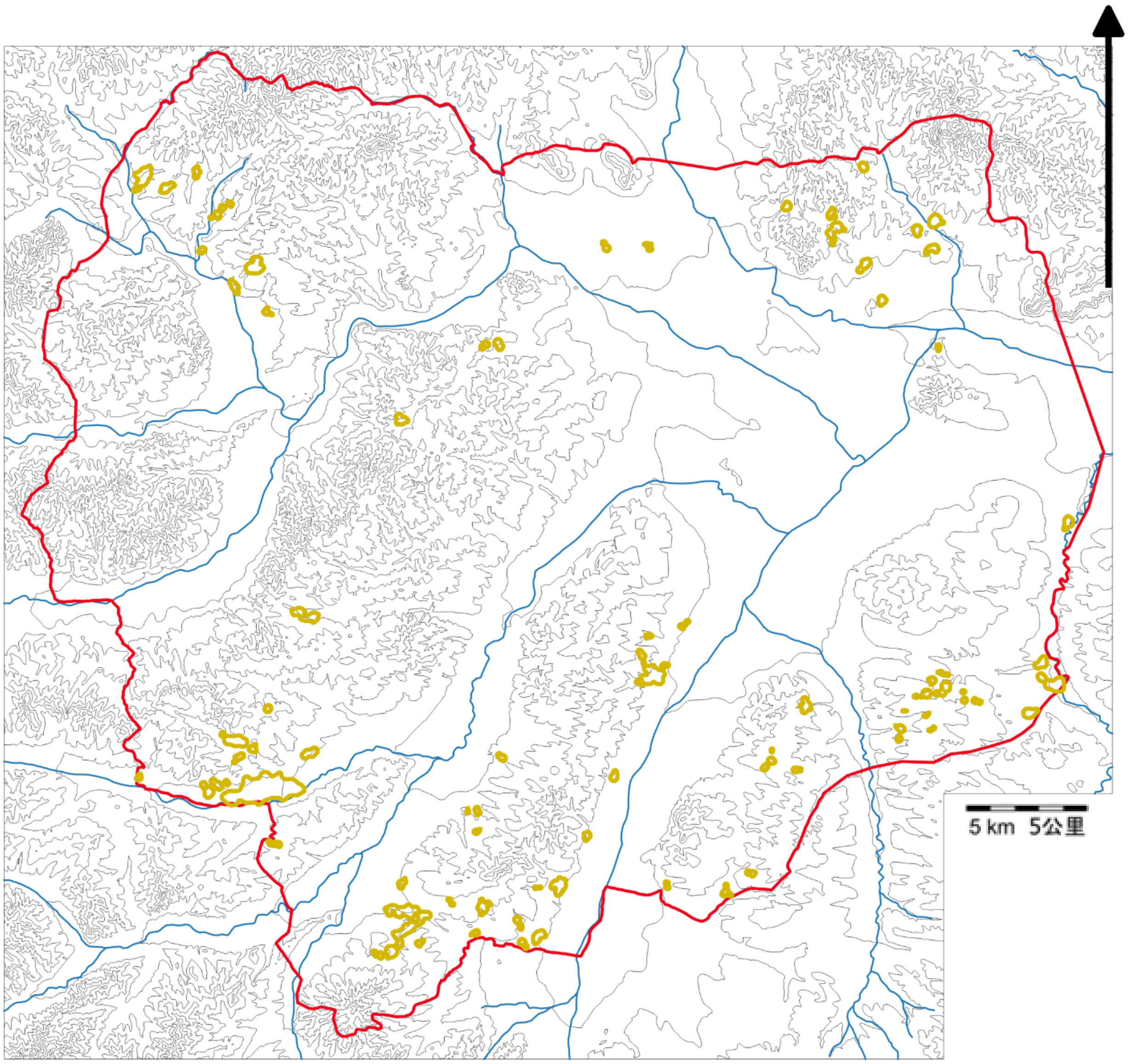
2011; Linduff, et al. 2004)). The results of this study were primarily aimed at identifying large scale shifts in settlement pattern in this region during the Neolithic and Bronze Age. However, latter periods such as the Liao were also collected when encountered (although the definition of Liao used by this survey is very broad, covering a 1000 year period from the end of the Han Dynasty to the Yuan Dynasty, rather than the 200 year Liao dynastic period). This survey area happened to be located between two of the capitals of the Liao Dynasty and, as such, represents one of the largest regional collections of Liao non-elite ceramics currently in existence.

Figure 2.4

Location of Chifeng City[17] (Source: Wikimedia Commons Work, File: China Inner Mongolia Chifeng.svg)

[17] Administrative units designated as cities in the PRC can be regional in scale

Figure 2.5



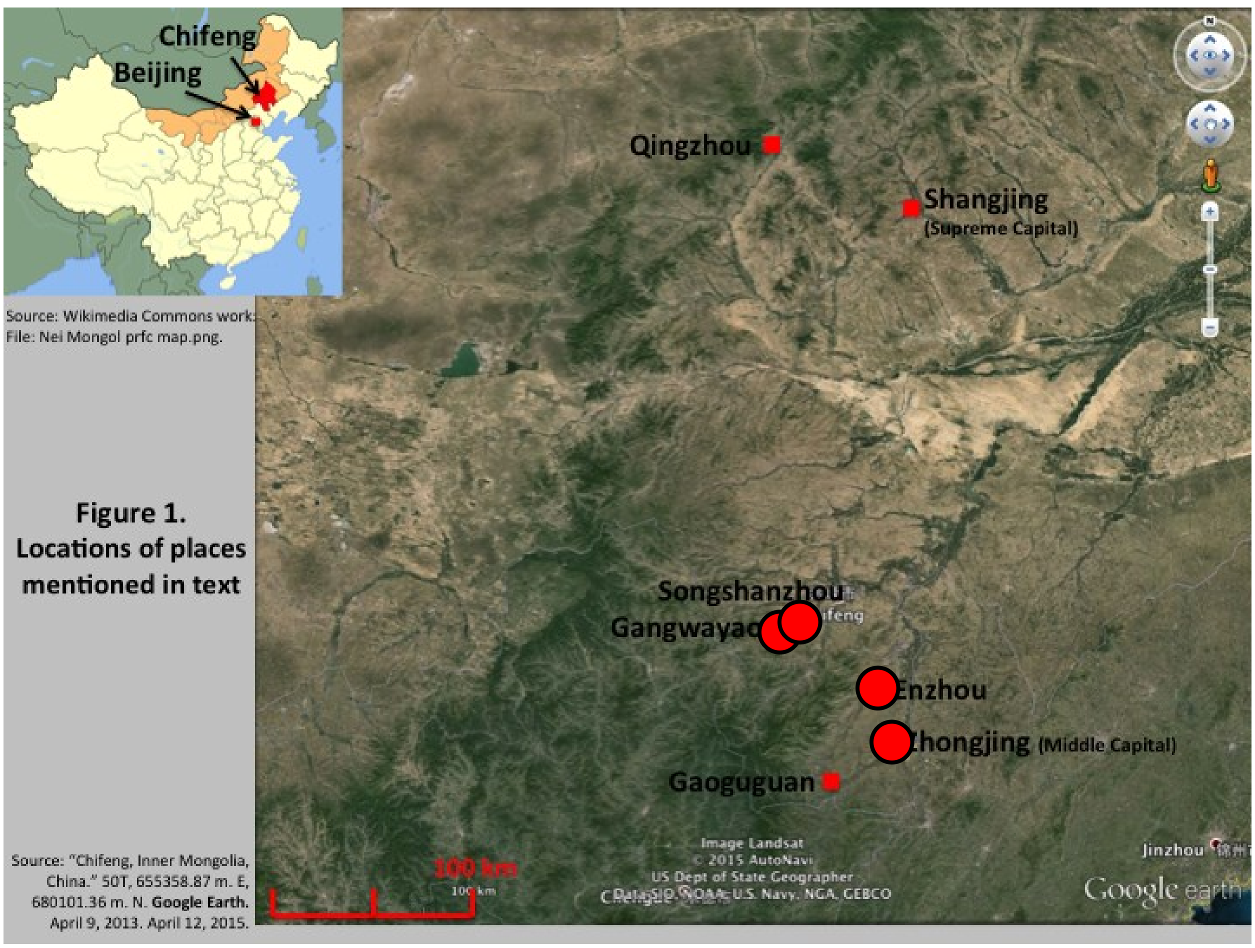
Liao sites (grouped into community polygons) within the CICARP Survey Area. GIS layers used are from: Chifeng International Collaborative Archaeological Research Project (2011a) Settlement Patterns in the Chifeng Region. Pittsburgh: University of Pittsburgh Center for Comparative Archaeology. Chifeng International Collaborative Archaeological Research Project (2011b) Chifeng Settlement Dataset. Comparative Archaeology Database, University of Pittsburgh. URL: http://www.cadb.pitt.edu (Chifeng International Collaborative Archaeological Research 2011). These layers were modified using QGIS.

The newly begun KLASH project (The Kitan Liao Archaeological Survey and History Project)[18] will also involve the intensive pedestrian survey of a 900km^2 area within the Chifeng region, consisting of three

[18] The parent project of this study

non-contiguous 300km^2 survey units bounded by natural borders and centered on the Liao Central Capital, the prefectural level town of Songshanzhou and the associated Gangwayao Kiln Complex, and the prefectural level town of Enzhou. Songshanzhou is located on the southern boundary of the CICARP survey area while Gangwayao is just outside of the boundary, and Enzhou and the Liao Central Capital are located to the southeast of the CICARP survey area in Chifeng (The region and survey areas are shown in Figure 2.6). This survey also aims to identify and sample all sites of all periods within these three regions, but with a focus on the Liao materials as opposed to the Neolithic. Also planned are a series of geophysical and auger core surveys of the interior of the three city sites to obtain a better understanding of the components and layout of each city, as well as stratified Liao materials. Notably, some of this project's stated aims involve resolving the issues identified above, especially the lack of chronological control and the bias towards elite populations (Bennett and Standen 2011).

Figure 2.6



The KLASH Survey Area and Survey Units. Adapted from Bennett (2015: Figure 1)

Research Outside of China

However, the published efforts of these projects have so far been primarily oriented towards basic information on the location and artefactual content of Liao period sites. As such, what major work has been published specifically on the subaltern populations of the Liao Empire and their material culture, has come primarily from scholarship on Liao period sites located outside of China. The Bohai state that was conquered by the Liao in 926CE, and whose population became a substantial segment of the overall Liao population, has received sustained archaeological attention for quite some time in China, Japan, Korea and Russia (Dyakova 2014; Kim 2008, 2011, 2013, 2016; Sloane 2014a, 2014b; Yubin 2010). The subaltern archaeology of Liao period Bohai sites, however, has come primarily from Russian investigations in Bohai sites located in Primorsky Krai (Gelman 2010) and joint Russian and Mongolian Investigations of forcibly relocated Bohai populations residing in Kitan cities in Central Mongolia (Kradin and Ivliev 2008, 2009, 2011). These investigations have seen the use of geochemistry (Junko, et al. 2015; Mitchell, et al. 2012), the archaeology of kilns, households and city precincts (Kradin and Ivliev 2008, 2009, 2011; Kradin, et al. 2008; Yamaguchi, et al. 2009; Zhushchikhovskaya and Nikitin 2014) as well as faunal analysis (Sayenko, et al. 2015). These techniques have not yet been applied to Liao subaltern sites in China. The publication of these studies, which have been ongoing since the Soviet period, has unfortunately received very little attention outside of East Asia. This has been attributed to a lack of materials translated into English until the last few years, as well as an inability to access North Korean scholarship at all (Kim 2008, 2016; Sloane 2014b). The Jurchen, a subject population of the Liao who later overthrew them and formed the Jin Dynasty, have also received sustained archaeological attention in East Asia; however, again this literature has generally not been translated from Russian or Korean, and as such it is hard to ascertain how much of this work pertains to the Liao period Jurchen (Kim 2010).

Since the fall of the Soviet Union, Mongolia has become one of the most intensely archaeologically investigated areas on the Eurasian steppe, with numerous recent publications in international journals (Hanks 2010; Honeychurch and Amartuvshin 2007). With this relatively new intensity of investigation in Mongolia, Kitan sites have seen some serious interest - especially Kitan walled cities and military settlements. Foremost among these have been the investigations at the walled sites of Chintolgoi Balgas (Kradin and Ivliev 2008, 2009, 2011; Kradin, et al. 2005; Ochir and Erdenebold 2009; Perlee 1962), Khermen Denzh (Kradin, et al. 2015), Emgentiin Kherem (Kradin, et al. 2014), Khar Balgas (Grützner, et al. 2012; Yamaguchi, et al. 2009) Baibalik, Khar Balkan Bulgas (Wright and Makino 2007), Kherlen Bars (Wright 2015) and ceramic scatters at places such as Baga Gazaryn Chuluu (Makino 2007; Wright and

Makino 2007). These projects utilize a wide range of approaches from surface collections and geophysical survey to intensive sub-surface investigations of city precincts. The materials collected during the course of these projects have provided extremely important contributions to the basic understanding of the level of variability in Kitan material culture. One such contribution, stemming from the large quantities of occasionally stratified ceramics analysed in these studies, is to provide a chronology of unglazed Liao ceramics for Mongolia which is able to somewhat differentiate the Xiongnu, Türk, Uighur, Xianbei, Kitan and Mongol wares (Makino 2007; Wright and Makino 2007). This chronology, however is currently unpublished.

2.4 Literature on Liao Ceramics

Studies of Liao ceramics have for the most part focused on porcelains and other high fired glazed wares, while un-glazed earthenwares have seen very little attention. When un-glazed earthenware is studied, it tends to be in the descriptive format encouraged in Chinese historical archaeology. It is generally focused on forming chronologies or typologies for complete vessels found in funerary contexts (Liang 2007; Peng 2002, 2011), rather than identifying aspects of provenience or production. These aspects are much more common in studies of Chinese glazed wares and porcelains (Cui, Lei, et al. 2010; Cui, Rehren, et al. 2010; Peng 2002; Yong, et al. 2005). However, outside of China, as was mentioned above, Kitan (and Bohai) earthenware has received substantial attention, especially in Mongolian and Russian excavations (Junko, et al. 2015; Kradin and Ivliev 2008, 2009; Mitchell, et al. 2012; Wright and Makino 2007; Zhushchikhovskaya and Nikitin 2014). As a result Mongolian and Bohai archaeology is generally able to distinguish “Liao” period ceramics from other periods, although, “Liao” here denotes a ~1000 year period from the end of the Han Dynasty (206BCE-220CE) up until the early Yuan (~1271CE) period, rather than the ~200 year period of the Liao Dynasty proper (Bennett and Standen 2011). There is not yet the ability to separate out the Xianbei, Liao, Jin or Early Mongol periods within this ~1000 year period (Bennett and Standen 2011; Wright and Makino 2007). With regard to Bohai ceramics, some of the studies of Liao period sites in the Russian Maritime Province and Mongolia have made some progress in being able to distinguish Bohai-made earthenware from other “Liao” earthenware (Kradin and Ivliev 2008, 2009; Kradin, et al. 2005).

Description

Several features are primarily used to identify “Liao” earthenware, and distinguish them from earlier Türk or Xiongnu earthenwares. First among these is the fact that Liao ceramics tend to be comparatively high fired, extremely hard, and often have evidence of being made with the fast wheel technique (Wright and Makino 2007). Liao period vessels also tend to have flat or flaring bases, as well as distinctive hook, oblong drop, circular or head-indented rim shapes (Wright and Makino 2007:26). Also diagnostic is that Liao unglazed wares tend to be gray or black (although brown sherds are also attributed to this period in northern China) (Bennett and Standen 2011; Wright and Makino 2007). At least in some cases this colouration is the result of firing in a reducing environment, as sherds have been observed exhibiting a "sandwich" colouration when broken which is an indicator that the sherds had been fired in a reducing environment insufficiently long enough for the entire sherd to be reduced (Quinn 2013). In terms of decoration, "Liao" earthenwares often have burnished surfaces (occasionally in a net pattern) or have angular punctate or applique designs on the exterior surfaces that can extend all the way to the base or rim of the vessel. The angular punctate design is the most clear diagnostic feature of "Liao" Period earthenwares (Wright and Makino 2007). Figure 2.7 provides several examples of typical grey/black "Liao" earthenware sherds. Liao glazed ceramics, on the other hand, are highly variable; however, they are much easier to identify (Wright and Makino 2007) and very well understood chemically, technically and chronologically (Lu 2008).

Figure 2.7

Typical Liao Earthenware Sherds (Sample Numbers: 80, 97, 125, 130, 134, 138, 139, 157)

Production Context

Wright and Makino (2007) have asserted that one of the features that separate the earthenwares labelled in Mongolia as "Kitan/Liao"[19] from other ceramics produced by pastoral nomadic empires and populations on the steppe, is that they have a relatively uniform thickness and that they represent "…the introduction of pottery that could have been produced on an industrial scale" (2007:25). Certainly in China the Liao had the capacity to be producing ceramics on an industrial scale. This is evidenced by the presence of Imperial Kilns[20], several of which have been archaeologically investigated (Lu 2008). One of these, the Gangwayao kiln[21], is the largest known kiln complex in Northeast Asia during the Liao period, and its wares are found in sites a great distance from the Chifeng region in which it is located (Bennett 2015). The site covers an area of more than two square kilometres in which there are between 20 and 30 kilns (Lu 2008:26). These kilns certainly were able to reach the high temperatures required to produce stonewares and porcelains (between 1200-1400 °C) as these are the primary wares manufactured at this complex (Lu 2008: 227). The Gangwayao kilns, like most Liao kilns, are primarily *mantou* (steam bun) style constructions with a domed firing chamber reminiscent of a steamed bun and fired using wood or coal (Lu 2008:229-230). One of the sites within the larger Gangwayao complex, the Shuiquangou kiln site, has around 12 kilns, some of which have been reported to be dragon kilns (Lu 2008). Dragon kilns are often much larger structures than *mantou* kilns and are constructed from a series of updraft kiln chambers placed on a hillside so that heat from the chambers closest to the firebox will rise up and can be reused in firing chambers higher up the hillside (Kerr, et al. 2004:347-357). Large Song Dynasty dragon kilns were known to have been able to fire tens of thousands of ceramic objects in a single firing, much more than would be possible in a *mantou* kiln (Kerr, et al. 2004:348)[22].

While industrial style ceramic production was certainly possible during this time period, it is unknown if Liao unglazed earthenwares were produced in these large kiln contexts[23] (Bennett pers. com). Certainly

[19] Kitan is most often used over Liao in Mongolian archaeology

[20] Kilns that are under the control of Liao officials and produce wares bearing the "guan" (offical) mark that indicates these ceramics are for governmental use (Lu 2008)

[21] This kiln complex is located just outside the survey area of the aforementioned CICARP project and is nearby the Liao market town of Songshanzhou. Sherds from Songshanzhou form a large part of the sample analysed in this study.

[22] However, the Gangwayao dragon kiln remnants indicate the dragon kilns in use at Gangwayao were much shorter than the much longer Song Dynasty dragon kilns, and thus would have fired nowhere near as many objects per firing.

[23] As unglazed earthenwares are not found in the large imperial kiln contexts like Gangwayao.

small family and workshop-like conditions are mentioned in at least one contemporary textual source from the Song Dynasty[24] and could be where the primary production of earthenwares was carried out. Sites in Mongolia and the Russian Maritime Province, however, have provided evidence for small scale earthenware ceramic production within or just outside city sites (Kradin and Ivliev 2009; Yamaguchi, et al. 2009; Zhushchikhovskaya and Nikitin 2014). This would seem to suggest a range of ceramic production contexts were in operation during the Liao period ranging from massive industrial production, like Gangwayao, to small scale urban workshop production such as that seen in Mongolia and possibly also to rural local family workshop production, although there is no evidence for this as of yet (perhaps due in large part to the bias against investigating non-elite sites).

Geochemistry and petrography

With regard to the geochemistry of Liao ceramics, elite ceramics such as porcelains, stonewares and glazed earthenwares (including Bohai glazed wares), have been thoroughly investigated (Lu 2008; Mitchell, et al. 2012). This is part of a wider general trend in Chinese archaeology where the technological and chemical aspects of elite and glazed ceramics receive substantial attention and are very thoroughly investigated (Bennett and Standen 2011; Kerr, et al. 2004). It should be noted that there is little literature on the petrography of these materials. This should be unsurprising however as vitrified fine grained ceramics with few mineral inclusions are petrographically very uniform and thus relatively uninteresting (Quinn 2013). Un-glazed non-elite ceramics, on the other hand, especially those from historic periods, are not often well understood chemically or technologically. This holds true for the Liao, as there does not appear to be any published literature at all on the geochemistry or petrography of un-glazed Liao earthenware ceramics.

[24] a poem entitled "The Potter" written by the scholar Mei Yao Chen:

> "Pots cover every inch of space before the door
> But there's not one single tile on the roof.
> Whereas the mansions of those who wouldn't soil their fingers with clay
> Bear tiles overlapping tightly like the scales of a fish"
>
> (Mei Yao Chhen (1036CE) in Kerr, et al. 2004:19)

3. Aims

In light of the above summary of the literature on the Liao, it should be clear that there are serious lacunae in our knowledge of the subaltern population of the Liao Empire and their material culture; particularly utilitarian un-glazed earthenware ceramics. Several explanations for this have been mentioned, specifically the difficult position of the Liao as a dominant yet “alien” regime outside of the ‘line of political succession’ (Olsen 1987), the textual focus of traditional Chinese archaeology that privileges the study of elite populations and their material culture and the relative difficulty of investigating pastoral nomadic populations through archaeology. The exact form of these lacunae can be summarized by four statements

1. There is little examination of Liao non-elite contexts,
2. There is little examination of Liao non-elite material culture,
3. There is little examination of Liao non-glazed ceramics and no investigations of their mineralogy or chemistry,
4. There is very little chronological control in Liao non-elite contexts.

Combined, these factors vastly limit the *questions* that can be asked about subaltern populations until such time as we acquire basic information regarding variation in non-elite material culture and methods of chronologically organizing that material culture. Bennett and Standen have suggested that “What we need is data that will give us access to non-elites, and a methodology for obtaining that data” (2011:87).

The above statements and this call for the development of a methodology form the impetus behind the current research. This study aims to help with resolving these factors by analysing a series of Liao non-elite utilitarian ceramics through geochemistry and ceramic petrography. Ceramic analysis seems the most direct method available at this time to address these lacunae as it is a data source with high information potential, it is abundant in contexts that do not require excavation, several collections have already been made in the region of interest (Chifeng International Collaborative Archaeological Research Project 2011; Linduff, et al. 2004), these collections are accessible and are viewed as expendable enough to allow for semi-destructive testing (petrography), and finally, ceramics materials in general are often very sensitive to chronological change. The aims of these analyses are as follows:

1. To discern a suitable methodology for future investigations of Liao non-elite material culture by evaluating the effectiveness and validity of pXRF and petrography for analysing these materials,

2. To assist in the process of acquiring the aforementioned basic information on the variation in Liao non-elite material culture by collecting baseline data on the variation in geochemistry and minerology of Liao utilitarian earthenware,
3. To identify features of these ceramics that may provide opportunities to employ other methodologies for analysing Liao un-glazed earthenware.

The materials used for this analysis are primarily[25] unglazed ceramic sherds collected as a part of the CICARP project. This provides the opportunity to also make a contribution to the archaeology of the Chifeng region (and the greater KLASH project) by attempting to identify geochemical or petrographic groupings in the assemblage of ceramic materials from this area that may allow for materials from different sites to be linked. This could facilitate the elucidation of exchange networks in this region.

[25] With the addition of some materials from the Enzhou site located southeast of the CICARP survey area and within the KLASH survey area.

4. Methodology

The methodology employed by this study utilizes stepped visual, geochemical and petrographic analysis. The use of these three methods together provides a means of checking and verifying the substantive results of each method against the others. This in turn provides a means of assessing the suitability of each technique for analysing Liao period earthenware, the primary methodological result of this study.

4.1 Sampling

The CICARP survey assemblages are administered by The Inner Mongolia Archaeological Research Institute, which kindly granted access to the assemblage, held at the Inner Mongolia Archaeological Institute Field Station (colloquially known as “Da Ta”, or “Big Pagoda” due to the 80 m. tall Daming Pagoda on site) at the Liao Central Capital in the village of Tiejiangyingzi in Ningcheng County, Chifeng. The Institute granted permission for access to the material for one week, which would include the sampling, optical, and geochemical analyses to be carried out at the Ningcheng field station. Given the limited time available for both the sampling and analysis, the sampling regime adopted was not a traditional random sample often used in more conventional laboratory contexts, but instead non-probabilistic judgemental sampling was used. The reasons for this are twofold; first, within the site assemblages (and each individual sample bag) labelled “Liao” were samples that visually did not appear to be Liao Dynasty period sherds, but in fact potentially represented a ~1500 year time period from the Xiongnu Empire (209BC-93 CE) to as late as the Mongol Empire (1206-1368 CE) (Bennett pers. com). Each sherd sampled had to be identified as an actual Liao period sherd before being sampled. This task was not possible with the available sherd database, and as such, each sherd had to be visually checked to ensure it was likely Liao. Therefore, the time needed to construct a database that would allow random sampling of only the Liao materials would, given the number of “Liao” samples, greatly exceed the time granted for both the sampling and analysis.

Furthermore a random sample seemed unlikely to greatly further the aims of this particular project over a judgemental sample. The reasons for this are twofold; Firstly, the assemblages used are themselves not truly random samples of the sites they belong to, but rather systematic collections of material available on the land surface. Secondly, the goal of the analyses is to look for geochemical, petrographic and optical difference within the assemblage, particularly differences between sherds significant enough to allow for the identification of exotics or to distinguish and link places of interest, particularly Enzhou, Songshanzhou and the smaller occupation sites located between the Liao Middle and Supreme Capitals. As such judgmental sampling in this instance seemed justifiable.

Sampling was carried out using several criteria; firstly sample bags were selected from site locales (collection units) of interest, specifically those within the Chifeng region having been recorded in the CICARP database as possessing only "Liao" sherds and those regions known as being Liao prefectural towns and centres. Sherds within these samples were then examined, and samples deemed likely to be Liao were selected as possible candidates for geochemical analysis and a small subset of these samples was selected for petrographic analysis.

Criteria for which samples were identified as being Liao primarily rested on decorative and form indicators, specifically; *bidianwen* decoration (vertical comb incised decoration), flat bottomed vessels, fineness of fabric, hardness, and brown-black surface color.

Once samples had been identified by these criteria of "Liao-ness" as more likely Liao than any other time period, then samples were inspected for their suitability for pXRF analysis (the constraints of which will be discussed later) and any samples that were deemed suitable were then selected. A subset of these samples was then selected for petrographic analysis. These samples were selected to cover, as much as possible, the range of visually identifiable variability[26] within the sherds sampled for pXRF.

Sampling was run concurrently with the geochemical analysis and ceased when the time allocated at the Ningcheng Field Station finished. Although only a small fraction of the Liao sherds collected were analysed (215 in total, with a subset of 44 also subjected to petrographic analysis), the sherds included in the study cover much of the Chifeng region and the two prefectural towns of particular interest to this study, Enzhou and Songshanzhou.

[26] Specifically variation in paste colour, texture, surface treatment, visual temper and hardness.

4.2 Details of the Sample

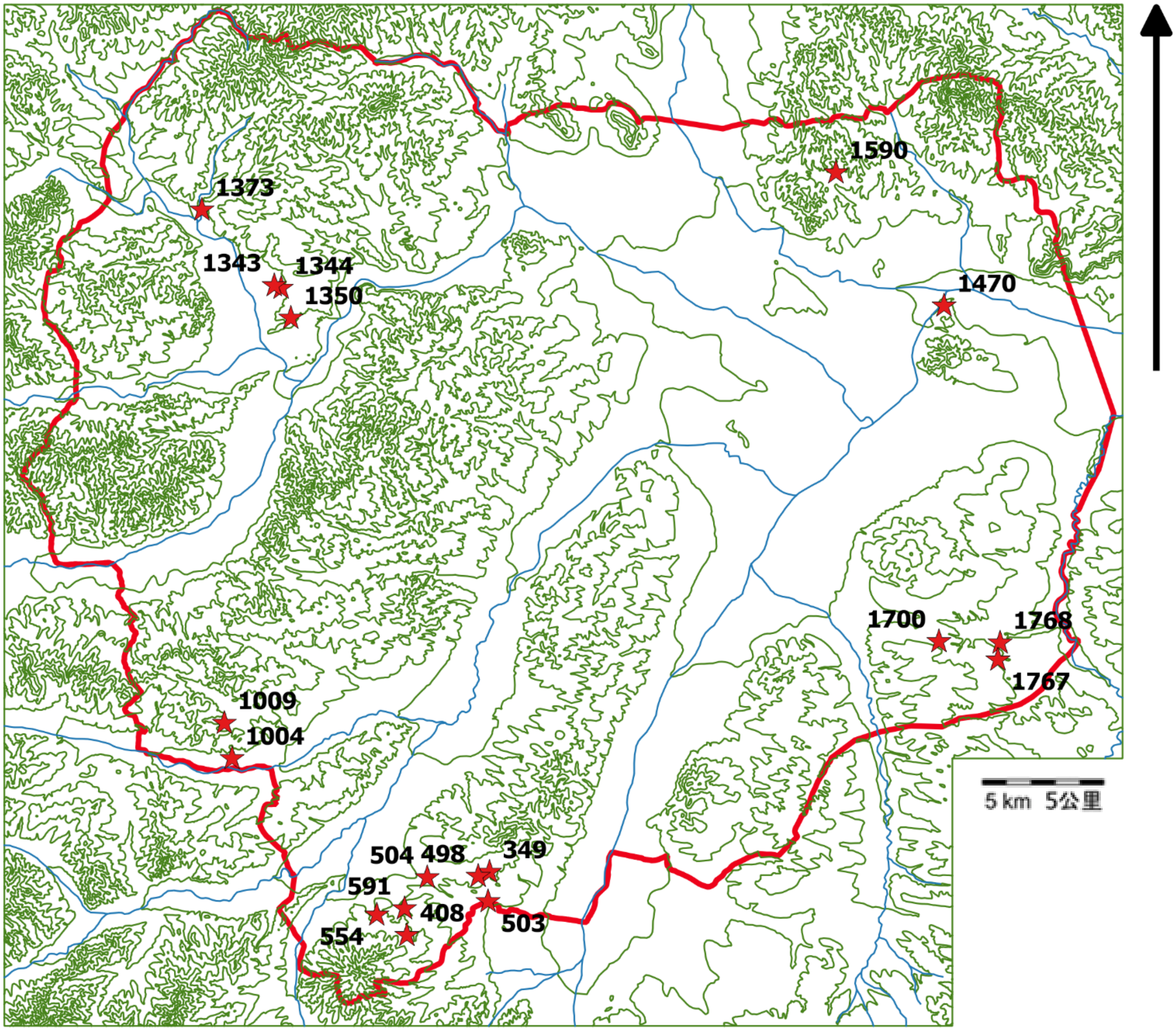
Overall, 215 earthenware sherds were sampled from 20 site localities including Songshanzhou, Enzhou and a number of smaller sites distributed across the CICARP survey universe. Figure 4.1 shows the locations of these sites while the approximate numbers of sherds from each of these sites are provided in Table 4.1.

Table 4.1. Samples by Site

Site Name/ CICARP Site Code	Number of Earthenware Samples	Number of Glazed Stoneware Samples	locality description if available[1]
ENZH	29		Enzhou
1768	5		
1767	5		
1700	3		
1590	8		
1470	1		Burned earth and ash pits
1373	5		
1350	13		Probable grave
1344	5		
1343	8		
1009	14	2	
1004	71	7	Songshanzhou
591	4		
554	3	1	
504	5		
503	5		
498	5		
408	4		
349	12		
Total	205	10	

([1] Locality descriptions are from the CICARP database website (Chifeng International Collaborative Archaeological Research Project 2011))

Figure 4.1



Locations of all sites sampled within the CICARP Survey Area. The Enzhou site is not shown on this map as it is located southeast of the CICARP Survey Area. GIS layers used are from: Chifeng International Collaborative Archaeological Research Project (2011a) Settlement Patterns in the Chifeng Region. Pittsburgh: University of Pittsburgh Center for Comparative Archaeology. Chifeng International Collaborative Archaeological Research Project (2011b) Chifeng Settlement Dataset. Comparative Archaeology Database, University of Pittsburgh. URL: http://www.cadb.pitt.edu (Chifeng International Collaborative Archaeological Research 2011). These layers were modified using QGIS.

While the primary focus was earthenware, some utilitarian stoneware was also sampled to use as an out-group in the geochemistry and petrography. The earthenware sample also contains roof tiles as these materials are abundant at Liao sites in the region, and potentially some elements of their manufacture (specifically the type of fabric backing onto which they are moulded) could be specific to the Bohai communities forcibly relocated from the region around the Liao Eastern Capital.

A small sub-sample, approximately 43 sherds (among them several roof tiles and one stoneware sample), provided material for the later production of petrographic thin sections. These samples (see appendix 12.1 for sample numbers and photographs) were selected based on optical criteria in an effort to characterize samples from across the range of visual variation present in the Liao sherds, which it was hoped would also allow for samples from within different geochemical groupings, if any were found, to be compared to provide a check on group consistency.

4.3 Macroscopic Visual Analysis

Initial visual analysis of the samples (post-washing) consisted of samples being photographed and several macroscopic observations being recorded; specifically: type (roof tile or vessel), part of vessel (rim, base or body), matrix coarseness (fine or coarse), matrix colour (red, brown, grey), presence or absence of glaze, presence or absence of decoration, decoration type, temper visibility and any descriptive notes about the sherd.

4.4 Petrographic Analysis

Pieces of the sub-sample selected for petrographic analysis were transported to Beijing for the production of petrographic thin sections. These thin sections were prepared by a commerical workshop located in Beijing recommended by Dr. Yu Yongbin, a post-doctoral researcher at Peking University who had previously used the services of this workshop. The thin sections produced were epoxy impregnated and then hand ground to 30 microns, a standard means of preparation in archaeological ceramic petrography (Quinn 2013). The resulting thin sections were of high quality, likely due to the processing experience of this particular workshop.

Since PRC law states no archaeological samples may be taken out of the country, the analysis of the petrographic thin sections was carried out at Peking University in Beijing using the petrographic microscope within the Peking University Archaeometric Laboratory, with the permission and support of Professor Cui, Dr. Yu, and the Peking University School of Archaeology and Museology. Analysis primarily consisted of photographing the thin sections using a petrographic microscope at 50x, 100x, and 200x magnifications in both plane and cross polarized (XP) light and at a variety of rotations. These photographs later provided the basis for petrographic mineral identifications performed outside of China.

Ideally, one would have access to detailed local geological maps for petrographic analysis; however, due to the controls on such maps within the PRC only larger scale regional geologic maps were available, which limited the effectiveness of specific temper mineral identifications[27]. Therefore, the focus had to be on more general mineral identifications and comparisons between the different petrographic slides. The low resolution (at the country rather than county scale) geologic maps used in this analysis were those from Hsu and Chen (1999). The basic geology of the Chifeng region is quite complex and contains "…Pre-Cambrian metamorphic complexes … intruded by magmatic bodies and accompanied by volcanic rocks of the Jurassic to Cretaceous age." (Avni, et al. 2010:1254). This underlying lithology is overlain by loess, alluvial gravels and conglomerate.

4.5 Geochemical Analysis

Justification for pXRF

A portable X-ray florescence spectrometer (pXRF) was selected as the best available option for the geochemical analysis. The main advantages of pXRF, compared to more accurate laboratory methods, are often listed as: it is non-destructive; requires minimal or no preparation of samples; is comparatively fast; is relatively accurate; costs only time (apart from the initial purchase of the instrument); is extremely easy to operate and, unlike lab-based systems, it is small enough to be field portable (Shackley 2011). This last advantage provides the most important justification for its use in this study over more accurate lab based systems, as analysis had to be carried out at the Ningcheng Field Station where the CICARP assemblage is held.

Additionally, while there are still some concerns in the literature as to its accuracy (for example see Speakman and Shackley 2013), generally pXRF has been found to be, regardless of accuracy, adequately precise for answering many archaeological questions *if* used correctly, and with an understanding of the potential error that can result from poor sample choice or operating conditions (Frahm 2013b, 2014; Frahm and Doonan 2013). In fact Frahm (2013b) conducted a study where "sub-optimal" operating conditions and sample choice were purposefully maximised in order to test whether pXRF would still be precise enough under these conditions to source an assemblage of Near Eastern obsidian. Surprisingly he found that the vast majority of samples could still be assigned to the correct source, indicating a

[27] Local geological institues in the Chifeng region will be consulted in future to acquire more detailed local geologic information.

surprising degree of archaeological validity (defined by Frahm as a technique's ability to adequately answer archaeological questions regardless of accuracy and precision).

This being said, ceramic materials are much harder to characterize and source than the obsidians analysed by Frahm (2013b) as, unlike obsidian, ceramics are heterogeneous materials with the potential for significant variation within a single sample (Forster, et al. 2011). However, despite this, several studies such as Forster et al. (2011) have shown that if attention is paid to correct sample choice and best practice in operating conditions, then many ceramic materials can still be characterized adequately by pXRF despite their inherent heterogeneity. However, pXRF characterization is much less accurate and sensitive than most non-portable techniques (Speakman et al. 2011). As such, even when attention is paid to sample choice and operating conditions, distinguishing groupings within ceramic assemblages may still be impossible due to insufficient regional geochemical variability or within sherd variation exceeding between sherd variation (Speakman, et al. 2011).

Instrumentation

Geochemical characterization of the ceramic samples was carried out using a Bruker Tracer III portable x-ray fluorescence spectrometer. This instrument utilizes a Si-Pin detector (190 eV at 10,000 counts per second) and an x-ray tube utilizing an Rh anode with a max voltage of 40kV. While this system can be equipped with a vacuum system, in this case it was not utilized due to its bulk. Additionally, the instrument was used in its laboratory stand rather than handheld, as this minimises error associated with air being present between the detector and the sample (which will be discussed later).

While this system has the ability to utilize different filters to detect a range of elements (from elements heavier than Mg to elements lighter than U), in this instance only the green filter (comprised of 1 mil Al, 1 mil Ti, 6 mil Cu) was used. This filter aids in the detection of mid-Z trace elements (namely: Th, Rb, Sr, Zr, Y and Nb) yet also provides determinations on metals heavier than Fe (eg. Mn, Ga and Pb).

Ideally one would want to measure as many elements as possible as this greatly aids in the statistical techniques most often used with geochemical data, as the more elements that are characterized the more likely diagnostic elements will be found (Wilson 1978). However, in this case analysis was limited to the elements detectable with this filter only, as utilizing a second filter to expand the number of elements considered would have doubled the analysis time and thus halved the number of samples able to be analysed. Additionally, the trace elements detected with this filter are both well detected by the Tracer III (as it has a low limit of detection for these elements), and have the potential to vary significantly with different geologies, making them ideal candidates for the ultimate goal of geochemical differentiation of the ceramic samples (Glascock et al. 2004).

Potential for Contamination

Samples for analysis all come from surface collections. Unfortunately in Northeast China, due to ongoing issues with soil and water pollution associated with China's rapid industrialization, the sediments that these sherds were deposited in have the potential to be contaminated with industrial pollutants and particulates, particularly heavy metals such as Pb (Chen, et al. 1999; Cheng 2003). Additionally, as samples were primarily collected from dryland agricultural field contexts, there is the additional possibility that samples could be contaminated by inorganic fertilizers. Phosphate-based fertilizers account for a significant deposition of minerals that are heavy enough to be detected by pXRF (unlike nitrate and oxygen based fertilizers), which could in this case provide a source of surface contamination especially as phosphate rich apatite fertilizer is used in China (Luo, et al. 2009). It should be noted, however, that organic fertilizers are unlikely to represent a significant source of error as Forster et al. (2011) have shown that thin organic coatings have minimal effects on the pXRF of archaeological ceramics.

Sample Preparation

In an attempt to alleviate the possibility of surface contamination, samples were washed prior to analysis to remove any residual soil. An experimental study by Stoner et al. (2013) showed that rinsing ceramic materials that had been contaminated with sodium and potassium from immersion saline water was very effective in the removal of said sodium and potassium. While certainly saline and heavy metal contamination are not perfectly analogous situations, rinsing provided the only course of action available in this situation. Ideally within a laboratory context this would be carried out using an ultrasonic bath; however, this was not possible at the Ningcheng Field Station. During the washing of the sherds, store-bought purified Nongfu brand water was used in an effort to avoid local groundwater, which was also potentially contaminated. Furthermore, in order to check the purity of the water used, numerous varieties of local purified water (including the Nongfu brand which was eventually used) were analysed by pXRF and none were found to contain any detectable impurities. After washing, samples were left to air dry overnight and were analysed the next day.

It is as yet unclear exactly how great the potential for contamination of archaeological ceramics is in Northeast China as the subject appears to have not yet been broached in the literature. It is here suggested that in the future a fruitful course of action would be an experiment involving the geochemical analysis of a sample of surface collected pottery that had been both pre-washed and post-washed with purified water, with post-washing having been done in an ultrasonic bath to examine the potential for contamination and also the effectiveness of various sample preparation methods.

Analytical Conditions and Error Reduction

Analyses were carried out with the instrument operating at 40 kev and the highest amplitude available, as these settings maximise the sensitivity to the trace elements of interest for this study. Additionally, these conditions are useful in that they allow for the post-hoc correction of the data utilizing a Bruker ceramic calibration run at the same settings. Analyses were run as timed assays and were limited to one minute of live time for the x-ray tube. While the analysis becomes more accurate the longer the x-ray tube is active, one minute was judged as a good compromise between accuracy and the limited time available for the analyses. The elements identified using these settings were Manganese (Mn), Iron (Fe), Zinc (Zn), Gallium (Ga), Thorium (Th), Rubidium (Rb), Strontium (Sr), Yittrium (Y), Zirconium (Zr), and Niobium (Nb).

Surface Irregularity

Analyses were carried out on the flattest available non-concave surface of each ceramic sample, and if possible, were consistently carried out on non-textured surfaces. This is vital as pXRF has been shown to be less reliable when used on irregular surfaces (Liritzis and Zacharias 2011). This is firstly because pXRF analyses are calibrated with the assumption that analysed surfaces will be flat and reflect x-rays uniformly (Potts, et al. 1997) and secondly that surface variation increases the air between the sample and the Instrument detector (Liritzis and Zacharias 2011). This is problematic as air can absorb low energy x-rays, particularly those emitted by lighter elements (specifically elements above Ti), interfering with detection of these elements, and to a lesser extent heavier elements as well (Forster, et al. 2011; Shackley 2011:30).

Although there are studies on surface irregularity effects, such as that of Davis, et al. (2011), indicating that the potential error from surface effects on homogenous sialic rocks like obsidian is often minimal (>1% of CV) and much less than the error involved in the basic element concentration measurement (2011:179), ceramics seem to be more affected by surface irregularity. Forster et al. (2011) present a study indicating that even heavy elements can be seriously affected by the concavity of samples and the presence of surface etching. They note however that; "Accuracy within ± 10% (and frequently better) is possible for elements with an atomic number ≥ 26 (Fe) when irregular surface structures are shallow and there is no concavity." (Forster et al. 2011:393).

While the samples analysed in this study were not consistently perfectly flat, they ranged from concave to sub-concave, and convex surfaces were avoided. Although occasionally textured surfaces had to be analysed, this is unlikely to represent a serious source of error as these sherds represent a very small fraction of the total sample, the decoration/texture on these sherds was relatively shallow and not etched in a fashion that would attenuate x-rays; these sherds were also often analysed on a non-textured surface as well; and finally, no elements lighter than Fe, the elements most adversely affected by surface effects, were considered in the final statistical analyses.

Infinite Thickness and Heterogeneity

Apart from surface effects, the main potential source of error in analysing archaeological ceramics comes from the size and thickness of the sample (Davis, et al. 2011; Forster, et al. 2011). Samples need to be large enough to adequately cover the instrument aperture and thick enough that all emitted x-rays are absorbed by the sample (referred to in the literature as infinitely thick). However, with regard to ceramics, this is much harder to calculate as infinite thickness depends on the density and grain size of the sample, and non-homogenous materials like tempered ceramics can be composed of minerals with radically different densities (Forster, et al. 2011). While in this case the issue of infinite thickness cannot be mathematically resolved for each sherd, it is sufficient to say that all samples analysed were likely sufficiently thick to reliably assume all x-rays were absorbed and thus that the sample had infinite thickness for the elements of interest. Samples ranged from ~50-400mm and by way of example, infinite thickness for mid-z elements in obsidians is achieved at 3mm (Davis, et al. 2011).

In order to deal with sample heterogeneity, each ceramic sample was analysed three times at three different localities on its surface. This allows for a check on the accuracy of the individual measurements and also allows for the measurements from each sample to be averaged. This averaging is necessary as tempered ceramics are particularly non-homogenous materials and, as such, a single reading is unlikely to be accurate in its characterization of the entire material (Forster, et al. 2011). Greater numbers of analyses provide a more accurate characterization of the total geochemistry of the sherd, with five analyses being regarded as ideal for fine grained materials like the majority of Liao period sherds

(Forster, et al. 2011). Multiple readings also allow for the calculation of a coefficient of variation for the average of each sample, allowing for the determination of variability in the readings. Within the literature on the pXRF of archaeological ceramics, variation under 10% is regarded as useful (Forster, et al. 2011) and as such, within this study samples with coefficients of variation consistently above 10% were not considered in the statistical analysis and were regarded as too heterogeneous for non-destructive geochemical characterization by pXRF; however, only four samples were found to exceed this 10% variation limit (Samples 25, 213, 214, 215).

Standards

The analysis of standards is a vital part of any form of geochemistry and has been a prominent concern in the literature on archaeological pXRF (Shackley 2011). The analysis of standards allows not only for a check on the accuracy, precision, and potential variation in instrument operation over the course of the analyses but is also vital for calibration of instruments and providing the ability to compare between datasets produced by different instruments (which can often vary in the accuracy of their output (Craig, et al. 2007; Goodale, et al. 2012; Nazaroff, et al. 2010). As such, at the beginning and end of each analytical session one specific Liao period unglazed ceramic sherd, referred to as Kitan Standard 1 (KS1), was analysed as an in-house solid standard. This sherd occupies the middle ground of the assemblage in terms of its hardness and the coarseness of its temper.

The primary use for standards in archaeological geochemistry is to calculate the precision of the analytical instrument, as most archaeological applications rely more on high precision than accuracy to answer the questions of interest (Frahm 2013a, 2013b, 2014; Frahm and Doonan 2013). To do this, every analysis of the standard across the total time of the analysis is collected, each element is averaged and its standard deviation is divided by its mean to provide a coefficient of variation, which in this instance is a measure of how precise the instrument is at detecting each element. Table 4.2 shows the coefficients of variation for the elements detected in this study. Elements exhibiting variation greater than 10% were excluded from analysis leaving Fe, Rb, Sr, Y, Zr and Nb as the elements of interest. Trace elements such as Rb, Sr, Y, Zr and Nb are among those elements most often found to be useful in differentiating ceramic materials (M. D. Glascock, et al. 2004).

Table 4.2 CVs for KS1 standard

n=26	Mn	Fe	Zn	Ga	Th	Rb	Sr	Y	Zr	Nb
CV*100	14.7	8.6	31.3	10.5	10.8	4.5	4.1	6.9	4.1	9.1

4.6 Quantitative Methods

Analysis of ceramic geochemical data can prove quite difficult and the literature surrounding geochemical approaches to ceramic assemblages often relies on quantitative approaches. These approaches range from simple bivariate plots to more powerful multivariate methods, particularly hierarchical cluster analysis and principal component analysis (methods that can identify groupings and structure within the data), and occasionally also k-means cluster analysis (a method that will construct a given number of groupings) as a verification of the groupings that result from the other methods (for examples see (Forster, et al. 2011; M. D. Glascock, et al. 2004; Marengo, et al. 2005)). This standard array of quantitative methods is employed here, and how each of the methods was used is described below.

Bivariate plots

The initial quantitative analysis of the data was carried out using bivariate plots to check for clear groupings of samples as well as any outliers that might represent machine error or exotics. While bivariate scatter plots alone can be sufficient in the differentiation of extremely homogenous materials like obsidian, this is only rarely the case for ceramics. One notable regional example of this was Mitsuji's (1993) differentiation of the major Japanese Kofun period Sueki ware kilns on the basis of Rb/Sr and Ca/K plots alone. However, this is an exceptional case, and here it was expected more powerful multivariate techniques would be needed.

Data Transformation

As the elements analysed include both trace elements (elements occurring at low concentrations, specifically Zr, Sr, Rb, Y and Nb) and major elements (elements occurring at very high concentrations, specifically Fe) a transformation must be made to compensate for these differences in magnitude when using multivariate techniques (Michael D. Glascock, et al. 1998). To correct for these differences, all elemental data was log10 transformed prior to the multivariate analyses. This has additional benefits in that if geochemical data is not normally distributed, then normalising it with a log10 transformation can be beneficial to multivariate analysis (Bishop and Neff 1989).

Principal Components Analysis

After bivariate plots were used to check for, and eliminate outliers that could affect the multivariate techniques, principal component analysis (hereafter referred to as PCA) was used to find groupings in the data. While a full explanation of PCA is beyond the scope of this thesis (see Shennan (1997) for a better introduction to PCA), simply put, it is a means of summarising variation in a dataset from multiple variables down to a few components that explain the majority of the variation so it can be represented in 2D or 3D form (Shennan 1997). Groupings evident in the scatterplots produced by the PCA were then re-plotted with their site name identifiers to check for possible congruence that could indicate a grouping originating from a single site.

Hierarchical Cluster Analysis (HCA)

After checking the groupings revealed by the PCA, both the original data and the principal components from the PCA were further analysed by two hierarchical cluster analyses (hereafter referred to as HCA). HCA utilizes a table of the similarities and differences between samples to link samples together and build a dendrogram of the relative mathematical difference (here calculated as either Euclidian distances) between samples (Shennan 1997). Two HCAs were calculated, one using the Average Linkage method and the other using Ward's method. Average Linkage is the most commonly used HCA linkage method in archaeology and is calculated using the average of the similarities between samples (Shennan 1997). Ward's method differs in that it is calculated by linking samples with the lowest squared deviation of all group members summed together (referred to as the error sum of squares) (Shennan 1997). Ward's method is often used in geochemistry as it tends to create very homogenous groupings (Shennan 1997). An additional two HCAs were also calculated using Mahalanobis distances. This was due to the possibility of groupings in the data being elliptical rather than circular due to covariance. If this is the case, Mahalanobis distances (here abbreviated as MD) are more suitable to calculating distances between the data points than Euclidian distances (Glascock, et al. 2004). The MD HCAs were restricted to the PCA data as the main limitation of MD is that the groupings calculated will not be reliable if they are smaller than the number of variables used (2004) and in this case the PCA data should always have a smaller number of variables (2-3) than the log10 data (6).

The use of two linkage methods and two distance methods provides a means to check the consistency of the group assignments made by each method, as does the use of both the original data and the PCA data. However, it should be noted that one of the distinct features of hierarchical cluster analysis is that it will look for structure in the data to find groupings. However, this structure may or may not reflect real world clusters and instead the method could potentially interpret stochastic variation in the data as a meaningful cluster (Shennan 1997). The separate use of both the Ward's and Average Linkage methods helps to assess this possibility as it provides a check on how method dependent the results are.

K-means Cluster Analysis (K-MCA)

To test the idea that the groupings identified by the cluster analysis are real or not, the original untransformed data and PCA data were submitted to K-means cluster analysis (hereafter referred to as K-MCA). This technique also uses similarities and differences in multivariate data to identify clusters in the data but differs in that the researcher provides the analysis with the number of clusters it should generate (Shennan 1997). In this case the number of clusters generated by the hierarchical cluster analyses was used to provide a check on the veracity of the clusters generated by the HCA/PCA. If separate multivariate methods generate congruent clusters then it is more likely that the resulting clusters represent actual geochemical groupings rather than stochastic structure in the data. As such, only groupings that exhibited high congruence between the HCA/PCA and their associated K-MCA were used to construct the final posited groupings.

5. Geochemical Results

While a full account of the results of each statistical analysis would be valuable to a specialist in geochemistry or statistics, the majority of readers will not require such a thorough run through of the analyses. As such, this information has been included as an appendix (Appendix 12.1) and in its stead a summary of the results for each of the varieties of sherd analysed (which were separated due to obvious chemical differences) is provided below.

5.1 Roof Tile Summary

A total of 6 HCAs with 6 paired KMCAs was carried out on the roof tile data and the assignments produced by each method employed are provided in Appendix 12.2; Tables 12.2.1, 12.2.2, 12.2.3 and 12.2.4. Examination of the HCAs and their associated K-MCAs indicates that good congruence between the two methods is achieved with all methods employed (congruence ranges from 74-100%); however, excellent to perfect congruence is only achieved by the PCA data Mahalanobis Ward's Method (100% congruence), PCA data Mahalanobis Average Linkage Method (97% congruence), Log10 data Euclidian Ward's Method (95% congruence), and the PCA data Euclidian Ward's Method (92%). If we limit our analyses to only these high congruence methods (see Table 5.1) the assignments between these methods are also highly congruent (97% congruence).

The results of the highly congruent analyses point to one very solid conclusion— that roof tiles from the Enzhou site, with the exception of samples 27 and 28 and the addition of sample 106 from the Songshanzhou site (1004-00E074-S106), form a geochemical grouping that is distinguishable by all statistical methods employed here, and as such is likely an actual archaeological grouping. The remaining roof tiles may also form up to three additional groupings, but it is unclear if this reflects an archaeological reality or stochastic trends in the data interpreted as groupings. Of these groupings, the group of samples 96 and 177 form the most convincing grouping as they are identified as belonging to the same group by multiple methods, and they tend to plot together and away from the other samples in the PCA data.

Table 5.1 High Congruence Methods Cluster Assignments – Roof Tiles

Case #	Site #	Sample #	LOG10 WARD Cluster	PCA WARD Cluster	PCA MD WARD Cluster	PCA MD Cluster
1	349	84	2	2	2	2
2	349	96	2	2	2	4
3	498	73	2	2	3	3
4	554	78	2	2	3	3
5	1004	106	2	1	1	1
6	1004	107	2	2	2	2
7	1004	120	2	2	3	3
8	1004	165	2	2	3	3
9	1004	178	2	2	3	3
10	1004	179	2	2	3	3
11	1004	180	2	2	3	3
12	1004	181	2	2	3	3
13	1004	182	2	2	3	3
14	1004	183	2	2	2	2
15	1004	184	2	2	2	2
16	1004	191	2	2	3	3
17	1004	193	2	2	3	3
18	1004	194	2	2	3	3
19	1004	195	2	2	3	3
20	1004	198	2	2	3	3
21	1009	172	2	2	3	3
22	1009	174	2	2	3	3
23	1009	207	2	2	3	3
24	1009	169	2	2	3	3
25	1009	177	2	2	2	4
26	Enzhou	2	1	1	1	1
27	Enzhou	21	1	1	1	1
28	Enzhou	22	1	1	1	1
29	Enzhou	23	1	1	1	1
30	Enzhou	26	1	1	1	1
31	Enzhou	27	2	2	2	2
32	Enzhou	28	2	2	2	2
33	Enzhou	29	1	1	1	1
34	Enzhou	24	1	1	1	1

5.2 Glazed Sherd Summary

A total of 6 HCAs and 6 paired K-MCAs was carried out on the glazed sherd data and the assignments produced by each method employed are provided in Appendix 12.2; Tables 12.2.5, 12.2.6, 12.2.7 and 12.2.8. The groupings identified by the HCA analyses are diverse, and while these assignments are often internally congruent with the K-MCAs generated to check their assignments (at least under five groupings), between analyses these groupings are often not congruent. However, if limited to the analyses that have perfect congruence (Log10 data Ward's Method, PCA data Ward's method and PCA data Mahalanobis Ward's method) inter-analyses groupings become much more consistent (80% congruence between the different methods). Some groupings of sherds are then, correcting for varying group numbers, visibly consistent across multiple analyses and thus worthy of closer scrutiny (see Table 5.2). Samples 189, 129 and 203; samples 205 and 212; 115 and 188; and potentially also 116, 211 and 79 form groupings across multiple methods. While sample 79 would appear to be an outlier, based on the bivariate plots of the PCA factors, none of the high congruence HCAs identify it as such.

However, there is a serious issue with these groupings in that they seem to make little archaeological sense. Apart from sample 79, all these groupings contain glazed sherds found in the vicinity of Songshanzhou, a prefectural level Liao market town located a short distance from the Liao Imperial kilns at Gangwayao and likely serving as the distribution point for Gangwayao glazed wares. Gangwayao is known to have produced very large quantities of white glazed wares that visually, are extremely similar to all the glazed sherds analysed here. As such, It would seem unlikely then that (if they are not an artefact of the statistical analyses or stochastic patterning) the groupings identified here represent different loci of production, as it would make little sense to import significant quantities of non-local white glazed ware into a township that exports white glazed ware.

That these groupings represent stochastic patterning in the data is a distinct possibility that can't be discounted using the geochemical data alone, especially as all the glazed sherds are visually extremely similar. However, another possibility that might go some way to explain the rather unusual results of these analyses might be variation in the time at which the sherds were produced. Gangwayao produced material throughout the Liao and subsequent Jin period (Lu 2008) and potentially, over time the method of ceramic production at the Gangwayao kilns was slightly altered. One potential method of alleviating this uncertainty would be to investigate extant clay sources local to the Gangwayao area, or sample ceramic sherds broken during manufacture and deposited in the locality of the kilns, both of which could provide a geochemical signature of the Gangwayao kiln against which these ceramic groupings could be compared.

Table 5.2 High Congruence method assignments – glazed sherds

Site number	Sample #	Case #	Log10 WARD	PCA WARD	PCA MD WARD
554	79	1	1	1	4
1004	115	2	1	2	2
1004	116	3	1	1	4
1004	128	4	2	1	1
1004	188	5	1	2	2
1004	189	6	2	1	1
1009	203	7	2	1	1
1009	205	8	2	3	3
1004	211	9	1	1	4
1004	212	10	2	3	3

5.3 Earthenware Sherd Summary

A total of 6 HCAs and 6 paired KMCAs was carried out on the earthenware sherd data and the assignments produced by each method employed are provided in Appendix 12.2; Tables 12.2.9, 12.2.10, 12.2.11 and 12.2.12. Overall, the earthenware samples exhibit much less congruence between the HCAs and associated K-MCAs, and also poor congruence between each other. As noted with the bivariate plots, potentially this is due to the much more complicated picture that the earthenware sherds present. This provides more possibilities for grouping the data, or alternatively there may not be any groupings within the data to be found and rather minor variation within a single dataset could be interpreted as distinct groupings. However, given the time period and visual variability that these sherds represent, it would seem unlikely for there to be no archaeological groupings among them even if there are no geochemical groupings. The use of a technique that can detect a much broader range of major and rare earth elements may prove a fruitful method in the future for clarifying earthenware groups if there are any; however this would require the transport of the samples to an available laboratory as these instruments are generally non-portable.

If we restrict ourselves to the HCA results that exhibit better congruence with the K-MCA data (methods with congruence above 80%, namely PCA data Average Linkage method HCA, PCA data Ward;s method HCA and the Log10 data Ward's method HCA) it is notable that, correcting for the number of groupings in each method, they also exhibit 80% congruence with each other, providing some support for the reality of their groupings (See Appendix 12.1, Table 12.1.4). Although rather coarse and much less secure than those from the other sherd classes, these grouping do reveal some trends from which several observations can be made. While most sites have a mix of sherds from different groupings, some sites seem to have a preponderance of one or the other sherd groupings. Sites 408, 498, 503 and 504 have a preponderance of samples from the same grouping (Group A in Appendix 12.1, Table 12.1.4), while sites 1373, 1350 and Enzhou also seem to have a preponderance of samples from the same grouping (Group B in Appendix 12.1, Table 12.1.4).

While these coarse groupings would seem to reveal little about production locales, another aspect of the analyses may hint at a general feature of Liao production locales. The bivariate plots revealed that samples from some sites were much more geochemically variable than samples from others. This could represent the breadth of ceramics from different workshops used at the different sites. Notably the two larger sites sampled here-- Songshanzhou (CICARP Site Code 1004) and Enzhou have much more variation in sherd geochemistry than the smaller sites. This could indicate that most sites are producing and consuming ceramics locally, while the larger settlements are consuming ceramics from a much wider range of sources. The geochemical similarity of many of these sherds could then be a reflection of the geological variability within the Chifeng region, with all potters producing unglazed ceramics with much the same basic geological constituents. However, an alternative explanation could relate to sample size issues. The larger sites, having larger assemblages, were more intensively sampled by this project, and as such the geochemical richness of the smaller sites might not be accurately represented by the smaller samples from those sites.

Table 5.3 High Congruence method assignments – earthenware sherds

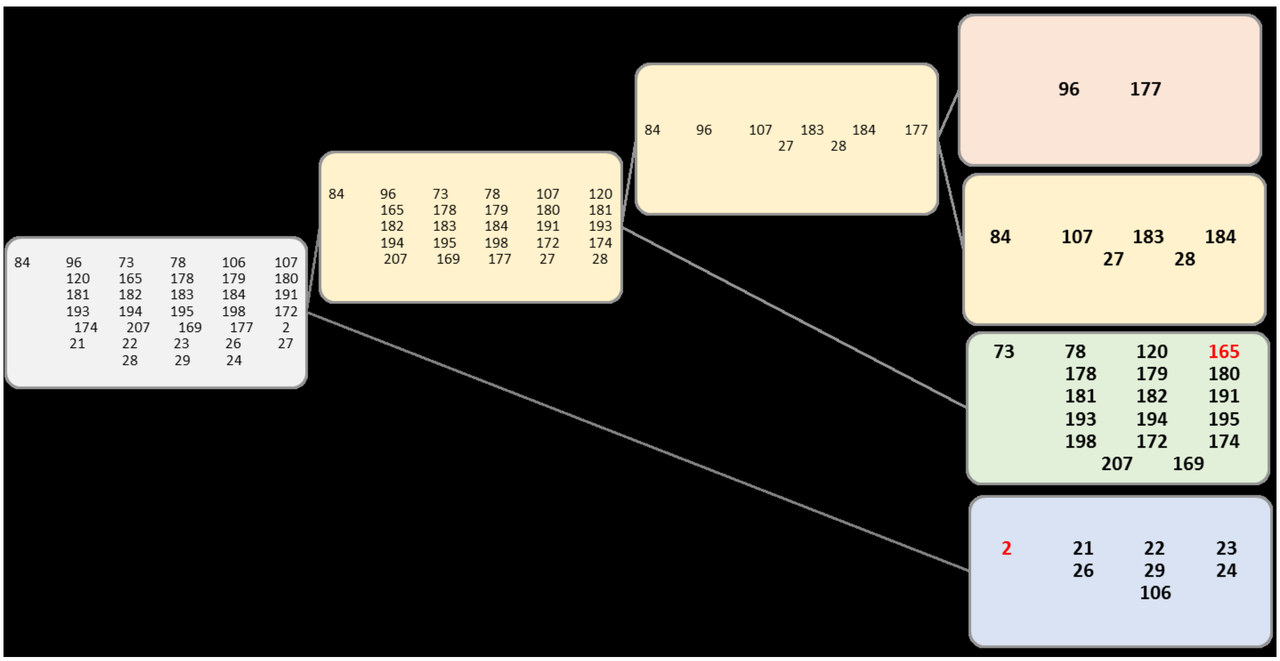
Site code	Sample	Lg10 WARD	PCA WARD	Site code	Sample	Lg10 WARD	PCA WARD
349	85	A	B	1004	138	A	A
349	86	A	A	1004	139	B	B
349	89	A	A	1009	170	B	B
349	99	A	A	1009	171	A	A
349	87	B	B	1009	173	A	A
349	88	B	B	1009	175	B	A
349	94	B	B	1009	176	B	B
349	95	A	B	1009	204	A	A
349	97	B	B	1009	206	B	B
408	80	A	A	1009	208	B	B
408	81	A	B	1009	209	B	B
408	82	A	A	1343	41	A	B
408	83	A	B	1343	46	B	B
498	71	A	B	1343	45	B	B
498	72	A	B	1343	48	B	B
498	74	A	B	1343	42	A	B
498	75	A	A	1343	43	B	C
503	61	A	A	1343	44	B	B
503	62	A	B	1343	47	A	B
503	63	A	A	1344	30	A	B
503	64	A	A	1344	32	A	A
503	65	A	A	1344	34	A	A
504	66	A	A	1344	31	B	B
504	67	A	A	1344	33	B	B
504	68	A	B	1350	36	A	B
504	69	A	A	1350	40	B	C

504	70	B	B	1350	37	A	A
554	77	B	C	1350	51	B	A
554	76	B	A	1350	52	B	C
591	92	A	A	1350	53	B	C
591	90	A	B	1350	35	B	B
591	91	B	B	1350	38	B	C
591	93	B	B	1350	39	B	B
1004	103	B	B	1350	49	B	C
1004	109	B	B	1350	50	B	C
1004	110	A	B	1350	54	B	A
1004	112	B	B	1350	55	B	C
1004	114	B	A	1373	56	A	B
1004	124	B	B	1373	57	B	C
1004	126	B	B	1373	58	B	B
1004	127	B	B	1373	59	B	C
1004	129	B	B	1373	60	B	B
1004	134	B	C	1590	142	A	A
1004	135	B	C	1590	146	A	B
1004	140	B	C	1590	147	A	A
1004	141	B	C	1590	149	A	A
1004	167	A	A	1590	143	B	B
1004	201	B	A	1590	144	B	B
1004	100	B	B	1590	145	B	B
1004	101	B	B	1590	148	A	A
1004	102	A	A	1700	152	A	A
1004	104	A	A	1700	150	A	B
1004	105	B	B	1700	151	A	A
1004	108	B	B	1767	155	A	A
1004	111	A	A	1767	153	B	B
1004	113	B	C	1767	154	A	B
1004	117	A	B	1767	156	A	A
1004	118	B	B	1767	157	A	A
1004	119	A	B	1768	160	A	A
1004	121	A	A	1768	161	A	A
1004	122	B	B	1768	158	A	A
1004	123	B	B	1768	159	B	B
1004	125	A	B	1768	162	B	B
1004	130	B	C	Enzhou	18	B	C
1004	131	B	B	Enzhou	6	B	B
1004	132	B	C	Enzhou	8	B	B
1004	133	B	B	Enzhou	10	B	B
1004	136	B	C	Enzhou	12	B	C
1004	164	A	A	Enzhou	14	B	B
1004	166	A	A	Enzhou	16	B	B
1004	168	B	B	Enzhou	17	B	B
1004	185	B	A	Enzhou	19	B	C
1004	186	B	B	Enzhou	20	B	C
1004	187	A	A	Enzhou	1	A	A
1004	190	A	B	Enzhou	4	B	B
1004	192	B	A	Enzhou	5	B	B
1004	196	B	B	Enzhou	7	B	B
1004	197	B	B	Enzhou	9	B	B
1004	199	B	A	Enzhou	11	A	A
1004	200	B	B	Enzhou	13	B	B
1004	202	B	B	Enzhou	15	A	A
1004	210	B	C	Enzhou	3	B	A
1004	137	B	B				

5.4 Summary of Geochemical Results

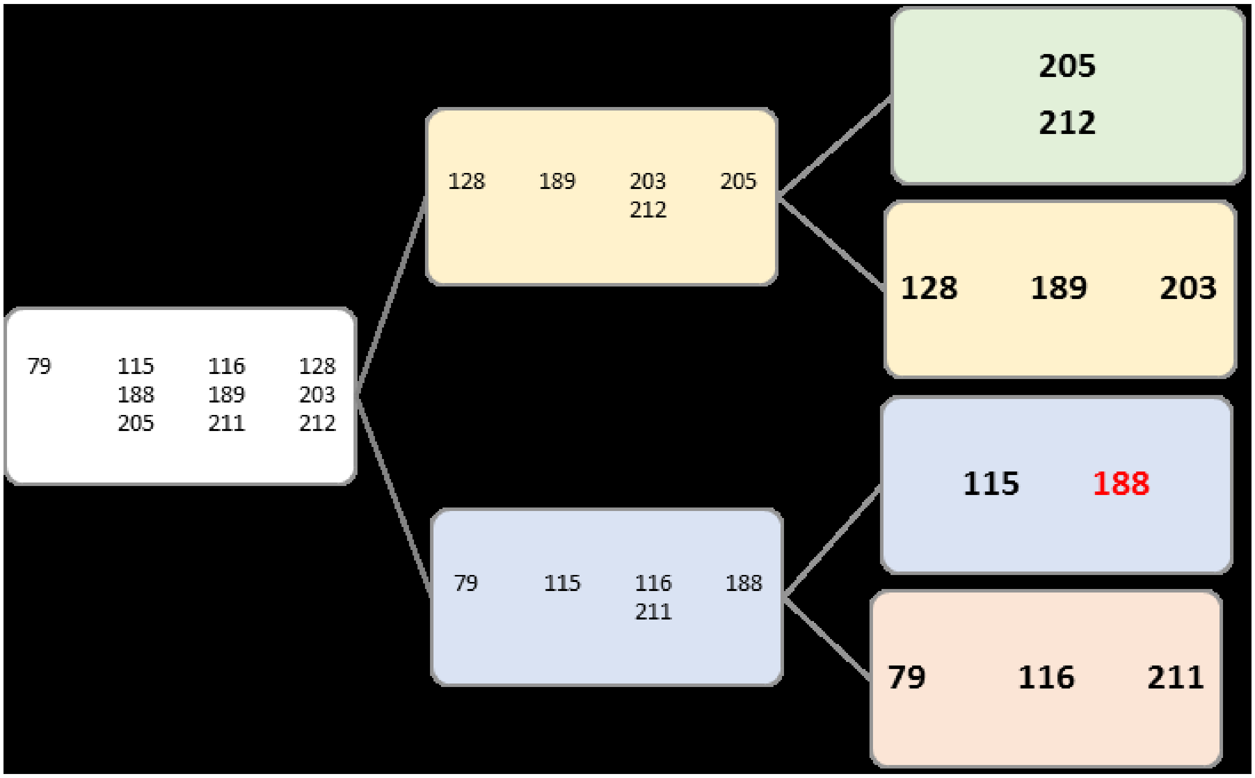
In summary, using the K-MCAs as a check on the results of the various HCAs allows for the results to be limited to only those methods that exhibit high congruence data between the methods. This allows for the positing of a series of groupings for each sherd type that can be further investigated using the results from the petrographic analyses. However, since the different methods produce different numbers of nested groupings, these posited groupings themselves can be illustrated with dendrograms. These final posited groupings are presented in Figures 5.1, 5.2 And 5.3. Sample numbers listed in red are those sampled for petrography.

Figure 5.1



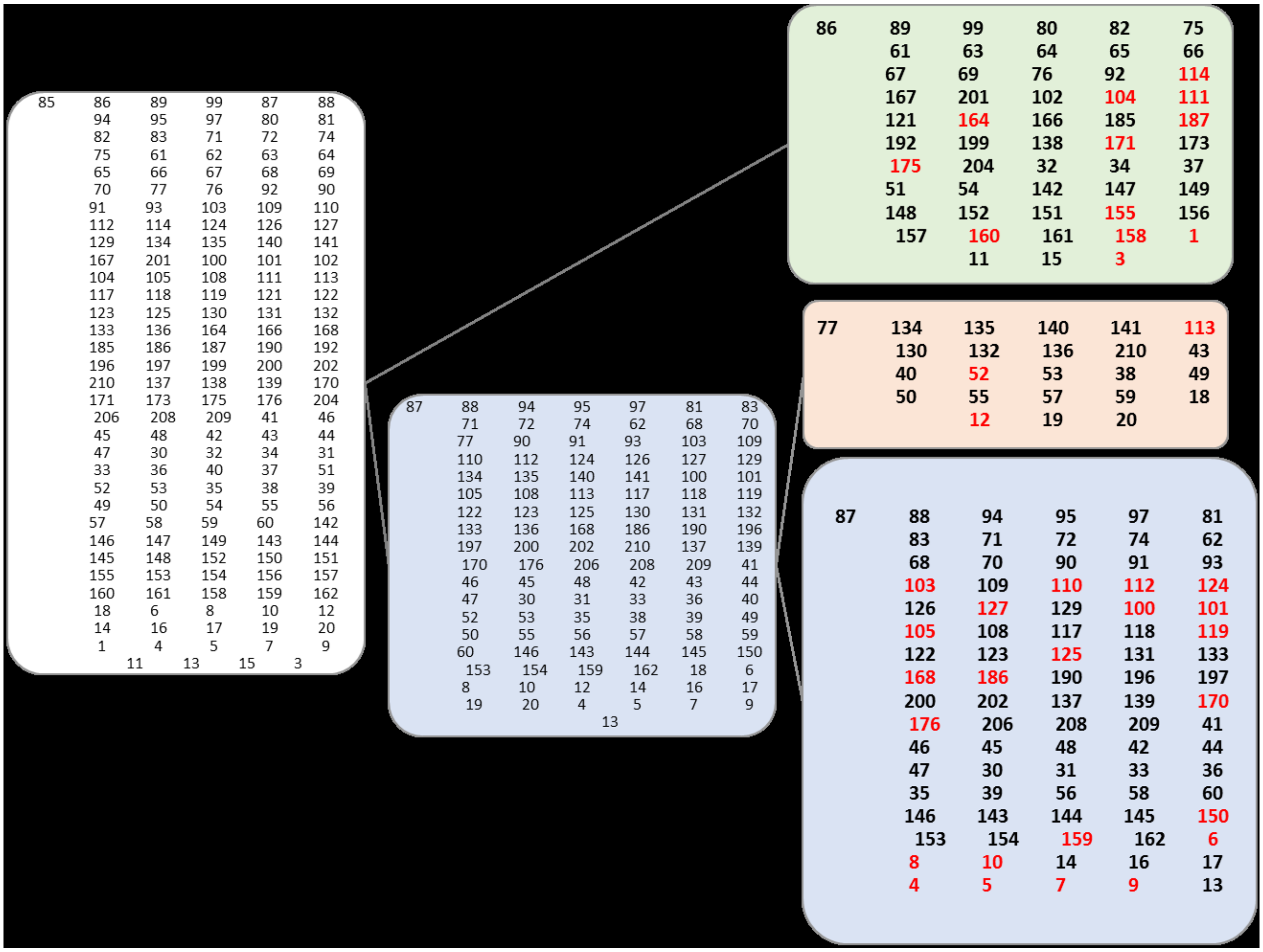
Final posited groupings of roof tile sherds showing sample numbers

Figure 5.2



Final posited groupings of glazed sherds showing sample numbers

Figure 5.3



Final posited groupings of unglazed earthenware sherds showing sample numbers

6. Petrography Results

6.1 Initial Petrographic Groupings

Of the 44 samples sent to be made into petrographic thin sections, one proved too friable and the workshop was unsuccessful at making a thin section from it. Two samples also had issues with labelling that made it impossible to determine which sample was represented by these thin sections. Unfortunately one of these samples was one of the few roof tile samples selected, limiting the number of samples from this category to just two. The remaining samples were those used in the analysis and are listed in Table 6.1. The purpose of these thin sections is twofold: to identify petrographic groupings which can provide a check on the groupings produced by the geochemical analyses; and, to make basic observations about the variability of the minerology of the sherds and to identify any petrographic features that can shed light on the production processes of Liao unglazed ceramic materials.

Unfortunately detailed geological maps of the Chifeng region could not be obtained at this time due to the strict controls the PRC imposes on maps and geographic information, which introduced a severe limitation on the ability to conclusively identify minerals found in the thin sections as belonging to a specific lithology. Additionally, as Chinese law forbids the removal of archaeological material from China, samples had to be analysed at Peking University's Archaeometry Laboratory in Beijing and the short span of time available for this allowed only for the detailed photographing of the thin sections (1036 photographs of both plane polar (pp) and crossed polars (XP)) rather than the identification of minerals or quantitative analysis of the mineral inclusions. Analysis of the thin sections was carried out on these photographs rather than the slides themselves, further impeding conclusive mineral identification.

As such, a complete formal or quantitative description of each sample was beyond the scope of this project (and under the present constraints not possible). Rather, the petrographic thin sections were grouped based on a relatively coarse level that took into account the overall presence/absence or frequency of certain features (voids/vughs, unusual inclusions, grog, strong lamination, microfossils), unimodal vs. bimodal grain size distribution, relief, evidence of firing temperature related mineral transformation and the texture/roundedness/density of inclusions in the clay matrix. These are some of the major standard criteria used in the grouping of ceramic thin sections (Quinn 2013). Samples found to be visually rather than quantitatively similar in these respects were grouped together to form somewhat more inclusive groupings than might have occurred through a more detailed analysis. Initial visual grouping of the petrographic samples (blind with no reference to the sherd type) identified 26 distinct groups based on the above features and Table 6.2 provides the membership for these groupings. While detailed formal and quantitative descriptions were beyond the scope of this project, given the variation seen within the samples this would certainly be a profitable endeavour for the future.

All observations made during the course of the analyses, and methodology used to make those observations were based on the ceramic petrography text: Quinn's "Ceramic Petrography" (2013), and the optical minerology text: Perkins and Henke's "Minerals in Thin Section: Second Edition" (2004). Images of the slides for each of these petrographic groupings are provided in Appendix 2.

Table 6.1 Petrographic Samples and Groupings

Slide Number	Sample Number	Site Number	Petrographic Group	Geochemical Group
39	170	1009	5	Earthenware Blue
36	4	ENZH	8	Earthenware Blue
13	101	1004	10	Earthenware Blue
20	119	1004	10	Earthenware Blue
21	159	1768	10	Earthenware Blue
28	150	1700	10	Earthenware Blue
8	6	ENZH	11	Earthenware Blue
10	10	ENZH	11	Earthenware Blue
40	8	ENZH	11	Earthenware Blue
3	103	1004	12	Earthenware Blue
19	105	1004	13	Earthenware Blue
23	127	1004	13	Earthenware Blue
25	186	1004	13	Earthenware Blue
6	100	1004	14	Earthenware Blue
1	9	ENZH	15	Earthenware Blue
4	168	1004	15	Earthenware Blue
42	110	1004	15	Earthenware Blue
18	7	ENZH	16	Earthenware Blue
27	5	ENZH	19	Earthenware Blue
16	124	1004	22	Earthenware Blue
31	176	1009	22	Earthenware Blue
30	125	1004	26	Earthenware Blue
32	112	1004	26	Earthenware Blue
29	114	1004	3	Earthenware Green
22	1	ENZH	4	Earthenware Green
33	155	1767	7	Earthenware Green
37	104	1004	9	Earthenware Green
38	187	1004	12	Earthenware Green
14	111	1004	20	Earthenware Green
43	160	1768	21	Earthenware Green
2	158	1768	21	Earthenware Green
12	171	1009	21	Earthenware Green
24	164	1004	21	Earthenware Green
34	3	ENZH	21	Earthenware Green
15	175	1009	24	Earthenware Green
7	52	1350	2	Earthenware Red
35	12	ENZH	6	Earthenware Red
9	113	1004	23	Earthenware Red
41	188	1004	1	Glazed
11	165	1004	14	Roof Tile Green
5	2	ENZH	10	Roof Tile Blue

6.2 Glazed Sherds

A single glazed sherd (Sample 188; Slide 41) was selected for petrographic analysis to form an out group from the roof tile and earthenware sherds. Unsurprisingly, this sample was very distinct from the other samples, exhibiting an optically inactive sintered clay matrix and potential quartz grain melting and bloating pores characteristic of high fired ceramics (Quinn 2013).

6.3 Roof Tiles

Two roof tile sherds (Sample 165; Slide 11 and Sample 2; Slide 5) were selected for petrographic analysis. These sherds were found to be petrographically distinct and assigned to different petrographic groupings. Sample 2 (Group 14) exhibits a lower density of mineral inclusions and a bimodal inclusion size. The sample contains what appear to be igneous rock fragments and plagioclase feldspar grains, a mineral common to igneous rocks (Perkins and Henke 2004). Sample 165 (Group 10) exhibits a higher density of mineral inclusions, a unimodal inclusion size and what appears to be inclusions of microcline feldspar (often associated with granites).

Without the means to check these groupings more thoroughly or quantitatively, little can be said of these samples other than they are clearly different. Given the extremely low sample size, all that can be asserted from this is that it provides weak circumstantial support for the results of the geochemistry as the petrographic grouping is congruent with the geochemical grouping in that these samples do not group together.

Also of interest is that the petrographic groupings (which were performed blind without reference to the type of material being seen) group these samples not by themselves but with other earthenware sherds. This implies that mineralogically, if not geochemically, Liao roof tiles and earthenwares may be identical. However, due caution should be exercised regarding this implication due to the low sample size involved.

6.4 Earthenware Sherds

Thirty-eight earthenware sherds were selected for petrographic analysis (See Table 6.1 for details). The results for these sherds are much more representative than the roof tile samples as they represent a 23% sub-sample of the entire earthenware assemblage. The results of the petrographic analysis assigned these samples to 17 separate groupings.

It should be noted that due to the constraints listed above, these groupings should be viewed as preliminary and subject to revision if and when these slides are analysed again. However, at this point in time they represent the best groupings that can be made on the evidence that is available.

With the preliminary nature of these groupings in mind, the groupings still show a surprising level of congruence with the geochemical results. Of the 17 groups only 1 was found to have samples assigned to more than one geochemical grouping; an overall congruence of 97%.

6.4.1 Geochemical Group 1

The first geochemical group (illustrated as green in Figure 5.3 above) contained sherds assigned to eight petrographic groupings (24, 21, 20, 12, 9, 7, 4 and 3). They are described below:

Group 24 (Slide 15) exhibits a isotropic brown clay matrix, bimodal inclusion size distribution, large mineral inclusions exhibiting lamellar twining with first order interference colours, and extremely large mineral inclusions showing complex zoning and second order interference colours.

Group 21 (Slides 2, 12, 24, 34, 43) exhibits a birefringent light brown clay matrix with a bimodal mineral inclusion size distribution, small dark argillaceous inclusions and frequent, small mineral inclusions showing complex zoning and first order interference colours and mineral inclusions showing parallel twins and first order interference colours.

Group 20 (Slide 14) exhibits an isotropic brown clay matrix, bimodal inclusion size distribution, weak planar orientation of mineral inclusions, clear inclusions of grog with a much lighter brown clay matrix and very dense tiny isotropic mineral inclusions in plane polar view.

Group 12 (slide 38 and others from the third geochemical grouping) exhibits a brown clay matrix showing very low birefringence ranging to isotropic in some areas, frequent planar voids, weak to moderate planar concordance, medium to small argillaceous inclusions as well as potential inclusions of sedimentary rock fragments.

Group 9 (Slide 37) exhibits a lightly vitrified isotropic brown matrix, a birefringent slipped exterior surface, dense frequent large highly weathered mineral inclusions showing first order or potential high-order white interference colours as well as large high relief mineral inclusions showing first order interference colors and simple twins.

Group 7 (Slide 33) exhibits a dark brown isotropic clay matrix mixed with light brown extremely birefringent patches and mineral inclusions with neutral optical density and diffuse boundaries giving the appearance of at least partial vitirification in plane polar view. These features are wholly unlike any other petrographic group and may represent an error in the thickness that the thin section was ground to.

Group 4 (Slide 22) exhibits an extremely dark potentially vitrified isotropic brown to black clay matrix with a bimodal mineral inclusion size distribution and poorly sorted and extremely large mineral inclusions ranging from angular rhomboids to sub rounded equant grains and clear fragments of grog with shrinkage rims. The mineral inclusions include highly weathered rock fragments showing zoned first order interference colours, small inclusions with strong simple twins and first order or high-order white interference colours and small angular inclusions showing second order interference colours.

Group 3 (Slide 29) exhibits a light brown birefringent clay matrix, isotropic planar inclusions that are likely carbonised plant remains or charcoal fragments, diffuse argillaceous inclusions, a strongly bimodal mineral inclusion grain size distribution, weathered inclusions exhibiting strong simple twins, zoning and first order interference colours, small planar angular fragments exhibiting third order pale yellow interference colours and what appear to be igneous rock fragments (phenocrysts).

As noted above one of the geochemical group one sherds (Sherd 187; Slide 38) was assigned to group 12 which also contains sherds assigned to the third geochemical grouping (illustrated as blue in Figure 5.59 above) presenting a miss-match between the geochemical and petrographic groupings. However, when this sherd was re-examined potential reasons were identified that could indicate that this sherd may be wrongly assigned to this grouping; including slight differences in the degree of birefringence of the clay matrix, misidentification of argillaceous clay pellets as grog, and small differences in the grain size distributions.

6.4.2 Geochemical Group 2

The second geochemical group (illustrated as red in Figure 5.3 above) contained sherds assigned to three petrographic groupings (2, 6 and 23) all of which were not present in the other geochemical groups. Optically they appear very distinct compared to the other petrographic groupings and are also very dissimilar to each other.

Group 6 (Slide 35) exhibits a very fine dark brown isotropic clay matrix more reminiscent of a high fired stoneware than an earthenware (Quinn 2013), a comparatively low number of mineral inclusions compared to all other petrographic groups, several large argillaceous inclusions (likely grog), what appear to be bloating pores and several large sub rounded equant mineral inclusions with first order interference colours with shrinkage rims. The combination of these features, especially the bloating pores, suggest that this grouping is of a very high fired earthenware; potentially indicating this sherd was from an industrial refractory ceramic as opposed to a domestic vessel.

Group 2 (Slide 7) exhibits strongly vitrified brown isotropic clay matrix, a strongly bimodal grain size distribution, frequent sub-angular inclusions with first order birefringence colours with complex zoning and twins (some exhibiting foliation suggesting metamorphic origin, other exhibiting random orientation suggesting volcanic origin), several light blue rhomboidal inclusions exhibiting third order birefringence colours and what appears to be fragments of biotite mica which are splitting along their cleavage planes, a change that takes place at 900-1000°C (Quinn 2013).

Group 23 (Slide 9) exhibits a dark brown isotropic clay matrix, a strongly lamellar structure and a large number of planar vughs, discordant argillaceous inclusions (potentially grog), frequent small elongate tabular mineral inclusions that are red in plane polar view and exhibit second order interference colours in crossed polar view. This sample also includes a much lower number of the few small dark isotropic mineral inclusions common to most other groupings (likely an iron rich mineral like magnetite or hematite).

6.4.3 Geochemical Group 3

The third geochemical group (illustrated as blue in Figure 5.3 above) contained sherds assigned to 11 petrographic groupings (26, 22, 19, 16, 15, 14, 13, 12, 11, 10, 8 and 5).

Group 26 (Slides 32 and 30) exhibits a light grey/brown isotropic clay matrix, numerous very small mineral inclusions showing first order interference colours, a unimodal inclusion grain size distribution and small infrequent argillaceous inclusions (likely clay pellets) and infrequent very small mineral inclusions showing second to third order interference colours.

Group 22 (Slides 31 and 6) exhibits a moderately birefringent light brown clay matrix, bimodal mineral inclusion grain size distribution, numerous mineral inclusions showing first order interference colours some showing moderate weathering as well as infrequent small mineral inclusions showing strong parallel twinning.

Group 19 (Slide 27) exhibits an entirely isotropic light grey clay matrix, frequent small to medium angular to sub-angular mineral inclusions, high frequency of planar voids and vughs, infrequent argillaceous inclusions, large isotropic mineral inclusions, very large mineral inclusions exhibiting complex cleavage, first order interference colours and potential sericite mineral replacement in some inclusions.

Group 16 (Slide 18) exhibits a moderately birefringent light brown clay matrix, bimodal grain size distribution, infrequent concordant planar voids, large weathered sub-rounded to angular mineral inclusions showing complex zoning, lamellar cleavage and first order interference colours, frequent medium tabular mineral inclusions that appear cyan in PP view and show third order pastel yellow interference colours in XP view as well as elongate argillaceous inclusions (not likely to be grog) and potential igneous rock fragments (phenocrysts).

Group 15 (Slide 1, 4, 42) exhibits a light grey isotropic clay matrix, unimodal mineral inclusion grain size distribution, frequent inclusions of grog (from a ceramic with lighter coloured slightly birefringent clay matrix) with clear shrinkage rims, inclusions of argillaceous material that appear to be clay pellets, lamellar isotropic inclusions which likely represent carbonized organic material and small planar mineral inclusions with second order interference colours showing birds eye type extinction.

Group 14 (Slide 6) exhibits a light grey/brown isotropic clay matrix, bimodal inclusion grain size distribution, frequent medium to small isotropic mineral inclusions, Infrequent extremely large mineral inclusions exhibiting clear zoning, first order interference colours and foliation that may indicate metamorphic origin, as well as small mineral inclusions that are potentially of sedimentary origin; possibly calcite or marl.

Group 13 (Slides 19, 23 and 25) exhibits a minimally birefringent (although not isotropic) brown clay matrix, unimodal mineral inclusion grain size distribution, frequent discordant argillaceous inclusions as well as clear fragments of grog with what appear to be reaction rims, small mineral inclusions that are potentially sedimentary in origin, as well as very small angular mineral inclusions with second order interference colours.

Group 12 (Slides 3 and others from the first geochemical grouping) is described in section 6.4.1. as this group is shared with geochemical group 1 (Green).

Group 11 (Slides 40, 10 and 8) exhibits a highly birefringent light brown clay matrix, unimodal mineral inclusion grain size distribution, frequent argillaceous inclusions that are most likely grog, small angular mineral inclusions with first order interference colors showing parallel twinning and frequent small tabular mineral inclusions that are pale yellow in PP view and XP, a characteristic common of bone fragments (Quinn 2013); although no osteons are observable in the microphotographs so confirmation of this is impossible at this time.

Group 10 (Slides 28, 21, 20 and 13) exhibits a dark brown/grey isotropic clay matrix, unimodal mineral inclusion grain size distribution, what appear to be partially melted sub-rounded feldspar inclusions, large infrequent planar vughs, occasional small angular mineral inclusion that show second order interference colours and frequent medium to very small isotropic mineral inclusions.

Group 8 (Slide 36) exhibits a dark brown/black isotropic vitrified looking clay matrix, unimodal mineral inclusion grain size distribution, frequent planar to sub-rounded elongate vughs, infrequent small mineral inclusions that show what may be high-order white, or first order interference colours, occasional medium weathered mineral inclusions showing lamellar cleavage and first order interference colours.

Group 5 (Slide 39) exhibits dark brown/black isotropic clay matrix, discordant equant argillaceous inclusions (likely clay pellets not grog), strong planar orientation of inclusions, numerous small angular mineral inclusions exhibiting first order interference colours.

6.5 Petrography Summary

To summarize, the main petrographic question has been: Are the geochemical groupings congruent with the petrographic groupings? The results of the above analysis certainly point towards good congruence between the petrographic and geochemical results (97%). However, it must once more be emphasized that the petrographic groupings are still preliminary and constructed under severe analytical limitations. As such this congruence could be significantly altered when further analyses of these thin sections can be completed.

7. Discussion

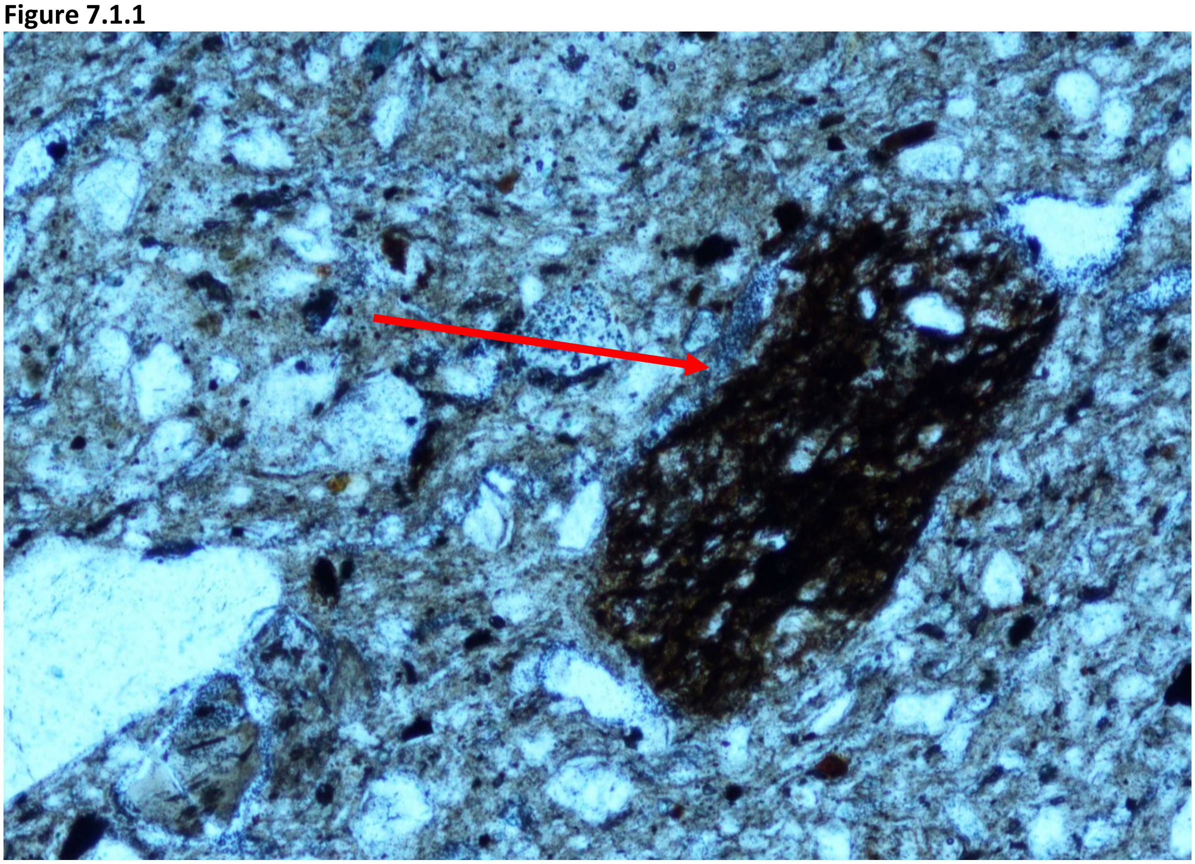
7.1 Ceramic Petrography Observations

Apart from the intended result of the petrographic analyses being used to assess the reliability of the geochemical results, several observations made during the analysis of the thin sections are significant findings in and of themselves.

Grog

This is the first time grog (crushed ceramic material used as a temper) has been identified in Liao earthenware; although it should be remembered there are currently no other published petrographic analyses of it. Thirty-five such instances of grog were identified across the 1038 microphotography images as well as fifty more instances of argillaceous inclusion that could possibly also be grog or another form of argillaceous inclusion such as clay pellets. Figure 6.5.1 shows a clear example of this. Traditional narratives within Chinese archaeology surrounding ceramic technology would suggest that during this time period grog was not used (Bennett pers. com); however the results of this study clearly suggest otherwise.

Figure 7.1.1

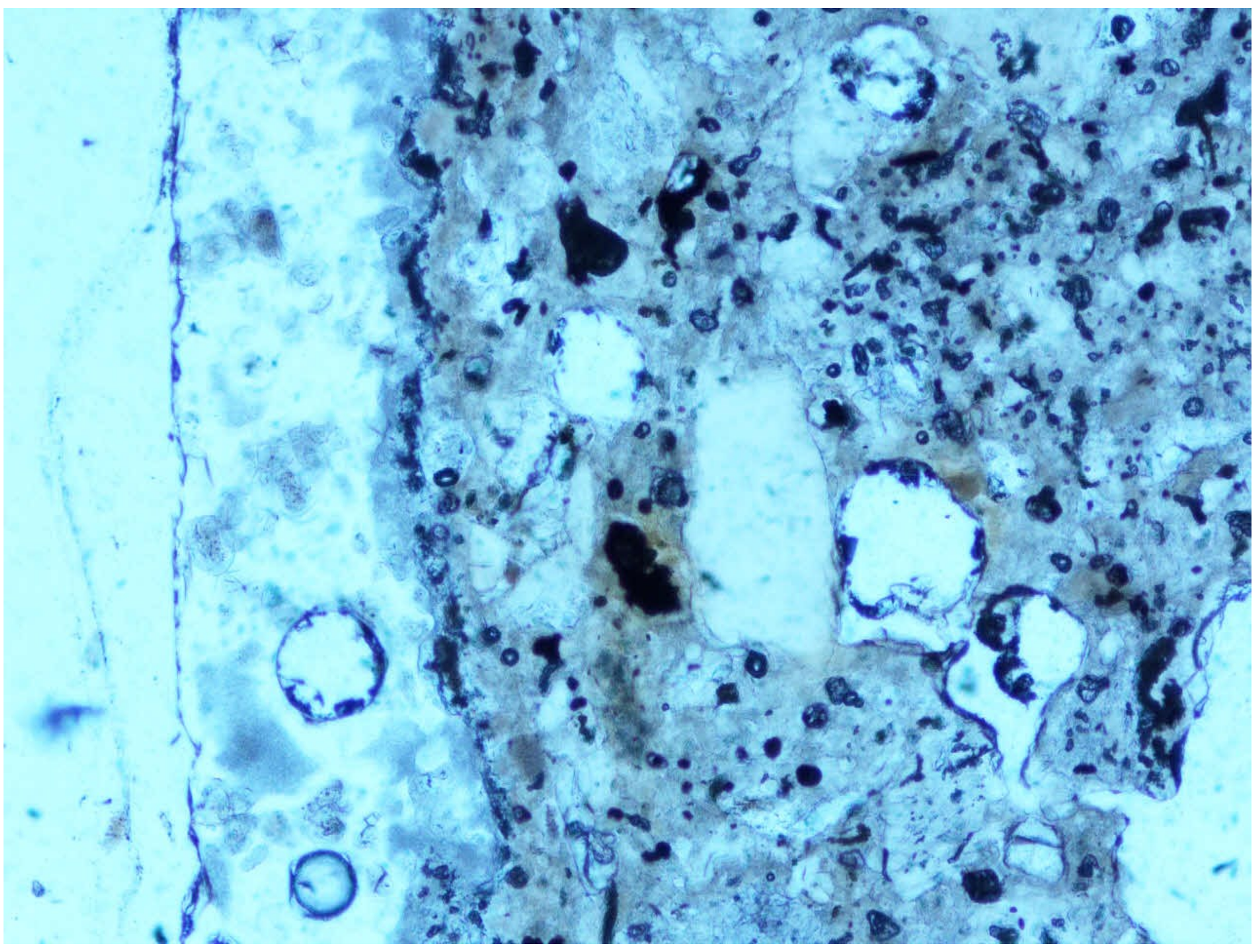


Sample 114 (Slide 29) plane polarized light image of grog inclusion (Image width = 1.3mm).

Firing temperature

Several features identified in the microphotographs also have the potential to be used as indicators of the temperature at which the sherds were fired. Bloating pores were identified in several of the sherds analysed. Figure 7.1.2 provides an example of this. These pores in the ceramic fabric only appear when a ceramic is fired above the vitification temperature of the clay being used, leading to the release of gasses from mineral alterations taking place (Quinn 2013:203). The temperature at which this occurs can vary depending on the clay and temper content of the ceramic, but generally it is from between 800-850°C for earthenware clays and up to 1200°C for Kaolin porcelain clays (Quinn 2013:191). As such samples with bloating pores must have been fired at temperatures >800°C.

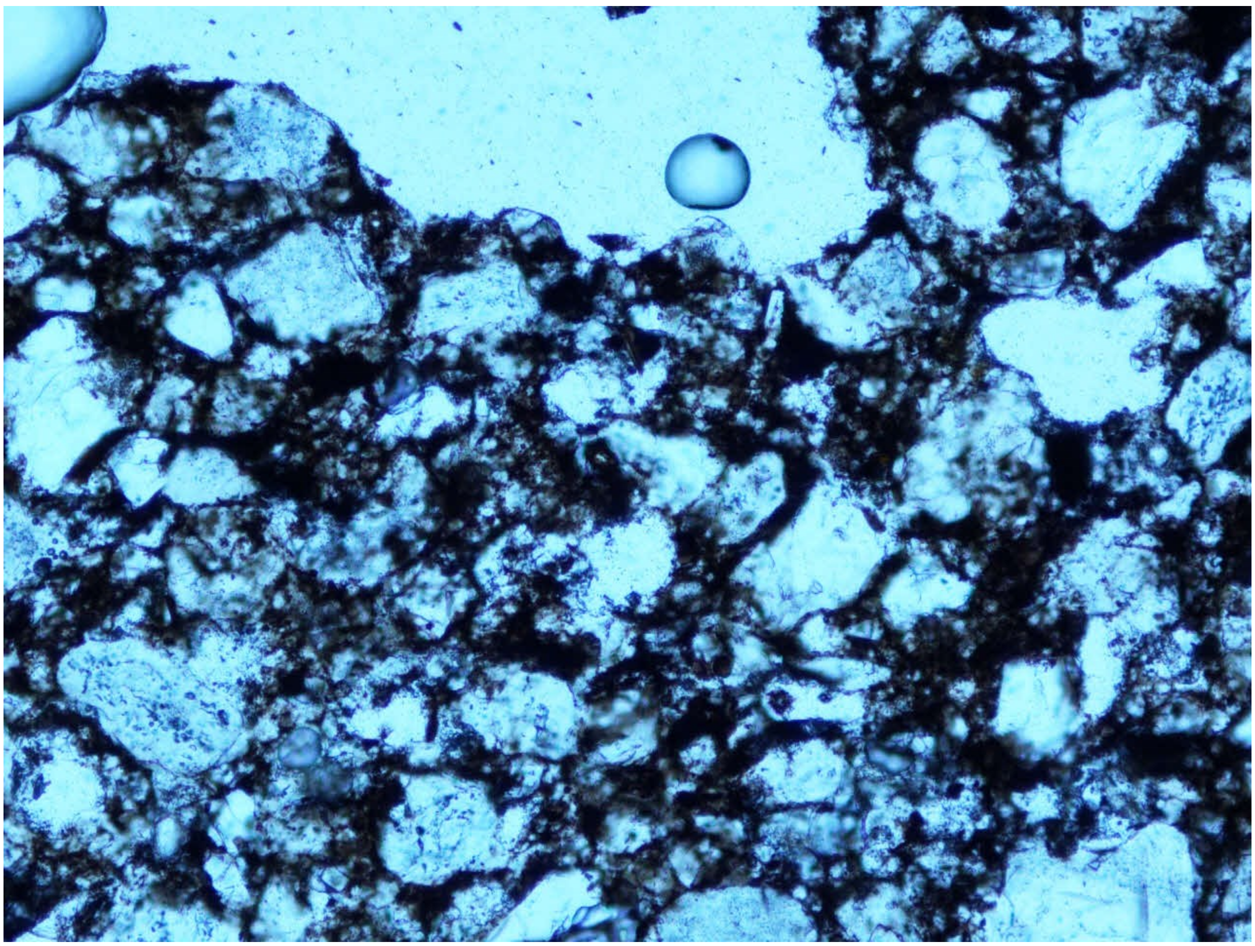
Figure 7.1.2



Sample 188 (Slide 41) Plane polar view of bloating pores (Image width = 0.65mm)

The melting of feldspar gains occurs at temperatures >1100°C (Quinn 2013:191,196). The majority of samples analysed here do not show clear evidence of this and as such were likely fired at temperatures under 1100°C, although several samples show what might be the beginning of this process. Figure 7.1.3 shows an example of this.

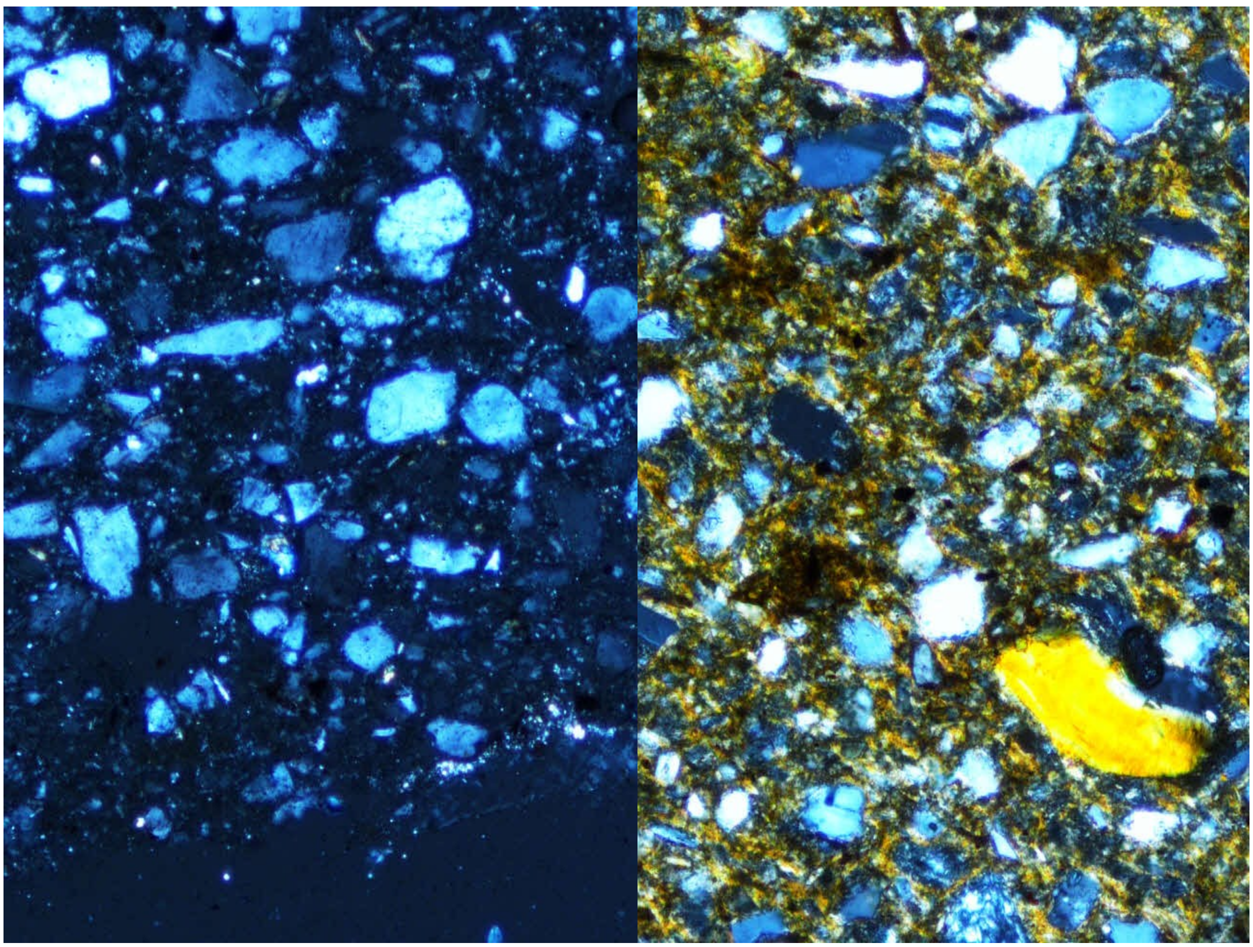
Figure 7.1.3.



Sample 104 (Slide 37) Partially melted feldspar grains (Image width = 1.3mm)

Firing temperature also affects the birefringence of clay minerals. When the firing temperature passes that at which the clay minerals vitrify they cease being birefringent (Quinn 2013: 190-191). As mentioned above, for earthenware this temperature is between 800 to 850°C. Birefringence provides a very simple method for identifying the firing temperatures of the ceramics analysed here; those that show birefringent clay minerals were most likely fired at a temperature under ~800°C, while those that show isotropic clay minerals were most likely fired at temperatures above 800-850°C. Figure 7.1.4 shows a comparison of a birefringent clay matrix and an isotropic one.

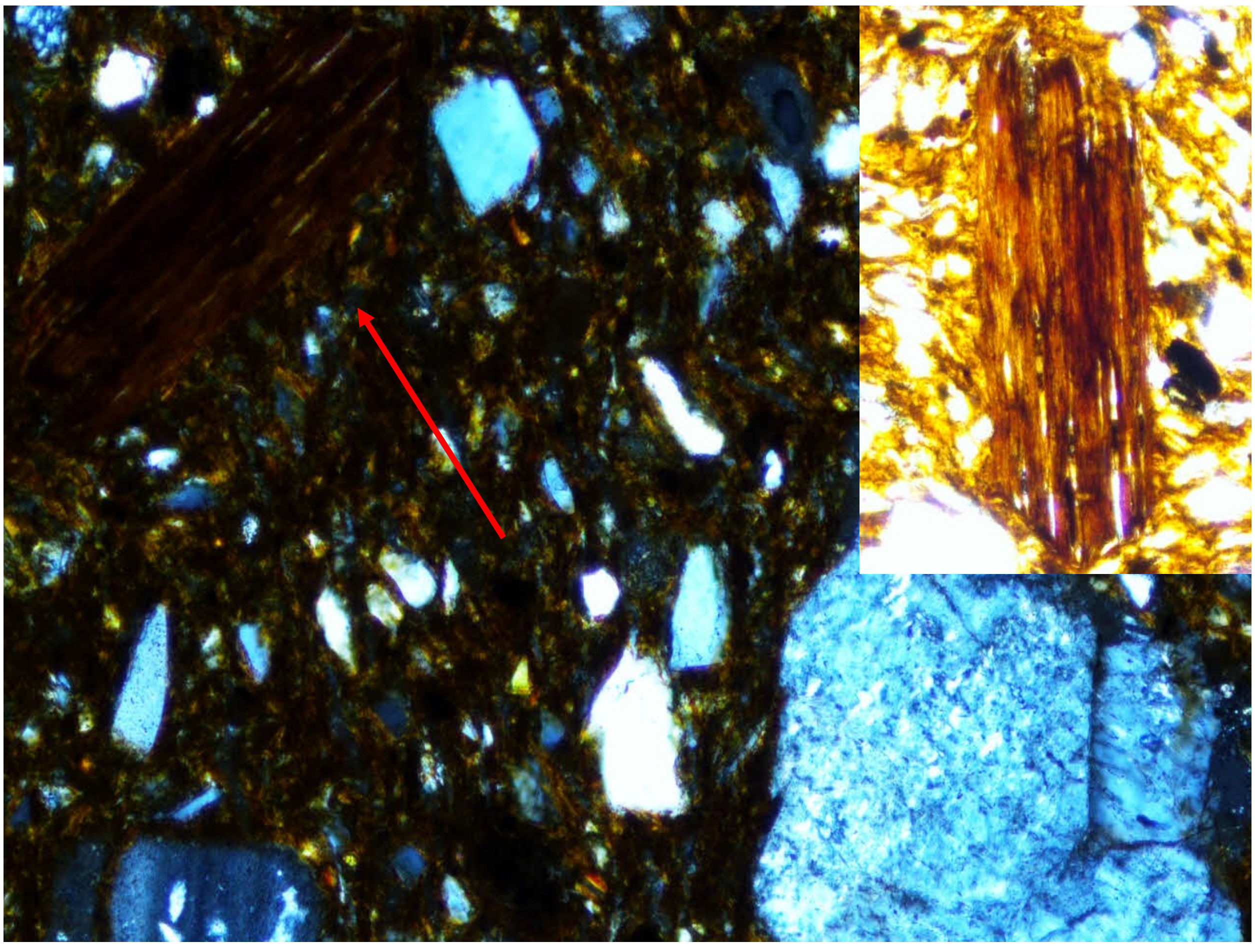
Figure 7.1.4.



Comparison of birefringent matrix (Slide 10 - Right) and isotropic matrix (Slide 42 Left) (XP view and Image width 1.3mm)

Finally some minerals undergo predictable alterations at certain temperatures. Biotite mica grains tend to exhibit strong planar cleavage, and at high temperatures will split along these cleavages (Quinn 2013:191). There is no current accurate measure of the exact temperature at which this happens but it is between 900-1000°C (Quinn 2013:191). Figure 7.1.5 shows a possible example of this.

Figure 7.1.5



Sample 52 (Slide 7) Possible example of biotite mica splitting along its cleavage (main image is XP, Image width = 2.6mm; inset image is PP with the contrast altered to improve visibility)

Given the above information it should be possible to calculate an approximate range at which the sherds represented in the petrographic thin sections were fired, based on the petrographic observations alone. An attempt to do this is provided in Table 7.1. Although it provides a rather coarse range for many samples, this would seem to be a viable alternative method for estimating Liao ceramic firing temperatures rather than using traditional equipment to conduct intensive re-firing studies.

Table 7.1 Firing Temperature Range Estimates for Petrographic Thin Section Sherds

Slide #	Sample #	Clay Birefringence	Observations	Estimated Temp Range
1	9	No		> 850°C
2	158	Yes		< 850°C
3	103	Minimal		~850°C
4	168	No		> 850°C
5	2	No		> 850°C
6	100	No		> 850°C
7	52	No	Mica Cleavage	900-1000°C
8	6	Yes		< 850°C
9	113	No		> 850°C
10	10	Yes		< 850°C
11	165	No		> 850°C
12	171	Yes		< 850°C
13	101	No		> 850°C
14	111	No		> 850°C
15	175	Yes		< 850°C
16	124	Yes		< 850°C
17	153/157	No		> 850°C
18	7	Yes		< 850°C
19	105	No		> 850°C
20	119	No		> 850°C
21	159	No		> 850°C
22	1	No		> 850°C
23	127	Yes		< 850°C
24	164	Yes		< 850°C
25	186	Yes		< 850°C
26	153/157	No		> 850°C
27	5	No		> 850°C
28	150	No		> 850°C
29	114	Yes		< 850°C
30	125	No		> 850°C
31	176	Yes		< 850°C
32	112	No		> 850°C
33	155	Yes		< 850°C
34	3	Yes		< 850°C
35	12	Yes	Bloating	800-850°C
36	4	No		> 850°C
37	104	No	Partial Feldspar Melt	~1100°C
38	187	Yes		< 850°C
39	170	No		> 850°C
40	8	Yes		< 850°C
41	188	No	Bloating, Full Melting	> 1100°C
42	110	No		> 850°C
43	160	Yes		< 850°C

Firing Environment

Petrographic observations can also indicate firing environment. The final colour of a ceramic is often determined by whether it was fired in a reducing environment without available oxygen or in an oxidizing environment with available oxygen. Reducing environments tend to produce black or grey ceramics, while oxidizing environments will tend to produce red ceramics (Shepard and Jay 1961). However if the firing time of the sample is short then oxygen may not penetrate or escape the entire sample leaving a core of lighter or darker material which is easily visible in a thin section (Quinn 2013: 200). In this case no samples exhibit this phenomena leading to the conclusion that firing times for all these ceramics were not short.[28] The practise of smudging (placing organic matter on ceramics as they are cooling to produce reduction effects on their surfaces) or uncovering recently fired ceramics can also produce petrographically visible results as a thin band of reduced or oxidized material on a different coloured core (Quinn 2013:200); but again none of the samples analysed here exhibit this phenomena indicating smudging was not performed and recently fired ceramics were left to cool within the environment of the kiln[29].

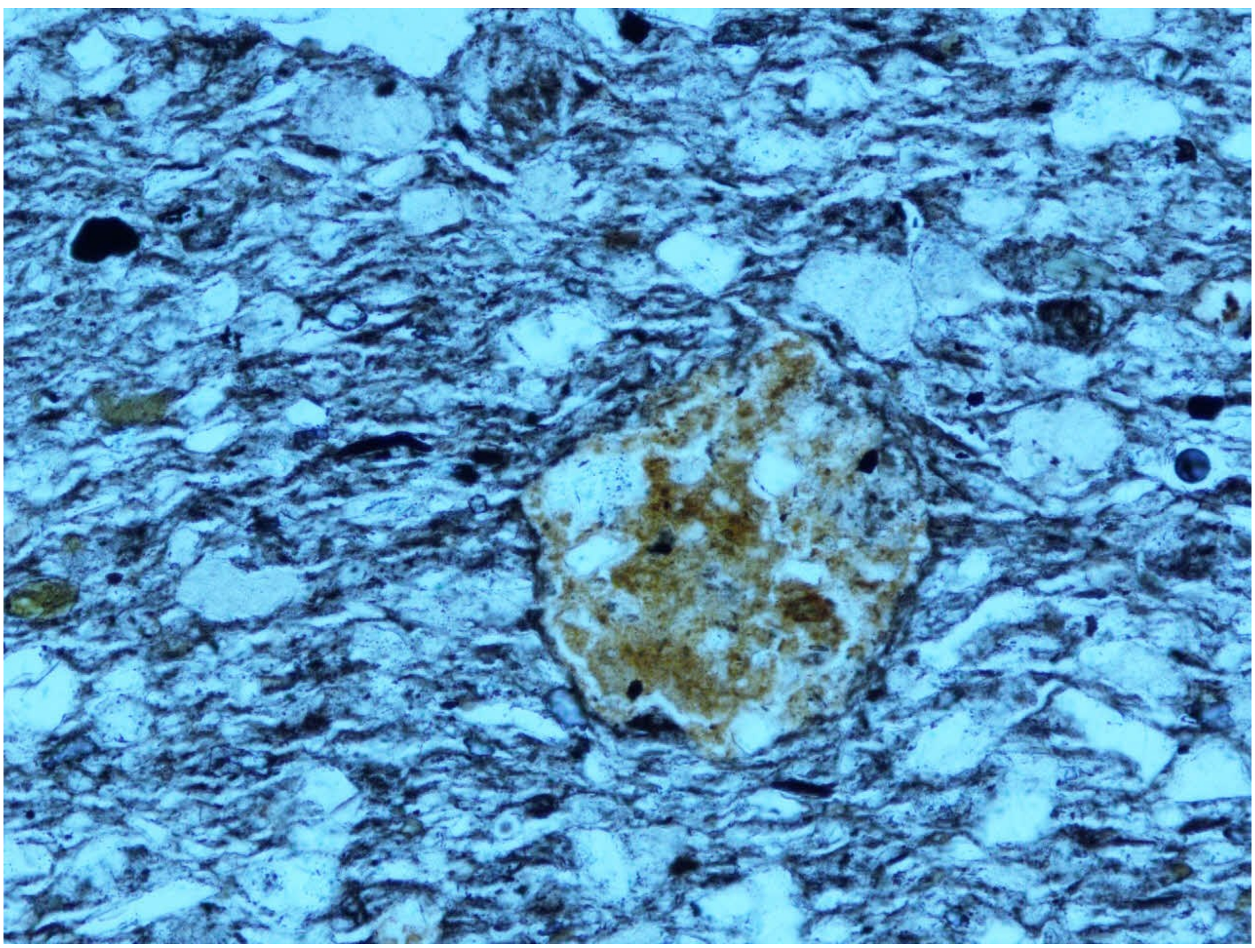
[28] However, numerous other samples from the Chifeng region have been observed to have this appearance (Bennett pers. Com.)

[29] However, this has been observed in several other samples from the Chifeng region (Bennett pers. Com)

Locus of production

The observation of grog inclusions within the petrographic thin sections may also point towards some basic factors of the locus and conditions of Liao ceramic production. The presence of grog with a light brown (oxidized) matrix within the fabric of sherds with a grey (reduced) matrix (see figure 7.1.6) indicates that reduced and oxidized ceramics were manufactured in the same workshop or kiln setting. As such, colour should not be used in grouping Liao ceramics as it is not likely to be indicative of its locus or time of production. Additionally, the use of grog implies the presence of numerous unsuccessfully fired ceramics which supply the grog, indicating that likely these ceramics were manufactured in the vicinity of the kiln at which they were fired (although the possibility that such grog could represent the reuse of ceramic materials from earlier time periods, specifically ceramic sherds from older occupations of the same site, cannot be ruled out).

Figure 7.1.6

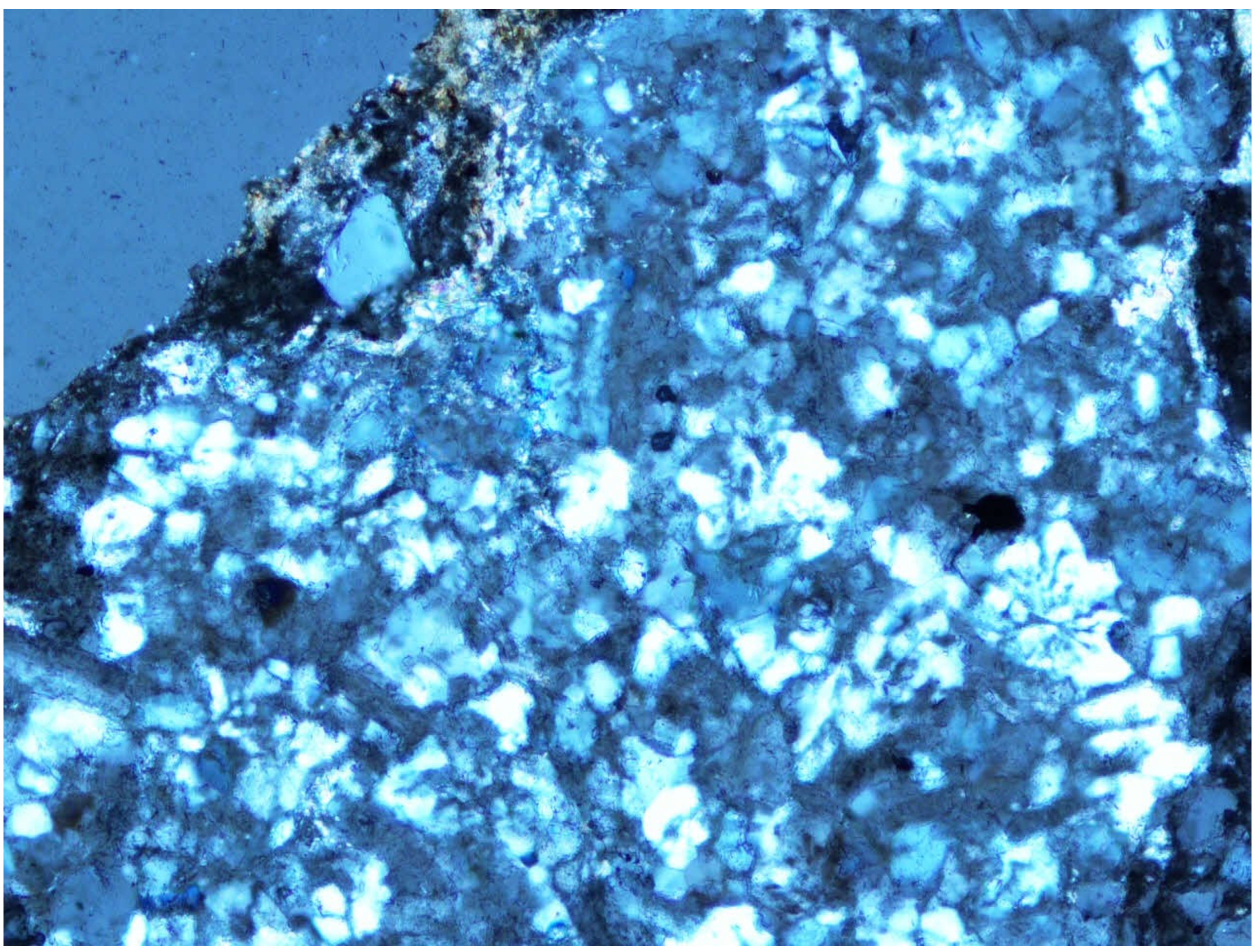


Sample 168 (Slide 4) Light grog in a grey clay paste (Image width = 1.3mm)

Clay Type and Source

Finally the presence and absence of certain mineral inclusions within a ceramic can provide an indication of the geology in which the ceramics were produced and also potentially the geology in which the ceramics were formed (Quinn 2013). In this instance most of the distinctive minerals identified in these sherds are primarily from igneous and plutonic settings indicating these samples were manufactured in an area with igneous lithology. However, this is of limited usefulness as the entire Chifeng region is characterized by granitic plutonic and basaltic igneous lithology (Hsü and Chen 1999) and potentially these inclusions could represent the results of using volcanic relic clays as opposed to purposefully adding igneous minerals as temper. More interesting, however, are the sherds with potential sedimentary or metamorphic inclusions (see figure 7.1.7.) which, due to their relative scarcity, could in the future (if accurate geologic maps can be acquired) prove very useful in narrowing down a source for these sherds.

Figure 7.1.7

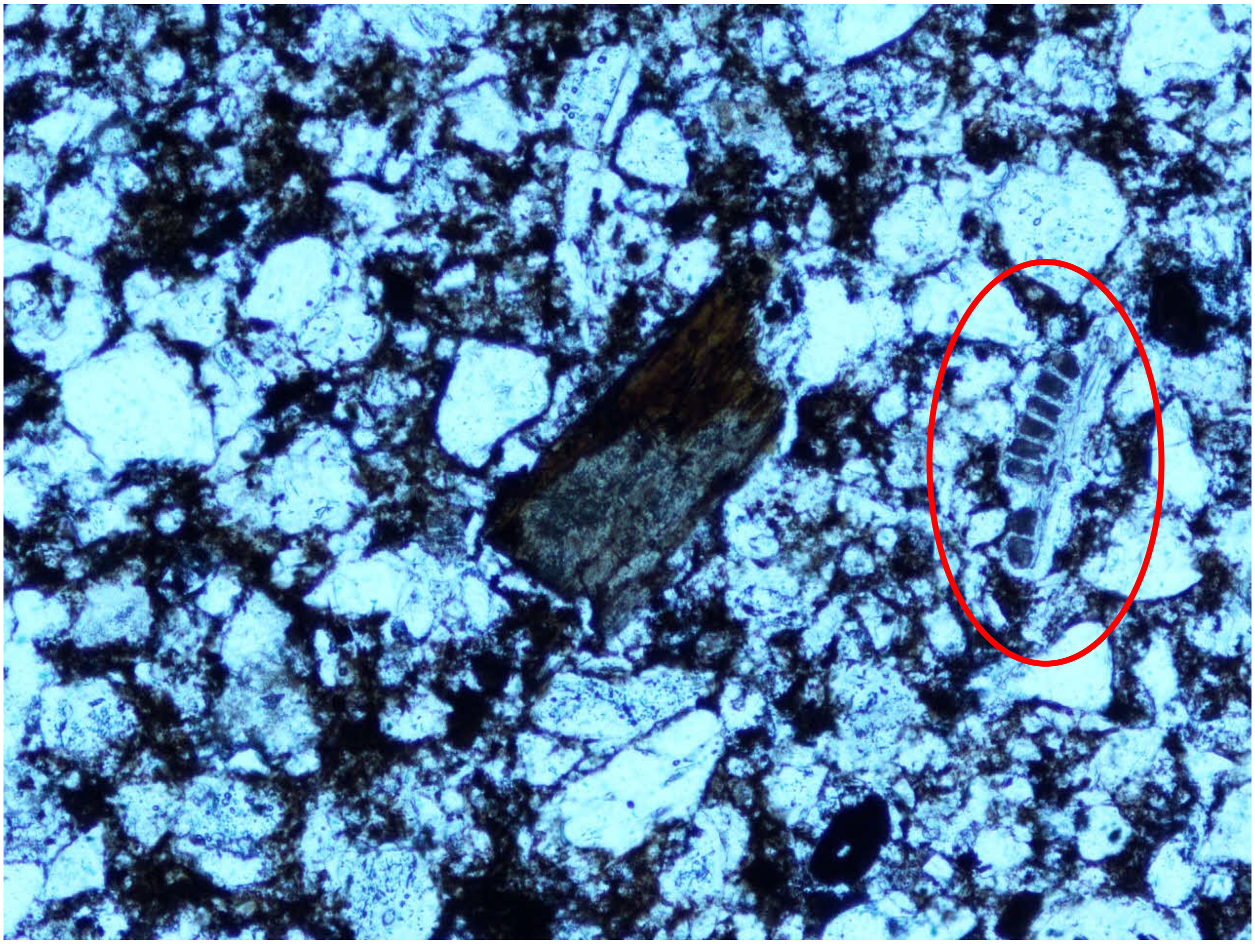


Sample 100 (Slide 6) Possible metamorphic inclusion (Image width = 1.3mm)

Microfossils

One sherd was also found to contain a microfossil (Figure 7.1.8). Microfossils are extremely useful in the identification of the possible parent rocks of the clay or temper used. The identification of this fossil falls outside of the aims of the current project but has the potential to be a profitable avenue of study In the future.

Figure 7.1.8

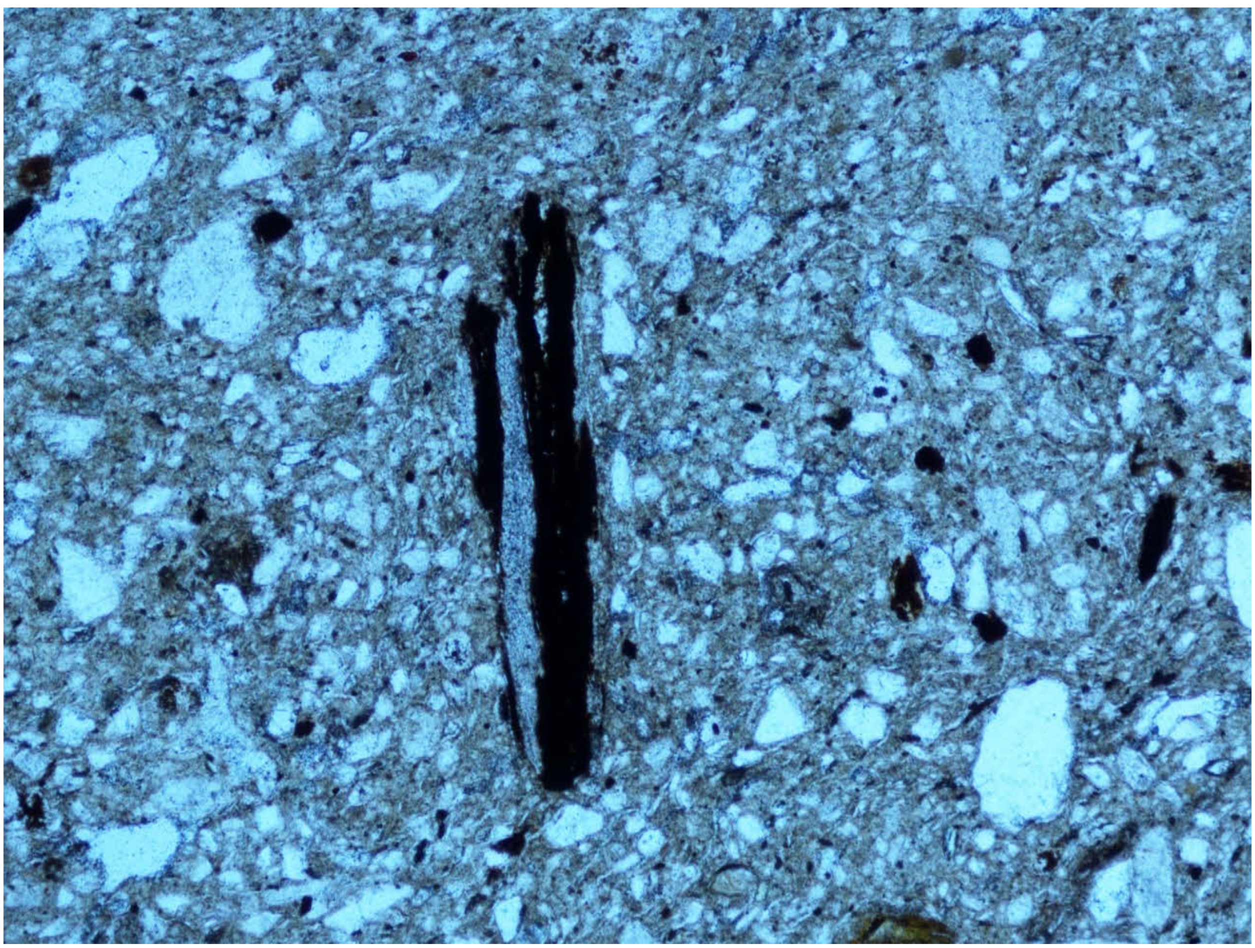


Sample 104 (Slide 37) Possible microfossil (Image width = 1.3mm)

Organics

The presence of carbonized organics, likely charcoal, in some of the sherds is also an exciting result (see figure 7.1.9 for an example). As has been mentioned several times, one of the main problems in Liao archaeology is generally poor chronological control and a lack of a basic unglazed earthenware ceramic chronology. The presence of charcoal within the ceramics provides the potential for these ceramics to be radiocarbon dated in an effort to begin the construction of an accurate unglazed earthenware ceramic chronology. While thermoluminescence could be used as an alternative in the absence of carbonized organics; issues with transporting ceramic samples outside of the PRC remain, and wait times for accurate thermoluminesence dates can be exceptionally long (Lisa Jantz pers. com).

Figure 7.1.9



Sample 114 Slide 29 Probable charcoal fragment (Image width = 2.6mm)

7.2 Substantive Observations

Meaning of the geochemical groupings

The primary substantive results produced by this study are the geochemical groupings shown in Figures 5.57, 5.58 and 5.59. However, the multiple, often inconsistent results produced by the different statistical methods introduce some uncertainty as to the archaeological reality of these groupings. It is certainly conceivable that, despite the final groupings being limited only to those with congruent K-MCA and HCA results, they represent stochastic patterns in the geochemical data or another unidentified process. The fact that the geochemical groupings appear to be congruent with the petrography (at least for the earthenware where the petrographic samples size is sufficient to determine this), however, is an uncommon occurrence in petrographic analyses of ceramics (Levine et al. 2015, Fitzpatrick 2008, Stoltman and Mainfort Jr. 2002, Day and Kiriatzi 1999), and seems to provide some support for the assertion that the geochemical groupings represent a real pattern also reflected in the mineralogy of the sherds, as opposed to a stochastic pattern. If these geochemical groupings then represent an accurate representation of sherds that are different petrographically, the question remains; what exactly do these groupings indicate in archaeological terms?

While it may be tempting to attribute the differences between the geochemical groupings to differences in the material's source or locus of production, this is not necessarily the case as several other possibilities present themselves. Differences in ceramic production over time is a possible alternative to differences in source for explaining this observation. Up to 1000 years of variation is potentially represented in the samples analysed here, and unsurprisingly, ceramic production in North eastern China and Mongolia changed considerably over this time period (Wright and Makino 2007). Changes over time in temper/clay availability, cultural preferences in ceramic production, technological requirements of vessel types, firing technologies, and the relations and means of production all could have altered the minerology of the ceramics produced in this region, producing mineralogical groupings that do not necessarily relate at all to source. Additionally, variation in these factors across the landscape of Chifeng during the Liao period could create groupings that do not relate to a specific source, as would the production of multiple kinds of ceramics in the same locus utilizing different "recipes" creating ceramics with mineralogy/temper suitable to specific technological functions.

The issue here, like in many geochemical analyses, is equifinality; as Hodder and Orton put it: "…a large number of processes could have produced the observed association and it is often impossible to distinguish between them from the form of the association itself."(1976:239). As such, for the majority of the sherds analyzed here it is not currently possible to conclusively identify the process, or processes, at work in the creation of the geochemical groupings to which the sherds belong. However, some sherds and groupings have additional archaeological information available that allows for certain of these processes to be ruled out, and for some form of Bayesian inference to be made as to why they form a particular grouping.

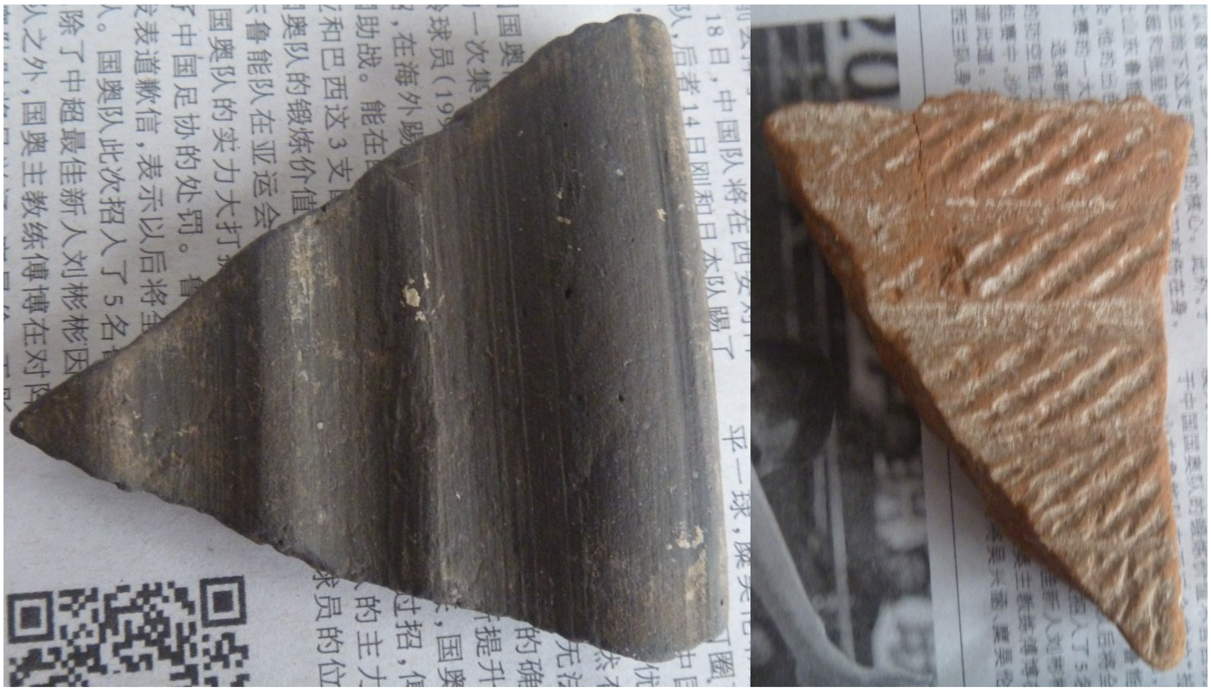
The glazed sherds are a prime example of this. All of these sherds are visually identical (see Figure 7.2.1) Liao period white glazed ware known in the archaeological literature as Gangwayao ware; named after the Liao imperial kiln at which they were presumably produced. All of these sherds (with the exception of sample 79) were also found in the vicinity of the market town of Songshanzhou which is thought to be associated with the Gangwayao kiln and is located only 9 km from the kiln. The Gangwayao kiln site also has evidence of at least one dragon kiln; and while the firing capacity of this particular kiln is unclear, dragon kilns are certainly are able to fire greater numbers of vessels than *mantou* style kilns; potentially thousands of ceramic objects per firing (Kerr, et al. 2004). Given the information that these sherds almost certainly come from the same locus of production - the Gangwayao kiln, as they are located nearby and the kiln has such a high potential production capacity it is unlikely that there would be a need or desire to import visually identical white glazed ware into this region. However, despite this, the white glazed sherds form four distinct groupings identified by the geochemistry. In this instance we can rule out one potential explanation for the difference in the groupings; locus of production, leaving the potential explanations to relate to changes in white ware production over time, stochastic differences in the data or, the use of several recipes for white wear at the Gangwayao kiln during the same time period. The last of these possibilities seems unlikely as there is not an apparent difference in the vessel types and thus no simple reason why an alternative recipe would be used. As such, this leaves only changes in ceramic production conditions over time or some stochastic patterning in the data being interpreted as a geochemical difference.

Figure 7.2.1.

Visual Similarity of Glazed Wares

Another example of Bayesian style inferences being used to resolve potential equifinality, and the most convincing instance of a geochemical grouping corresponding to a source identified in this study, is the roof tile sherd geochemical group 4. This grouping is composed of sherds from the Enzhou site with the addition of a single sherd (106) from the Songshanzhou site (Site 1004). This grouping was visible in the bivariate plots, PCA scatter plots and all of the high congruence HCAs/K-MCAs performed. Although it unfortunately could not be investigated petrographically, the sheer number of methods that identify this grouping would seem to provide somewhat secure evidence that it is a real geochemical grouping and not a result of stochastic patterning. As the membership of this grouping is entirely from the Enzhou site (with the exception of sample 106 which groups near the border of this cluster and the rest of the roof tiles in the bivariate plots, and could potentially be miss-assigned) it seems likely that what is identified by this geochemical grouping is a distinctive minerology of ceramics produced at or near this site, at some point in time. As this grouping does not contain all the roof tiles and earthenware sherds from the Enzhou site, it could also be evidence of a time period only represented at the Enzhou site and none of the other sites analysed here. However, visually this seems unlikely. The samples included in this grouping are visually extremely varied (see figure 7.2.2), more so than one would expect to see in a single time period, and also contain material that is almost certainly Liao roof tile fragments (Figure 7.2.2 Sample 2) as well as material that appears to be mistakenly attributed to Liao but actually represents an earlier period roof tile fragment (Figure 7.2.2 Sample 22). This would seem to rule out time as the determining factor, leaving the most likely explanation to be that this grouping represents the local production of roof tiles from locally available clay sources and mineral temper. On closer consideration this seems unsurprising as roof tiles represent a heavy form of ceramic and it would be counterproductive to transport all of the roof tiles used at a walled settlement like Enzhou for long distances. This potentially also explains why the earthenware at Enzhou does not group apart from the other sites as it could have been imported to Enzhou.

Figure 7.2.2



Liao roof tile sherd Sample 2 (left) and earlier period roof tile sherd Sample 22 (right)

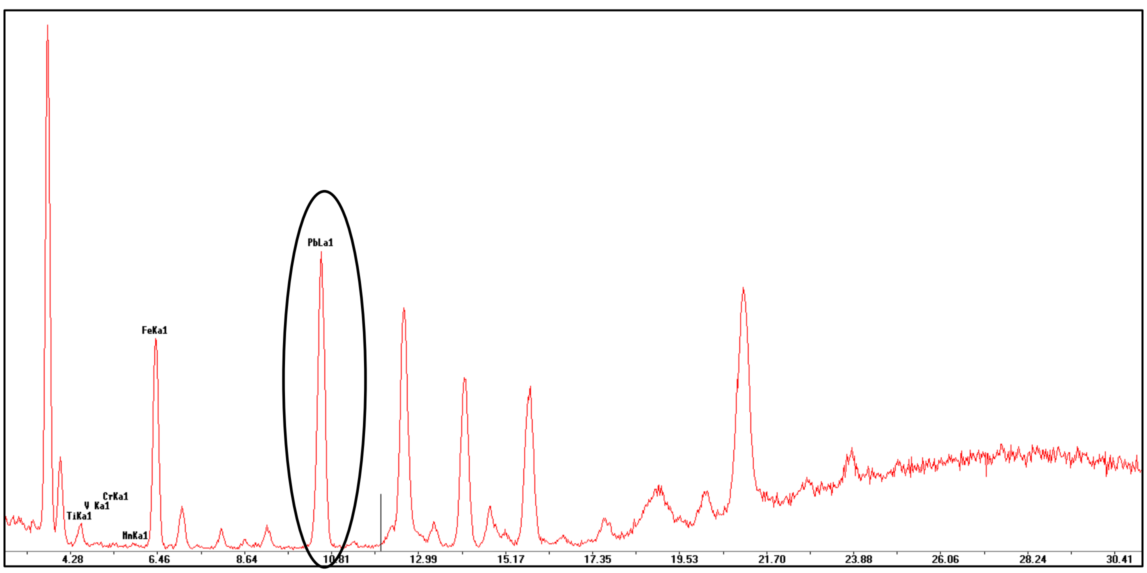
Local Production

The likely local production of roof tiles at the Enzhou site also raises the possibility of another potential substantive result; that some of the earthenware samples may be produced locally at the sites they were collected from. As mentioned previously in section 5, several of the sites exhibit only a small amount of variation in the geochemical content of their sherds and relatively tight confidence ellipses compared to some of the larger sites such as Songshanzhou and Enzhou (See Figures 5.41 and 5.42). This could indicate village production within the context of a larger market-based unglazed earthenware ceramic distribution network in an area with identical or very similar lithology. Despite the potential for this to represent an insight into Liao earthenware production contexts, once again equifinality must be considered. With this in mind, the reason for these tight confidence ellipses could be that the samples from the collection units at these sites represent multiple sherds from a single vessel. Refitting studies have not yet been performed on these sherds, and as such, this possibility cannot be ruled out.

Lead

While lead was not among the elements analysed in this study (as the filter used did that did not specifically target lead), high concentrations of lead were detected in the spectra acquired from several of the sherds (see Figure 7.2.3 for an example). There are several potential reasons why these sherds might contain such high concentrations of lead. The underlying geochemistry of the clay pastes or temper minerals used may be rich in lead or these wares might have been fired in the same kiln as glazed wares – lead contained in the glazes can potentially aerosolize when fired at high temperatures and be redeposited on unglazed surfaces. This phenomena was observed in a series of analyses of unglazed surfaces of glazed wares performed by the author at the Hohhot Inner Mongolia Archaeological Institute and also observed in Liao and Tang glazed ceramics by Professor J. Cui at Peking University (Cui pers. com). The lead content might also be the result of heavy metal containing soils contaminating the surfaces of these ceramics. As steps were taken to minimize the third possibility, the first two possibilities are viewed as significantly more likely.

Figure 7.2.3



Lead detected in a raw geochemical spectra (image created with Bruker S1PXRF software)

The presence of high lead concentrations in or on some of the ceramics sherds probably relates to their mineralogical source or to the kiln at which they were fired. This opens up several exciting possibilities for future investigations. Lead isotope studies of glazed ceramics have previously been used to fingerprint kilns at which these ceramics were produced (Cui, Lei, et al. 2010) or to fingerprint the geological source of the lead used (Wolf, et al. 2003) in much the same way as it is routinely done in the analysis of bronze artefacts (Tian, et al. 2010). If the lead content of the sherds is high enough (J. F. Cui, Lei, et al. 2010), it may be possible to do the same with Liao earthenwares, providing an accurate alternative method for determining the source of Liao ceramics. These lead isotopes may also provide valuable information in another way; ceramics with a high lead content will leach that lead into foodstuffs or liquids served or stored in them, causing anything from low level lead exposure to fatal acute lead poisoning (Harris and Elsea 1967; Klein, et al. 1970; Phan, et al. 1998). Cases of lead poisoning carry the isotopic signature of the source of their lead poisoning (Avila, et al. 1991) and thus, if human skeletal remains with evidence of lead poisoning can be identified, it is theoretically possible to link the source of that poisoning to a particular ceramic group or kiln. While this has not yet been attempted in the archaeological literature, forensic studies of lead poisoning have carried out a similar analysis to locate the source of lead poisoning in modern living populations (Avila, et al. 1991). Liao ceramics may provide a good opportunity to expand this method to archaeology. The potential to link individuals to the kilns from which they acquired ceramics is certainly an exciting prospect.

7.3 Methodological Observations

Geochemistry

One of the primary aims of this study was to assess the validity of the methodology and techniques employed for answering questions about Liao ceramics. Foremost among these was an assessment of the suitability of pXRF for the analysis of Liao inhomogeneous unglazed ceramics. With the above results in mind, it would seem that pXRF is indeed a moderately useful method for analyzing Liao unglazed ceramics. The coefficients of variation calculated for the Kitan standard run several times during each analytical session indicate that the technique is certainly reliable enough in the results it generates to characterize moderately inhomogeneous Liao ceramics without these samples being first homogenized. Additionally, the ability to distinguish geochemical groupings would also suggest that the within-sherd variation of Liao unglazed earthenware ceramics does not exceed the variation between sherds, the primary constraint on the geochemical grouping of ceramics.

That being said, there are certainly some ways in which pXRF methodology could be improved to better characterize Liao sherds. The complexity of the geochemical groupings for the roof-tiles and earthenware indicates that pXRF analyses limited to just Fe and trace elements may not in fact be sufficient to identify very fine groupings. Given the usefulness of Fe in the bivariate plots it is likely that the addition of more major elements would be a serious boon to analyses, especially as the more elements are analyzed the more accurate the results will become. Sherd analysis ideally could also be expanded to more than five analyses per sherd in order to reduce the variation in the measurements (which in this analysis was found to be anywhere up to 10%). Of course to perform analyses with both of these alterations to the methodology would require a greater outlay of analysis time, as each sherd would have to be analysed more than five times with each filter used, potentially bringing the total time spent per sherd to at least a quarter of an hour.

Alternatively and preferably, a more sophisticated technique than pXRF (potentially ICP-MS or SEM analyses of single temper grains) would be used to characterize (preferably homogenized) Liao ceramics as some elements of interest; such as rare earth elements, and isotopes of interest such as the aforementioned lead isotopes, are not detectable utilizing pXRF. These techniques, however, have serious issues in that they are not field portable. Samples must be transported to the instrument, something that is not always possible in China. Also these techniques are substantially more expensive than pXRF especially where large sample sizes are concerned, and their use would be dependent on acquiring substantial funding.

Petrography

Another important component of this study was to assess the potential usefulness of petrography for the analysis of Liao unglazed ceramics. The results of the above analysis unambiguously indicate that this is indeed the case. Provenience data for ceramic fabrics is primarily held within the inclusions as opposed to the clay paste, and as such, ceramic fabrics with large identifiable inclusions in high quantities provide a better opportunity to narrow down the specific source of a sherd than fabrics with comparatively fewer inclusions or inclusions too small for reliable identification (Quinn 2013). Almost all of the sherds examined in this study contain very high quantities of mineral inclusions the vast majority of which are large enough to enable mineral identifications, indicating that Liao ceramic fabrics are extremely well suited to petrographic analyses. Apart from the presence of inclusions suitable for identification, the petrographic analyses also identified a substantial degree of variability in the ceramic fabrics of the sherds (26 groupings from 43 samples) and the presence of several diagnostic features that are very easy to identify (e.g. microfossils, k-feldspar, microcline feldspar, plagioclase feldspar, biotite and possible metamorphic grains). This high degree of variation and easily identifiable diagnostic features means that when groupings are present they should be easily identifiable (despite a lack of local geological information). This once again indicates that Liao ceramic fabrics are particularly well suited to petrographic analyses and, given the quality of the information provided, petrography may be the most effective method for analyzing Liao earthenwares, despite the much larger outlay of time it requires.

Reducing Equifinality

The above analyses have also highlighted several opportunities to employ novel techniques to help resolve the issue of equifinality that can prevent the clear explanation of why particular samples group together. Foremost among these is the locating and sampling of geological outcrops in the Chifeng region to form a petrographic reference collection. This reference collection would be an invaluable resource in future petrographic analyses providing ready examples of local minerals to correlate with the ceramic fabric samples, as well as providing baseline geochemical data which could be useful if individual temper grains can be analysed geochemically. This is actually a particularly promising avenue of study, as some of the volcanic geology of the Chifeng region has been shown to have a very distinctive geochemistry (Han, et al. 1999).

The identification, and geochemical and petrographic sampling of local clay sources could also prove invaluable to the geochemical analyses and vital in determining what mineral inclusions in the ceramic fabrics are the result of intentional tempering, and what inclusions are relic inclusions form the clay source's parent mineral. Additionally the experimental firing of samples from these clay sources would be able to provide a baseline temperature at which these clays vitrify, providing the ability to more accurately determine the firing temperature of Liao unglazed ceramics and also provide a dataset to which re-firing studies could be calibrated.

While the above supplementary studies would be useful for the sourcing of unglazed ceramics, several other research projects could also address the major issue in Liao archaeology of poor chronological control. Locating and sampling numerous multi-component stratified sites, either by coring or excavation, could provide the necessary information for constructing a basic pottery sequence for the Liao period. Such studies are already planned; the KLASH project, the parent project under which this study falls, is already intending to start a program of such sampling in the Chifeng region (Bennett 2015; Bennett and Standen 2011). A related project with a slightly different focus would be the location and sampling of individual households or other datable single component sites. While this does not provide a long chronological sequence of ceramic variation, it would provide the ability to characterize the variability contained within a single period greatly supplementing the accuracy of a regional ceramic sequence. Similarly the location and sampling of kiln sites could provide exceptional provenience, technological and chronological information on Liao ceramic production, while also presenting the possibility of using lead isotopes to fingerprint individual kilns.

Finally the dating of individual ceramic samples would provide perhaps the most direct and accurate method for creating a simple ceramic chronology. As mentioned above, carbonized organics are present within some of the sherds which provides an excellent opportunity for acquiring dates for the sherds and also the often undated sites from which they were surface collected. AMS radiocarbon dates also bypass the major difficulties in dating ceramics by the other prominent method of thermoluminescence such as the wait times involved which can extend to several years (Jantz pers. com) and the potential for larger errors.

9. Conclusion

One of the original aims of this study was to assess the validity of geochemistry and petrography for analysing Liao unglazed earthenwares. This study has undoubtedly confirmed that both pXRF and optical thin section petrography are eminently suitable for the analysis of this variety of Liao ceramics. Petrographic information at this point seems much more promising in its ability to locate directly datable material among other things. In line with another of the original aims, this study has also highlighted some areas where the methodology employed could be altered to improve the accuracy of the measurements. It has also identified a number of aspects of Liao unglazed earthenwares that could provide opportunities to apply novel techniques. These avenues of research could be pursued in tandem with the geochemistry and petrography, with the purpose of providing prior probabilities for Bayesian style inferences that could help resolve the issue of equifinality that has so far prevented a firm understanding of the archaeological implications of geochemical and petrographic groupings. The combination of these results has allowed for the development of a series of methodological recommendations for future studies that would maximise the potential for archaeological groupings to be found, and understood. They are as follows:

1) The current pXRF analysis methodology should be supplemented with the use of additional filters to increase the number of elements targeted allowing for a more accurate characterization of the sherds.
2) Each sherd should be subjected to at least two additional pXRF assays (a minimum of 5 assays in total) in order to reduce the variation in the measurements of each sherd increasing the total accuracy of the analyses and potentially providing tighter more visible geochemical clusters.
3) Expand the number of samples assessed by petrography to a 1:1 ratio, as the petrography seems to be a much more promising method for acquiring provenience information, despite the time intensive nature of petrographic analyses compared to pXRF.
4) Expand the geochemistry to include more accurate techniques such as ICAP-MS, INAA or SEM-EDS that can be performed on thin sections and can also target individual mineral grains to simplify petrographic mineral identifications.
5) Expand the geochemistry to include techniques that can identify isotopic information to assist in fingerprinting kilns if possible.
6) A series of additional lines of inquiry should be carried out alongside the geochemistry and petrography, Specifically; the collection of geological reference materials from the local lithology

to aid in petrographic analyses, the identification and sampling of extant clay mineral sources to act as geochemical reference material as well as the firing of some of this material to act as petrographic reference material; the sampling of sherds for dating either by identifying organics left over from firing that are embedded within the sherds or the thermoluminesence dating of the sherds themselves, and the targeting of sherd collection to provide ceramics from kiln sites to provide source material as well as stratified ceramics to aid in basic chronological understanding.

7) Carry out a series of experimental studies to further improve existing methodology, namely: experiment with the homogenization of several ceramic samples to quantify the difference in reliability between analysing powdered homogenised and analysing heterogeneous solid samples; and experiment with various sample preparation methods to determine the effects, if any, of contaminated soils, and the most effective way of dealing with potential contamination.

The ideal methodology identified in these recommendations is scheduled to be applied in further analyses of Liao unglazed non-eltie ceramics that will be carried out in the future as a part of the KLASH project.

Regional Significance

This study represents, as far as the author is aware, the first geochemical and petrographic analysis of Liao period unglazed earthenwares. As such it is probably unsurprising that several new pieces of information have come to light as a result of this study that have a degree of local significance to the archaeology of the Kitan/Liao within the Chifeng region. This is the first time grog has been identified in Kitan/Liao ceramic production. While this may seem unsurprising to an international audience, regionally this is unexpected as narratives surrounding Chinese ceramic production assume different, more “advanced” techniques are being used during the Liao period.

Additionally, of regional significance, several geochemical groupings identified here have been proposed to have archaeological significance. Firstly the Enzhou materials seem to exhibit local production of roof tiles. While this in itself may be unsurprising, it has an exciting implication; there must be a ceramic industry operating somewhere In the vicinity of the Enzhou site which should have an archaeological signature. The location of this site, if it has survived the modern intensive agriculture of the region, would be a priority in further elucidating the conditions of ceramic production at Enzhou and wider relations of production in this region during the Liao, and possibly earlier periods. As Enzhou is the site of one of the Liao state-imposed forcible resettlements of Bohai communities, there is also the potential that further investigations into this ceramic industry could shed light on this subaltern population and the conditions of their dislocation, especially as Bohai craftspeople were known to be involved in ceramic production elsewhere (Kradin and Ivliev 2008).

Also of regional significance is the identification of possible chronological groupings of Gangwayao glazed stoneware. Although originally included to form a homogenous outgroup, the grouping of these materials presents the surprising possibility that these white wares may, despite their visual similarity, have the potential to be chronologically sensitive. However, ground truthing of this hypothesis is still needed to conclusively prove that these groupings are chronological, but this should be relatively unchallenging as the Gangwayao Kiln site has already been excavated (Lu 2008).

Wider Significance

Although the questions asked here are generally locally focused, they do have a wider regional as well as international significance. The unglazed ceramics collected in the Chifeng region are of a style that is distributed across the entirety of the Liao Empire, which stretches from the Russian Maritime Province to the Altai in Kazakhstan. While these ceramics will be made with different clay minerals and temper, fundamentally, the methodology developed here has the ability to be applied anywhere throughout this range with minimal alternations. Finally, although pXRF is by now a standard technique of wider archaeological geochemistry, there are as yet very few studies utilizing pXRF to examine non-homogenous earthenware ceramics. As such, very few studies have been published utilizing pXRF in quite the same way it is used here, where the focus is on grouping rather than sourcing, although the author is aware of several studies soon to be published. As such, this research represents a contribution to a burgeoning field of inquiry and its results will be of methodological interest to others attempting to perform studies on similarly non-homogenous materials.

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12. Appendix 1. Geochemistry

12.1 Expanded Geochemical Results

12.1.1. Sample Separation

Based on the visual analyses of the material, the geochemical data from the samples was separated into several different categories on the basis of the samples' material type (counts by site provided in Table 12.1). The reasoning behind this was that optical differences could potentially correlate to geochemical differences. This is easily testable using initial bivariate plots, principal component analysis and hierarchical cluster analysis.

Table 12.1 proposed sample separation and counts by site

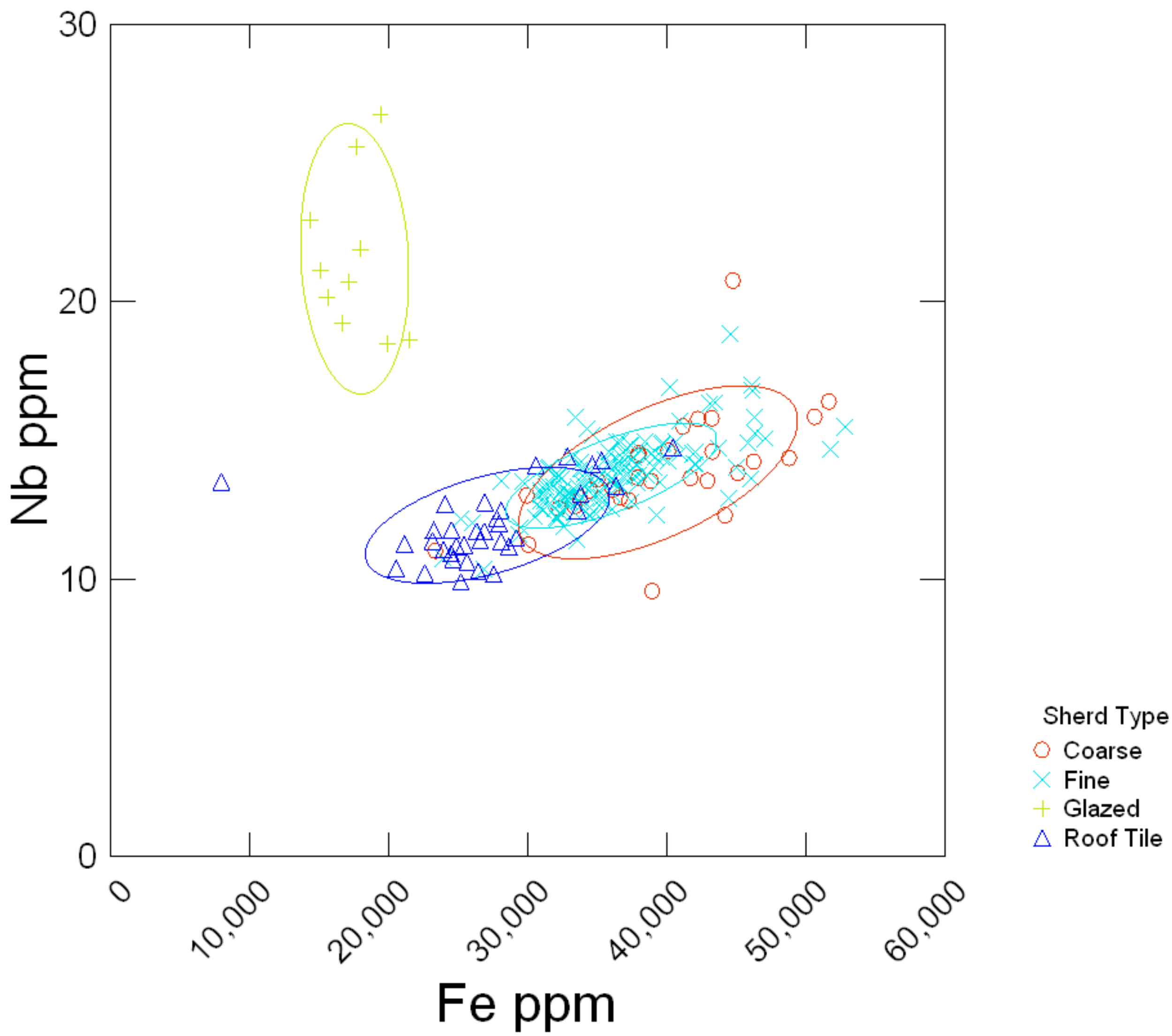
Site Code	Earthenware	Roof Tile	Glazed Stoneware
ENZH	19	9	
1768	5		
1767	5		
1700	3		
1590	8		
1470		1	
1373	5		
1350	13		
1344	5		
1343	8		
1009	9	5	2
1004	52	16	7
591	4		
554	2	1	1
504	5		
503	5		
498	4	1	
408	4		
349	9	2	
Total			

Bivariate Plots

Bivariate plots of the entire dataset grouped by sample type demonstrated that glazed stoneware samples were easily geochemically distinguishable from the unglazed earthenware and roof tile samples on the basis of Fe and Nb (Figure 12.1.1). Roof tiles were also distinguishable on the basis of Fe and Sr

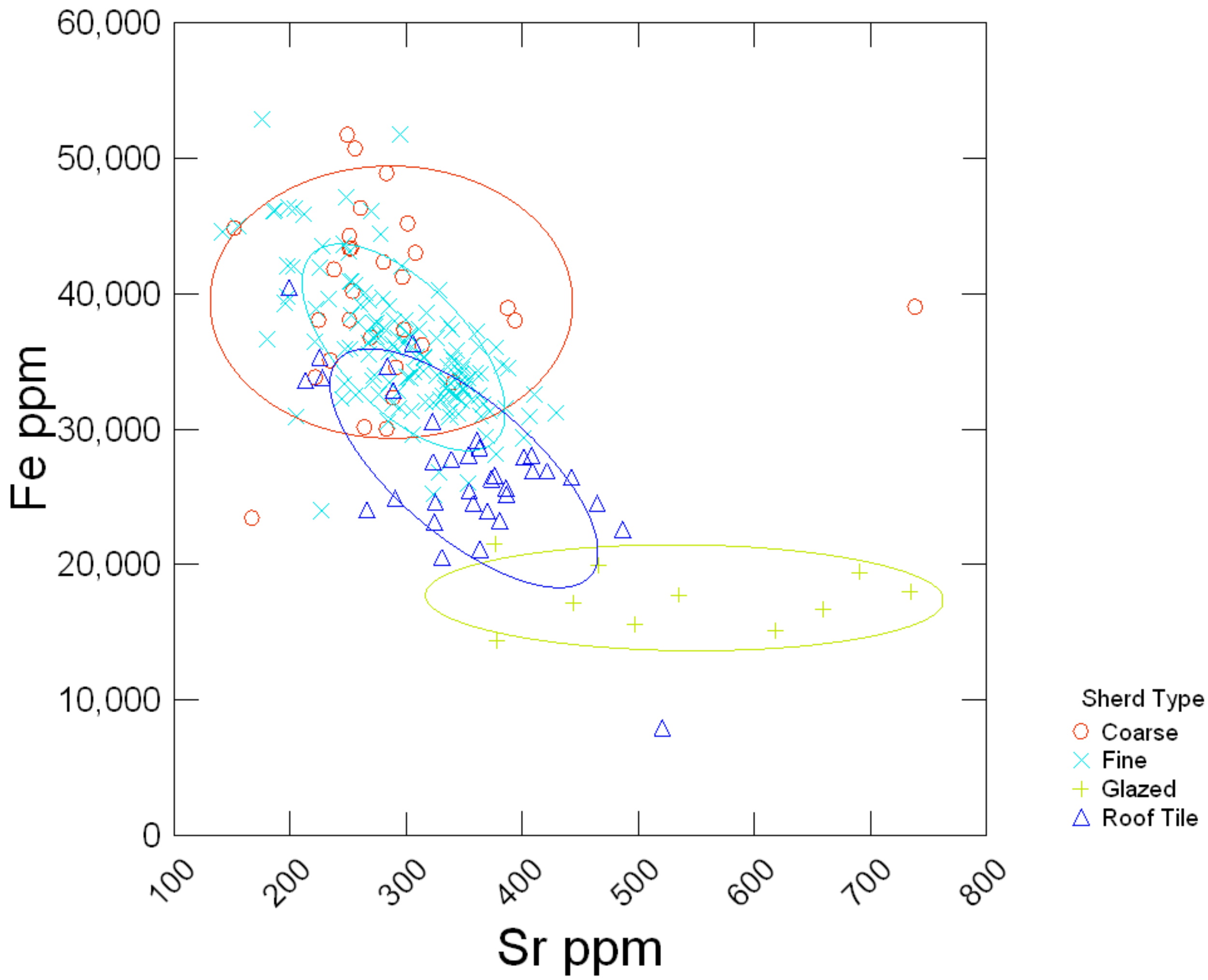
(Figure 12.1.2), and while they form a distinct grouping offset slightly from the earthenware sherds, this grouping overlaps significantly with the earthenware sherds occupying one of the extreme ends of the variation within the earthenware sherds.

Figure 12.1.1



Bivariate Plot of Fe ppm vs. Nb ppm for all sherds analysed, separated by type.

Figure 12.1.2

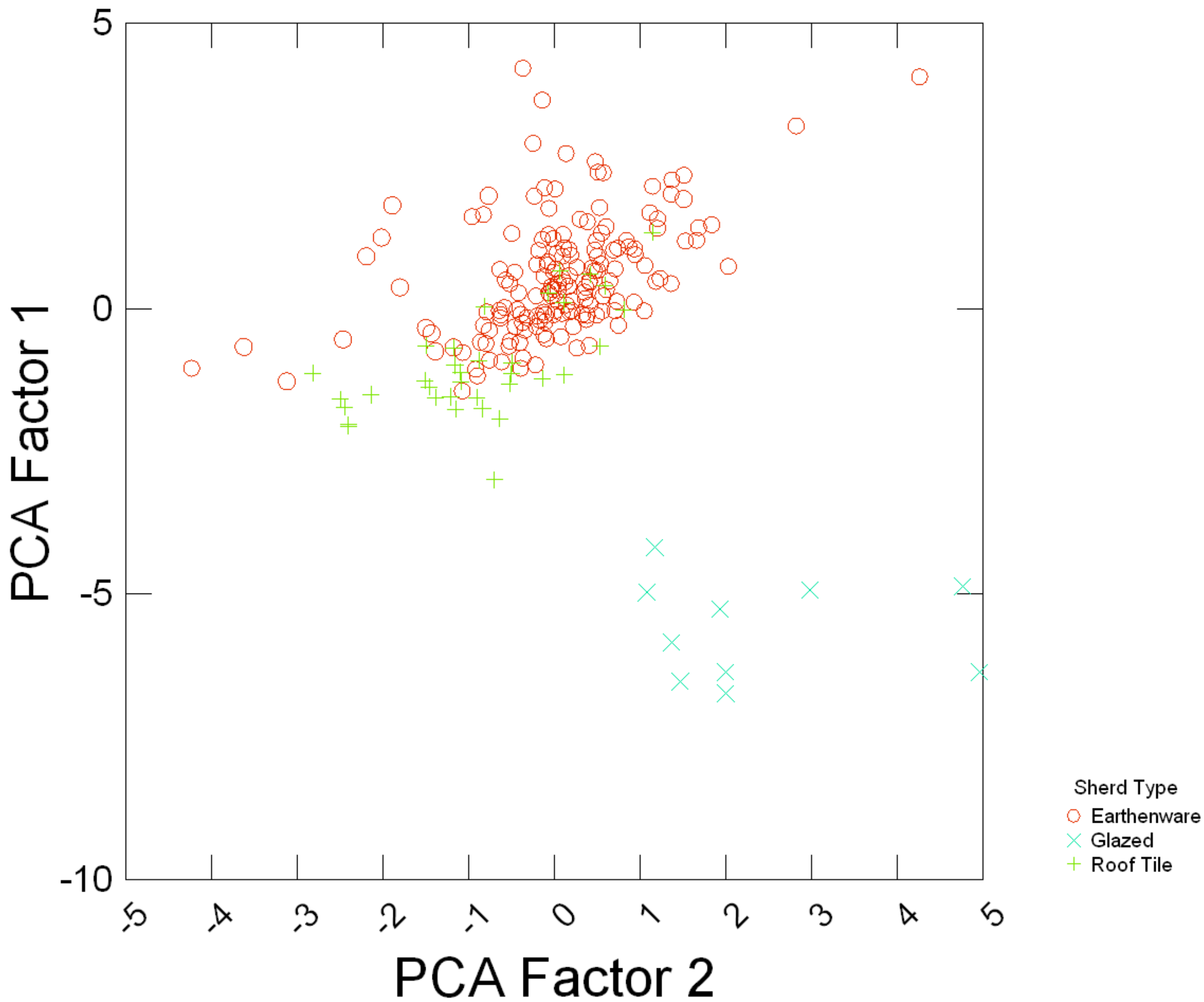


Bivariate Plot of Sr vs. Fe for all sherds analysed, separated by type.

Principal Component Analysis

A PCA was also performed on the entire dataset producing two factors with an Eigen value greater than one that together explain 71% (49% and 22% respectively) of the total variance within the dataset. When these factors are plotted against each other (Figure 12.1.3) the results confirm those of the bivariate plots (Figure 12.1.1 and 12.1.2). These elements easily distinguish the glazed stoneware sherds from the other samples, while the roof tiles and earthenware form distinct groupings which significantly overlap.

Figure 12.1.3

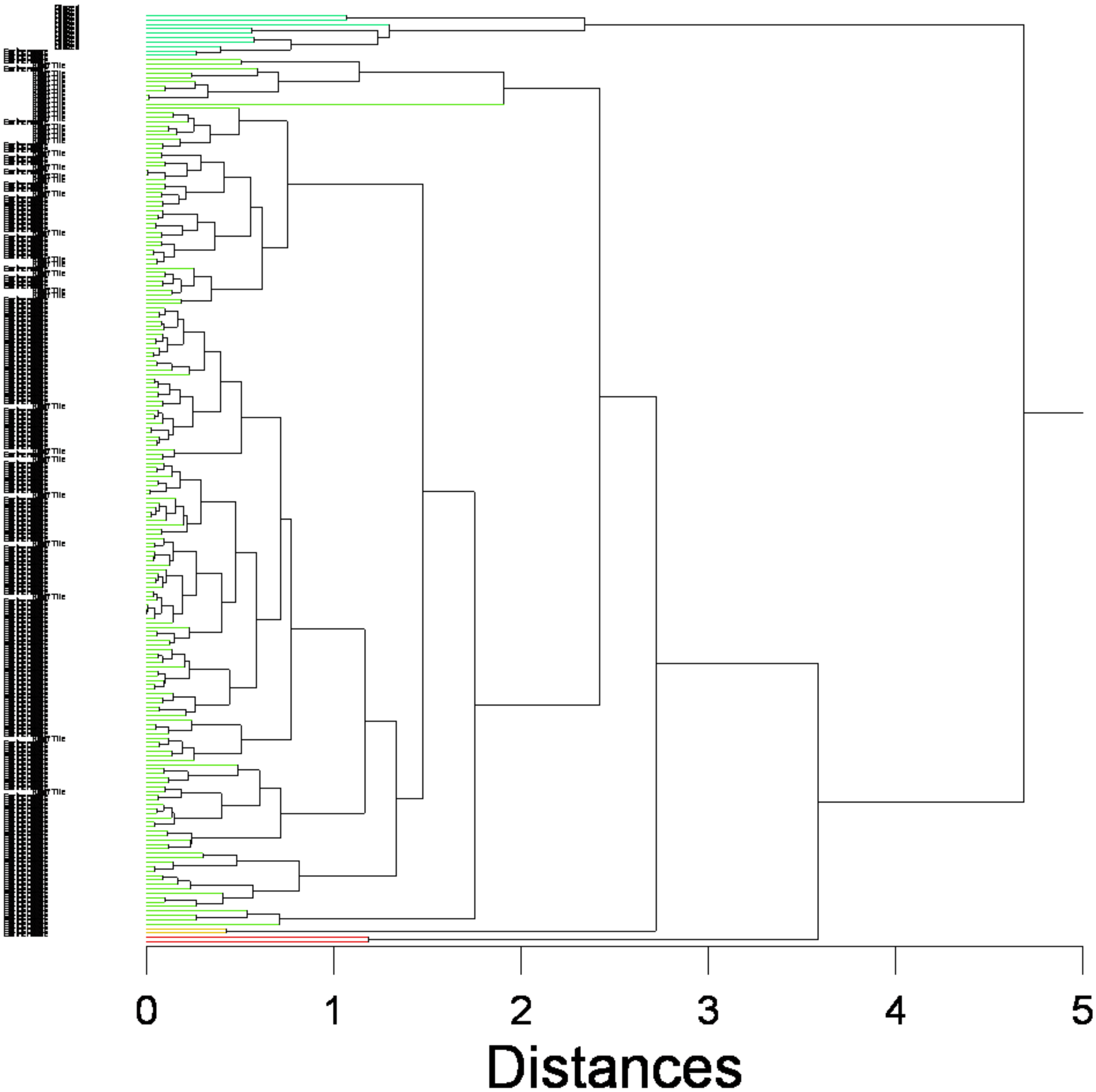


Bivariate Plot of PCA 1. vs. PCA 2. for all sherds analysed, separated by type

Hierarchical Cluster Analysis

An HCA was also performed on the above PCA data using Euclidian distances and the Average Linkage method. This produced a dendrogram exhibiting 4 groupings (Figure 12.1.4) and the assignments from this dendrogram are provided in Appendix 12 Table 12. The first order subdivision separated the glazed stoneware sherds from the rest of the sample, and the second grouping contained only samples 12 and 19 (both earthenware sherds from the Enzhou site). The third grouping contained only samples 43 and 113 (both earthenware sherds, one from site 1343 the other from site 1400), and the final grouping contained all of the remaining sherds. This again confirms the results of the PCA and bivariate scatter plots, more strongly confirming that the glazed sherds are easily distinguishable while the earthenware and roof tile samples are not.

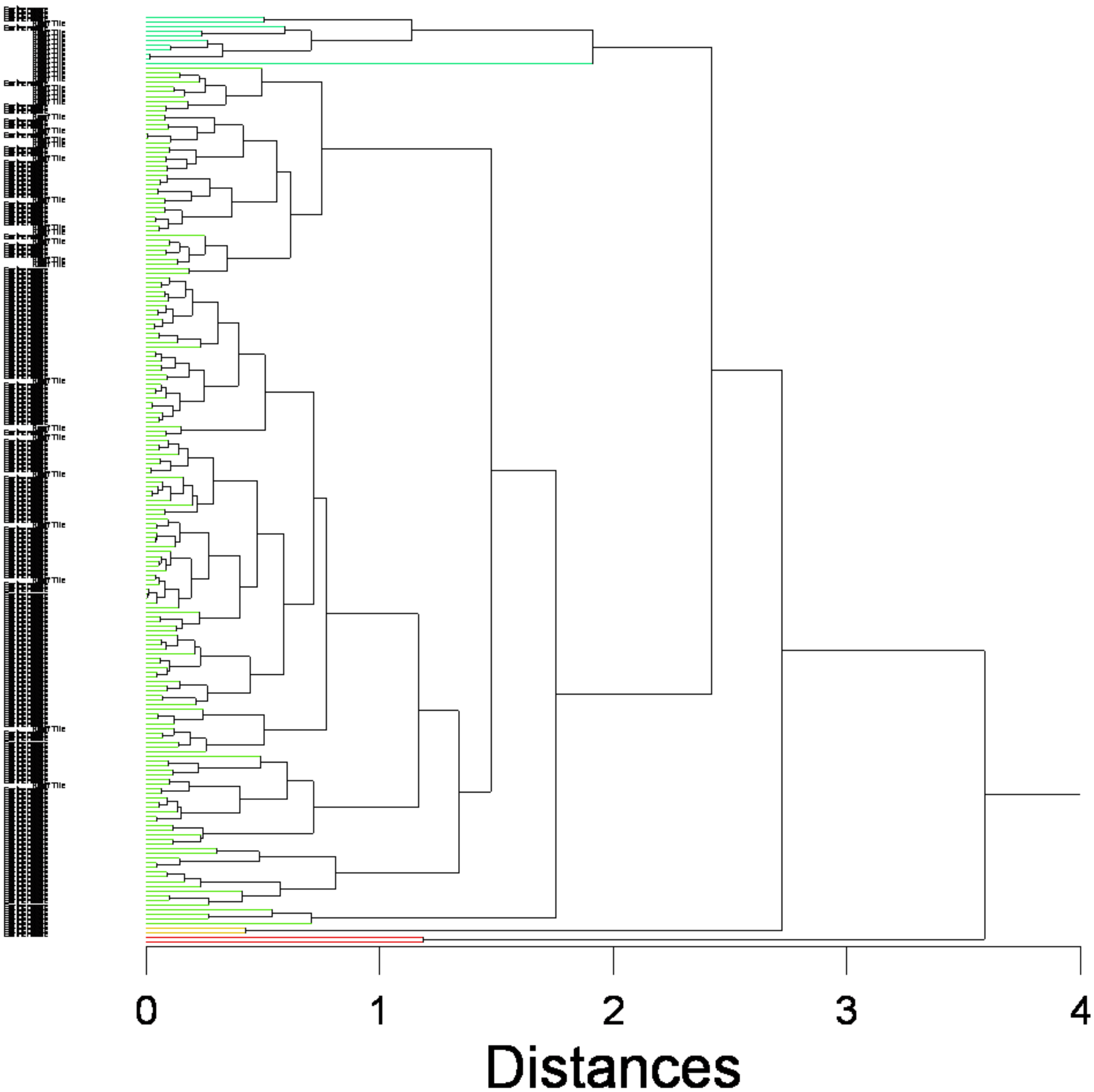
Figure 12.1.4



Dendrogram generated by the Average Linkage HCA of all samples

If the glazed wares are removed and the HCA is repeated without them, it still produces four groupings (Figure 12.1.4). There are again two groupings containing samples 12 and 19, and samples 43 and 113 respectively. The remaining two groupings are much larger and contain both roof tiles and unglazed earthenware sherds, however, one contains a majority of roof tile sherds while the other contains a majority of earthenware sherds. This would seem to suggest that, although they have considerable overlap, there may be some significant difference between the roof tiles and earthenware sherd even if they cannot be clearly separated out on these elements alone. As such, roof tiles were separated out in all further analyses in case there were distinct groupings among them that might be washed out by their inclusion in analyses within the larger earthenware sherd dataset.

Figure 12.1.4

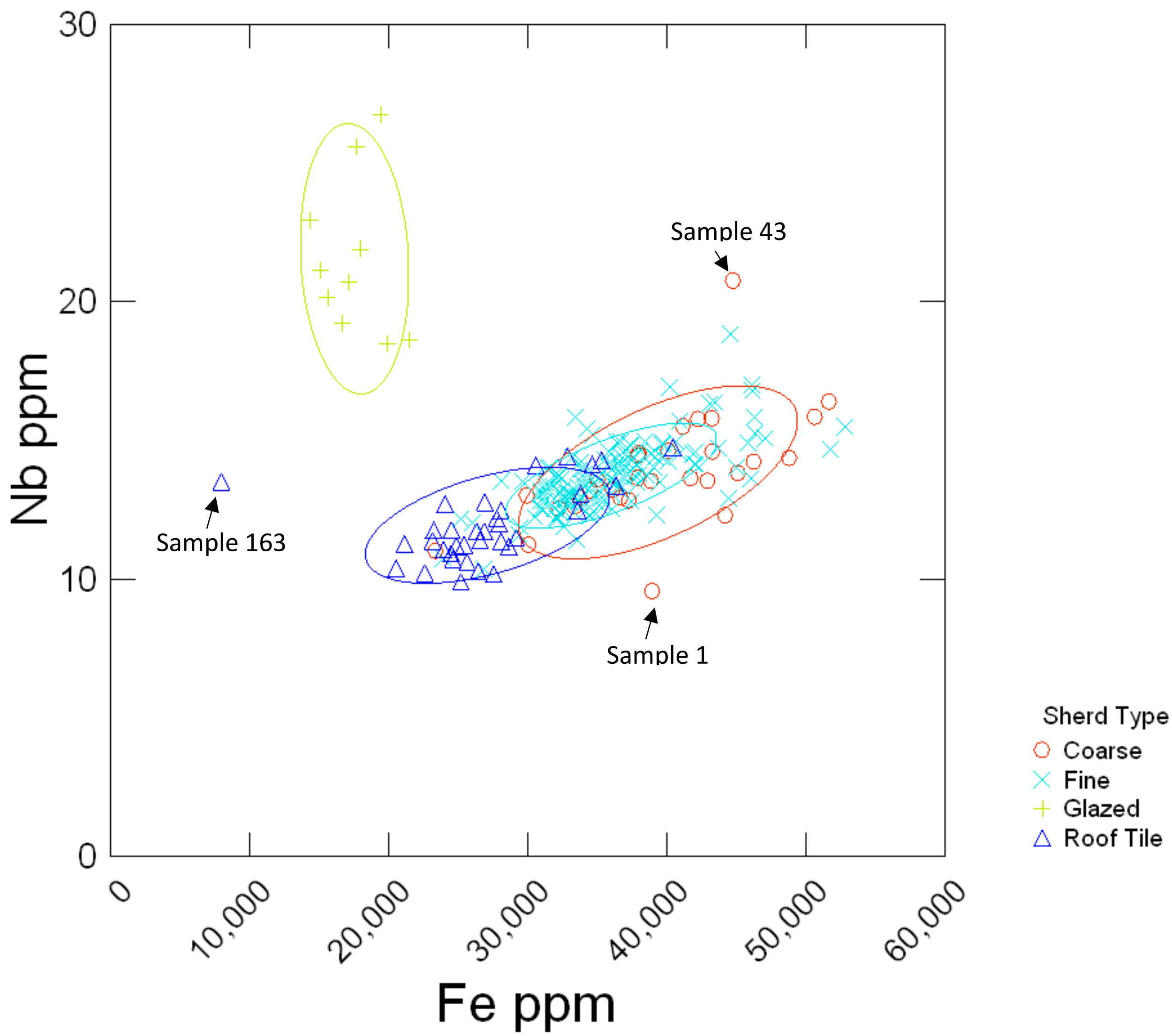


Dendrogram generated by the Average Linkage HCA of all Unglazed Samples

12.1.1.1 Identification of outliers

Several outliers were also identified during the plotting of these graphs, specifically sample numbers 1 and 163 (Figure 12.1.4).

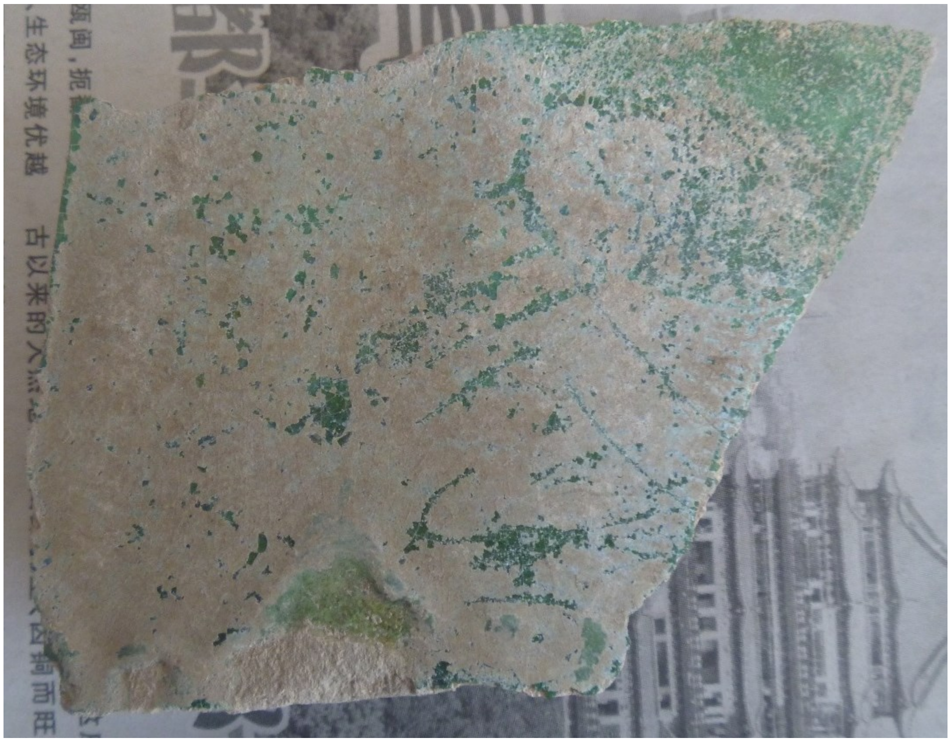
Figure 12.1.4



Outliers identified through a bivariate plot of Fe vs. Nb, all samples

Examination of photographs of these samples revealed possible reasons for their geochemical difference. Sample 163 (1470-07D013-S163 Figure 12.1.5) proved to be the only glazed roof tile sampled in the assemblage, which is almost certainly the reason why it proves geochemically distinct.

Figure 12.1.5



Photograph of outlier Sample 163 [1470-07D013-S163]

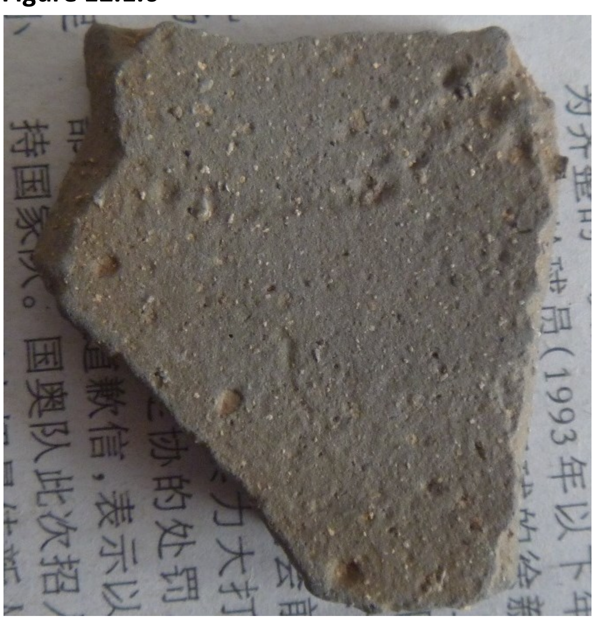
Sample 1 (ENZH-S1 Figure 5.7) is a black biscuity coarse tempered sherd that lies at the extreme edge of "Liao" sherd variation. It is suspected that this sample is actually either from a much earlier time period, likely the Neolithic, or is a highly weathered fragment of modern asphalt mistakenly collected as a sherd. These samples were excluded from further analyses as some of the statistical techniques used are strongly affected by outliers.

Figure 12.1.7

Photograph of outlier Sample1 [ENZH-S1]

Sample 43 (1343-07P021-S43 Figure 12.1.6) was also identified as a marginal potential outlier. The sherd has a pale brown matrix and is highly porous with no surface decoration and showing visible temper with a large grain size. The lack of surface decoration and high porosity are not distinctive markers of a time period other than the Liao Empire. As such, given no evidence to suspect it is not in fact Liao, it has been included in the subsequent analyses.

Figure 12.1.6



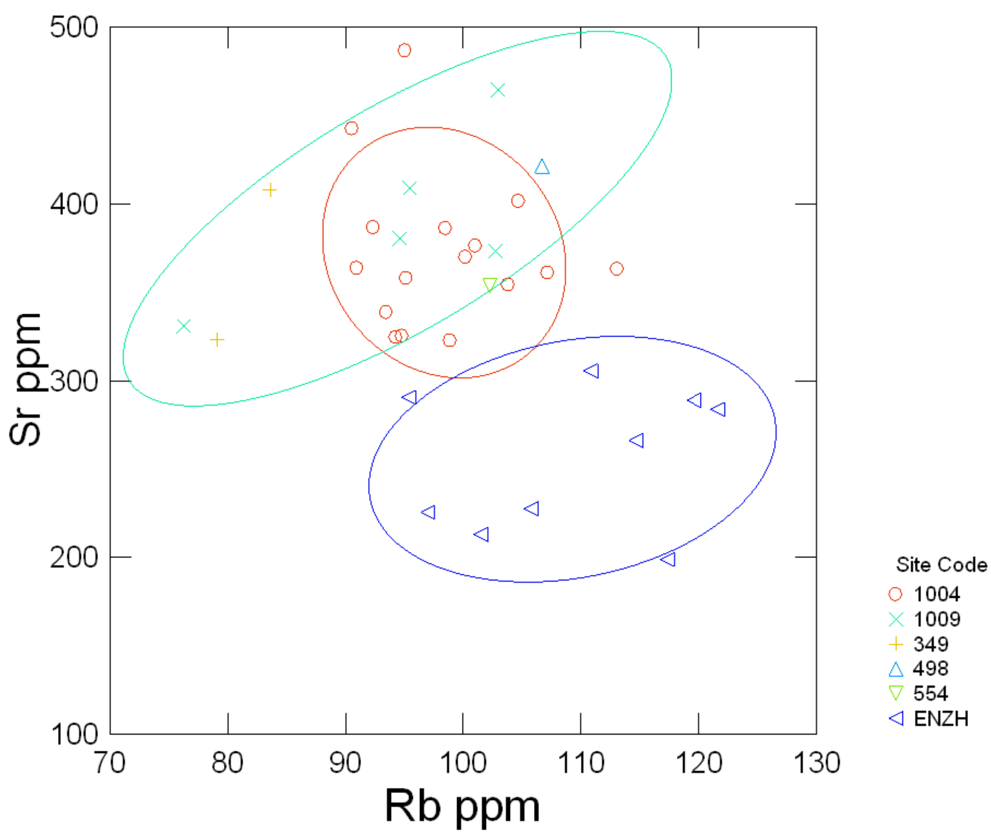
Photograph of outlier Sample 43 [1343-07P021-S43]

12.1.2 Roof tiles

12.1.2.1 Bivariate plots

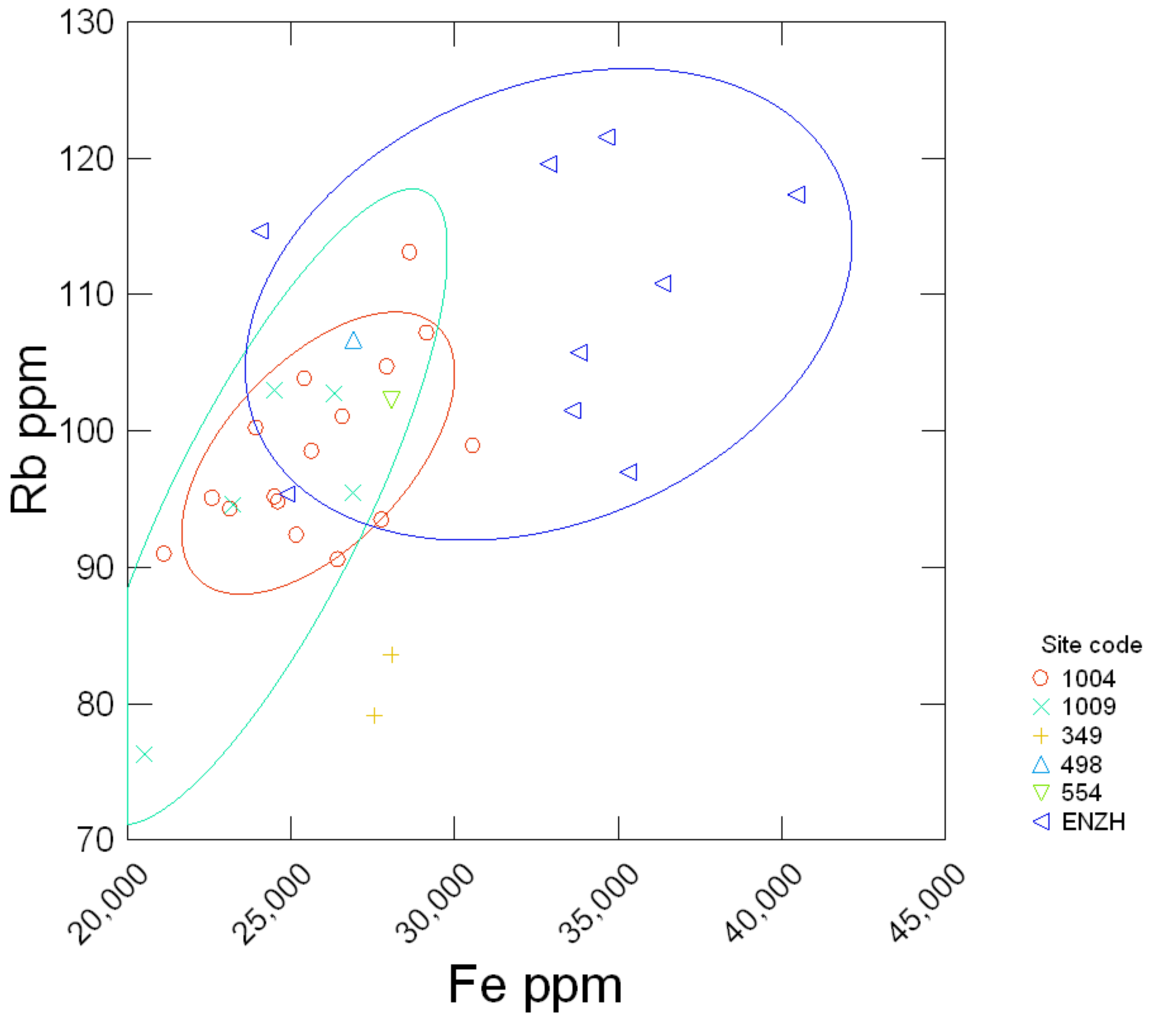
Simple bivariate plots of the samples identified as likely roof tiles (potentially including other ceramic construction materials manufactured in a similar fashion such as drainage tiles) does not generally show a relationship between ceramic geochemistry and collection locality or at least not one strong enough to be distinguished by bivariate plots alone (Figure 12.1.8). However, the roof tiles from the Enzhou site are an exception in that they are surprisingly distinguishable based solely on their elemental content, primarily on the Sr content of the sherds (Figure 12.1.8). Roof tiles from Site 349 notably also formed a relatively tight cluster, however, this cluster falls entirely within the 95% sample eclipse of the other sites making it much less distinguishable than the Enzhou material (Figure 12.1.9).

Figure 12.1.8



Bivariate plot of roof tile samples Sr ppm vs. Rb ppm

Figure 12.1 .9

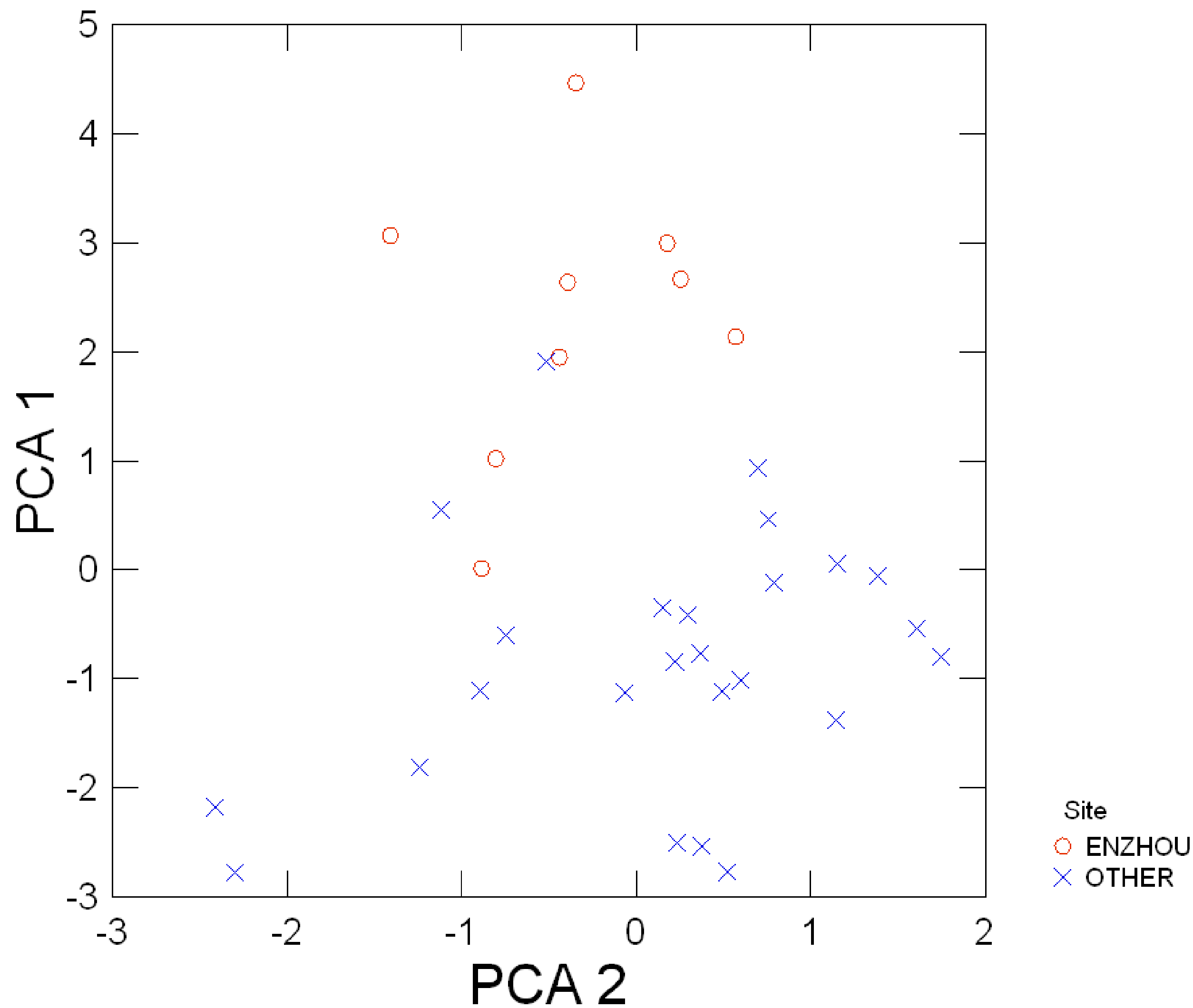


Bivariate plot of roof tile samples Rb ppm vs. Fe ppm, showing the separation of site 349

12.1.2.2 Principal Components Analysis

The PCA of the roof tile data (using all of the elements measured) provides only two factors with an Eigen value above 1.0, the limit at which a factor is considered to be useful for explaining variance (Shennan 1997). Together these two factors explain 73.4% of the total variance within the sample (Factor 1 56.7% Factor 2 16.7%). Plotting these two factors against each other however reveals little in the way of groupings. The previously noted Enzhou grouping is in fact less clear and the site 349 groupings is only very slightly clearer (Figure 12.1.10).

Figure 12.1.10

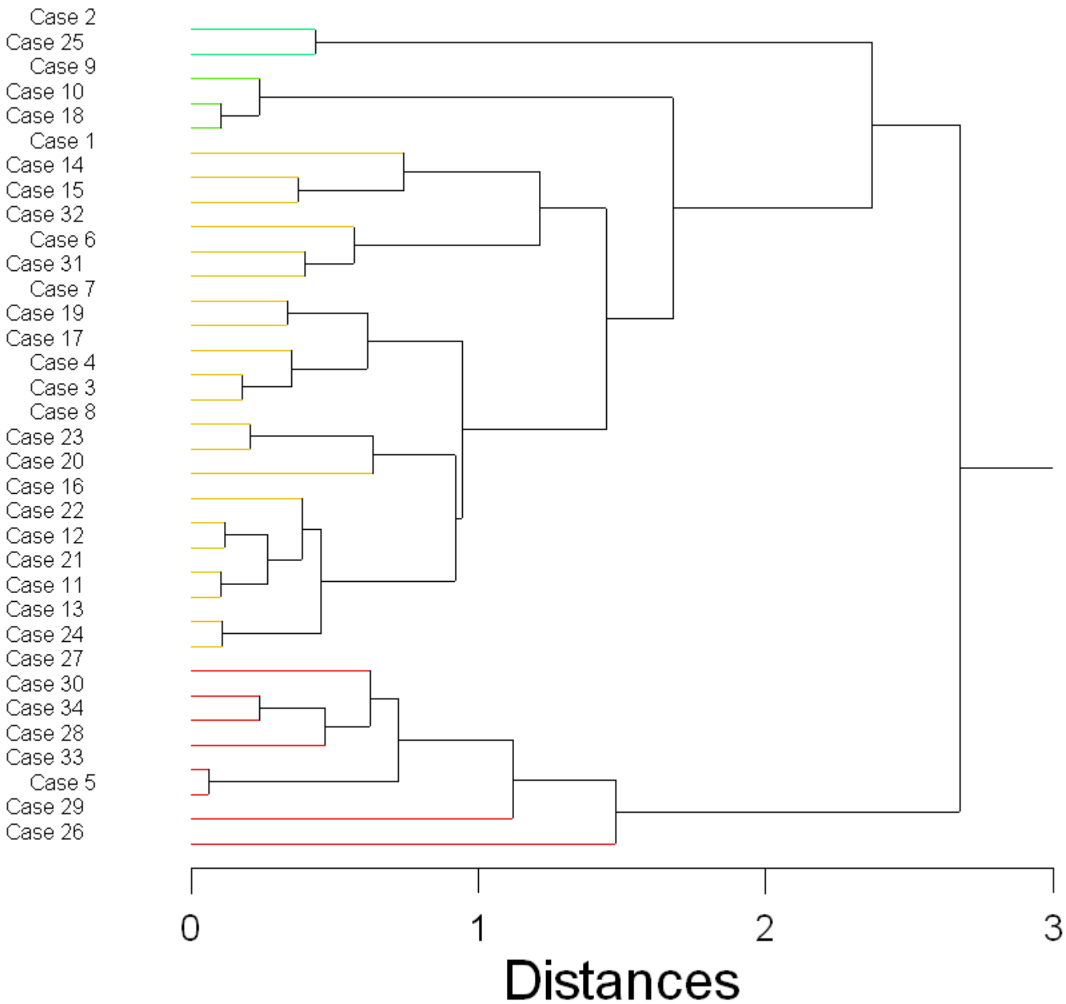


Bivariate plot of roof tile samples PCA1 vs. PCA2

12.1.2.3 PCA Hierarchical Cluster Analysis

An HCA performed on the two factors provided by the PCA results, utilizing the Average Linkage method, generates the dendrogram in Figure12.1.11 with its resulting assignments provided in Appendix 12.2; Table 12.2.3. This dendrogram generates four distinct geochemical groupings. The contents of these groupings are shown in Table 12.1.2. Notably however, the grouping created by the first order subdivision contains material primarily from the Enzhou site but with the addition of sherd 106 (site 554).

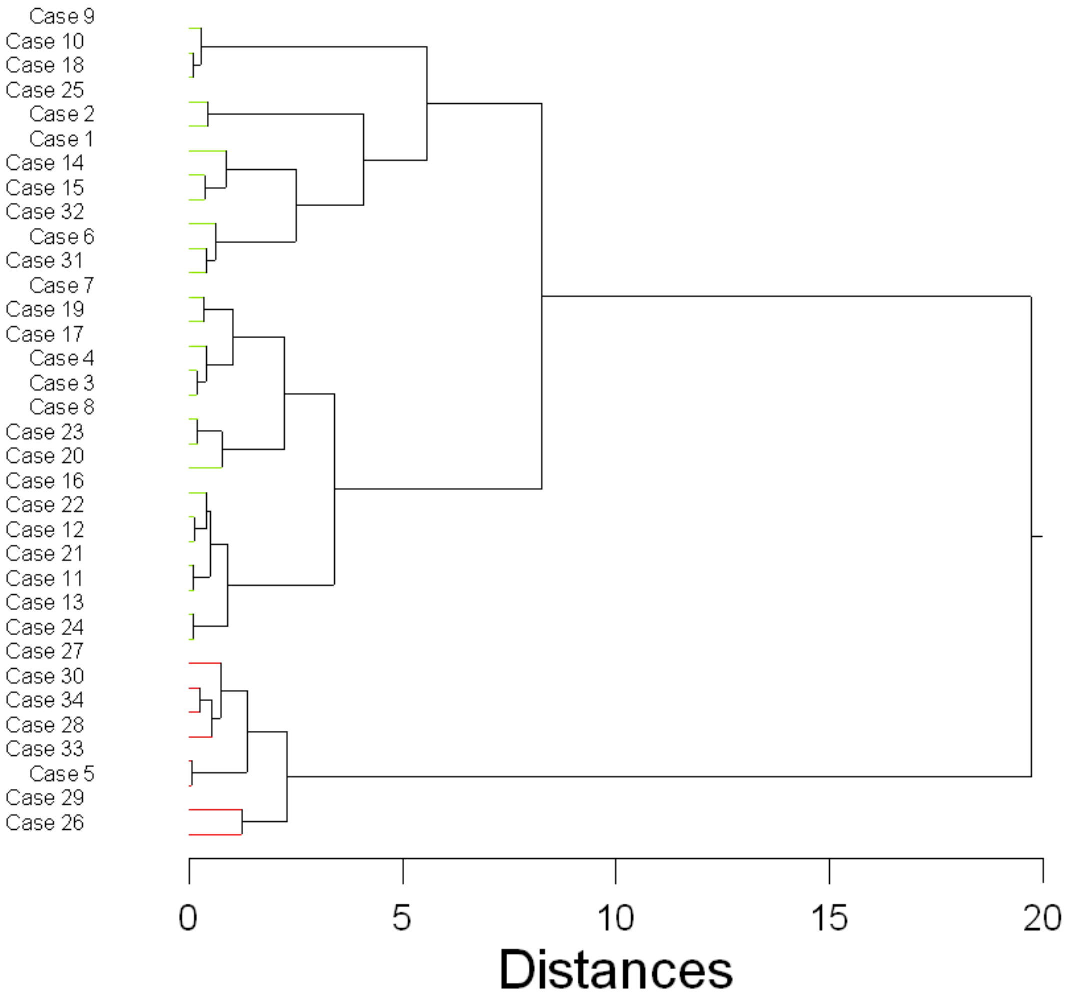
Figure 12.1.11



Dendrogram generated by the Average Linkage HCA on the roof tile PCA data

When this HCA was repeated utilizing the Ward's Linkage method, it generated a very different dendrogram, shown in figure 12.1.12 with its assignments proved in Appendix 12.2; Table 12.2.1. This dendrogram, unlike the Average Linkage method, only generates two distinct geochemical groupings. Again the grouping created by the first order subdivision of this dendrogram contains material primarily from the Enzhou site along with sherd 106.

Figure 12.1.12

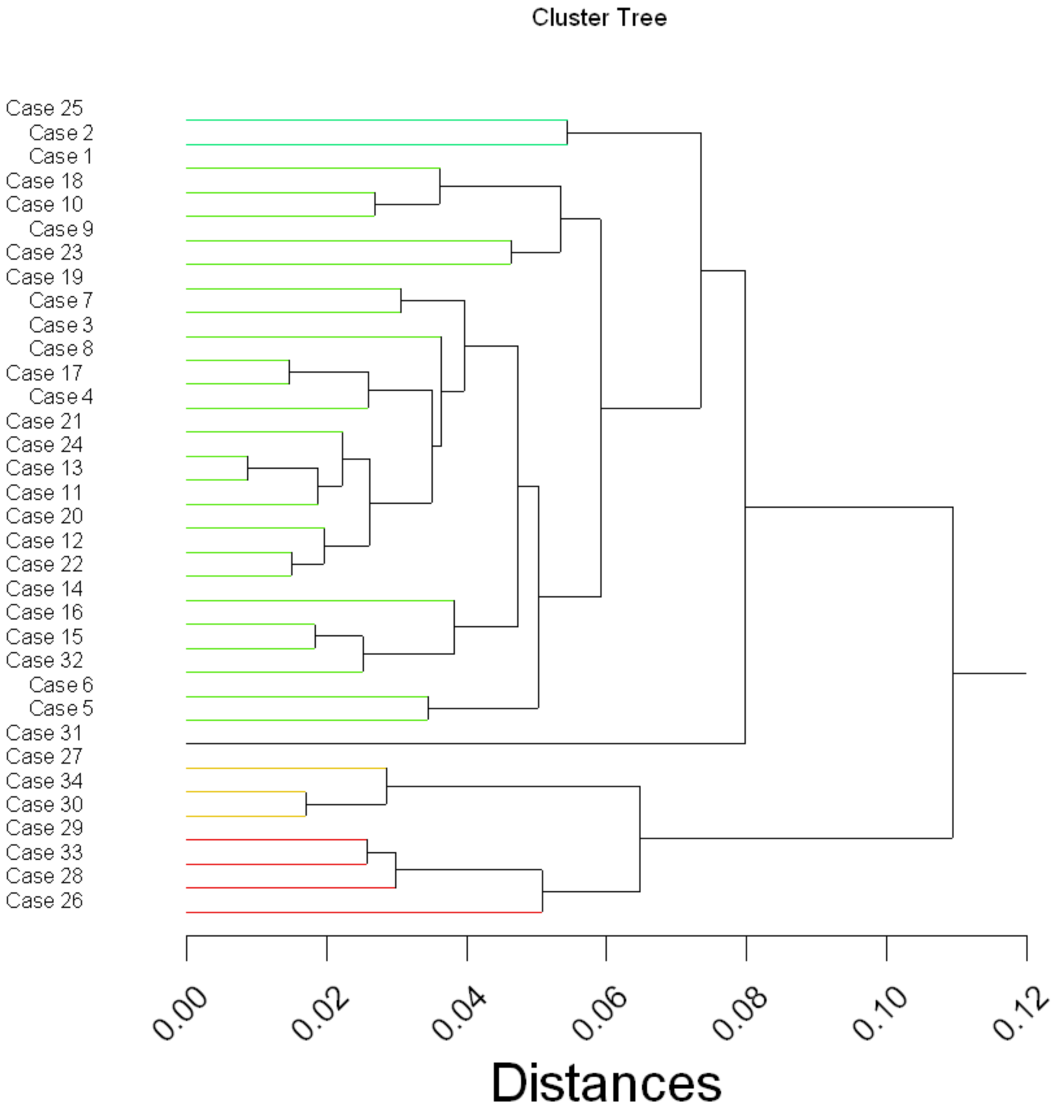


Dendrogram generated by the Ward's method HCA on the roof tile PCA data

12.1.2.4 Standardized Data Hierarchical Cluster Analysis

An HCA was also calculated utilizing the log10 standardized data results instead of the PCA factors. Utilizing the Average Linkage method, this generates a dendrogram with five groupings (Figure 12.1.13) and the resulting assignments are provided in Appendix 12.2; Table 12.2.4. However, these groups are not entirely congruent with those generated by the HCA performed on the PCA factors and are in fact drastically different from all other HCAs performed on this material. Three of the groupings generated correspond primarily to Enzhou site material (one of which contains only the Enzhou 27 sherd) while another contains only sherd 96 and sherd 177.

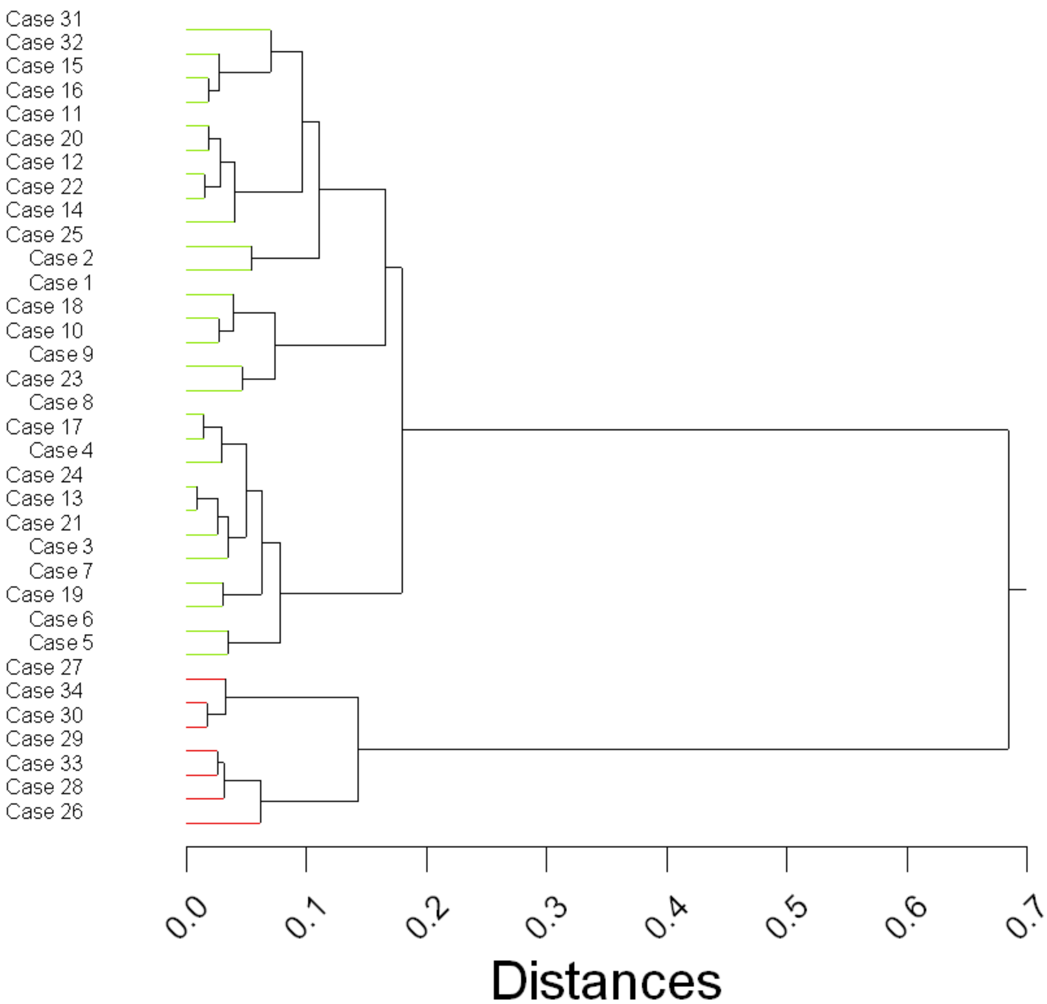
Figure 12.1.13



Dendrogram generated by the Average Linkage HCA on the roof tile Log10 data

When this HCA was again repeated utilizing the Ward's Linkage method, it generated a different dendrogram (see Figure 12.1.14) and the resulting assignments are provided in Appendix 12.2; Table 12.2.1. This dendrogram is mostly congruent with that generated by the Ward's method HCA performed on the PCA results, with the exception that sample 106 is not grouped with the Enzhou material.

Figure 12.1.14

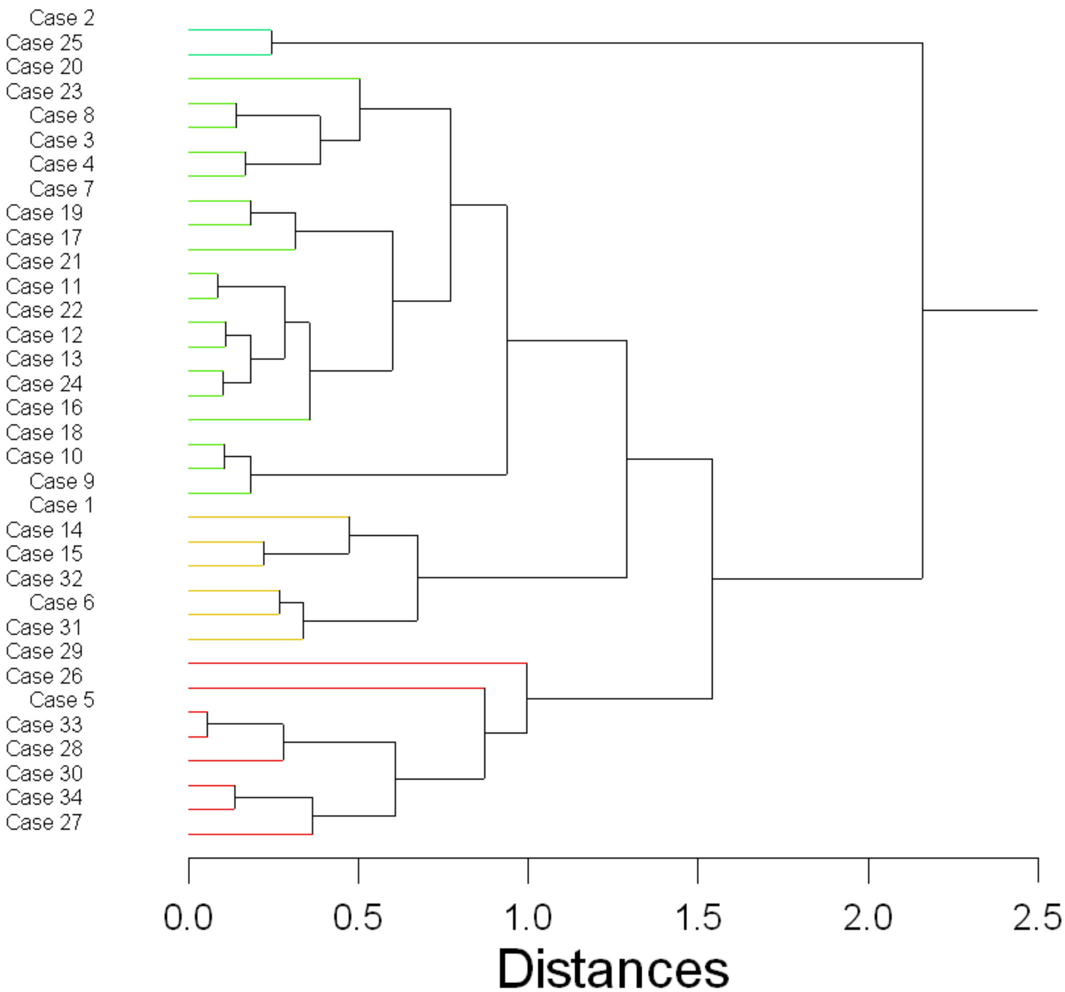


Dendrogram generated by the Ward's method HCA on the roof tile log10 data

12.1.2.5 Mahalanobis Distance HCA

Examination of the initial bivariate plots of the entire dataset (Figure 12.1.1, 12.1.2, 12.1.3) reveals that groupings in this dataset may be elliptical rather than circular (likely due to covariance). The previous HCAs were calculated using the Euclidian distances between the data, however, if groupings are elliptical it would be better to use the Mahalanobis distances instead (Glascock, et al. 2004). As mentioned above, the main limitation of the Mahalanobis distance method is that groupings are not reliable if they are not larger than the number of variables used (2004). In order to account for this possibility a further two HCAs were calculated utilizing the PCA data since this data has only two variables. The first Mahalanobis HCA uses the Average Linkage method (see Figure 12.1.15) and identifies four groupings, provided in Appendix 12.2; Tables 12.2.3. One of these groupings yet again proves to be primarily composed of Enzhou material along with sample 106.

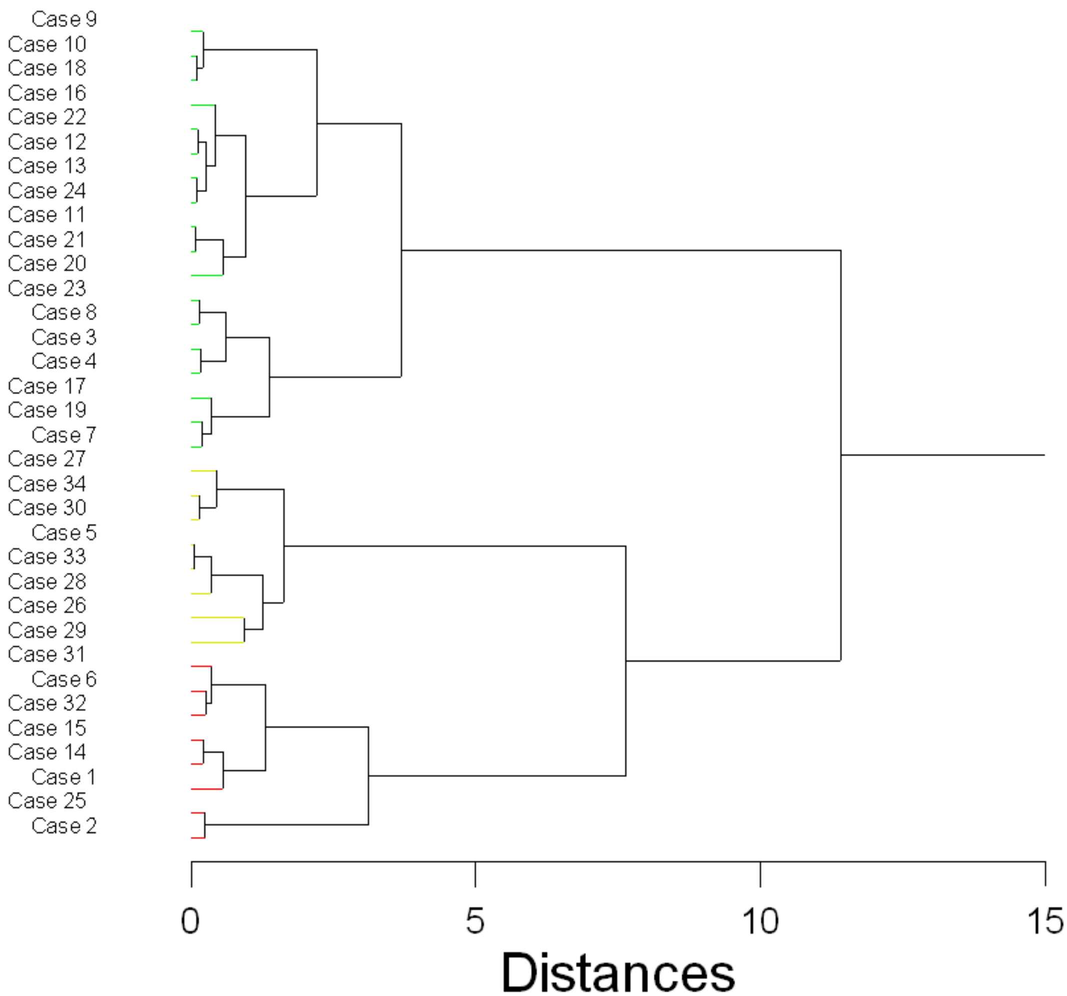
Figure 12.1.15



Dendrogram generated by the Average Linkage Mahalanobis distance HCA on the roof tile PCA data

The second Mahalanobis distance HCA uses the Ward's Linkage method (see figure 12.1.16) and identifies three groupings, provided in Appendix 12.2; Tables 12.2.2. Once more, one of these groupings is the exact same samples from the Enzhou site that have appeared in all of the other HCA dendrograms, along with sample 106.

Figure 12.1.16



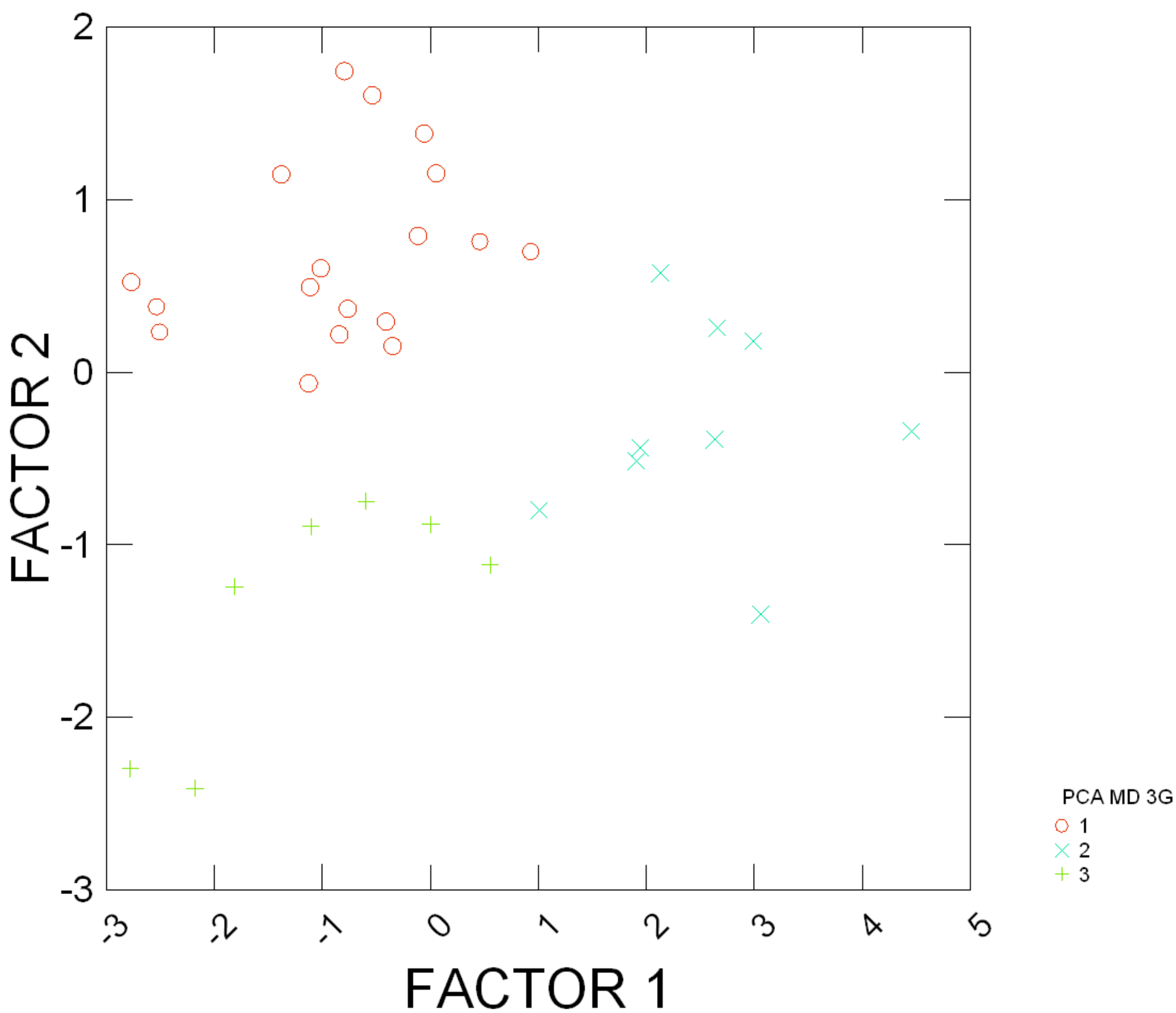
Dendrogram generated by the Ward's Method Mahalanobis distance HCA on the roof tile PCA data

12.1.2.6 K-Means Cluster Analysis

A K-MCA was performed for each of the HCAs in order to verify the reproducibility of the results, with congruency between HCA and K-MCA assignments taken as a strong indication that the results are not produced solely by the method used. HCAs performed on Mahalanobis distances were assessed using K-MCAs calculated using Mahalanobis distances while HCAs performed on Euclidian distances were assessed using K-MCAs calculated using Euclidian distances.

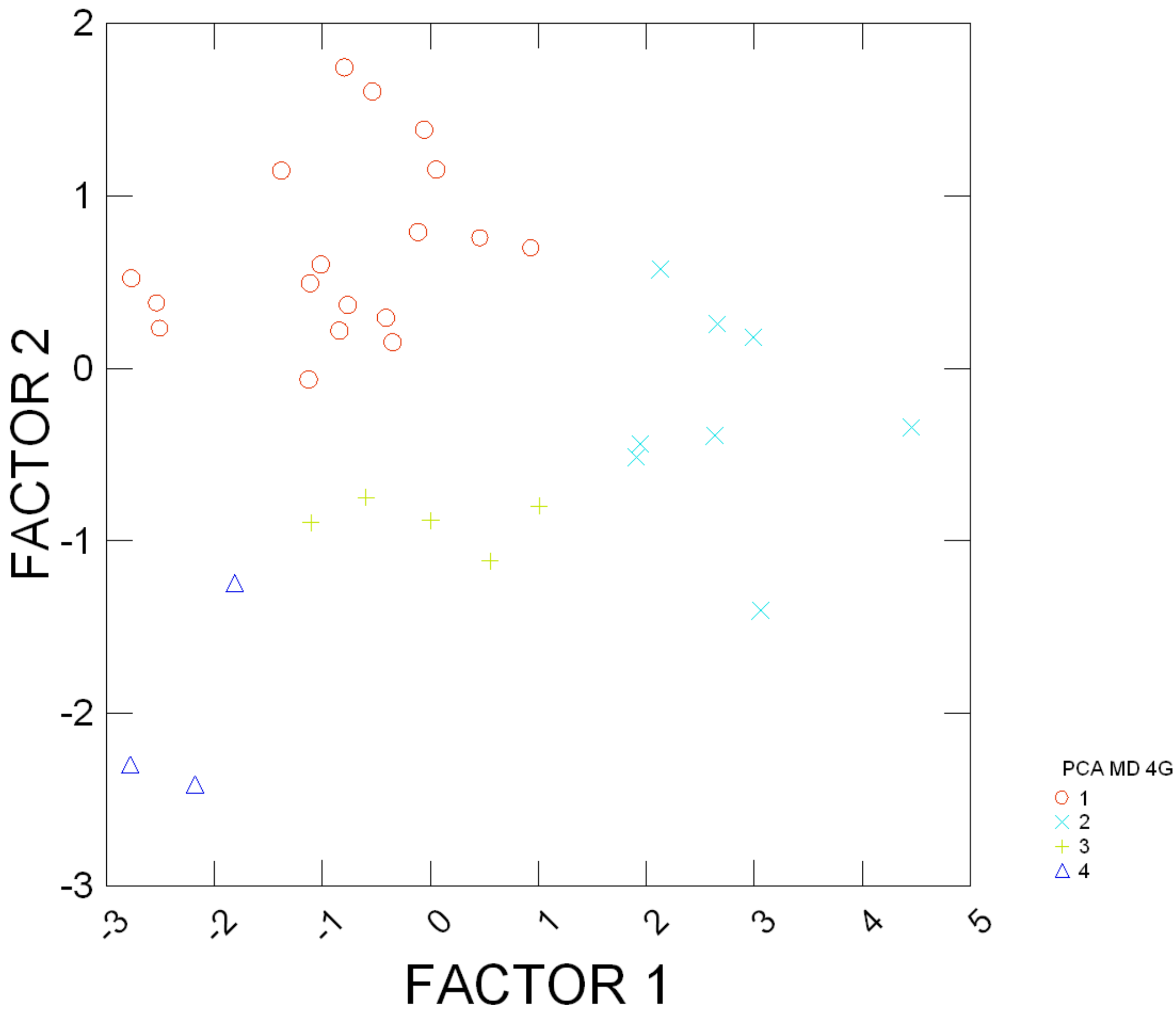
Two Mahalanobis K-MCAs were performed on the PCA factor data at 100 iterations and were instructed to generate four and three clusters respectively, to match the two MD HCA dendrograms generated from this data (See figures 12.1.17 and 12.1.18). The resulting assignments are presented in Appendix 12.2; Tables 12.2.2. And 12.2.3. The three cluster K-MCA exhibits perfect congruence with the associated HCA, generating exactly the same clusters while the four cluster K-MCA has only slightly worse congruence with its associated dendrogram, with only one sample assigned to a different cluster.

Figure 12.1.17



Bivariate plot of the roof tile PCA data grouped using the Mahalanobis distance K-MCA with three clusters

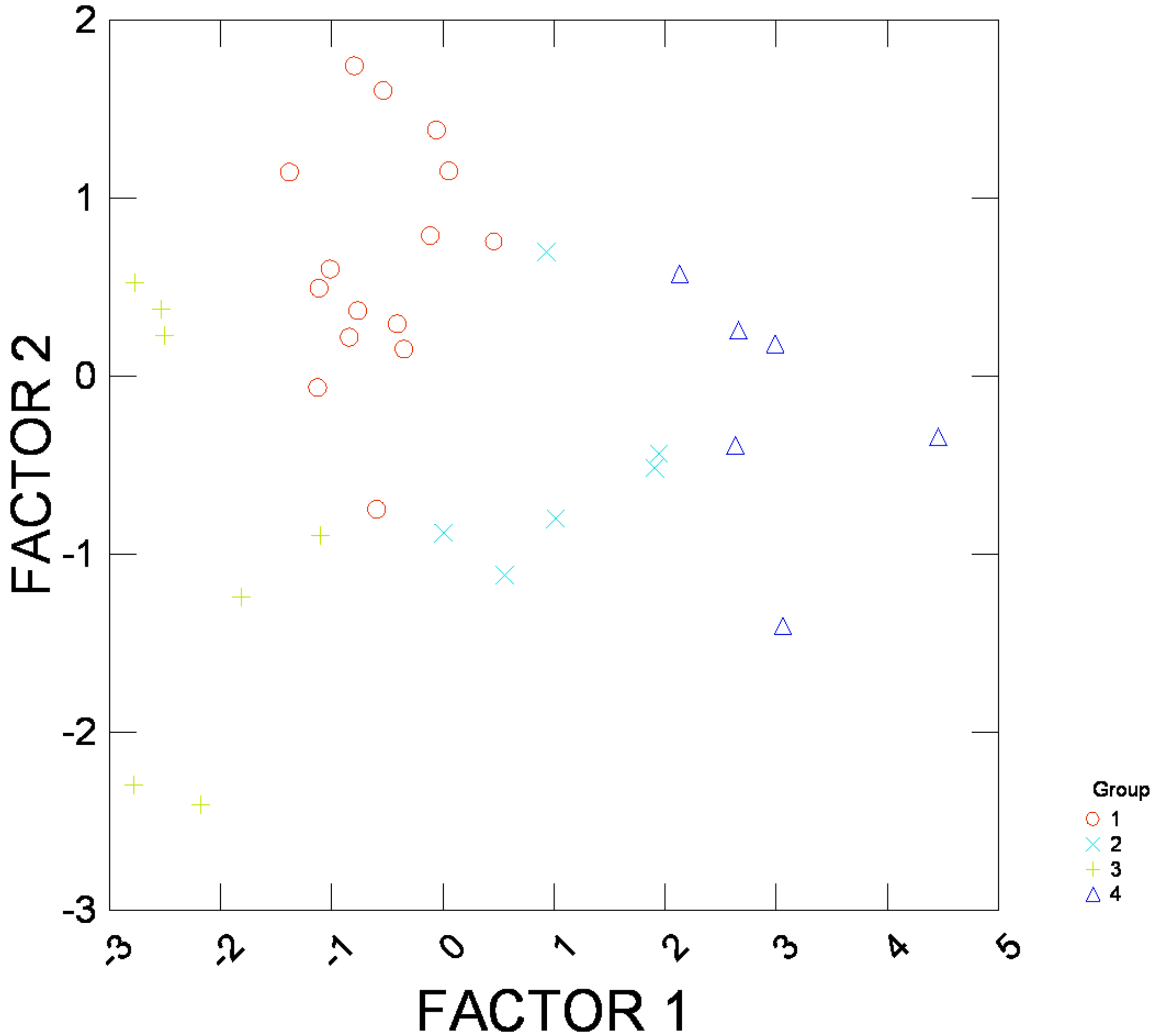
Figure 12.1.18



Bivariate plot of the roof tile PCA data grouped using the Mahalanobis distance K-MCA with four clusters

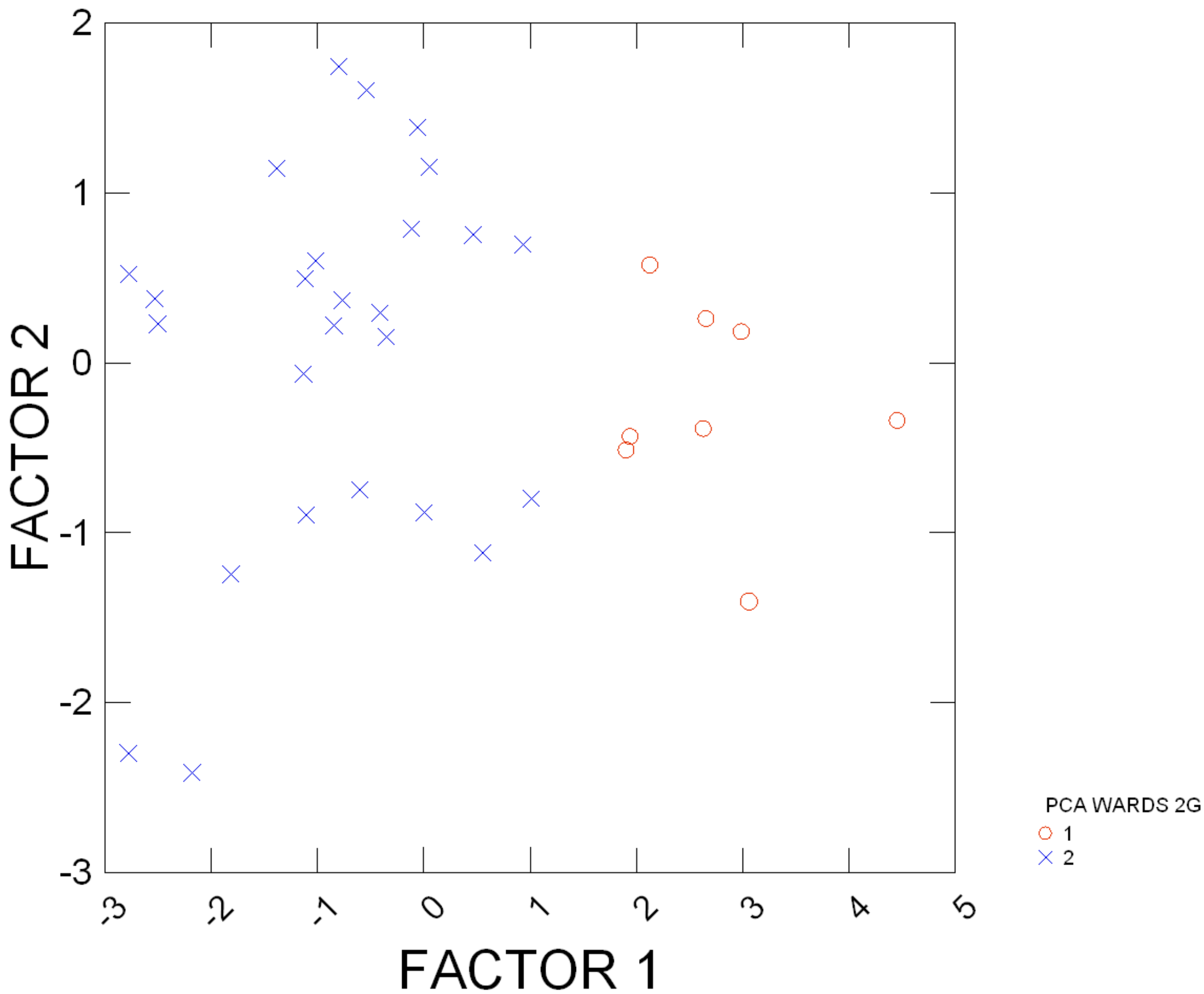
Two Euclidian K-MCAs were performed on the PCA data at 100 iterations and the resulting assignments are provided in Appendix 12.2; Tables 12. And 12.2.3. The KMCA told to generate four clusters is only semi-congruent with its associated dendrogram (the PCA HCA using Average Linkage); however, it still identifies the primarily Enzhou grouping, although the other groupings are largely non-congruent (See Figure 12.1.19). If the K-MCA is told to generate only two clusters, however, congruence is much improved and only three samples are classified differently. The primarily Enzhou grouping is slightly over-identified (based on the shape of the grouping in the associated graph) but overall there is good congruence with the Ward's method hierarchical cluster analysis of this data (see Figure 12.1.20).

Figure 12.1.19



Bivariate plot of the roof tile PCA data grouped using the K-MCA with four clusters

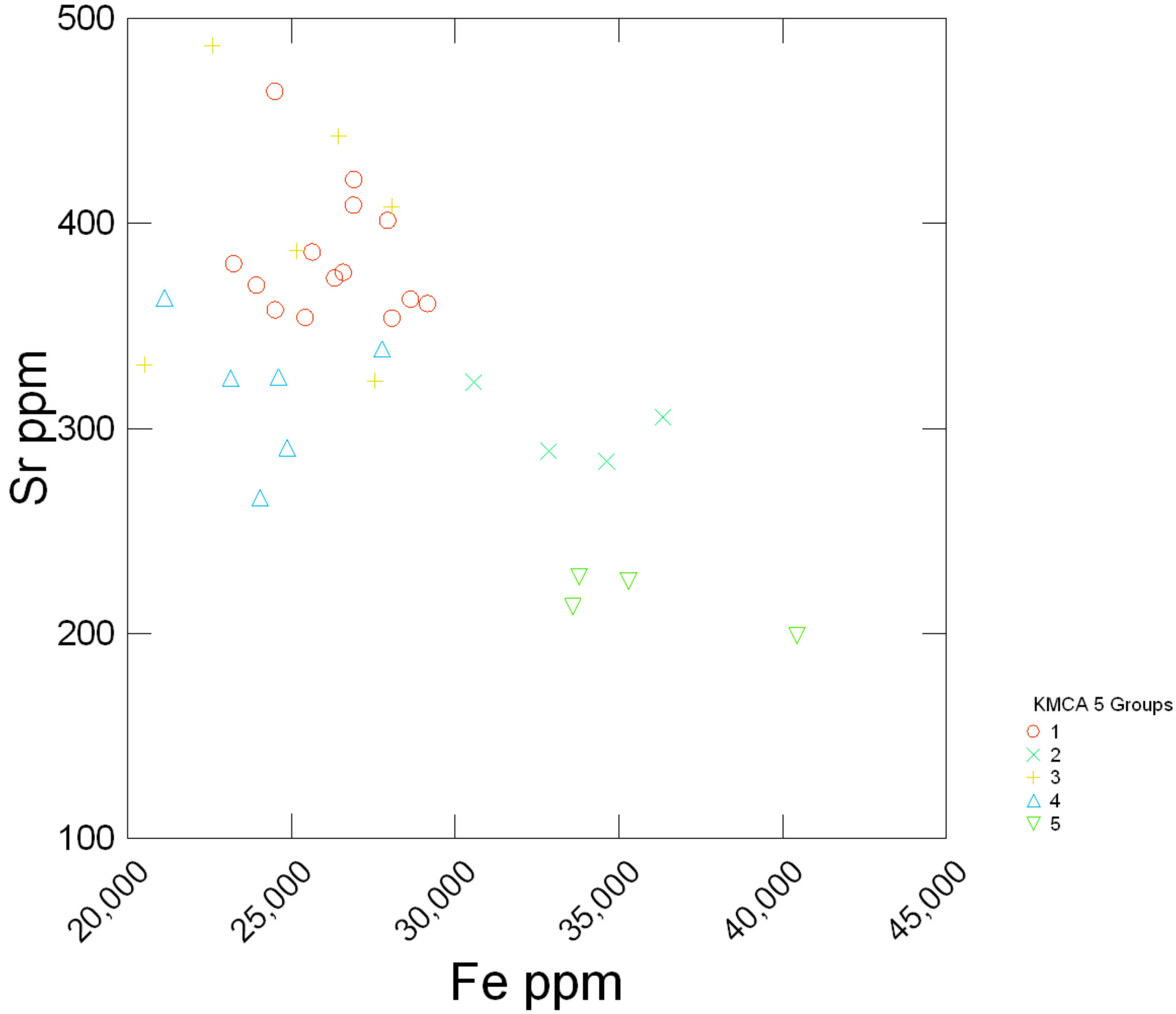
Figure 12.1.20



Bivariate plot of the roof tile PCA data grouped using the K-MCA with two clusters

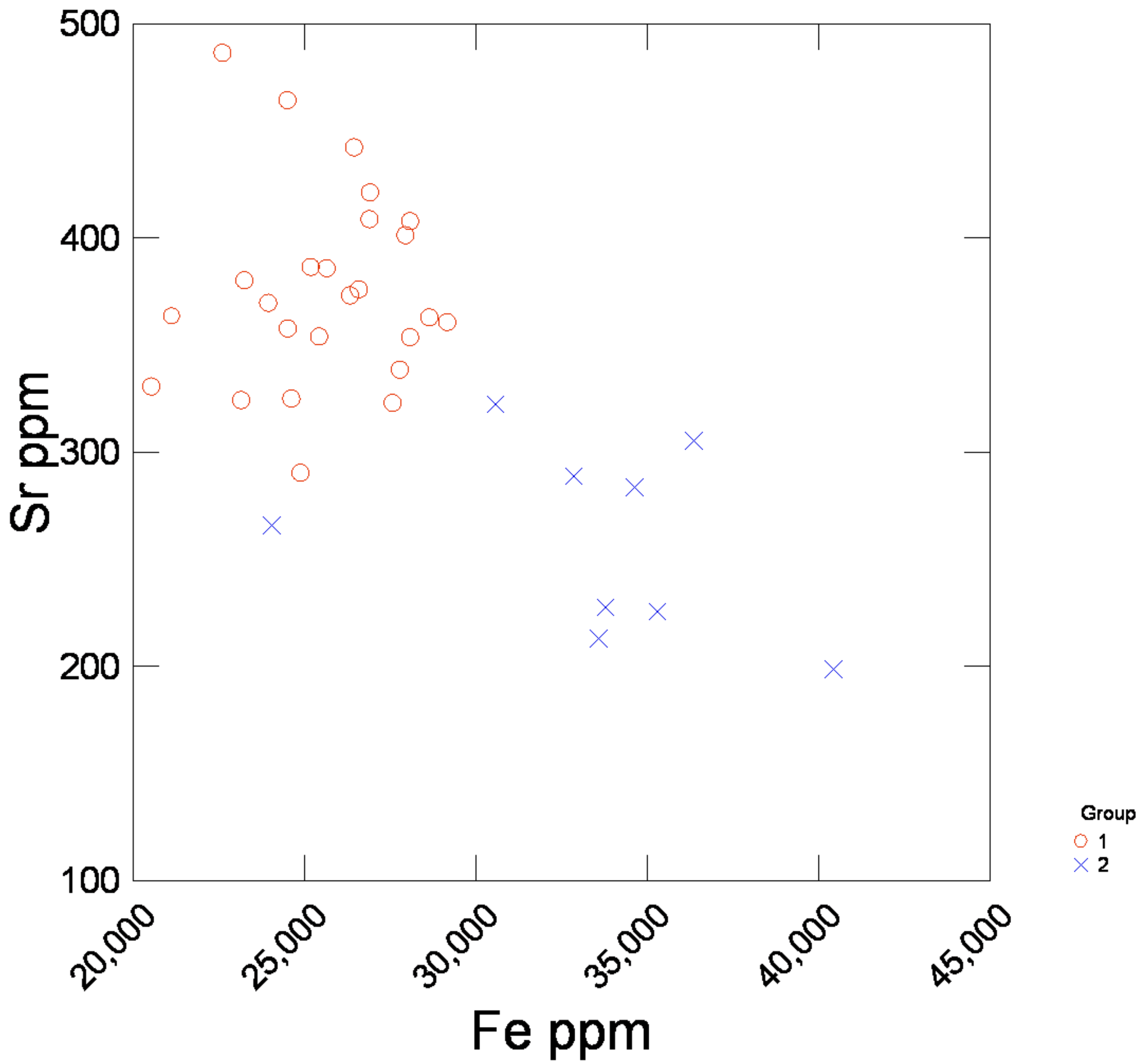
Two Euclidian K-MCAs were also performed on the log10 standardized data at 100 iterations and the resulting assignments are provided in Appendix 12.2; Tables 12.2.1 and 12.2.4. The K-MCA on the log10 transformed data instructed to generate five clusters again separates much of the Enzhou material into two groupings semi-congruent with the associated dendrogram; however, the other groupings are non-congruent which indicates some degree of method dependency to the results. If the K-MCA is told instead to fit two clusters, it exhibits a much greater degree of congruence as it differs from the Ward's Method HCA of this data by attributing only three samples differently, two to the primarily Enzhou (and sample 106) cluster and one to the primarily non-Enzhou cluster.

Figure 12.1.21



Bivariate plot of the roof tile Log10 data grouped using the K-MCA with five clusters

Figure 12.1.22



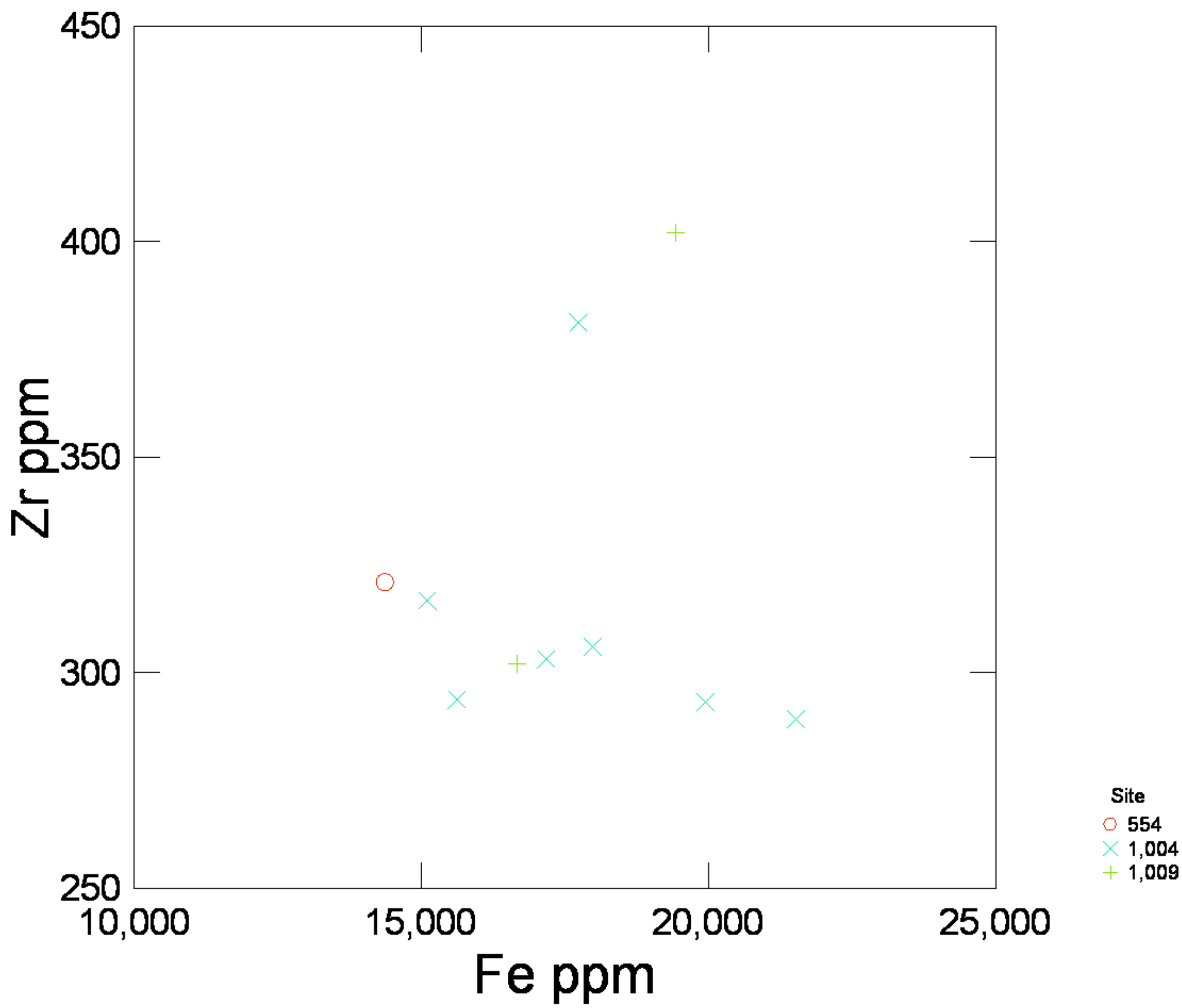
Bivariate plot of the roof tile Log10 data grouped using the K-MCA with two clusters

12.1.3 Glazed Sherds

12.1.3.1 Bivariate Plots

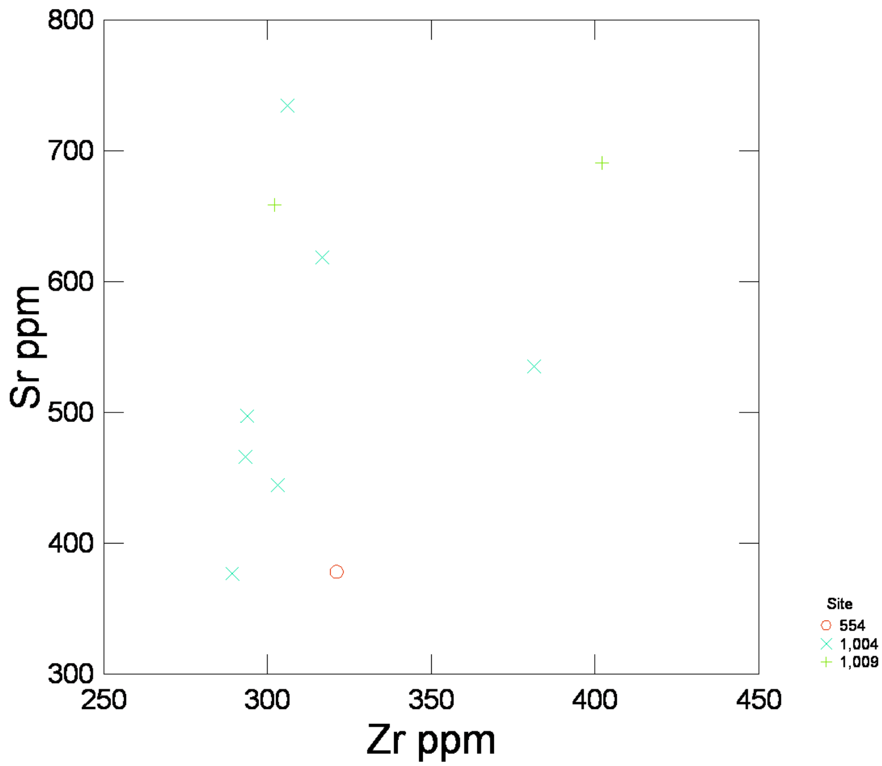
Simple bivariate plots of the samples with glazed surfaces (all of which are sherds of white glazed stoneware) reveal that in this case sherd geochemistry seems to again have little relationship with site locality from which the sherd was collected, or not one that can be distinguished on bivariate plots alone. However, several possible groupings are present in the data (Figure 12.1.23) (these groupings are suspect due to simple spatial information which will be discussed later), although group membership appears to change from plot to plot (Figures 12.1.24 and 12.1.25) rendering bivariate plots a poor method of grouping samples.

Figure 12.1.23



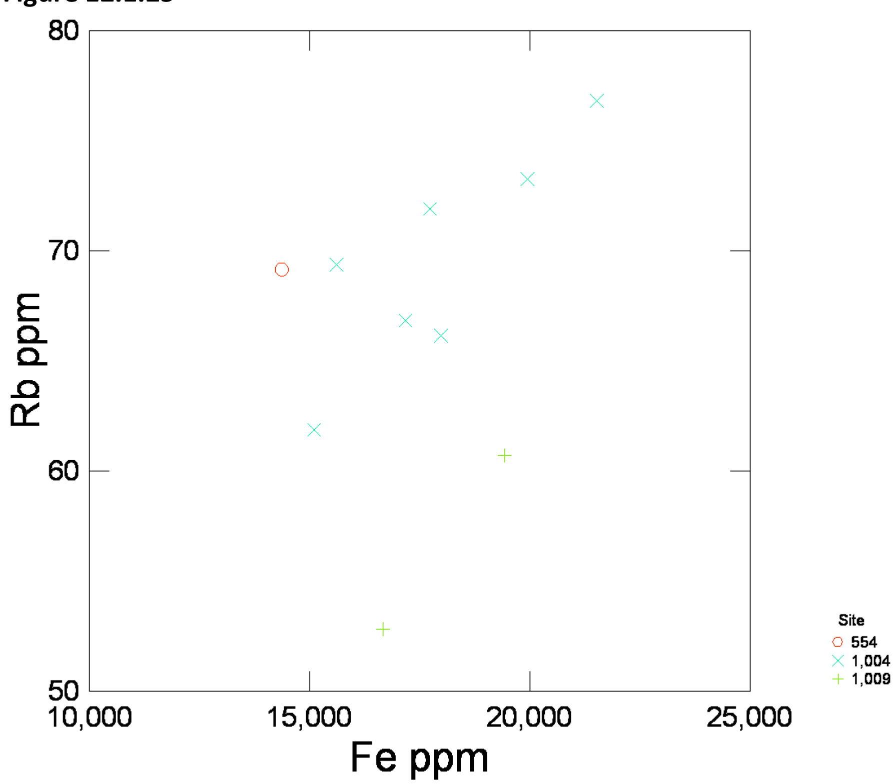
Bivariate plot of Fe ppm vs. Zr ppm for the glazed sherd data

Figure 12.1.24



Bivariate plot of Sr ppm vs. Zr ppm for the glazed sherd data

Figure 12.1.25

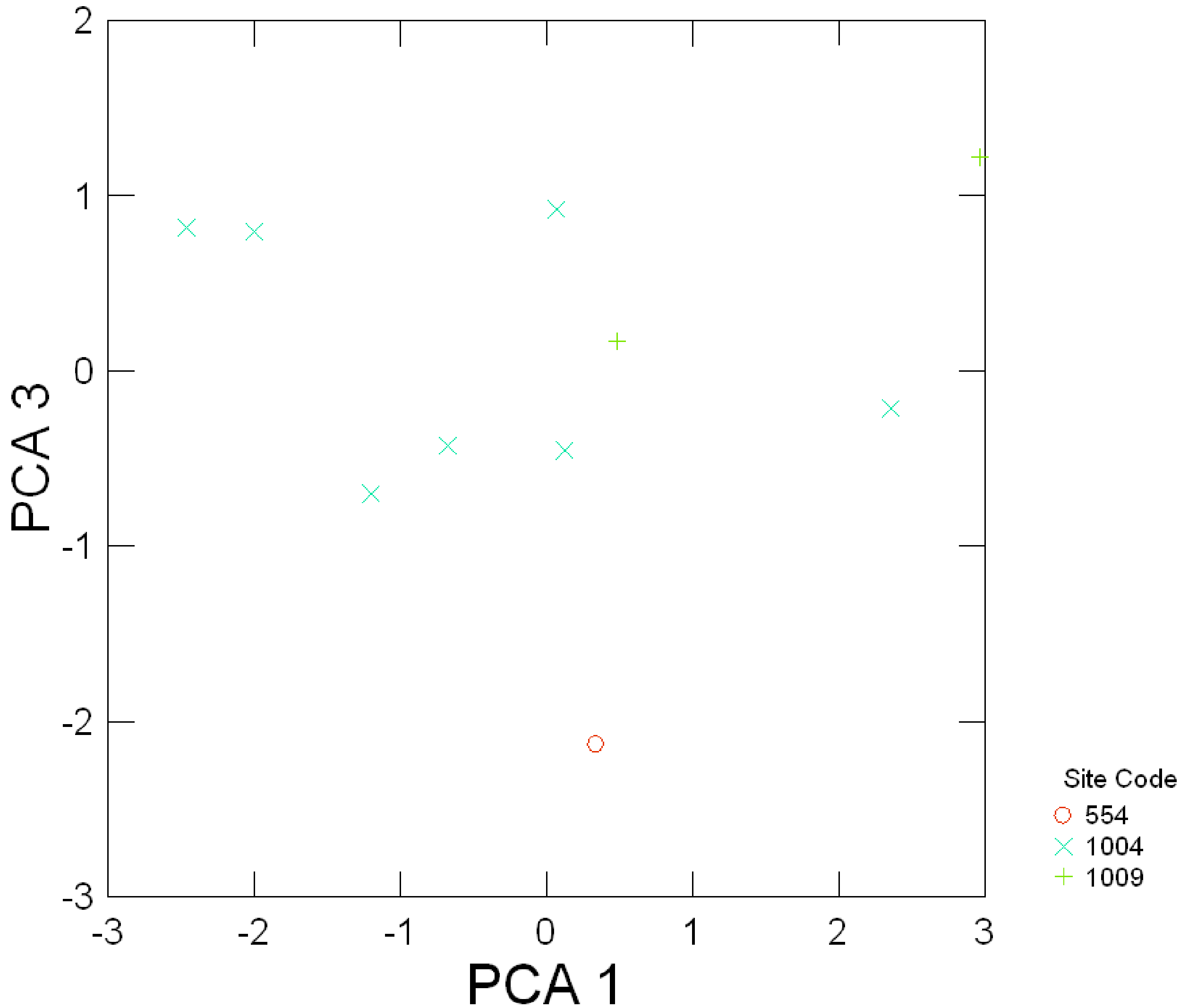


Bivariate plot of Rb ppm vs. Fe ppm for the glazed sherd data

5.3.2 Principal Component Analysis

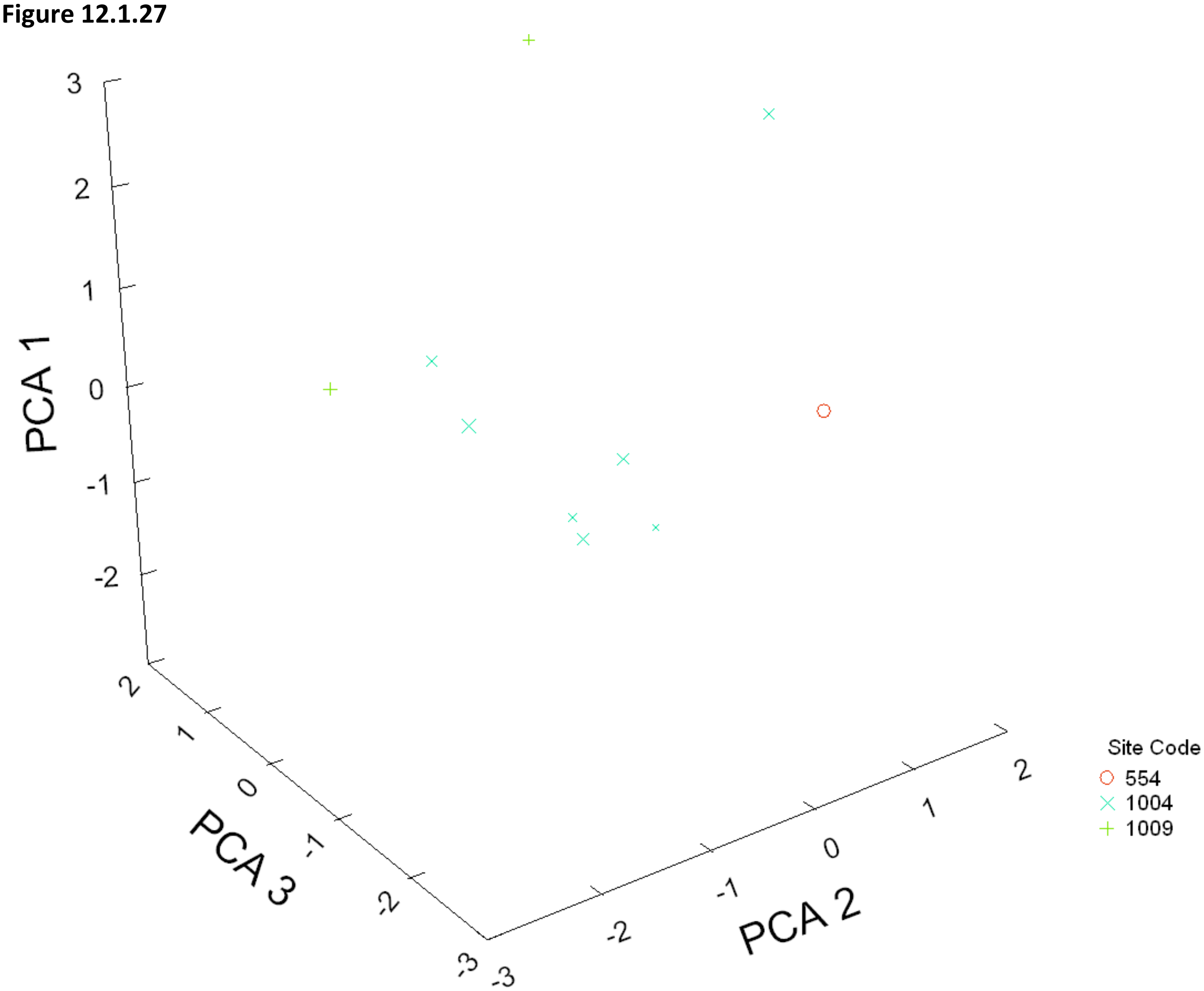
The PCA of the glazed sherd data (using all of the elements measured) provides three factors with an Eigen value over 1.0. These factors explain 49.4%, 25.2% and 16.9% of the total variation in the data respectively. Simple bivariate plots of these factors reveal several possible clusters however these clusters shift membership depending on the factor combination used and are difficult to see in a tri-variate plot of all factors together (Figure 12.1.26). One commonality, however, is that factor 3 seems to separate sample 79 (from site 554) out from the other samples (Figure 12.1.27)

Figure 12.1.26



Bivariate plot of glazed sherd PCA Factor 1 vs. PCA Factor 2.

Figure 12.1.27

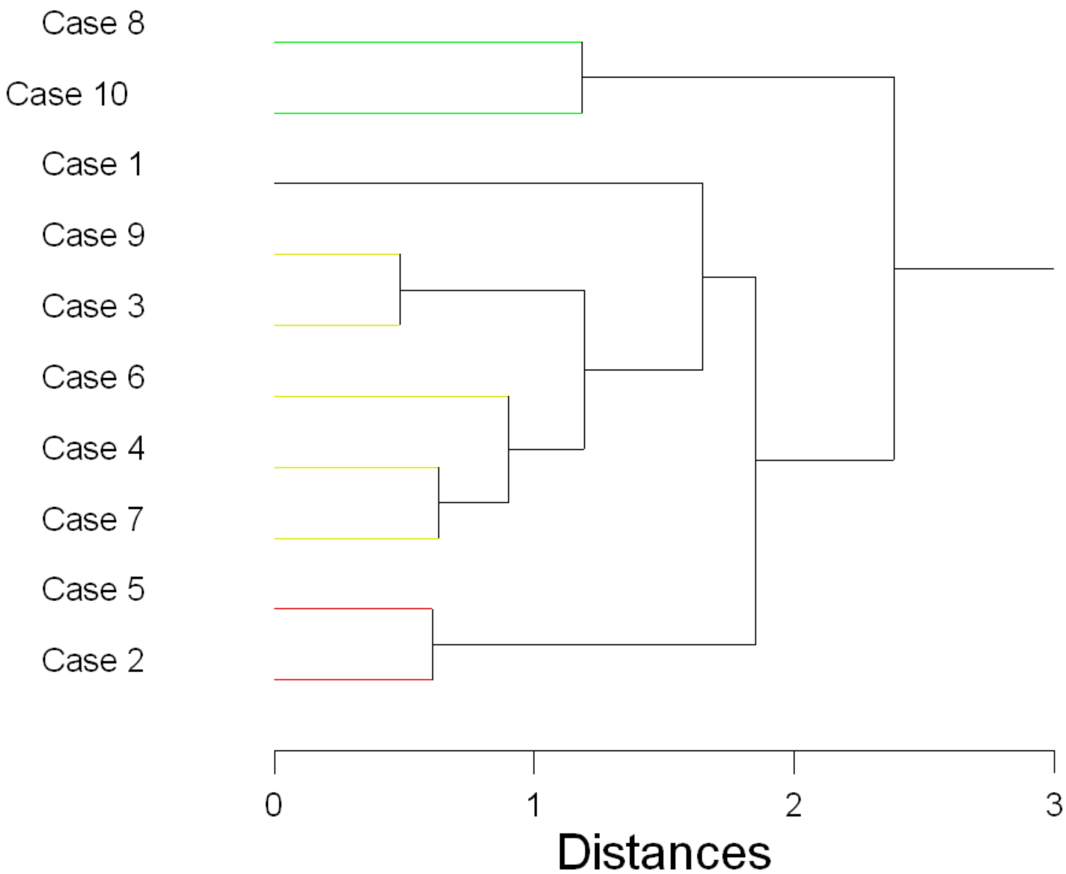


Trivariate plot of glazed sherd PCA Factor 1 vs. PCA Factor 2 vs. PCA Factor 3

5.3.3 PCA Hierarchical Cluster Analysis

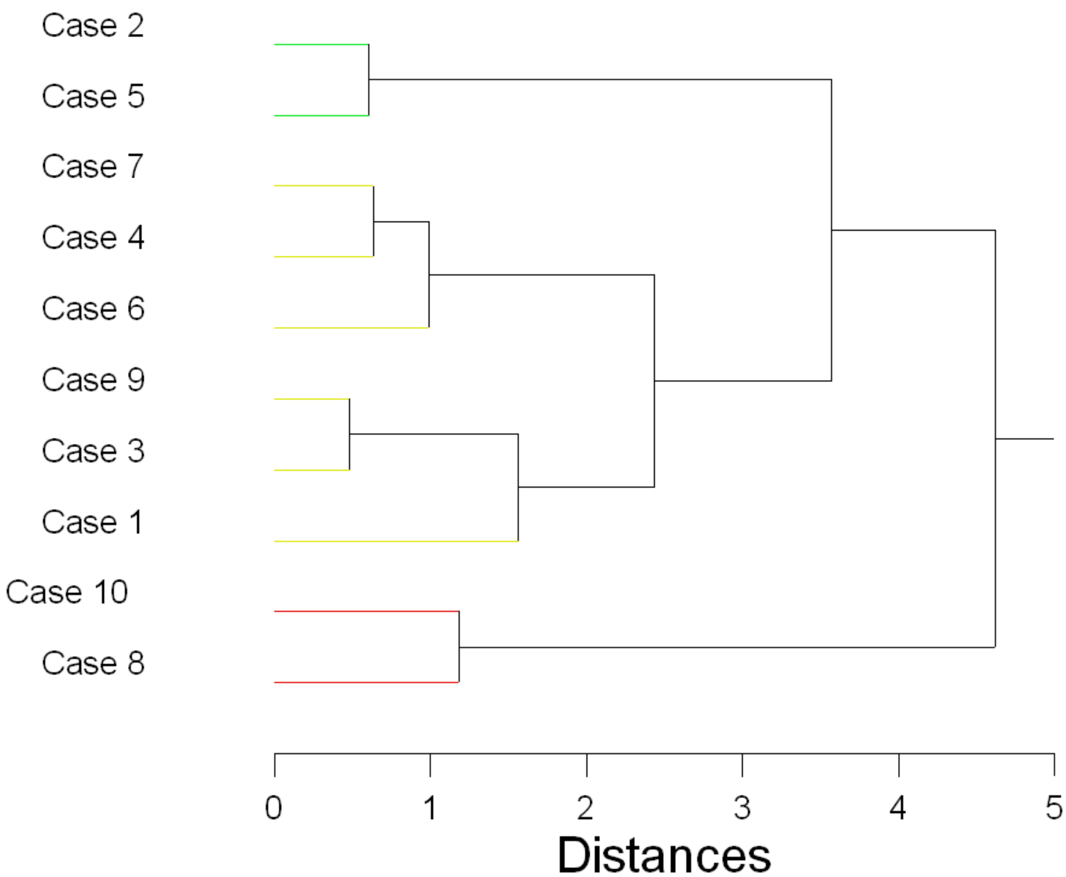
The three factors provided by the PCA results were used to perform two Euclidian HCAs, as above, one utilized the Average Linkage method and one utilized the Ward's method. These generated the dendrograms provided in Figure 12.1.28 and Figure 12.1.29 respectively, and the resulting assignments are found in Appendix 12.2; Tables 12.2.7 and 12.2.6 respectively. The Average Linkage method identifies four groupings while the Ward's method identifies three groupings. Notably, only the Average Linkage method separates out sample 79, which based on PCA bivariate plots (see above figure 12.1.27) would seem to be quite distinct.

Figure 12.1.28



Dendrogram generated by the Average Linkage HCA of the glazed sherd PCA data

Figure 12.1.29

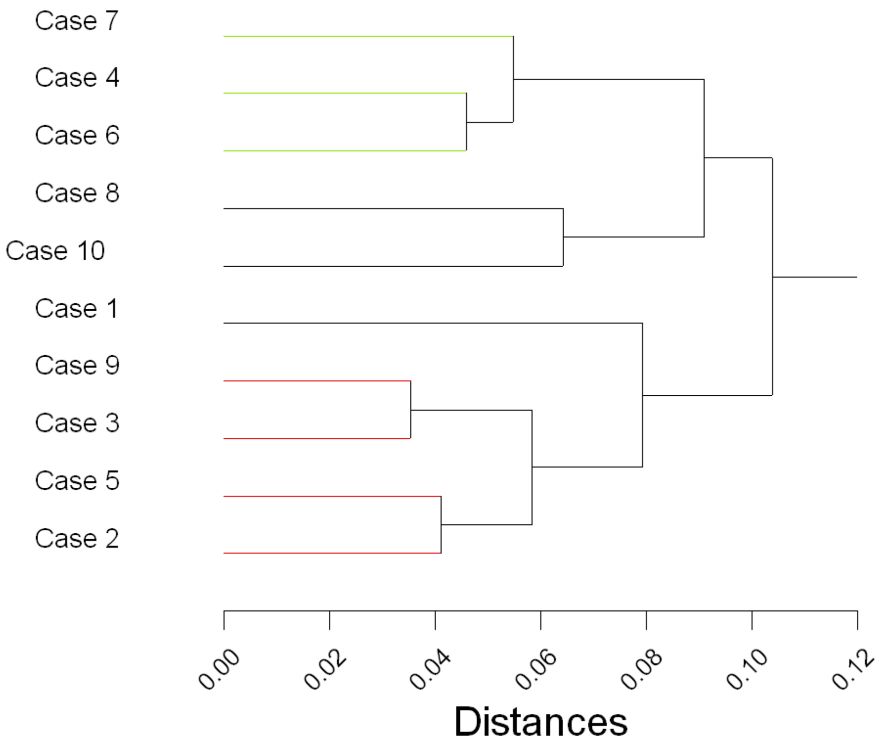


Dendrogram generated by the Ward's Method HCA of the glazed sherd PCA data

12.1.3.4 Standardized data Hierarchical Cluster Analysis

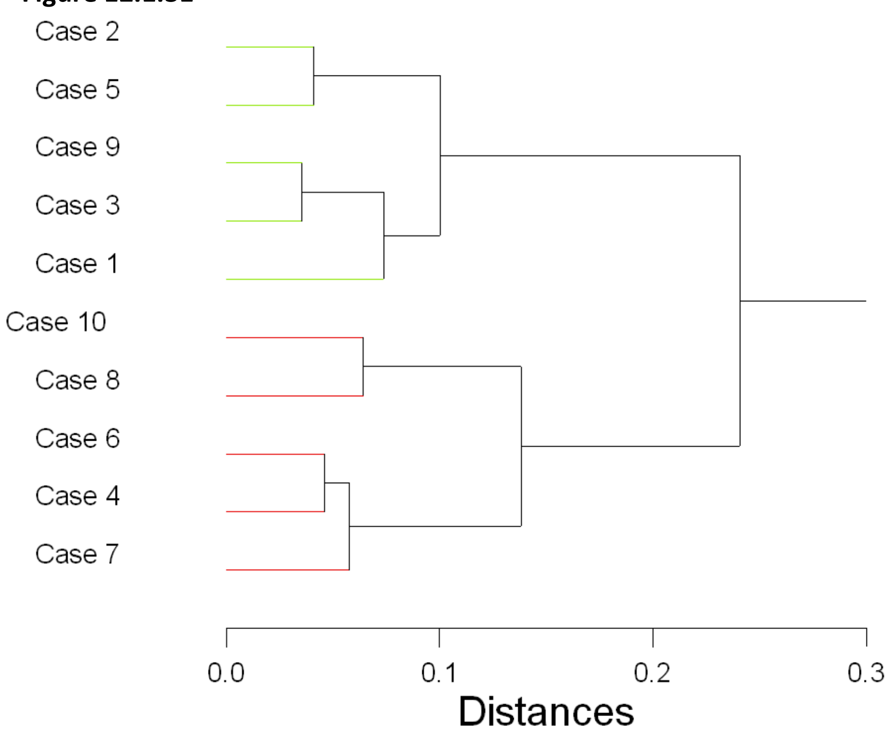
As with the roof tiles, two HCAs were performed on the standardized log10 data with Euclidian distances and both the Average Linkage and Ward's methods. These analyses generated the two dendrograms in Figures 12.1.30 and 12.1.31 and the resulting assignments are provided in Appendix 12.2; Tables 12.2.8 and 12.2.5. The Average Linkage method generates five groupings, however three of these have only one member and notably sample 79 is one of these. The Ward's method on the other hand generated only two groupings and did not separate out sample 79.

Figure 12.1.30



Dendrogram generated by the Average Linkage HCA of the Log10 glazed sherd data

Figure 12.1.31

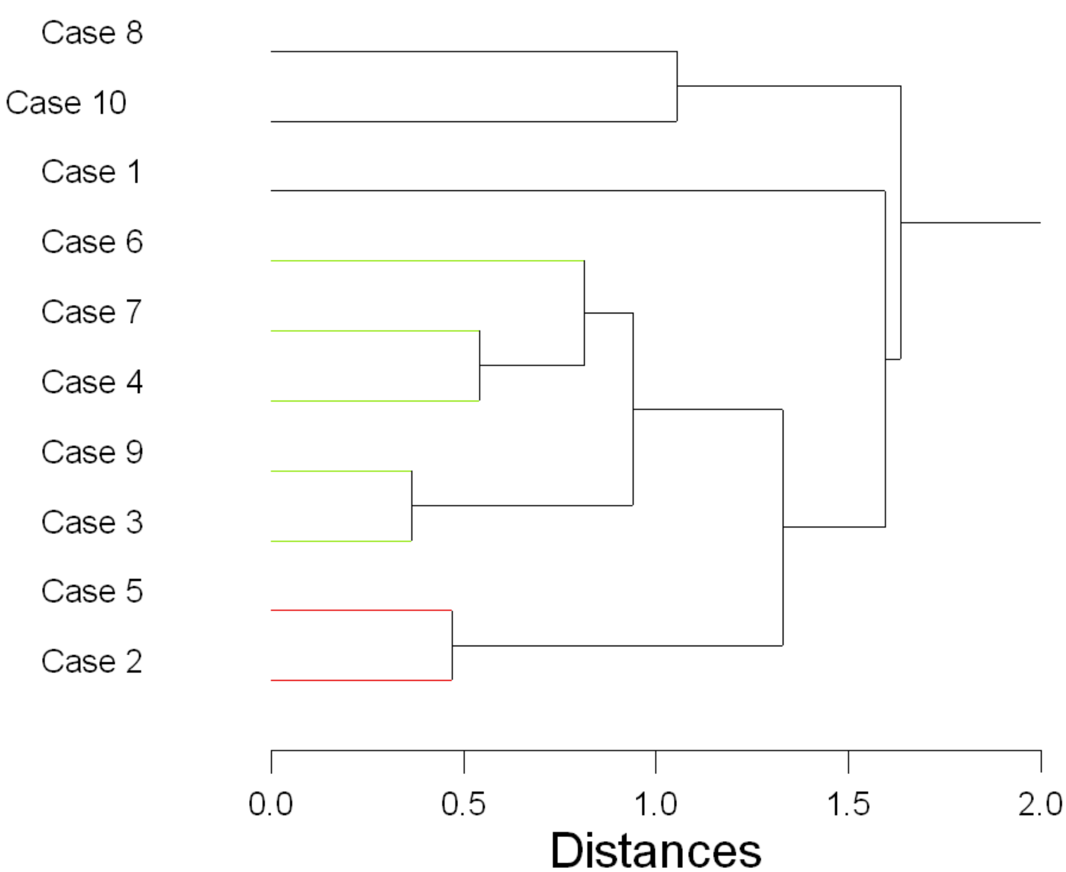


Dendrogram generated by the Ward's Method HCA of the Log10 glazed sherd data

12.1.3.5 Mahalanobis Distance HCA

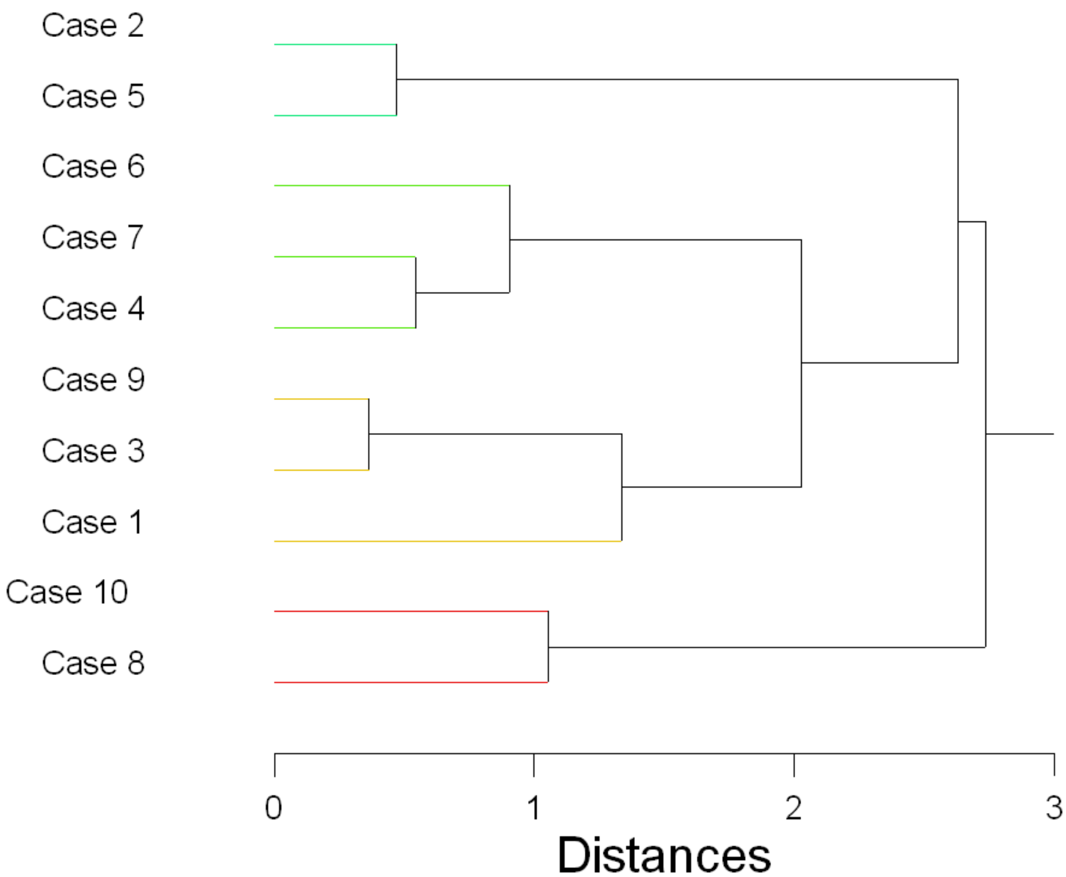
As with the roof tiles above, a further two HCAs were performed on the PCA data utilizing Mahalanobis distances and both the Average Linkage and Ward's methods. The dendrograms generated by these analyses are shown in Figures 12.1.32 and 12.1.33. The Average Linkage method generates five groupings and the Ward's method generates three groupings and the assignments for these groupings are provided in Appendix 12.2; Tables 12.2.8 and 12.2.6.

Figure 12.1.32



Dendrogram generated by the Mahalanobis Distance Average Linkage HCA of the glazed sherd PCA data

Figure 12.1.33 PCA MD HCA WARD method dendrogram

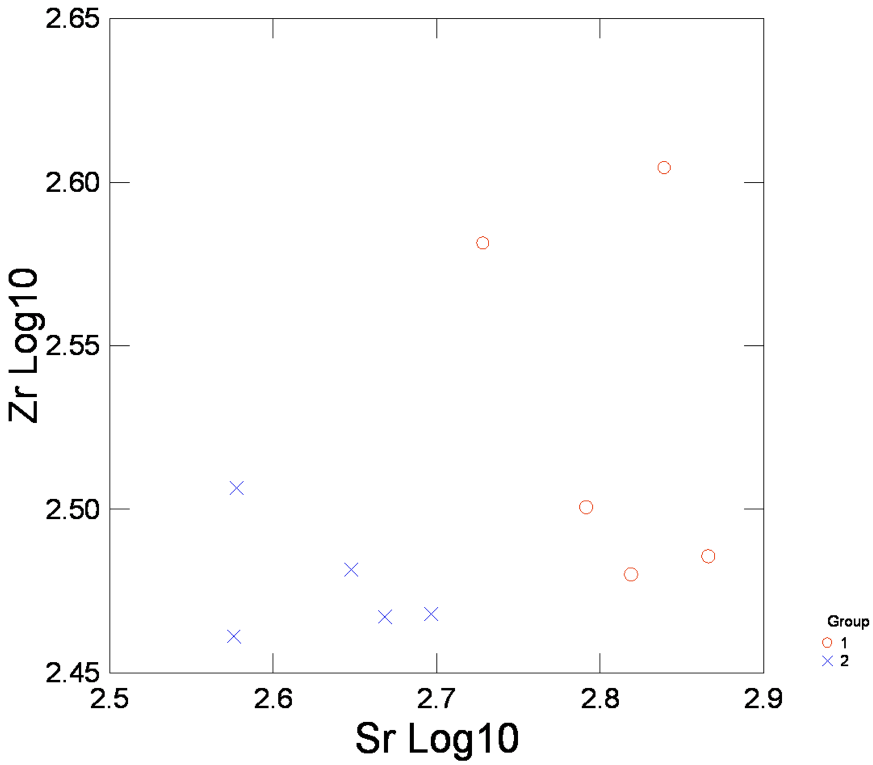


Dendrogram generated by the Mahalanobis Distance Ward's Method HCA of the glazed sherd PCA data

12.1.3.6 K-Means Cluster Analysis

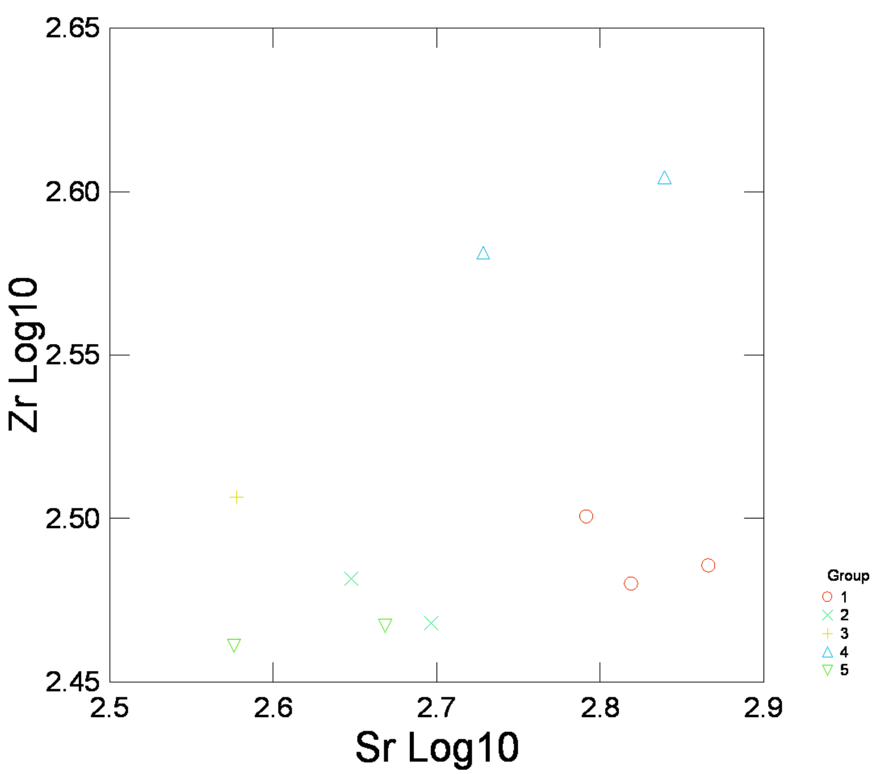
K-means cluster analyses were conducted for each of the previously mentioned HCA's utilizing the same base data, a matching distance measure (Euclidian or Mahalanobis) and were instructed to create the same number of clusters. The clusters created are shown in Figures 12.1.34, 12.1.35, 12.1.36, 12.1.37, 12.1.38 and 12.1.39 with the resulting assignments presented in Appendix 12.2; Tables 12.2.5, 12.2.6, 12.2.7 and 12.2.8. The assignments generated by the K-MCAs have good to perfect congruence with the HCAs that identify under five groupings. The five grouping K-MCAs (those produced using the Average Linkage method on the log10 data and Mahalanobis PCA data) show only moderate to very poor congruence, casting doubt on the presence of more than four groupings.

Figure 12.1.34



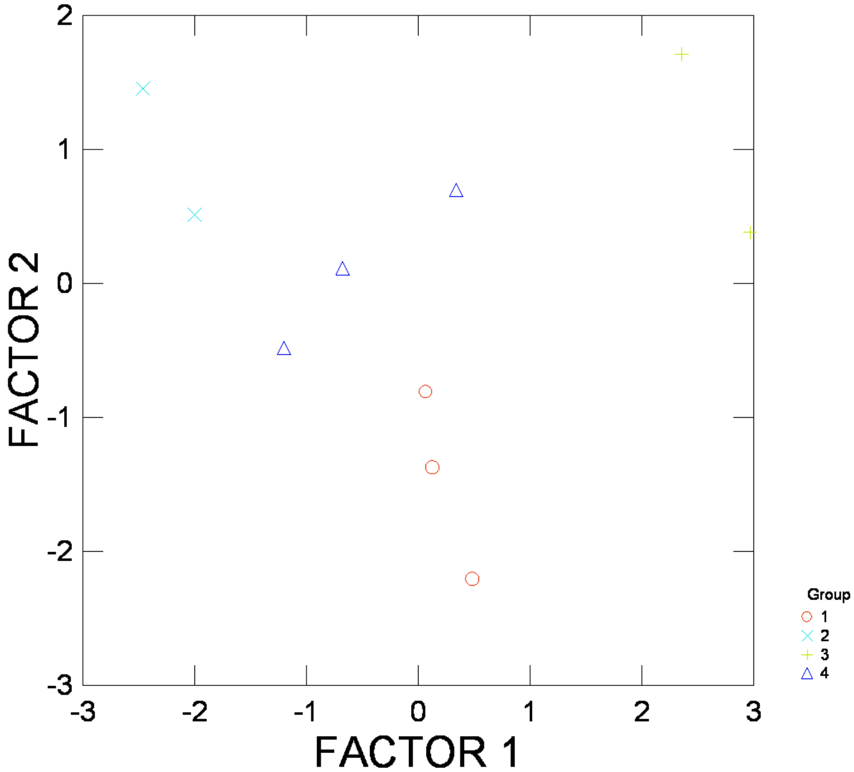
Bivariate plot of the glazed sherd Log10 data grouped using the K-MCA with two clusters

Figure 12.1.35



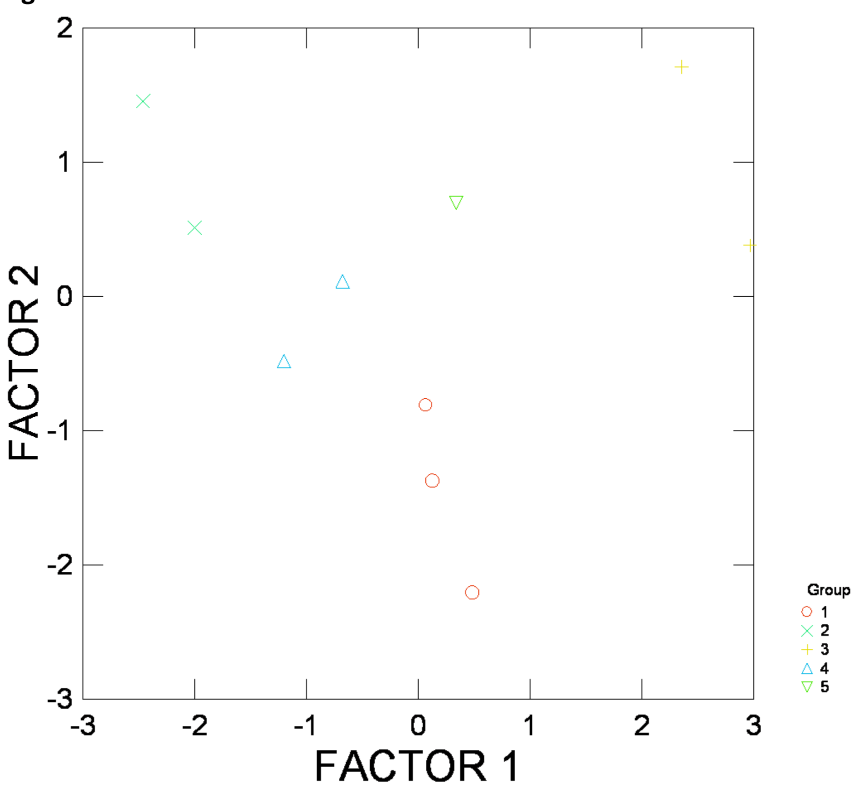
Bivariate plot of the glazed sherd Log10 data grouped using the K-MCA with five clusters

Figure 12.1.36



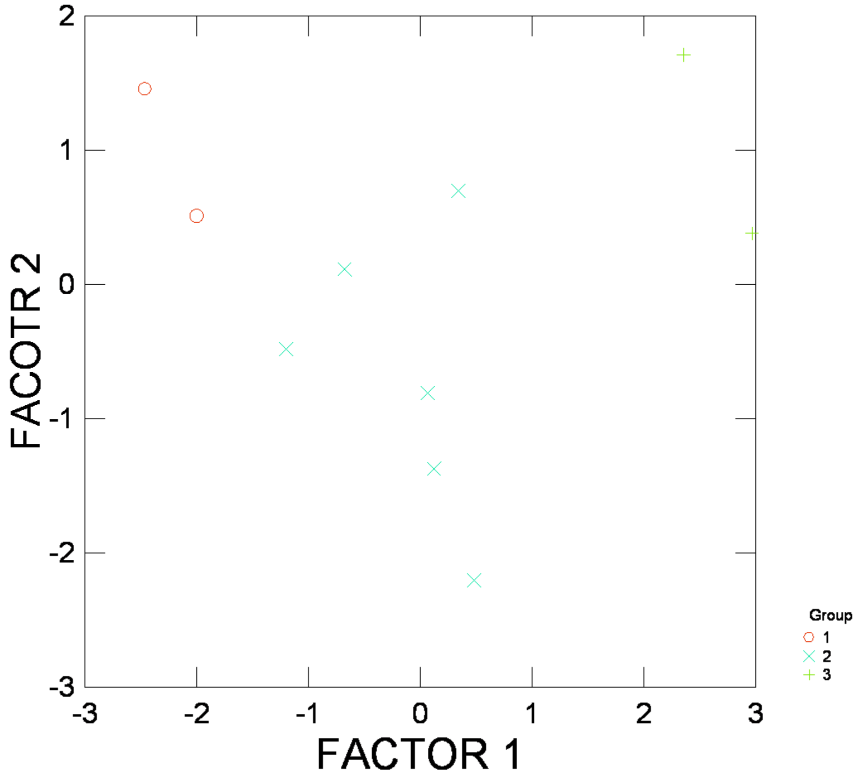
Bivariate plot of the glazed sherd PCA data grouped using the Mahalanobis distance K-MCA with four clusters

Figure 12.1.37



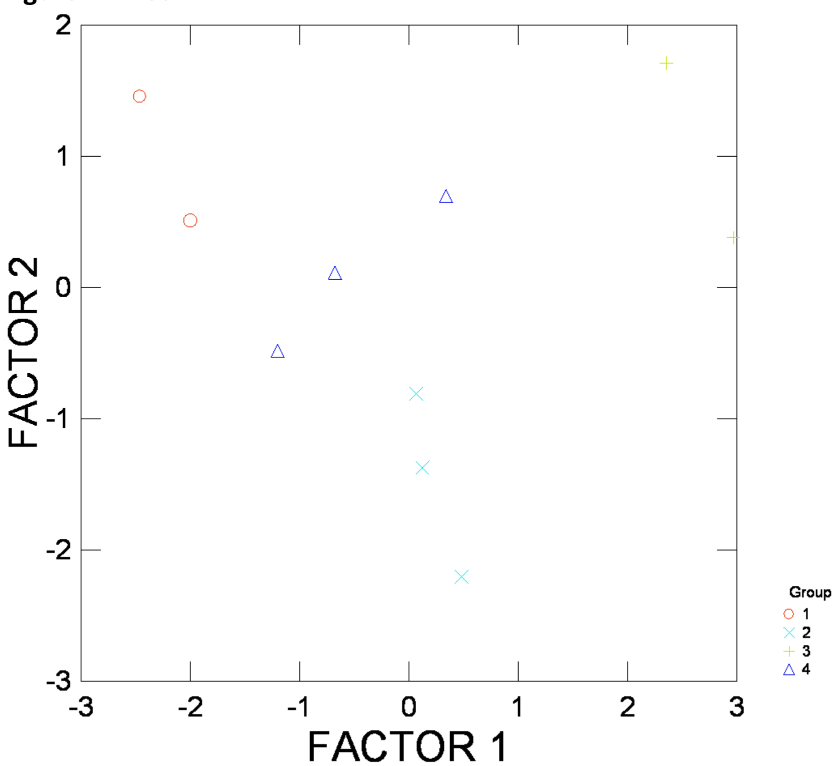
Bivariate plot of the glazed sherd PCA data grouped using the Mahalanobis distance K-MCA with five clusters

Figure 12.1.38



Bivariate plot of the glazed sherd PCA data grouped using the K-MCA with three clusters

Figure 12.1.39



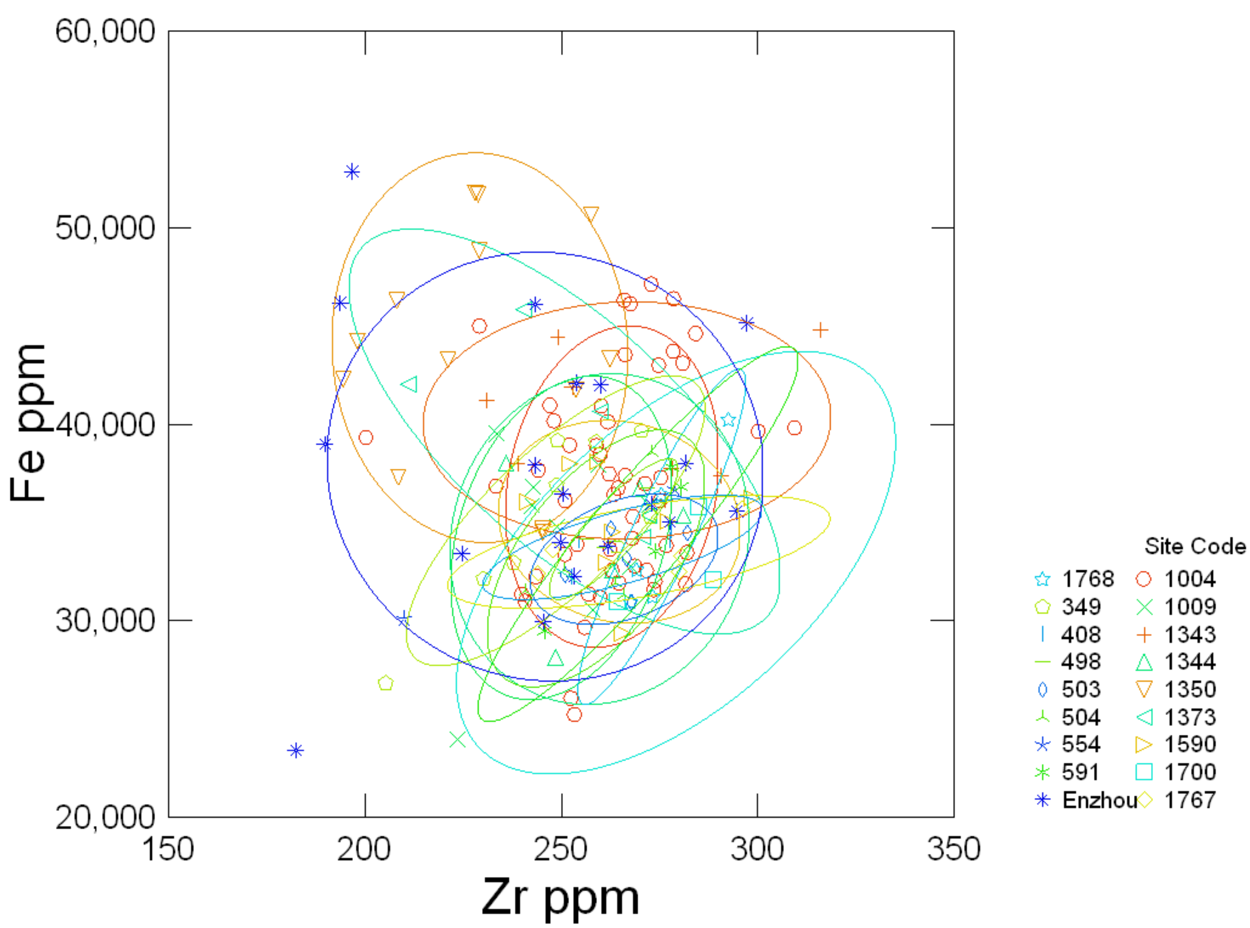
Bivariate plot of the glazed sherd PCA data grouped using the K-MCA with four clusters

12.1.4 Unglazed Earthenware Sherds

12.1.4.1 Bivariate Plots

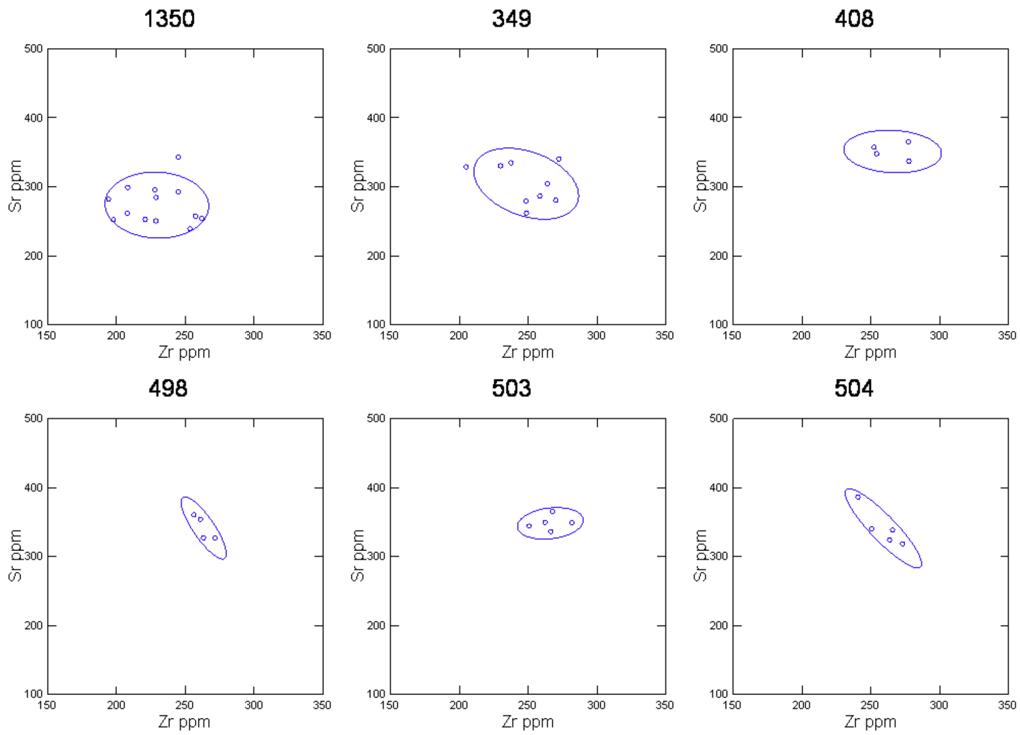
Bivariate plots of the unglazed earthenware sherds reveal a much more complex picture with no distinct groupings other than one large central cluster with a scattering of samples around it. With regard to sites, material from all sites overlaps at the 95% and even the 67% confidence ellipses (Figure 12.1.40). However when sites are plotted by themselves, there interestingly appears to be variation in how geochemically variable the materials are in different sites. Some sites exhibit extremely low geochemical variation in the ceramics collected from them, and form very tight clusters with small confidence ellipses; namely sites 504, 503, 498, 408, 349 and 135 (Figure 12.1.41). Others are much more geochemically variable with the data forming large loose clusters with large confidence ellipses; namely sites 591, 1004, 1009, 1343, 1344, 1373 and the Enzhou site (Figure 12.1.42).

Figure 12.1.40



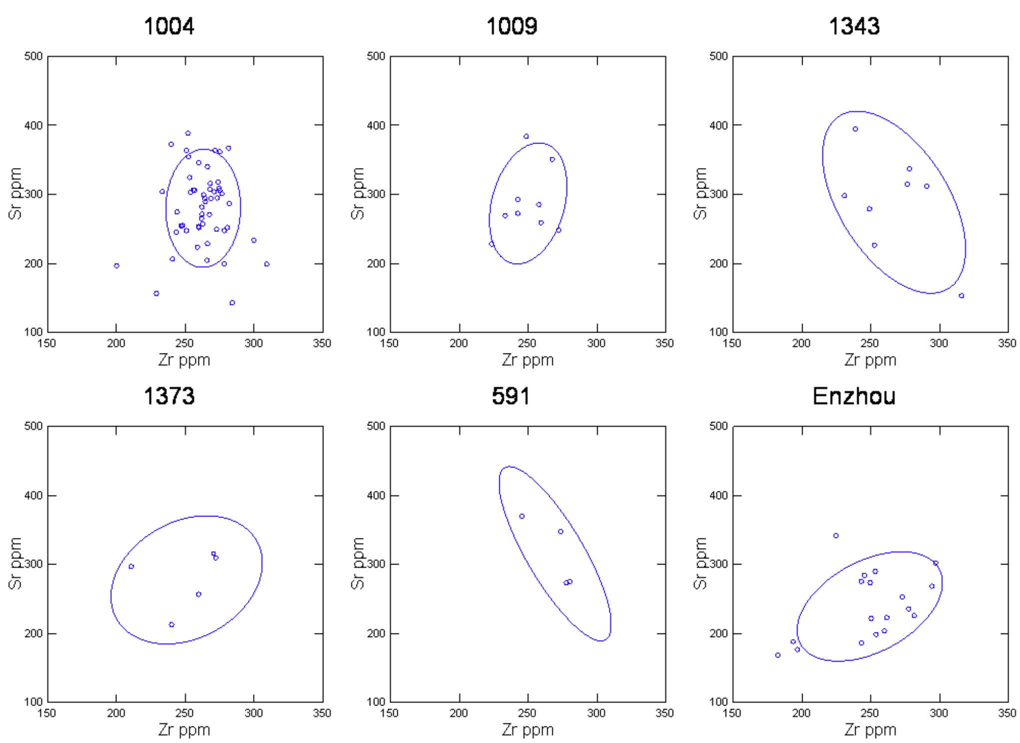
Bivariate plot of Fe ppm v. Zr ppm for the unglazed earthenware sherd data, grouped by site code

Figure 12.1.41



Bivariate plots of Zr ppm v. Sr ppm for unglazed earthenware sherd data for sites 504,503,498, 408, 349 and 1350

Figure 12.1.42

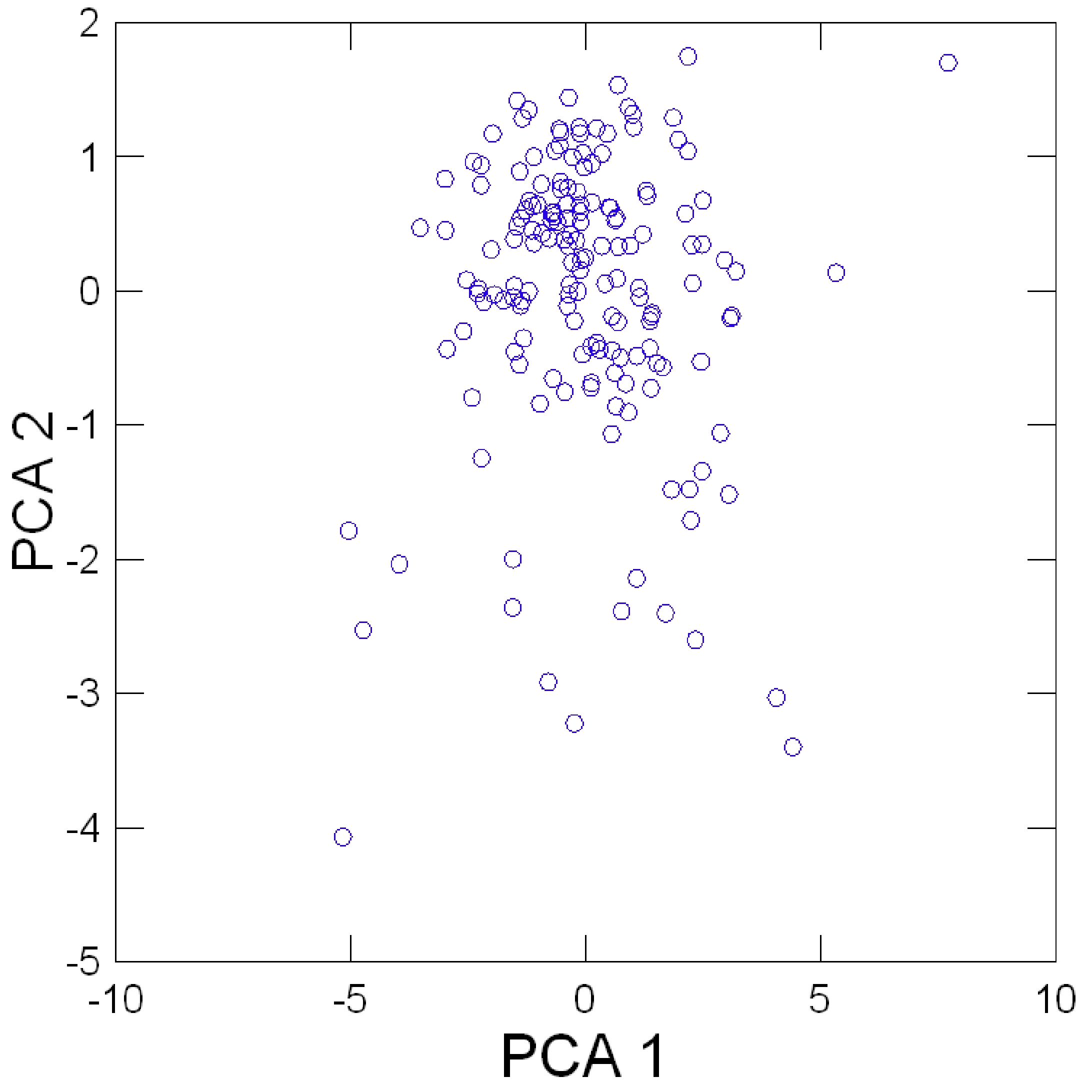


Bivariate plots of Zr ppm v. Sr ppm for unglazed earthenware sherd data for sites 591, 1004, 1009, 1343, 1373 and Enzhou

12.1.4.2 Principal Components Analysis

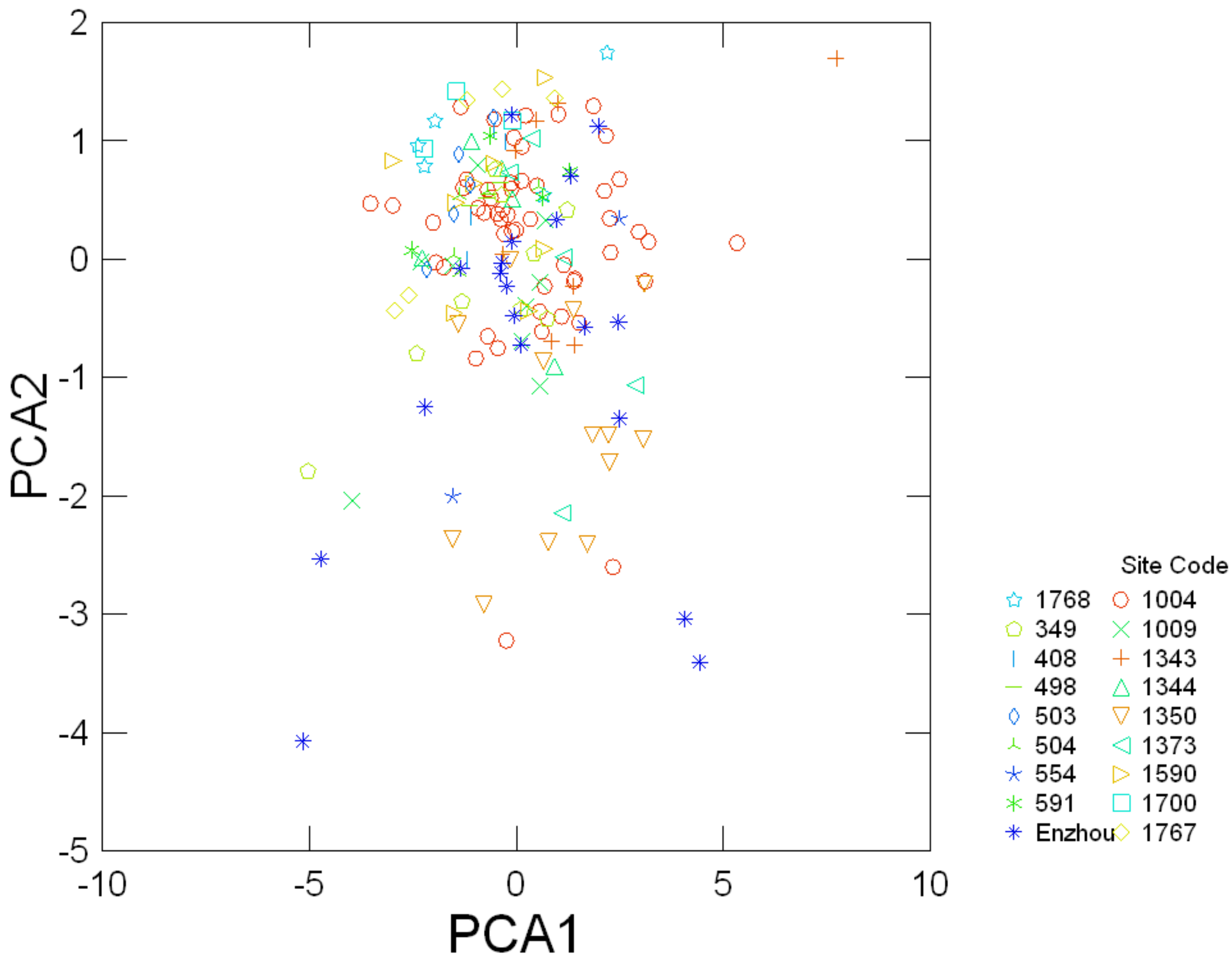
The PCA of the earthenware sherds provides only two factors with an eigenvalue greater than one. These factors explain 55.6% and 19.3% of the total variance in the sample respectively. When plotted against each other (Figure 12.1.43) these factors, like the previous bivariate plots, show one relatively tight cluster with a scatter of samples outside this cluster that could potentially represent other indistinct clusters. These clusters, however, do not correspond to sites (Figure 12.1.44).

Figure 12.1.43



Bivariate plot of PCA data for the unglazed earthenware sherds

Figure 12.1.44

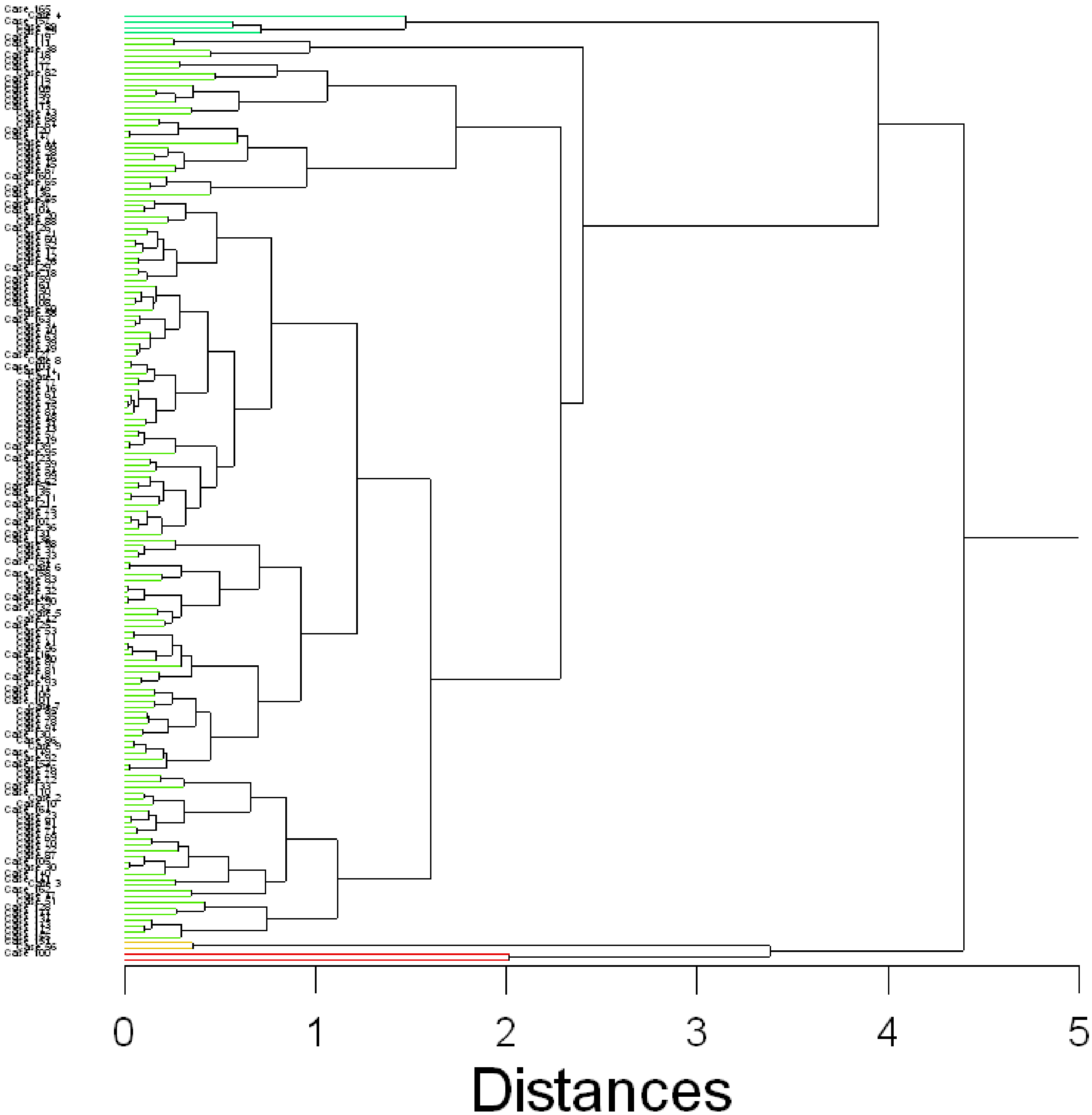


Bivariate plot of PCA data for the unglazed earthenware sherds grouped by site code

12.1.4.3 PCA Hierarchical Cluster Analysis

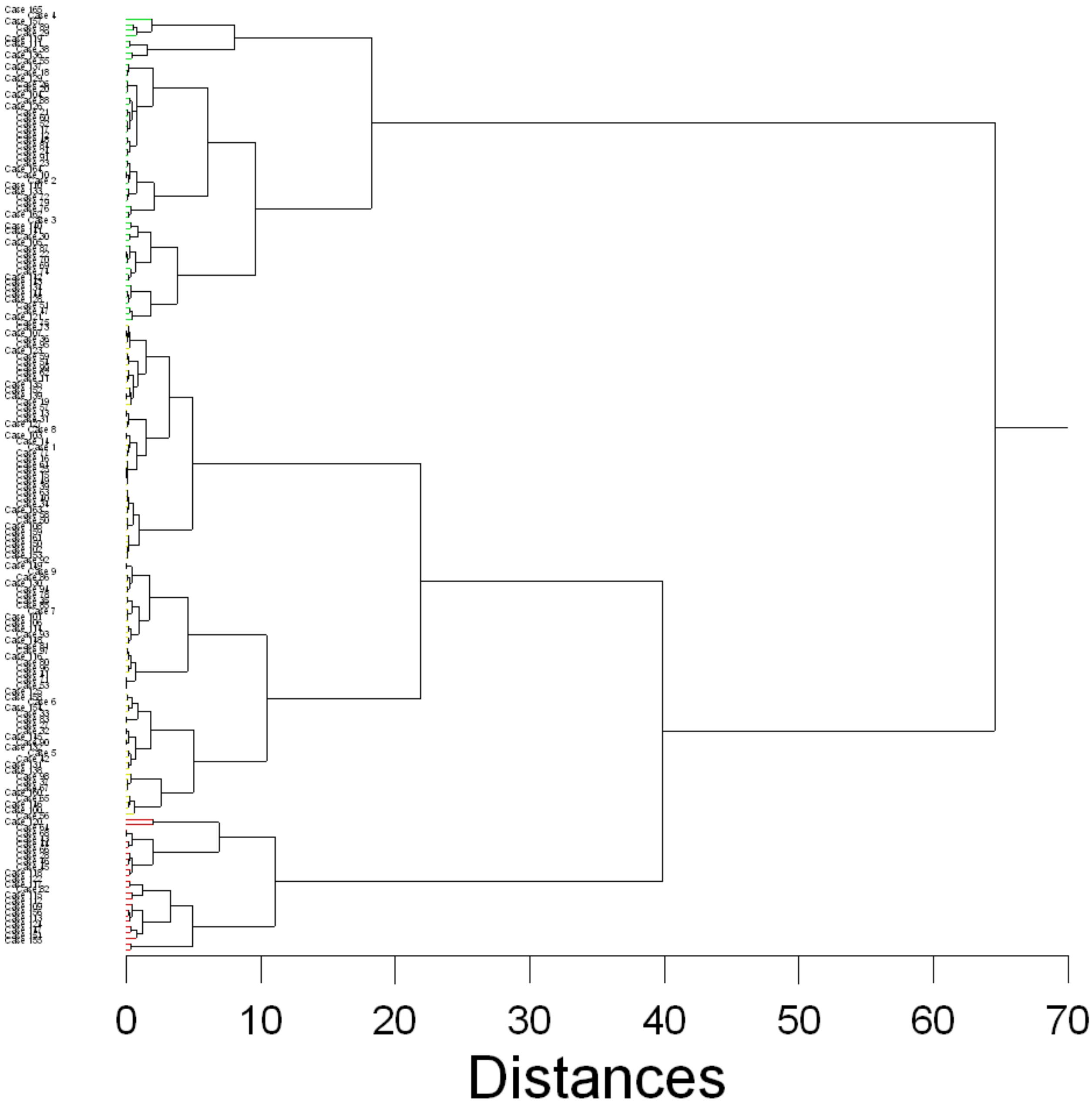
The two factors provided by the PCA results were used to perform two Euclidian HCAs, as with the above datasets, one utilized the Average Linkage method, and one utilized the Ward's method. These generated the dendrograms provided in Figure 12.1.45 and Figure 12.1.46 respectively, and the resulting assignments are found in Appendix 12.2; Tables 12.2.10 and 12.2.11. In this case the Average Linkage method identifies four groupings, with the majority of the samples forming one group and eight samples being split amongst the remaining three groups. The Ward's method, on the other hand, identifies three groupings with relatively large group membership in each. Overall, there seems to be little similarity in the groupings produced by these two methods.

Figure 12.1.45



Dendrogram generated by the Average Linkage HCA of the unglazed earthenware sherd PCA data

Figure 12.1.46

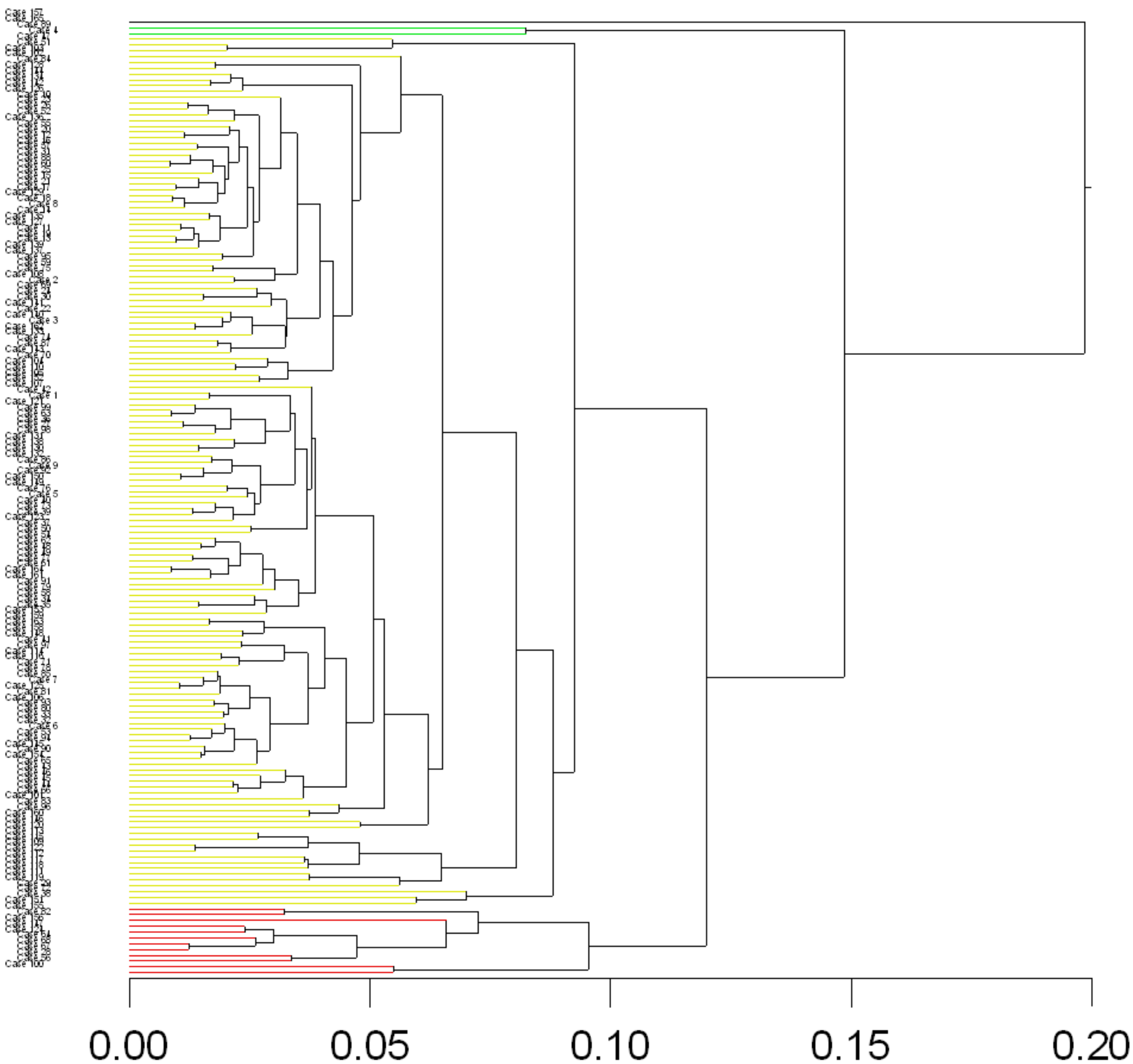


Dendrogram generated by the Ward's Method HCA of the unglazed earthenware sherd PCA data

12.1.4.4 Standardized data Hierarchical Cluster Analysis

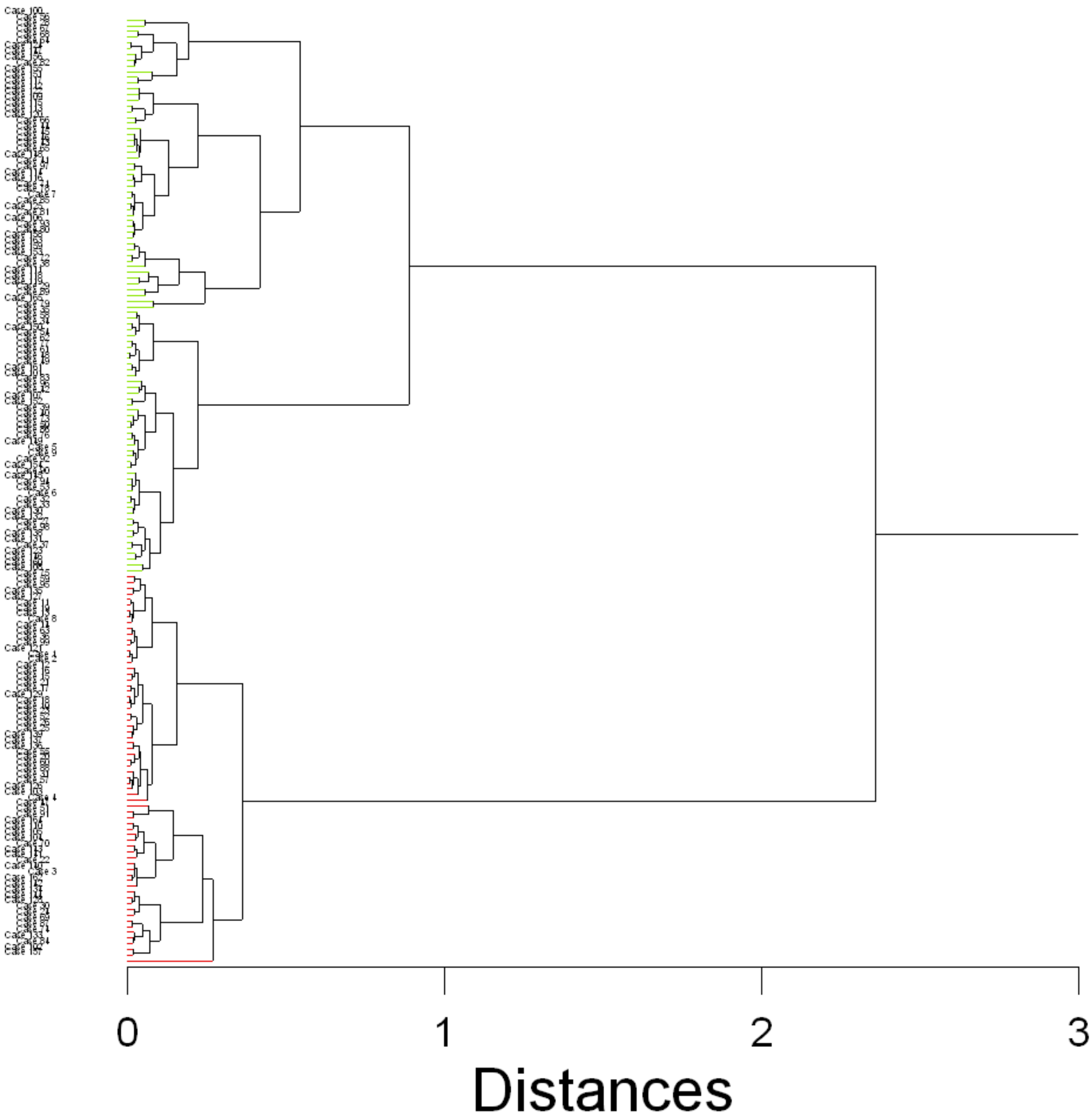
A further two HCAs were performed on the standardized log10 data with Euclidian distances and again used both the Average Linkage and Ward's methods. These analyses generated the two dendrograms in Figures 12.1.47 and 12.1.48 and the resulting assignments are provided in Appendix 12.2; Tables 12.2.11 and 12.2.9. The Average Linkage method generates four groupings while the Ward's method generates only two. Again, there seems little apparent similarity in the assignments produced by these methods, and with the previous HCAs.

Figure 12.1.47



Dendrogram generated by the Average Linkage HCA of the unglazed earthenware sherd Log10 data

Figure 12.1.48

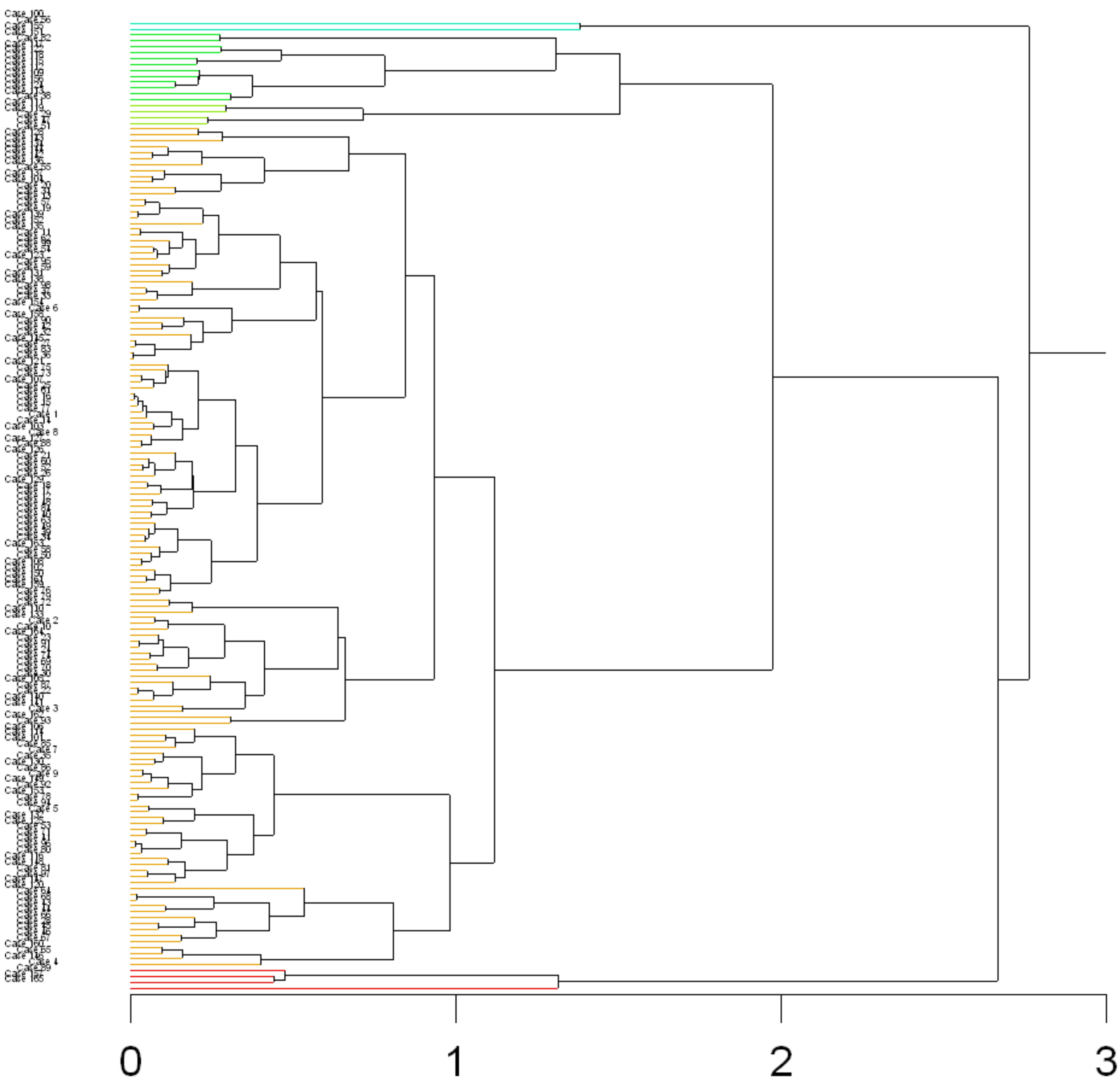


Dendrogram generated by the Ward's Method HCA of the unglazed earthenware sherd Log10 data

12.1.4.5 Mahalanobis Distance HCA

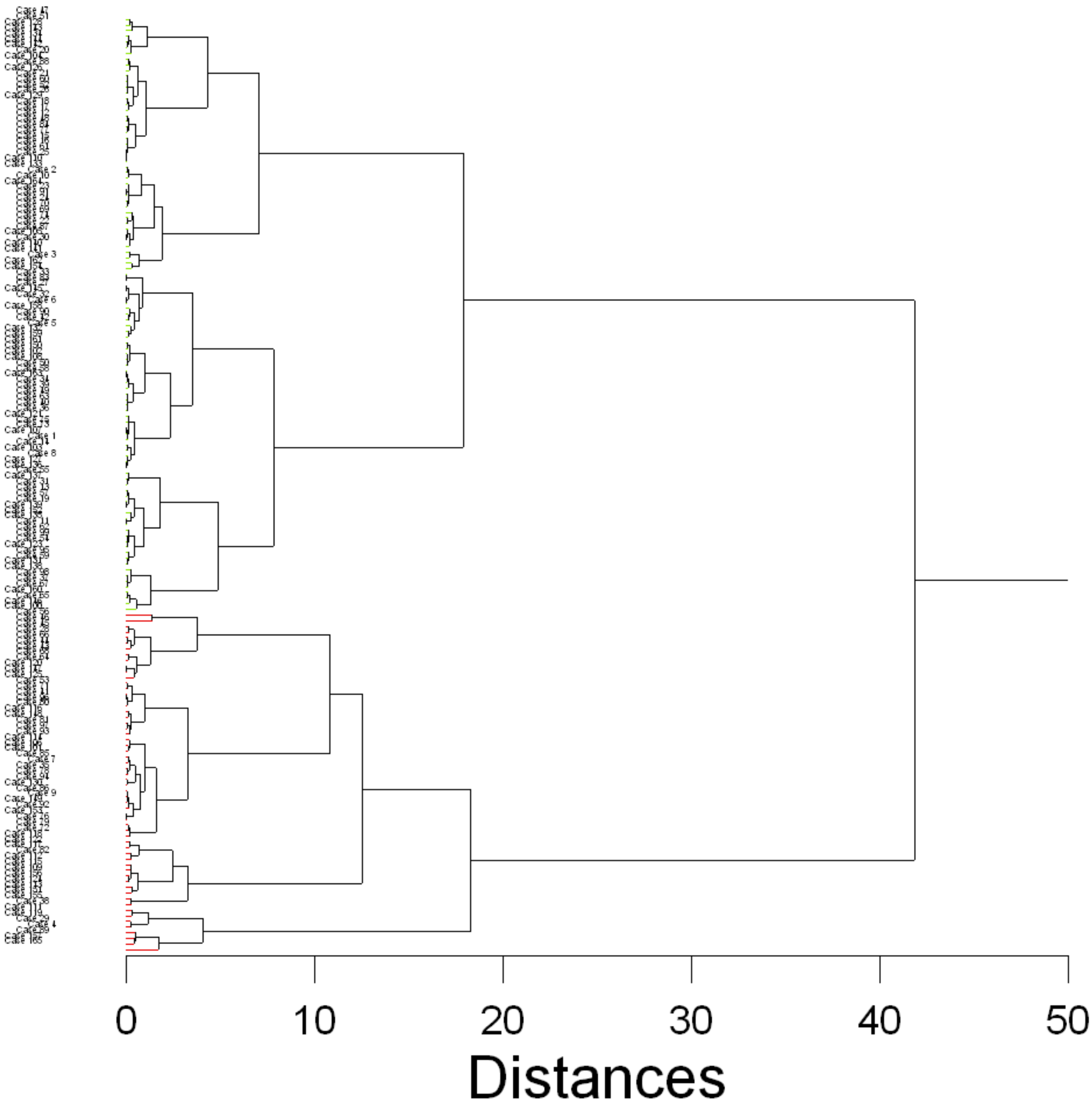
A final two HCAs were performed on the PCA data utilizing Mahalanobis distances and both the Average Linkage and Ward's methods. The dendrograms generated by these analyses are shown in Figures 12.1.49 and 12.1.50. The Average Linkage method generates five groupings, while the Ward's method generates four groupings. The assignments for these groupings are provided in Appendix 12.2; Tables 12.2.12 and 12.2.11. Again these methods, like the above HCAs, produce groupings with little apparent similarity to each other and also little similarity to the previous analyses.

Figure 12.1.49



Dendrogram generated by the Mahalanobis Distance Average Linkage HCA of the unglazed earthenware sherd PCA data

Figure 12.1.50

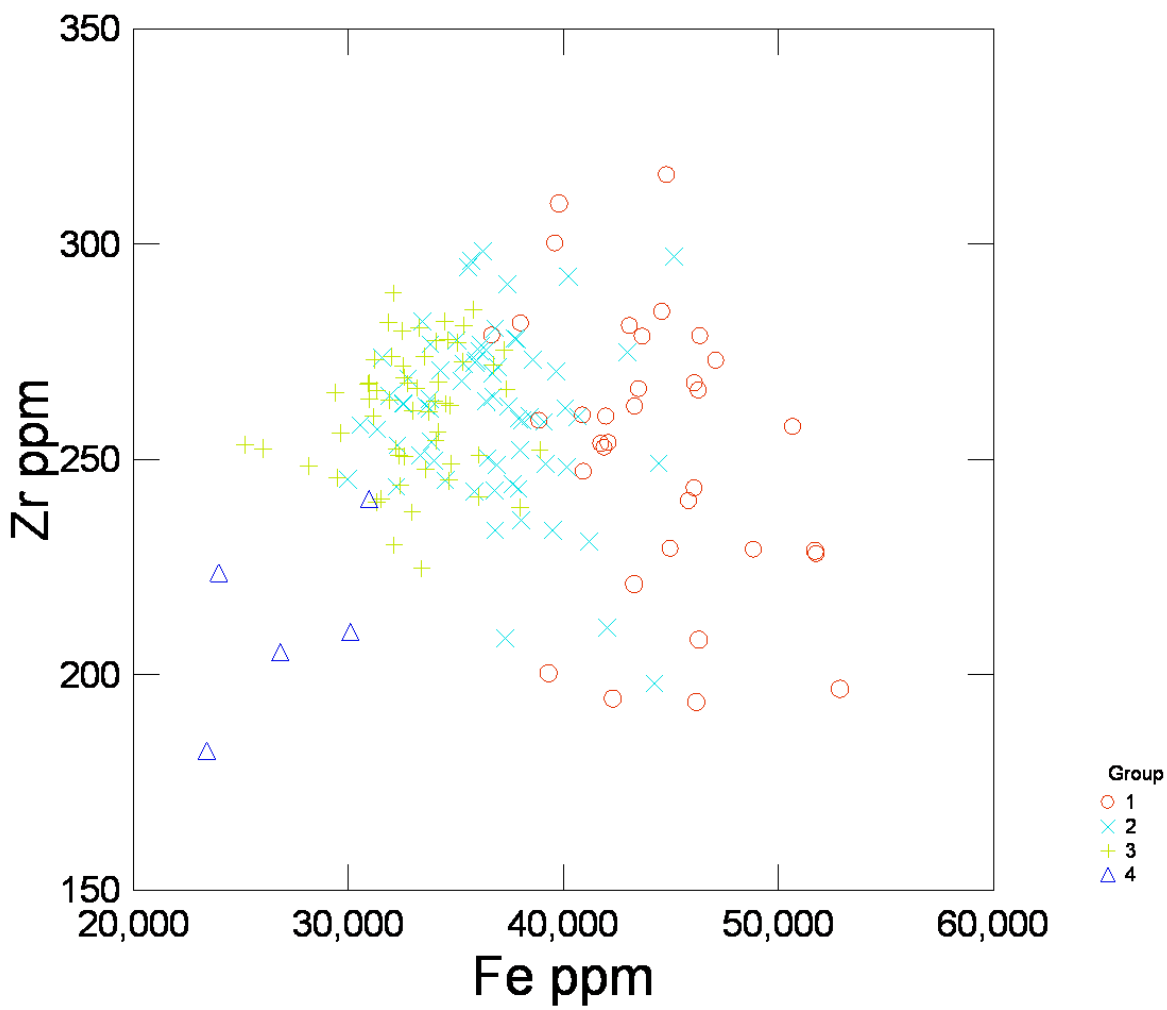


Dendrogram generated by the Mahalanobis Distance Ward's Method HCA of the unglazed earthenware sherd PCA data

12.1.4.6 K-Means Cluster Analysis

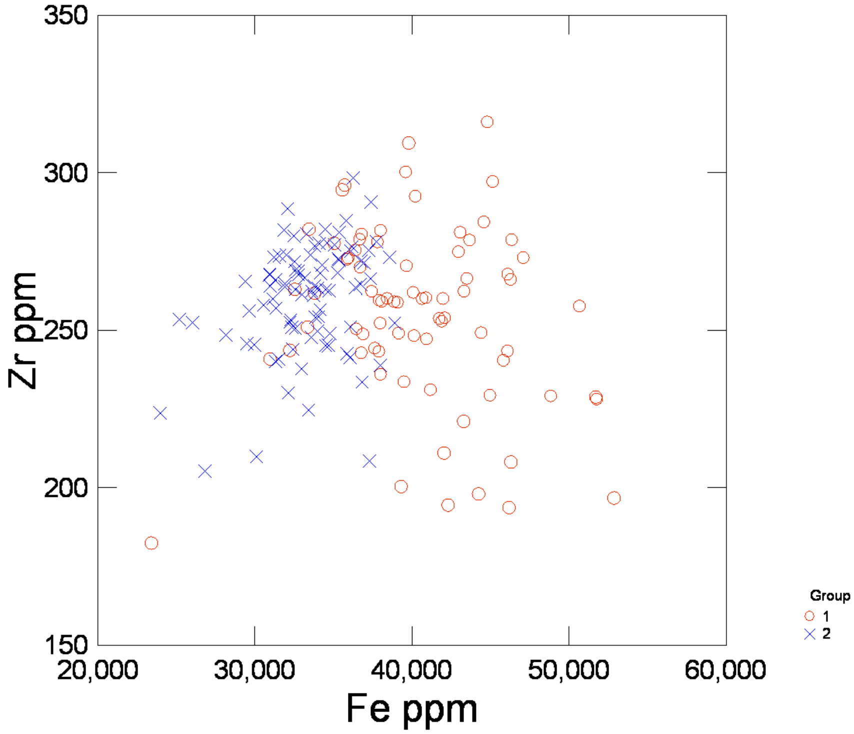
As with the roof tile and glazed sherd analyses, K-means cluster analyses were conducted for each of the previously mentioned HCAs utilizing the same base data, a matching distance measure (Euclidian or Mahalanobis) and instructed to create the same number of clusters. The clusters created are shown in Figures 12.1.51, 12.1.52, 12.1.53, 12.1.54, 12.1.55 and 12.1.56 and with the resulting assignments presented in Appendix 12.2; Tables 12.2.9, 12.2.10, 12.2.11 and 12.2.12. Unlike the roof tiles and glazed sherds, none of these K-MCAs show excellent or perfect congruence with the associated HCA. In fact, if this non congruence is quantified then the maximum congruence achieved by these K-MCAs was 87% for the Log10 Ward's method HCA and 81% congruence for the PCA Ward's method HCA. The other K-MCAs exhibit even worse congruence ranging from 56%-30%. In comparison, the roof tiles ranged from 74%-100% congruence and the glazed sherds ranged from 70%-100% congruence.

Figure 12.1.51



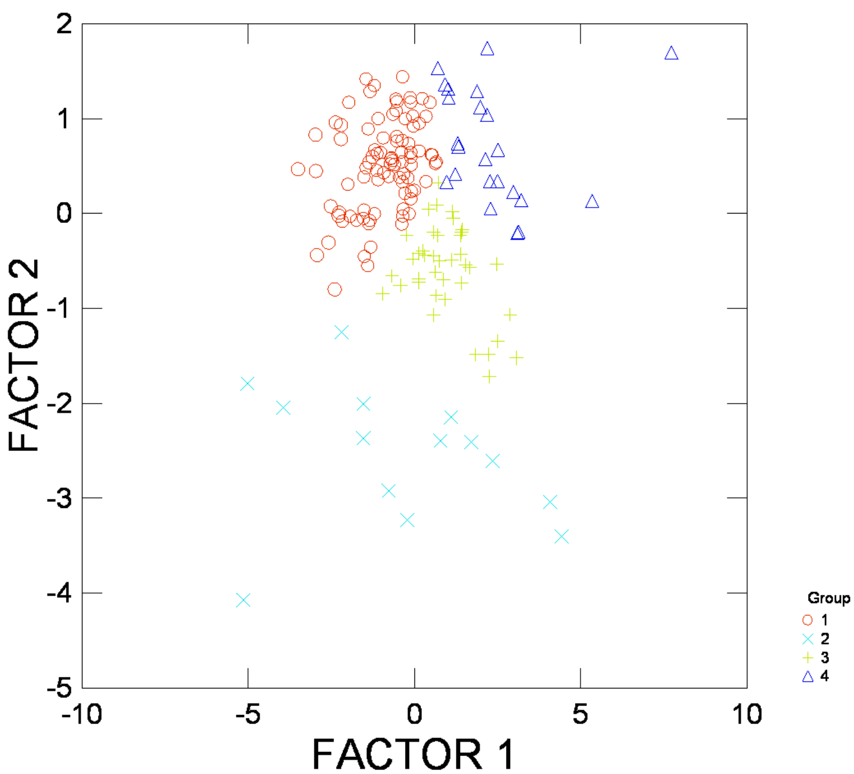
Bivariate plot of the unglazed earthenware sherd Log10 data grouped using the K-MCA with four clusters

Figure 12.1.52 K-MCA of Log10 Data 2 Clusters



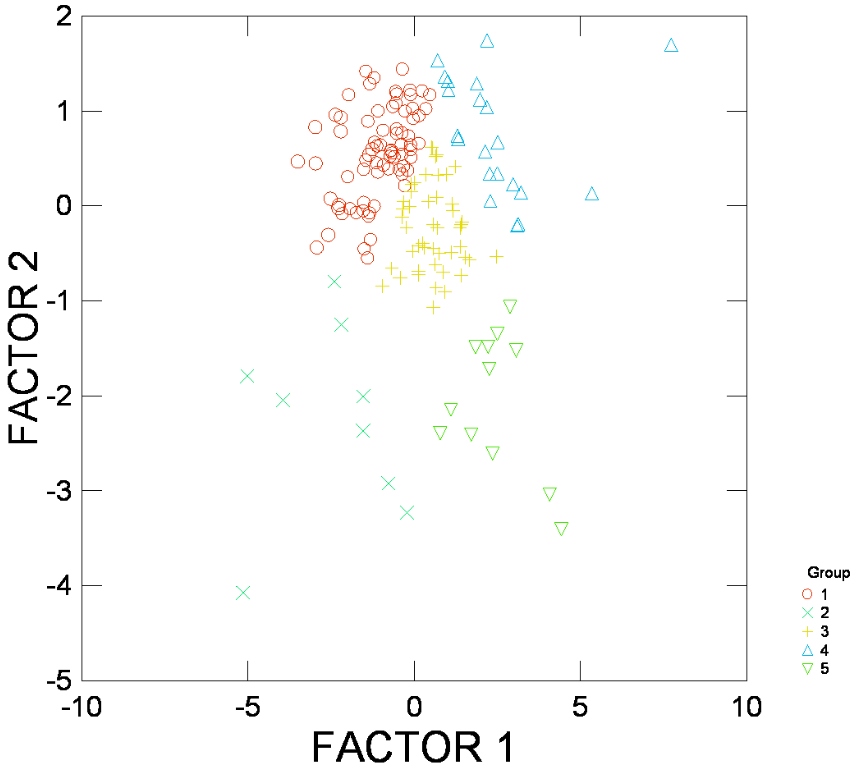
Bivariate plot of the unglazed earthenware sherd Log10 data grouped using the K-MCA with two clusters

Figure 12.1.53 K-MCA of MD PCA Data 4 Clusters



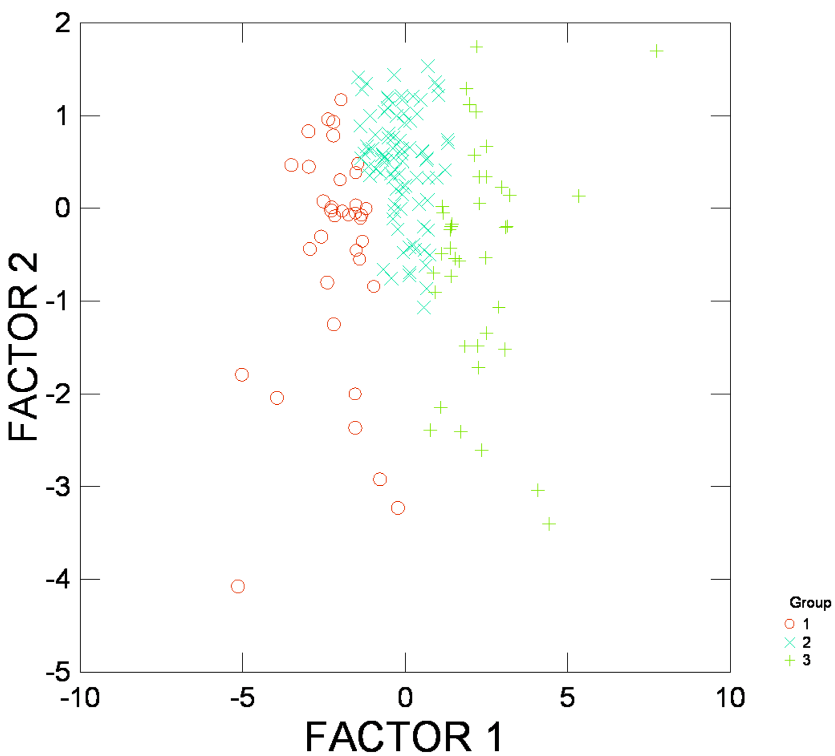
Bivariate plot of the unglazed earthenware sherd PCA data grouped using the Mahalanobis Distance K-MCA with two clusters

Figure 12.1.54



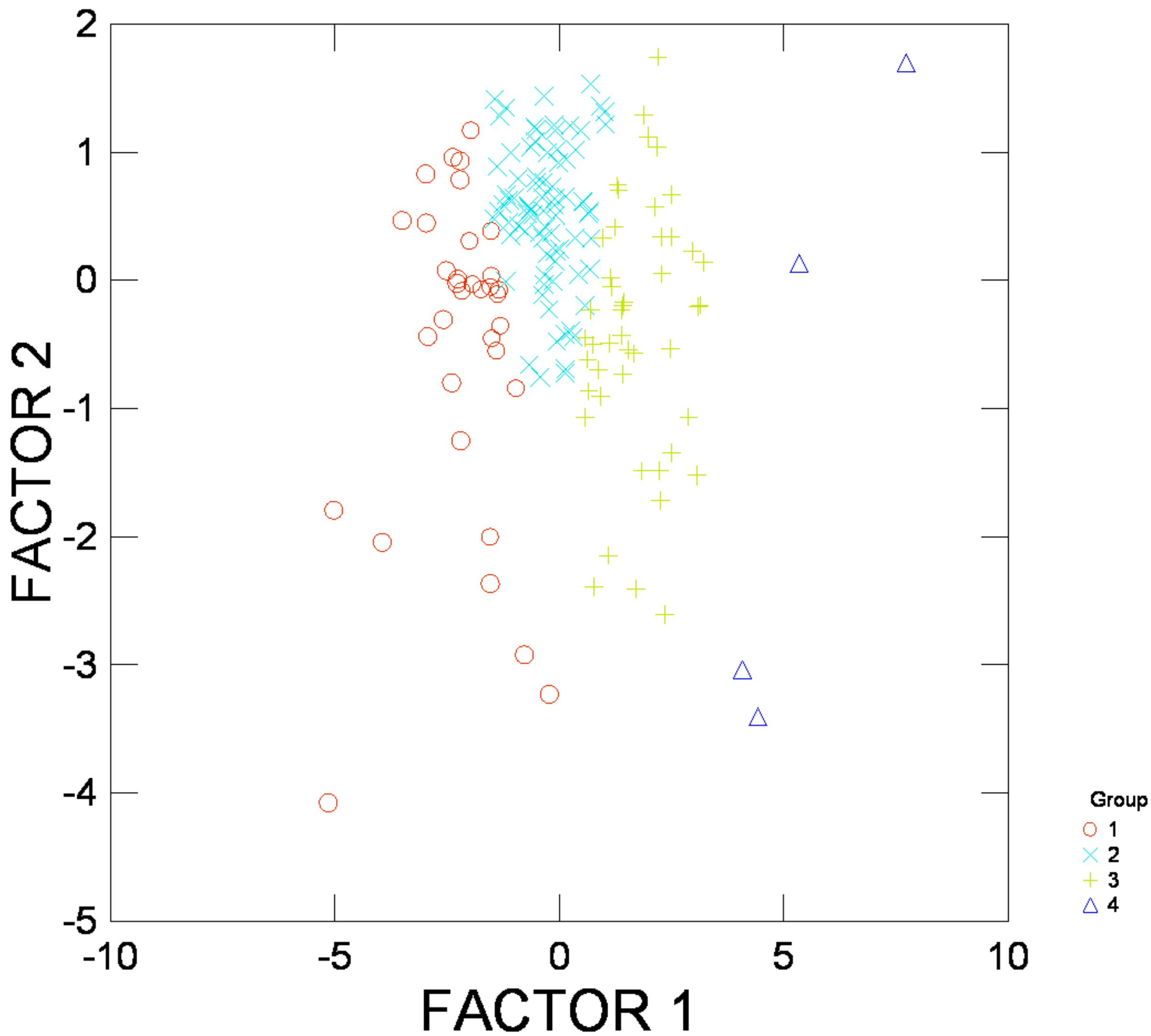
Bivariate plot of the unglazed earthenware sherd PCA data grouped using the Mahalanobis Distance K-MCA with five clusters

Figure 12.1.55



Bivariate plot of the unglazed earthenware sherd PCA data grouped using the K-MCA with three clusters

Figure 12.1.56



Bivariate plot of the unglazed earthenware sherd PCA data grouped using the K-MCA with four clusters

12.2 Sherd Assignment Tables

All Sherds

Table 12.2.0 HCA Assigned Sherd Groupings for the Entire Dataset

Type	Site number	Sample #	PCA HCA	UNGlazed PCA HCA
Earthenware	349	85	1	1
Earthenware	349	86	1	1
Earthenware	349	89	1	1
Earthenware	349	99	1	2
Earthenware	349	87	1	1
Earthenware	349	88	1	1
Earthenware	349	94	1	1
Earthenware	349	95	1	1
Earthenware	349	97	1	1
Earthenware	408	80	1	1
Earthenware	408	81	1	1
Earthenware	408	82	1	1
Earthenware	408	83	1	1
Earthenware	498	71	1	1
Earthenware	498	72	1	1
Earthenware	498	74	1	1
Earthenware	498	75	1	1
Earthenware	503	61	1	1
Earthenware	503	62	1	1
Earthenware	503	63	1	1
Earthenware	503	64	1	1
Earthenware	503	65	1	1
Earthenware	504	66	1	1
Earthenware	504	67	1	1
Earthenware	504	68	1	1
Earthenware	504	69	1	1
Earthenware	504	70	1	1
Earthenware	554	77	1	1
Earthenware	591	92	1	1
Earthenware	591	90	1	1
Earthenware	591	91	1	1
Earthenware	591	93	1	1
Earthenware	1004	103	1	1
Earthenware	1004	109	1	1
Earthenware	1004	110	1	1
Earthenware	1004	112	1	1
Earthenware	1004	114	1	1
Earthenware	1004	124	1	1
Earthenware	1004	126	1	1
Earthenware	1004	127	1	1
Earthenware	1004	129	1	1
Earthenware	1004	134	1	1
Earthenware	1004	135	1	1
Earthenware	1004	140	1	1
Earthenware	1004	141	1	1
Earthenware	1004	167	1	1
Earthenware	1004	201	1	1
Earthenware	1004	100	1	1
Earthenware	1004	101	1	1
Earthenware	1004	102	1	1
Earthenware	1004	104	1	1
Earthenware	1004	105	1	1
Earthenware	1004	108	1	1
Earthenware	1004	111	1	1
Earthenware	1004	113	2	3

Earthenware	1004	117	1	1
Earthenware	1004	118	1	1
Earthenware	1004	119	1	1
Earthenware	1004	121	1	1
Earthenware	1004	122	1	1
Earthenware	1004	123	1	1
Earthenware	1004	125	1	1
Earthenware	1004	130	1	1
Earthenware	1004	131	1	1
Earthenware	1004	132	1	1
Earthenware	1004	133	1	1
Earthenware	1004	136	1	1
Earthenware	1004	164	1	1
Earthenware	1004	166	1	1
Earthenware	1004	168	1	1
Earthenware	1004	185	1	1
Earthenware	1004	186	1	1
Earthenware	1004	187	1	1
Earthenware	1004	190	1	1
Earthenware	1004	192	1	1
Earthenware	1004	196	1	1
Earthenware	1004	197	1	1
Earthenware	1004	199	1	1
Earthenware	1004	200	1	1
Earthenware	1004	202	1	1
Earthenware	1004	210	1	1
Earthenware	1009	170	1	1
Earthenware	1009	171	1	1
Earthenware	1009	173	1	1
Earthenware	1009	175	1	2
Earthenware	1009	176	1	1
Earthenware	1009	204	1	1
Earthenware	1009	206	1	1
Earthenware	1009	208	1	1
Earthenware	1009	209	1	1
Earthenware	1343	41	1	1
Earthenware	1343	46	1	1
Earthenware	1343	45	1	1
Earthenware	1343	48	1	1
Earthenware	1344	30	1	1
Earthenware	1344	32	1	1
Earthenware	1344	34	1	1
Earthenware	1350	36	1	1
Earthenware	1350	40	1	1
Earthenware	1373	56	1	1
Earthenware	1373	57	1	1
Earthenware	1373	58	1	1
Earthenware	1373	59	1	1
Earthenware	1373	60	1	1
Earthenware	1590	142	1	1
Earthenware	1590	146	1	1
Earthenware	1590	147	1	1
Earthenware	1590	149	1	1
Earthenware	1590	143	1	1
Earthenware	1590	144	1	1
Earthenware	1590	145	1	1
Earthenware	1590	148	1	1
Earthenware	1700	152	1	1
Earthenware	1700	150	1	1
Earthenware	1700	151	1	1
Earthenware	1767	155	1	1
Earthenware	1767	153	1	1
Earthenware	1767	154	1	1

Earthenware	1767	156	1	1
Earthenware	1767	157	1	1
Earthenware	1768	160	1	1
Earthenware	1768	161	1	1
Earthenware	1768	158	1	1
Earthenware	1768	159	1	1
Earthenware	1768	162	1	1
Earthenware	Enzhou	18	1	1
Earthenware	Enzhou	6	1	1
Earthenware	Enzhou	8	1	1
Earthenware	Enzhou	10	1	1
Earthenware	Enzhou	12	3	4
Earthenware	Enzhou	14	1	1
Earthenware	Enzhou	16	1	1
Earthenware	Enzhou	17	1	1
Earthenware	Enzhou	19	3	4
Earthenware	Enzhou	20	1	1
Earthenware	554	76	1	1
Earthenware	1004	137	1	1
Earthenware	1004	138	1	1
Earthenware	1004	139	1	1
Earthenware	1343	42	1	1
Earthenware	1343	43	2	3
Earthenware	1343	44	1	1
Earthenware	1343	47	1	1
Earthenware	1344	31	1	1
Earthenware	1344	33	1	1
Earthenware	1350	37	1	1
Earthenware	1350	51	1	1
Earthenware	1350	52	1	1
Earthenware	1350	53	1	1
Earthenware	1350	35	1	1
Earthenware	1350	38	1	1
Earthenware	1350	39	1	1
Earthenware	1350	49	1	1
Earthenware	1350	50	1	1
Earthenware	1350	54	1	1
Earthenware	1350	55	1	1
Earthenware	Enzhou	1	1	2
Earthenware	Enzhou	4	1	1
Earthenware	Enzhou	5	1	1
Earthenware	Enzhou	7	1	1
Earthenware	Enzhou	9	1	1
Earthenware	Enzhou	11	1	1
Earthenware	Enzhou	13	1	1
Earthenware	Enzhou	15	1	1
Earthenware	Enzhou	3	1	2
Roof Tile	349	84	1	2
Roof Tile	349	96	1	2
Roof Tile	498	73	1	1
Roof Tile	554	78	1	1
Roof Tile	1004	106	1	1
Roof Tile	1004	107	1	1
Roof Tile	1004	120	1	1
Roof Tile	1004	165	1	1
Roof Tile	1004	178	1	2
Roof Tile	1004	179	1	2
Roof Tile	1004	180	1	1
Roof Tile	1004	181	1	1
Roof Tile	1004	182	1	1
Roof Tile	1004	183	1	1
Roof Tile	1004	184	1	1
Roof Tile	1004	191	1	1

Roof Tile	1004	193	1	1
Roof Tile	1004	194	1	2
Roof Tile	1004	195	1	1
Roof Tile	1004	198	1	1
Roof Tile	1009	172	1	1
Roof Tile	1009	174	1	1
Roof Tile	1009	207	1	1
Roof Tile	1009	169	1	1
Roof Tile	1009	177	1	2
Roof Tile	1470	163	1	2
Roof Tile	ENZH	2	1	1
Roof Tile	ENZH	21	1	1
Roof Tile	ENZH	22	1	1
Roof Tile	ENZH	23	1	1
Roof Tile	ENZH	26	1	1
Roof Tile	ENZH	27	1	1
Roof Tile	ENZH	28	1	1
Roof Tile	ENZH	29	1	1
Roof Tile	ENZH	24	1	1
Glazed	554	79	4	
Glazed	1004	115	4	
Glazed	1004	116	4	
Glazed	1004	128	4	
Glazed	1004	188	4	
Glazed	1004	189	4	
Glazed	1009	203	4	
Glazed	1009	205	4	
Glazed	1004	211	4	
Glazed	1004	212	4	

Roof Tiles

Table 12.2.1 Assigned roof tile Groupings if 2 groupings present.

Case #	Site	Sample #	LOG10 HCA WARD	K-M Log10 2G	PCA HCA WARD	K-M PCA 2G
1	349	84	2	2	2	2
2	349	96	2	2	2	2
3	498	73	2	2	2	2
4	554	78	2	2	2	2
5	1004	106	2	1	1	1
6	1004	107	2	2	2	1
7	1004	120	2	2	2	1
8	1004	165	2	2	2	2
9	1004	178	2	2	2	2
10	1004	179	2	2	2	2
11	1004	180	2	2	2	2
12	1004	181	2	2	2	2
13	1004	182	2	2	2	2
14	1004	183	2	2	2	2
15	1004	184	2	2	2	2
16	1004	191	2	2	2	2
17	1004	193	2	2	2	2
18	1004	194	2	2	2	2
19	1004	195	2	2	2	2
20	1004	198	2	2	2	2
21	1009	172	2	2	2	2
22	1009	174	2	2	2	2
23	1009	207	2	2	2	2
24	1009	169	2	2	2	2
25	1009	177	2	2	2	2
26	Enzhou	2	1	1	1	1

27	Enzhou	21	1	1	1	1
28	Enzhou	22	1	1	1	1
29	Enzhou	23	1	1	1	1
30	Enzhou	26	1	1	1	1
31	Enzhou	27	2	1	2	1
32	Enzhou	28	2	2	2	2
33	Enzhou	29	1	1	1	1
34	Enzhou	24	1	1	1	1

Table 12.2.2 Assigned roof tile groupings if 3 groups present.

Case #	Site	Sample #	PCA MD WARD HCA	PCA MD K-M 3G
1	349	84	2	2
2	349	96	2	2
3	498	73	3	3
4	554	78	3	3
5	1004	106	1	1
6	1004	107	2	2
7	1004	120	3	3
8	1004	165	3	3
9	1004	178	3	3
10	1004	179	3	3
11	1004	180	3	3
12	1004	181	3	3
13	1004	182	3	3
14	1004	183	2	2
15	1004	184	2	2
16	1004	191	3	3
17	1004	193	3	3
18	1004	194	3	3
19	1004	195	3	3
20	1004	198	3	3
21	1009	172	3	3
22	1009	174	3	3
23	1009	207	3	3
24	1009	169	3	3
25	1009	177	2	2
26	Enzhou	2	1	1
27	Enzhou	21	1	1
28	Enzhou	22	1	1
29	Enzhou	23	1	1
30	Enzhou	26	1	1
31	Enzhou	27	2	1
32	Enzhou	28	2	2
33	Enzhou	29	1	1
34	Enzhou	24	1	1

Table 12.2.3 Assigned roof tile Groupings if 4 groupings present.

Case #	Site	Sherd #	PCA HCA	K-M PCA 4G	PCA MD HCA	K-M PCA MD 4G
1	349	84	3	4	2	4
2	349	96	4	4	4	4
3	498	73	3	3	3	3
4	554	78	3	3	3	3
5	1004	106	1	2	1	1
6	1004	107	3	2	2	2
7	1004	120	3	2	3	3
8	1004	165	3	3	3	3
9	1004	178	2	4	3	3
10	1004	179	2	4	3	3

11	1004	180	3	3	3	3
12	1004	181	3	3	3	3
13	1004	182	3	3	3	3
14	1004	183	3	4	2	2
15	1004	184	3	3	2	2
16	1004	191	3	3	3	3
17	1004	193	3	3	3	3
18	1004	194	2	4	3	3
19	1004	195	3	3	3	3
20	1004	198	3	3	3	3
21	1009	172	3	3	3	3
22	1009	174	3	3	3	3
23	1009	207	3	3	3	3
24	1009	169	3	3	3	3
25	1009	177	4	4	4	4
26	Enzhou	2	1	1	1	1
27	Enzhou	21	1	1	1	1
28	Enzhou	22	1	1	1	1
29	Enzhou	23	1	1	1	1
30	Enzhou	26	1	1	1	1
31	Enzhou	27	3	2	2	2
32	Enzhou	28	3	2	2	2
33	Enzhou	29	1	2	1	1
34	Enzhou	24	1	1	1	1

Table 12.2.4 Assigned roof tile Groupings if 5 groupings present.

Case #	Site	Sample #	LOG 10 HCA Av	K-M Log10 5G
1	349	84	1	2
2	349	96	2	2
3	498	73	1	1
4	554	78	1	1
5	1004	106	1	4
6	1004	107	1	5
7	1004	120	1	1
8	1004	165	1	1
9	1004	178	1	2
10	1004	179	1	2
11	1004	180	1	1
12	1004	181	1	1
13	1004	182	1	1
14	1004	183	1	5
15	1004	184	1	5
16	1004	191	1	5
17	1004	193	1	1
18	1004	194	1	2
19	1004	195	1	1
20	1004	198	1	1
21	1009	172	1	1
22	1009	174	1	1
23	1009	207	1	1
24	1009	169	1	1
25	1009	177	2	2
26	Enzhou	2	3	3
27	Enzhou	21	4	4
28	Enzhou	22	3	3
29	Enzhou	23	3	3
30	Enzhou	26	4	4
31	Enzhou	27	5	5
32	Enzhou	28	1	5
33	Enzhou	29	3	3

34	Enzhou	24	4	4

Glazed Sherds

Table 12.2.5 Assigned glazed sherd groupings if 2 groups present.

Case #	Site number	Sample #	Log10 HCA WARD	Log10 KMCA 2G
1	554	79	1	1
2	1004	115	1	1
3	1004	116	1	1
4	1004	128	2	2
5	1004	188	1	1
6	1004	189	2	2
7	1009	203	2	2
8	1009	205	2	2
9	1004	211	1	1
10	1004	212	2	2

Table 12.2.6 Assigned glazed sherd groupings if 3 groups present.

Case #	Site number	Sample #	PCA HCA WARD	PCA KMCA 3G
1	554	79	1	1
2	1004	115	2	2
3	1004	116	1	1
4	1004	128	1	1
5	1004	188	2	2
6	1004	189	1	1
7	1009	203	1	1
8	1009	205	3	3
9	1004	211	1	1
10	1004	212	3	3

Table 12.2.7 Assigned glazed sherd groupings if 4 groups present.

Case #	Site	Sample #	PCA HCA	PCA KMCA 4G	PCA MD HCA WARD	PCA MD HCA 4G
1	554	79	4	4	4	4
2	1004	115	2	2	2	2
3	1004	116	1	4	4	4
4	1004	128	1	1	1	1
5	1004	188	2	2	2	2
6	1004	189	1	1	1	1
7	1009	203	1	1	1	1
8	1009	205	3	3	3	3
9	1004	211	1	4	4	4
10	1004	212	3	3	3	3

Table 12.2.8 Assigned glazed sherd groupings if 5 groups present.

Case #	Site number	Sample #	PCA MD HCA Av	PCA MD KMCA 5G	Log10 HCA Av	Log10 KMCA 5G
1	554	79	3	3	3	3
2	1004	115	5	5	5	5
3	1004	116	1	4	5	4
4	1004	128	1	1	1	1
5	1004	188	5	5	5	5
6	1004	189	1	1	1	1
7	1009	203	1	1	1	1
8	1009	205	2	2	2	2
9	1004	211	1	4	5	4

10	1004	212	4	2	4	2

Earthenware Sherds

Table 12.2.9 Earthenware if 2 Groupings

Case	Site number	Sample #	Log10 HCA WARD	K-MCA Log20 2G
1	349	85	1	1
2	349	86	1	1
3	349	89	1	1
4	349	99	1	1
5	349	87	2	2
6	349	88	2	2
7	349	94	2	2
8	349	95	1	1
9	349	97	2	2
10	408	80	1	1
11	408	81	1	1
12	408	82	1	1
13	408	83	1	1
14	498	71	1	1
15	498	72	1	1
16	498	74	1	1
17	498	75	1	1
18	503	61	1	1
19	503	62	1	1
20	503	63	1	1
21	503	64	1	1
22	503	65	1	1
23	504	66	1	1
24	504	67	1	1
25	504	68	1	1
26	504	69	1	1
27	504	70	2	1
28	554	77	2	2
29	554	76	2	1
30	591	92	1	1
31	591	90	1	1
32	591	91	2	2
33	591	93	2	2
34	1004	103	2	1
35	1004	109	2	2
36	1004	110	1	1
37	1004	112	2	2
38	1004	114	2	2
39	1004	124	2	1
40	1004	126	2	1
41	1004	127	2	2
42	1004	129	2	2
43	1004	134	2	2
44	1004	135	2	2
45	1004	140	2	2
46	1004	141	2	2
47	1004	167	1	1
48	1004	201	2	1
49	1004	100	2	1
50	1004	101	2	1
51	1004	102	1	1
52	1004	104	1	1
53	1004	105	2	2
54	1004	108	2	1

55	1004	111	1	1
56	1004	113	2	2
57	1004	117	1	1
58	1004	118	2	2
59	1004	119	1	1
60	1004	121	1	1
61	1004	122	2	1
62	1004	123	2	1
63	1004	125	1	1
64	1004	130	2	2
65	1004	131	2	2
66	1004	132	2	2
67	1004	133	2	2
68	1004	136	2	2
69	1004	164	1	1
70	1004	166	1	1
71	1004	168	2	2
72	1004	185	2	2
73	1004	186	2	1
74	1004	187	1	1
75	1004	190	1	1
76	1004	192	2	1
77	1004	196	2	1
78	1004	197	2	2
79	1004	199	2	2
80	1004	200	2	2
81	1004	202	2	2
82	1004	210	2	2
83	1004	137	2	2
84	1004	138	1	1
85	1004	139	2	2
86	1009	170	2	1
87	1009	171	1	1
88	1009	173	1	1
89	1009	175	2	1
90	1009	176	2	2
91	1009	204	1	1
92	1009	206	2	2
93	1009	208	2	2
94	1009	209	2	2
95	1343	41	1	1
96	1343	46	2	2
97	1343	45	2	2
98	1343	48	2	1
99	1343	42	1	1
100	1343	43	2	2
101	1343	44	2	2
102	1343	47	1	1
103	1344	30	1	1
104	1344	32	1	1
105	1344	34	1	1
106	1344	31	2	2
107	1344	33	2	2
108	1350	36	1	1
109	1350	40	2	2
110	1350	37	1	1
111	1350	51	2	2
112	1350	52	2	2
113	1350	53	2	2
114	1350	35	2	2
115	1350	38	2	2
116	1350	39	2	2
117	1350	49	2	2

118	1350	50	2	2
119	1350	54	2	1
120	1350	55	2	2
121	1373	56	1	1
122	1373	57	2	2
123	1373	58	2	1
124	1373	59	2	2
125	1373	60	2	2
126	1590	142	1	1
127	1590	146	1	1
128	1590	147	1	1
129	1590	149	1	1
130	1590	143	2	2
131	1590	144	2	1
132	1590	145	2	2
133	1590	148	1	1
134	1700	152	1	1
135	1700	150	1	1
136	1700	151	1	1
137	1767	155	1	1
138	1767	153	2	2
139	1767	154	1	1
140	1767	156	1	1
141	1767	157	1	1
142	1768	160	1	1
143	1768	161	1	1
144	1768	158	1	1
145	1768	159	2	2
146	1768	162	2	2
147	Enzhou	18	2	2
148	Enzhou	6	2	2
149	Enzhou	8	2	2
150	Enzhou	10	2	1
151	Enzhou	12	2	2
152	Enzhou	14	2	2
153	Enzhou	16	2	2
154	Enzhou	17	2	2
155	Enzhou	19	2	2
156	Enzhou	20	2	2
157	Enzhou	1	1	1
158	Enzhou	4	2	2
159	Enzhou	5	2	2
160	Enzhou	7	2	2
161	Enzhou	9	2	1
162	Enzhou	11	1	1
163	Enzhou	13	2	2
164	Enzhou	15	1	1
165	Enzhou	3	2	2

Table 12.2.10 Earthenware if 3 Groupings

Case	Site number	Sample #	PCA HCA WARD	KMCA PCA 3G
1	349	85	1	1
2	349	86	2	2
3	349	89	2	2
4	349	99	2	2
5	349	87	1	1
6	349	88	1	1
7	349	94	1	1
8	349	95	1	1
9	349	97	1	1

10	408	80	2	2
11	408	81	1	1
12	408	82	2	1
13	408	83	1	1
14	498	71	1	1
15	498	72	1	1
16	498	74	1	1
17	498	75	2	1
18	503	61	2	2
19	503	62	1	1
20	503	63	2	1
21	503	64	2	1
22	503	65	2	2
23	504	66	2	2
24	504	67	2	2
25	504	68	1	1
26	504	69	2	1
27	504	70	1	1
28	554	77	3	3
29	554	76	2	2
30	591	92	2	2
31	591	90	1	1
32	591	91	1	1
33	591	93	1	1
34	1004	103	1	1
35	1004	109	1	1
36	1004	110	1	1
37	1004	112	1	1
38	1004	114	2	2
39	1004	124	1	1
40	1004	126	1	1
41	1004	127	1	3
42	1004	129	1	1
43	1004	134	3	3
44	1004	135	3	3
45	1004	140	3	3
46	1004	141	3	3
47	1004	167	2	2
48	1004	201	2	1
49	1004	100	1	1
50	1004	101	1	1
51	1004	102	2	2
52	1004	104	2	1
53	1004	105	1	3
54	1004	108	1	1
55	1004	111	2	1
56	1004	113	3	3
57	1004	117	1	1
58	1004	118	1	1
59	1004	119	1	1
60	1004	121	2	1
61	1004	122	1	1
62	1004	123	1	1
63	1004	125	1	1
64	1004	130	3	3
65	1004	131	1	3
66	1004	132	3	3
67	1004	133	1	3
68	1004	136	3	3
69	1004	164	2	2
70	1004	166	2	2
71	1004	168	1	3
72	1004	185	2	2

73	1004	186	1	1
74	1004	187	2	2
75	1004	190	1	1
76	1004	192	2	1
77	1004	196	1	1
78	1004	197	1	1
79	1004	199	2	1
80	1004	200	1	3
81	1004	202	1	3
82	1004	210	3	3
83	1004	137	1	1
84	1004	138	2	1
85	1004	139	1	1
86	1009	170	1	1
87	1009	171	2	2
88	1009	173	2	1
89	1009	175	2	2
90	1009	176	1	1
91	1009	204	2	2
92	1009	206	1	1
93	1009	208	1	1
94	1009	209	1	1
95	1343	41	1	1
96	1343	46	1	3
97	1343	45	1	3
98	1343	48	1	1
99	1343	42	1	1
100	1343	43	3	3
101	1343	44	1	3
102	1343	47	1	1
103	1344	30	1	1
104	1344	32	2	1
105	1344	34	2	2
106	1344	31	1	3
107	1344	33	1	1
108	1350	36	1	1
109	1350	40	3	3
110	1350	37	2	2
111	1350	51	2	2
112	1350	52	3	3
113	1350	53	3	3
114	1350	35	1	1
115	1350	38	3	3
116	1350	39	1	3
117	1350	49	3	3
118	1350	50	3	3
119	1350	54	2	2
120	1350	55	3	3
121	1373	56	1	1
122	1373	57	3	3
123	1373	58	1	1
124	1373	59	3	3
125	1373	60	1	3
126	1590	142	2	1
127	1590	146	1	1
128	1590	147	2	2
129	1590	149	2	2
130	1590	143	1	1
131	1590	144	1	1
132	1590	145	1	1
133	1590	148	2	2
134	1700	152	2	2
135	1700	150	1	1

136	1700	151	2	1
137	1767	155	2	1
138	1767	153	1	1
139	1767	154	1	1
140	1767	156	2	2
141	1767	157	2	2
142	1768	160	2	2
143	1768	161	2	2
144	1768	158	2	2
145	1768	159	1	1
146	1768	162	1	3
147	Enzhou	18	3	3
148	Enzhou	6	1	3
149	Enzhou	8	1	1
150	Enzhou	10	1	1
151	Enzhou	12	3	3
152	Enzhou	14	1	1
153	Enzhou	16	1	1
154	Enzhou	17	1	1
155	Enzhou	19	3	3
156	Enzhou	20	3	3
157	Enzhou	1	2	2
158	Enzhou	4	1	1
159	Enzhou	5	1	1
160	Enzhou	7	1	3
161	Enzhou	9	1	1
162	Enzhou	11	2	2
163	Enzhou	13	1	1
164	Enzhou	15	2	2
165	Enzhou	3	2	2

Table 12.2.11 Earthenware if 4 Groupings

Case	Site	Sample	PCA Av	KMCA PCA	PCA MD WARD	KMCA PCA MD	Log10 Av	KMCA log10
1	349	85	1	1	2	1	1	2
2	349	86	1	2	1	1	1	1
3	349	89	1	2	1	1	1	1
4	349	99	2	2	3	2	1	3
5	349	87	1	1	2	3	1	2
6	349	88	1	3	2	4	1	2
7	349	94	1	3	4	3	1	2
8	349	95	1	1	2	1	1	1
9	349	97	1	1	4	3	1	2
10	408	80	1	1	1	1	1	1
11	408	81	1	1	2	1	1	1
12	408	82	1	1	1	1	1	1
13	408	83	1	1	2	1	1	1
14	498	71	1	1	2	1	1	1
15	498	72	1	1	1	1	1	1
16	498	74	1	1	1	1	1	1
17	498	75	1	1	1	1	1	1
18	503	61	1	2	1	1	1	1
19	503	62	1	1	2	1	1	1
20	503	63	1	1	1	1	1	1
21	503	64	1	1	1	1	1	1
22	503	65	1	2	1	1	1	1
23	504	66	1	2	1	1	1	1
24	504	67	1	2	1	1	1	1
25	504	68	1	1	1	1	1	1
26	504	69	1	1	1	1	1	1
27	504	70	1	1	2	1	1	2

28	554	77	1	3	4	4	2	4
29	554	76	1	2	3	2	1	3
30	591	92	1	2	1	1	1	1
31	591	90	1	1	2	1	1	1
32	591	91	1	1	2	1	1	2
33	591	93	1	3	2	4	1	2
34	1004	103	1	1	2	1	1	2
35	1004	109	1	3	4	3	1	2
36	1004	110	1	1	2	1	1	2
37	1004	112	1	1	2	4	1	2
38	1004	114	1	2	3	2	1	4
39	1004	124	1	1	2	1	1	2
40	1004	126	1	1	2	1	1	2
41	1004	127	1	3	4	3	1	4
42	1004	129	1	1	2	1	1	2
43	1004	134	1	3	4	4	1	4
44	1004	135	1	3	4	4	1	4
45	1004	140	1	3	4	4	1	4
46	1004	141	1	3	4	4	1	4
47	1004	167	1	2	1	1	1	1
48	1004	201	1	1	1	1	1	1
49	1004	100	1	1	2	1	1	2
50	1004	101	1	1	2	1	1	2
51	1004	102	1	2	1	1	1	1
52	1004	104	1	1	1	1	1	1
53	1004	105	1	3	4	3	1	2
54	1004	108	1	1	2	1	1	2
55	1004	111	1	1	2	1	1	1
56	1004	113	3	4	4	4	2	4
57	1004	117	1	1	2	1	1	1
58	1004	118	1	1	2	1	1	2
59	1004	119	1	1	2	1	1	1
60	1004	121	1	1	1	1	1	1
61	1004	122	1	1	1	1	1	2
62	1004	123	1	1	2	1	1	2
63	1004	125	1	1	2	1	1	2
64	1004	130	1	3	4	4	2	4
65	1004	131	1	3	2	4	1	4
66	1004	132	1	3	4	4	1	4
67	1004	133	1	3	2	4	2	4
68	1004	136	1	3	4	4	2	4
69	1004	164	1	2	1	1	1	1
70	1004	166	1	2	1	1	1	1
71	1004	168	1	3	4	3	1	4
72	1004	185	1	2	4	3	1	3
73	1004	186	1	1	2	1	1	2
74	1004	187	1	2	1	1	1	1
75	1004	190	1	1	2	1	1	1
76	1004	192	1	1	4	3	1	2
77	1004	196	1	1	1	1	1	2
78	1004	197	1	3	4	3	1	2
79	1004	199	1	1	4	3	1	2
80	1004	200	1	3	4	3	1	2
81	1004	202	1	3	4	3	1	4
82	1004	210	1	3	4	2	2	4
83	1004	137	1	1	2	1	1	2
84	1004	138	1	1	1	1	1	1
85	1004	139	1	3	4	3	1	2
86	1009	170	1	1	4	3	1	2
87	1009	171	1	2	1	1	1	1
88	1009	173	1	1	1	1	1	1
89	1009	175	2	2	3	2	3	3
90	1009	176	1	1	2	3	1	2

91	1009	204	1	2	1	1	1	2
92	1009	206	1	1	4	3	1	2
93	1009	208	1	3	4	3	1	2
94	1009	209	1	1	4	3	1	2
95	1343	41	1	1	2	1	1	2
96	1343	46	1	3	4	3	1	2
97	1343	45	1	3	4	3	1	4
98	1343	48	1	1	2	4	1	2
99	1343	42	1	1	2	1	1	2
100	1343	43	3	4	4	4	2	4
101	1343	44	1	3	4	3	1	2
102	1343	47	1	1	2	1	1	1
103	1344	30	1	1	2	1	1	1
104	1344	32	1	1	1	1	1	1
105	1344	34	1	2	1	1	1	2
106	1344	31	1	3	4	3	1	2
107	1344	33	1	1	2	1	1	2
108	1350	36	1	1	2	1	1	1
109	1350	40	1	3	4	3	1	4
110	1350	37	1	2	1	1	1	2
111	1350	51	1	2	3	2	1	2
112	1350	52	1	3	4	3	1	4
113	1350	53	1	3	4	3	1	4
114	1350	35	1	3	4	3	1	4
115	1350	38	1	3	4	3	1	4
116	1350	39	1	3	4	3	1	4
117	1350	49	1	3	4	2	1	4
118	1350	50	1	3	4	2	1	4
119	1350	54	1	2	3	2	1	2
120	1350	55	1	3	4	4	1	4
121	1373	56	1	1	2	1	1	2
122	1373	57	1	3	4	2	1	2
123	1373	58	1	1	2	1	1	2
124	1373	59	1	3	4	3	2	4
125	1373	60	1	3	4	3	1	2
126	1590	142	1	1	1	1	1	1
127	1590	146	1	1	2	1	1	1
128	1590	147	1	2	1	1	1	1
129	1590	149	1	1	1	1	1	1
130	1590	143	1	1	4	3	1	2
131	1590	144	1	1	2	4	1	2
132	1590	145	1	1	2	3	1	2
133	1590	148	1	2	1	1	1	1
134	1700	152	1	2	1	1	1	1
135	1700	150	1	1	2	1	1	1
136	1700	151	1	1	2	1	1	1
137	1767	155	1	1	2	1	1	1
138	1767	153	1	1	2	4	1	2
139	1767	154	1	1	2	1	1	1
140	1767	156	1	2	1	1	1	1
141	1767	157	1	2	1	1	1	1
142	1768	160	1	2	1	1	1	1
143	1768	161	1	2	1	1	1	1
144	1768	158	1	2	1	1	1	1
145	1768	159	1	1	2	1	1	2
146	1768	162	1	3	2	4	1	2
147	Enzhou	18	1	3	4	3	2	4
148	Enzhou	6	1	3	4	3	1	4
149	Enzhou	8	1	1	4	3	1	2
150	Enzhou	10	1	1	2	1	1	2
151	Enzhou	12	4	4	4	2	2	4
152	Enzhou	14	1	1	2	1	1	2
153	Enzhou	16	1	1	4	3	1	2

154	Enzhou	17	1	3	2	4	1	2
155	Enzhou	19	4	4	4	2	2	4
156	Enzhou	20	1	3	4	3	2	4
157	Enzhou	1	2	2	3	2	4	1
158	Enzhou	4	1	3	2	4	1	4
159	Enzhou	5	1	1	2	3	1	2
160	Enzhou	7	1	3	2	4	1	2
161	Enzhou	9	1	1	2	1	1	2
162	Enzhou	11	1	2	1	2	1	1
163	Enzhou	13	1	1	2	1	1	2
164	Enzhou	15	1	2	1	1	1	2
165	Enzhou	3	2	2	3	2	3	3

Table 12.2.12 Earthenware If 5 groupings

Case	Site number	Sample #	PCA MD HCA Av	KMCA PCA MD 5G
1	349	85	1	1
2	349	86	1	1
3	349	89	1	2
4	349	99	2	2
5	349	87	1	3
6	349	88	1	3
7	349	94	1	3
8	349	95	1	1
9	349	97	1	3
10	408	80	1	1
11	408	81	1	1
12	408	82	1	1
13	408	83	1	1
14	498	71	1	1
15	498	72	1	1
16	498	74	1	1
17	498	75	1	1
18	503	61	1	1
19	503	62	1	1
20	503	63	1	1
21	503	64	1	1
22	503	65	1	1
23	504	66	1	1
24	504	67	1	1
25	504	68	1	1
26	504	69	1	1
27	504	70	1	3
28	554	77	1	4
29	554	76	3	2
30	591	92	1	1
31	591	90	1	1
32	591	91	1	3
33	591	93	1	4
34	1004	103	1	1
35	1004	109	1	3
36	1004	110	1	1
37	1004	112	1	4
38	1004	114	3	2
39	1004	124	1	1
40	1004	126	1	1
41	1004	127	1	3
42	1004	129	1	3
43	1004	134	1	4
44	1004	135	1	4
45	1004	140	1	4

46	1004	141	1	4
47	1004	167	1	1
48	1004	201	1	1
49	1004	100	1	1
50	1004	101	1	3
51	1004	102	1	1
52	1004	104	1	1
53	1004	105	1	3
54	1004	108	1	1
55	1004	111	1	1
56	1004	113	4	4
57	1004	117	1	1
58	1004	118	1	3
59	1004	119	1	1
60	1004	121	1	1
61	1004	122	1	1
62	1004	123	1	1
63	1004	125	1	1
64	1004	130	1	4
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66	1004	132	1	4
67	1004	133	1	4
68	1004	136	1	4
69	1004	164	1	1
70	1004	166	1	1
71	1004	168	1	3
72	1004	185	1	3
73	1004	186	1	1
74	1004	187	1	1
75	1004	190	1	1
76	1004	192	1	3
77	1004	196	1	1
78	1004	197	1	3
79	1004	199	1	3
80	1004	200	1	3
81	1004	202	1	3
82	1004	210	5	5
83	1004	137	1	3
84	1004	138	1	1
85	1004	139	1	3
86	1009	170	1	3
87	1009	171	1	1
88	1009	173	1	1
89	1009	175	2	2
90	1009	176	1	3
91	1009	204	1	1
92	1009	206	1	3
93	1009	208	1	3
94	1009	209	1	3
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96	1343	46	1	3
97	1343	45	1	3
98	1343	48	1	4
99	1343	42	1	1
100	1343	43	4	4
101	1343	44	1	3
102	1343	47	1	3
103	1344	30	1	1
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105	1344	34	1	1
106	1344	31	1	3
107	1344	33	1	1
108	1350	36	1	3

109	1350	40	5	5
110	1350	37	1	1
111	1350	51	3	2
112	1350	52	5	5
113	1350	53	5	5
114	1350	35	1	3
115	1350	38	5	5
116	1350	39	1	3
117	1350	49	5	5
118	1350	50	5	5
119	1350	54	3	2
120	1350	55	1	4
121	1373	56	1	1
122	1373	57	5	5
123	1373	58	1	1
124	1373	59	5	5
125	1373	60	1	3
126	1590	142	1	1
127	1590	146	1	1
128	1590	147	1	1
129	1590	149	1	1
130	1590	143	1	3
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135	1700	150	1	1
136	1700	151	1	1
137	1767	155	1	1
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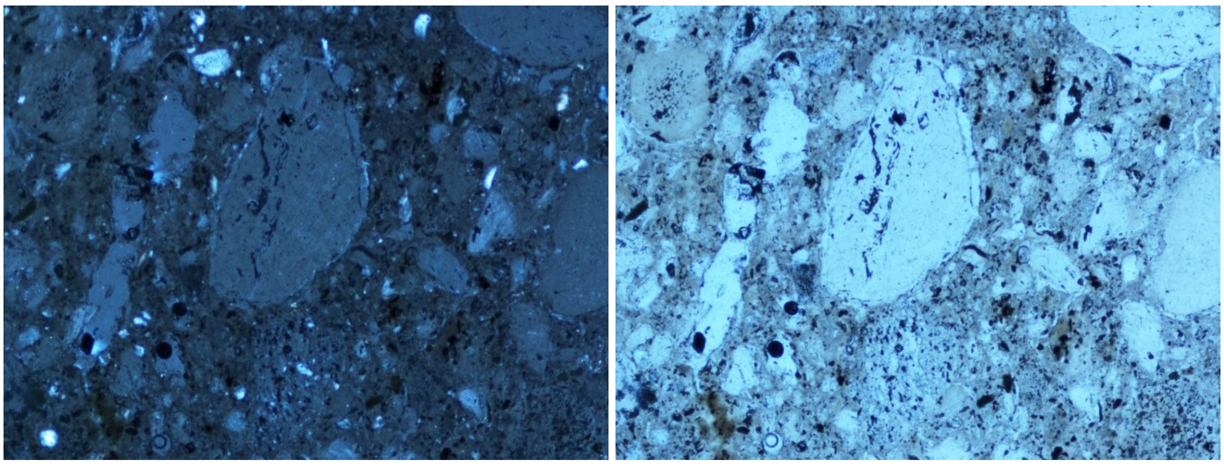
140	1767	156	1	1
141	1767	157	1	1
142	1768	160	1	1
143	1768	161	1	1
144	1768	158	1	1
145	1768	159	1	3
146	1768	162	1	4
147	Enzhou	18	1	3
148	Enzhou	6	1	3
149	Enzhou	8	1	3
150	Enzhou	10	1	3
151	Enzhou	12	5	5
152	Enzhou	14	1	1
153	Enzhou	16	1	3
154	Enzhou	17	1	4
155	Enzhou	19	5	5
156	Enzhou	20	5	5
157	Enzhou	1	2	2
158	Enzhou	4	1	3
159	Enzhou	5	1	3
160	Enzhou	7	1	4
161	Enzhou	9	1	3
162	Enzhou	11	1	2
163	Enzhou	13	1	3
164	Enzhou	15	1	1
165	Enzhou	3	2	2

13. Appendix 2. Petrographic Groupings

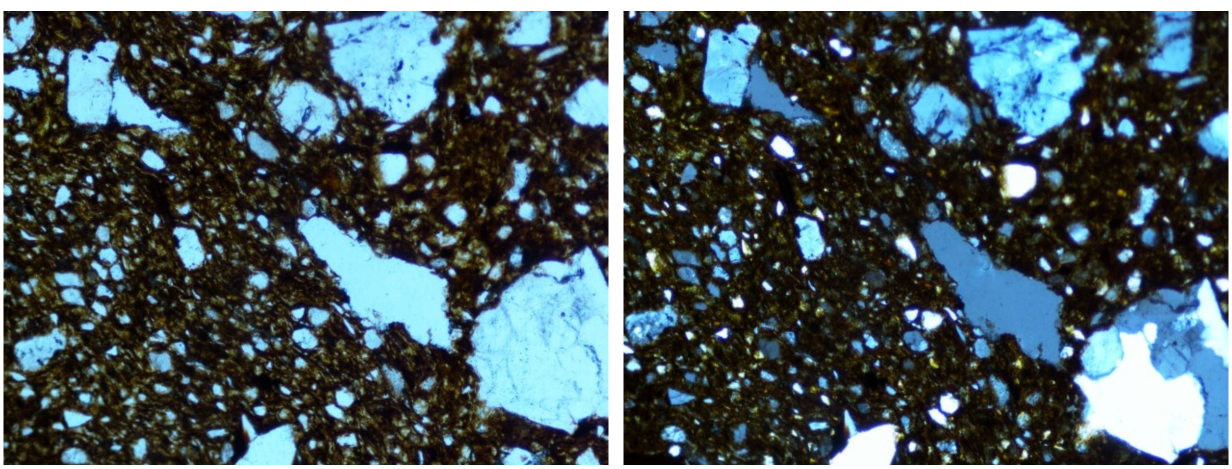
Each image was taken with the integrated camera on a Nikon polarizing microscope at a standard image width of 2.6mm. The image on the left for each slide is the section under plain polar light while the image on the right is the section under crossed polars. Petrographic groups 17, 18 and 25 were composed of the samples that were mislabelled in the lab and as such are not included here as they cannot be linked to a specific sample.

Figure 13.1 Petrographic Group 1



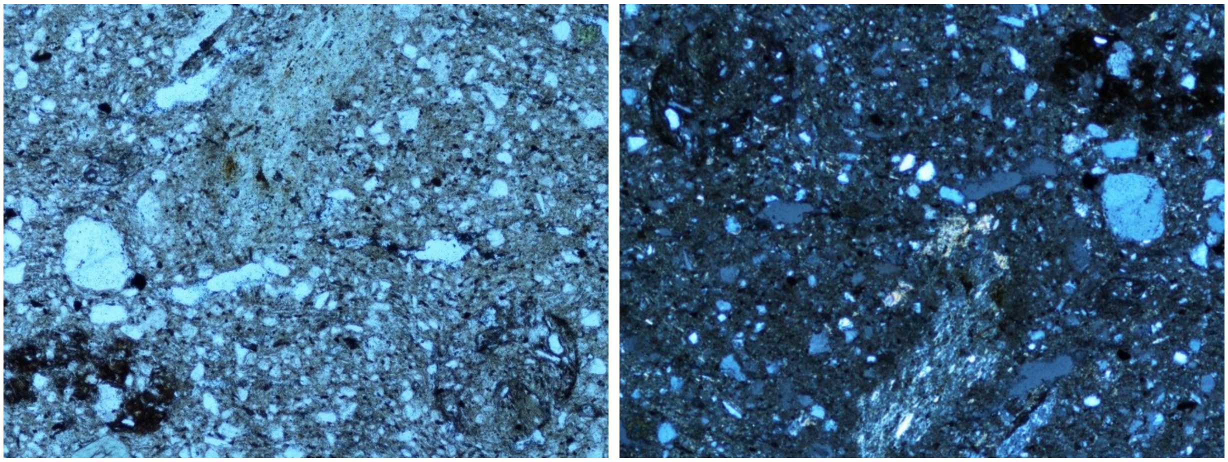
Slide 41, Sample 188

Figure 13.2 Petrographic Group 2



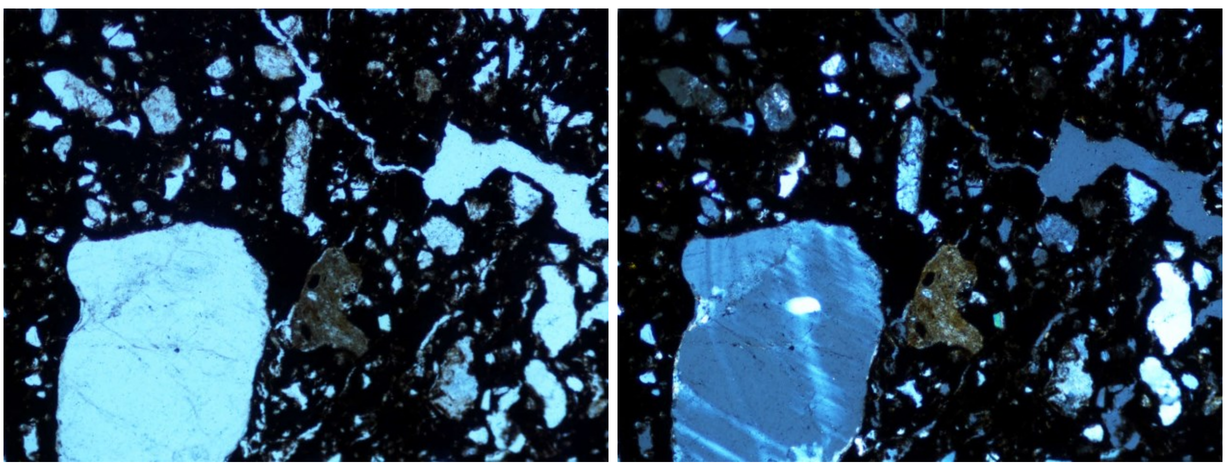
Slide 7, Sample 52

Figure 13.3 Petrographic Group 3



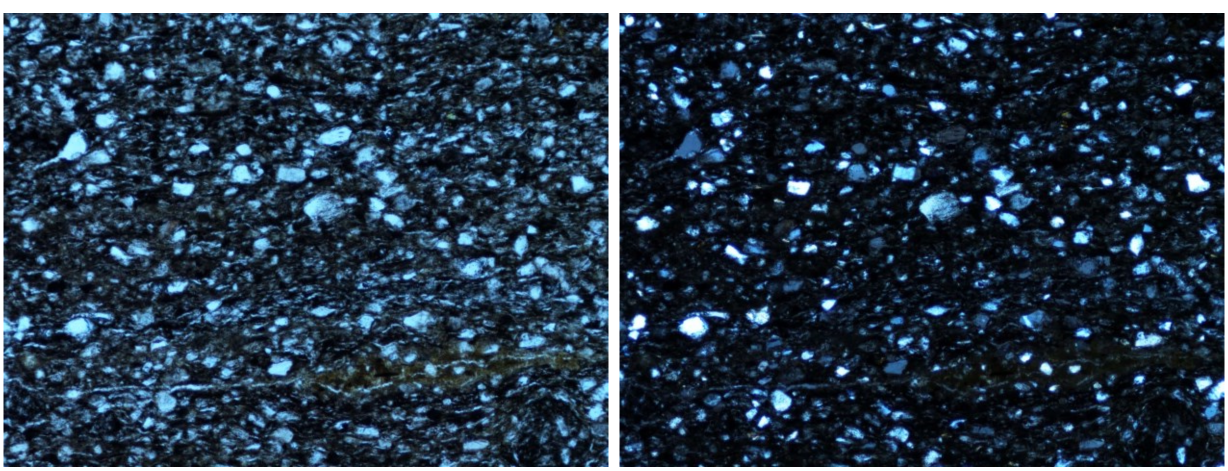
Slide 29, Sample 114

Figure 13.4 Petrographic Group 4



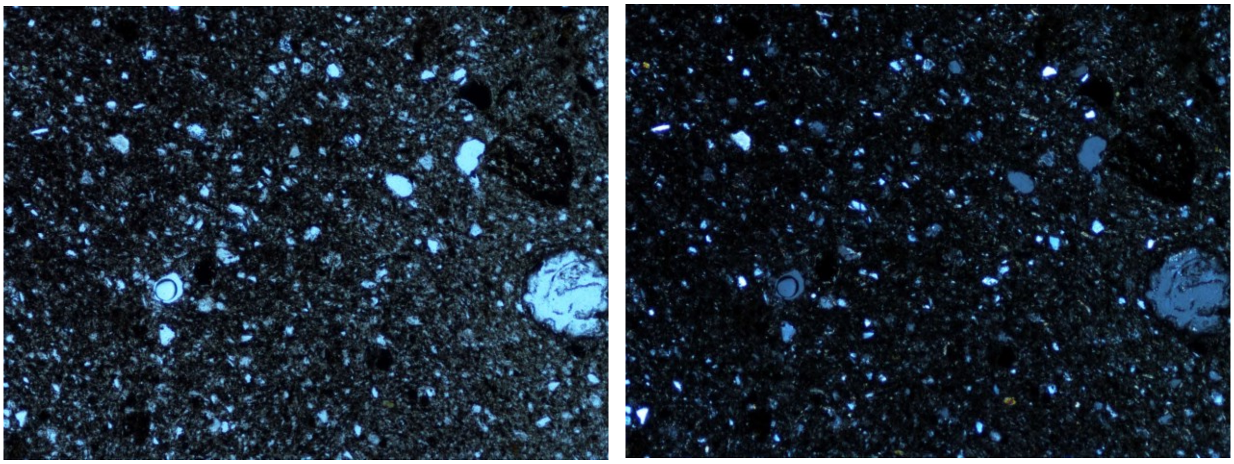
Slide 22, Sample 1

Figure 13.5 Petrographic Group 5



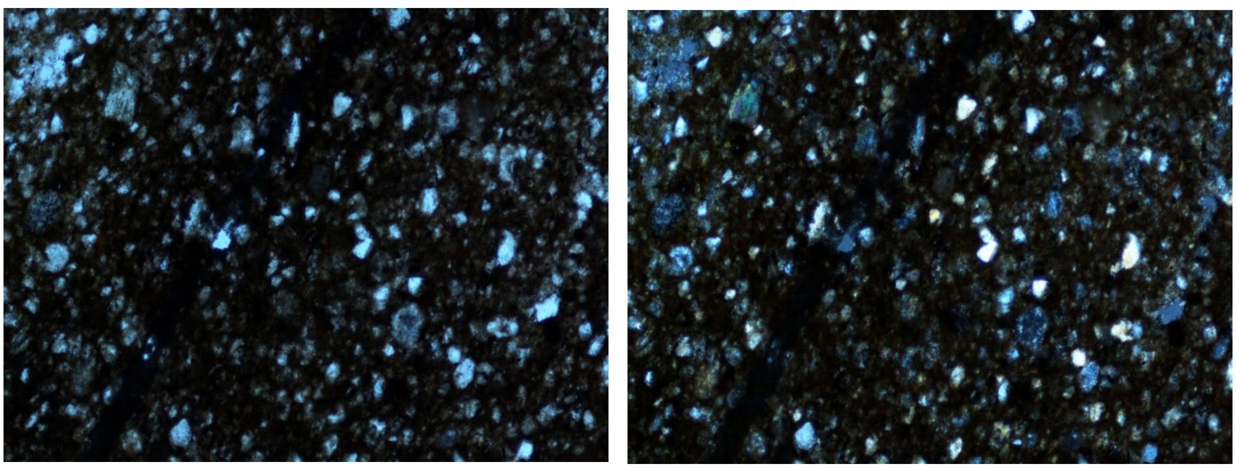
Slide 39, Sample 170

Figure 13.6 Petrographic Group 6



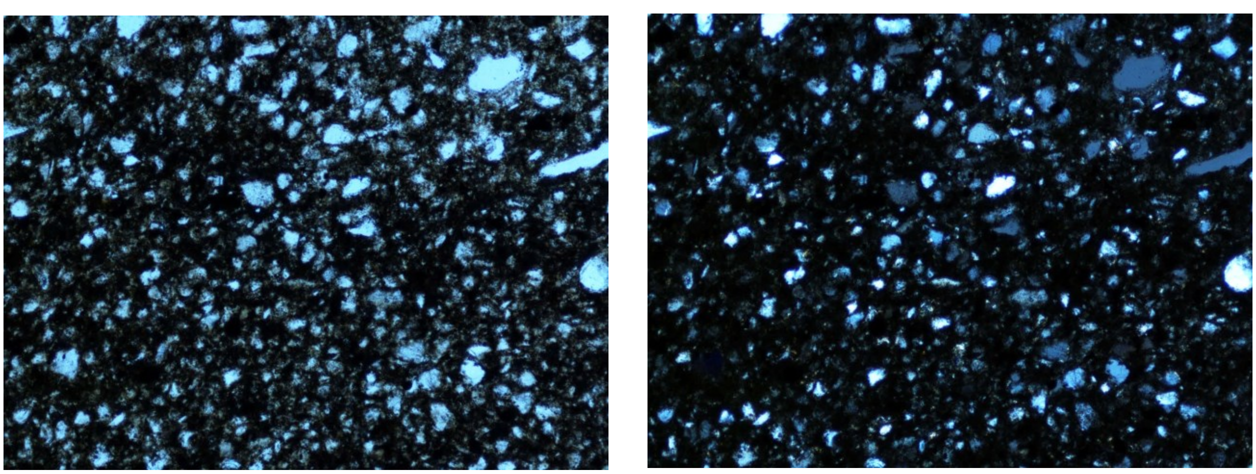
Slide 35, Sample 12

Figure 13.7 Petrographic Group 7



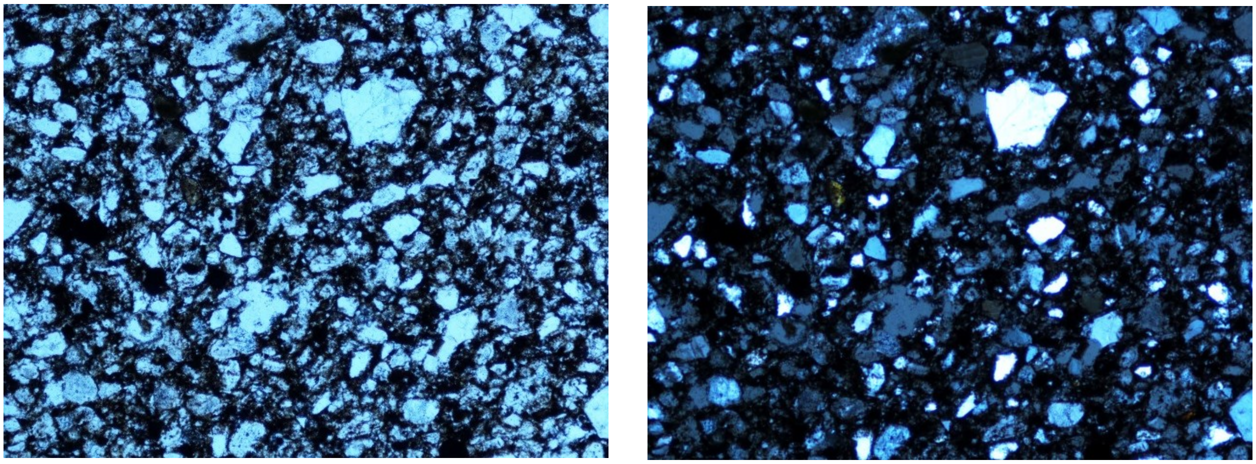
Slide 33, Sample 155

Figure 13.8 Petrographic Group 8



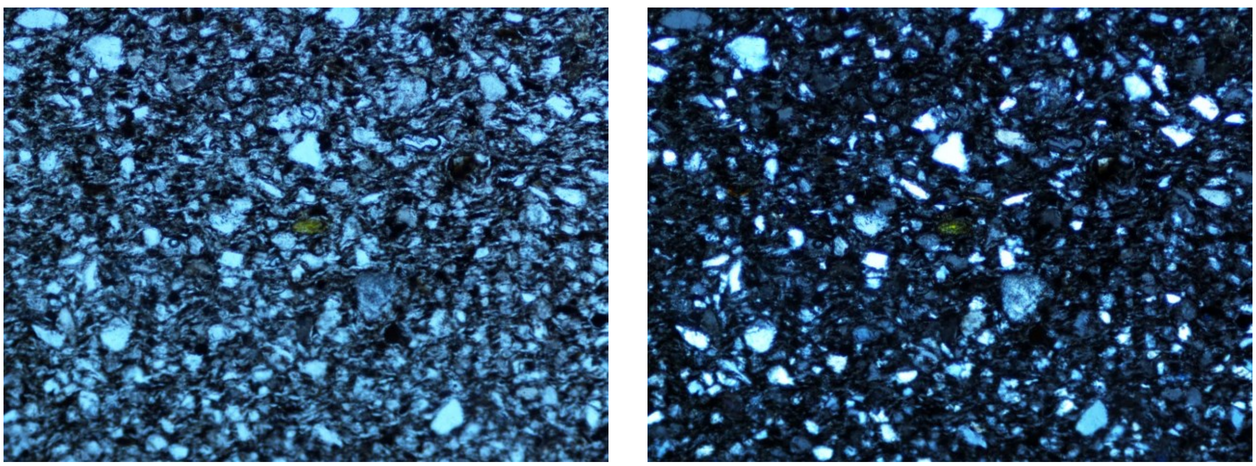
Slide 36, Sample 4

Figure 13.9 Petrographic Group 9

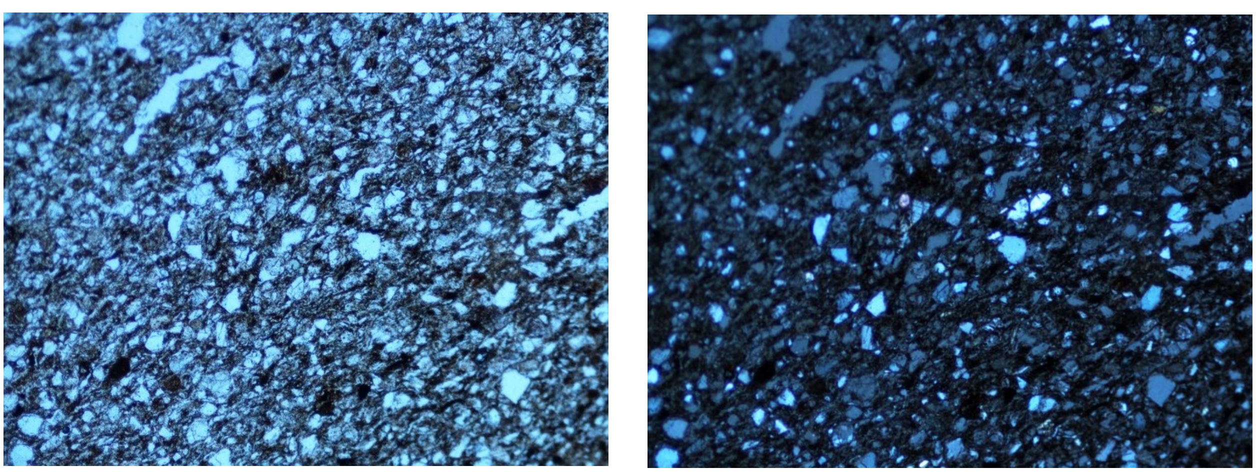


Slide 37, Sample 104

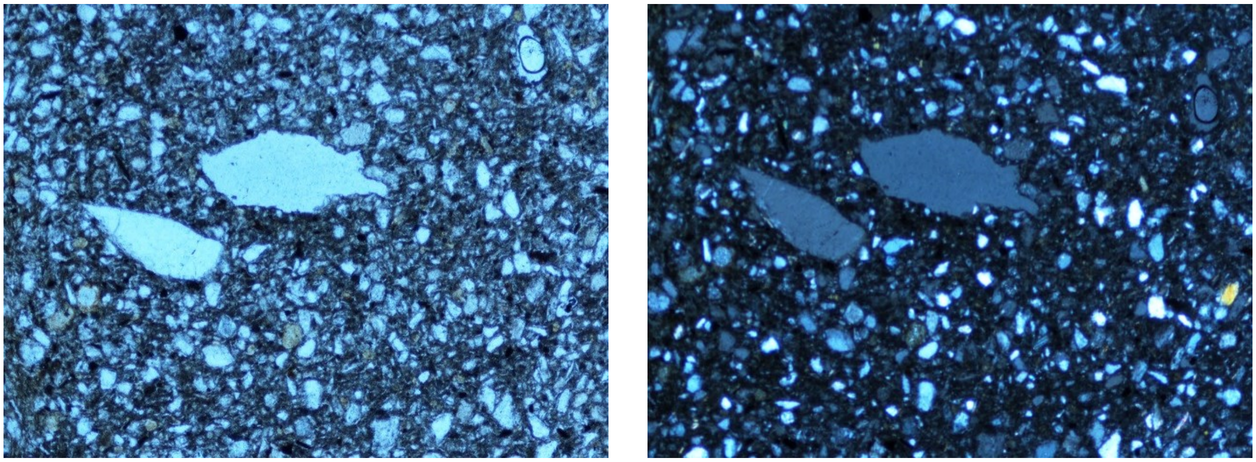
Figure 13.10 Petrographic Group 10

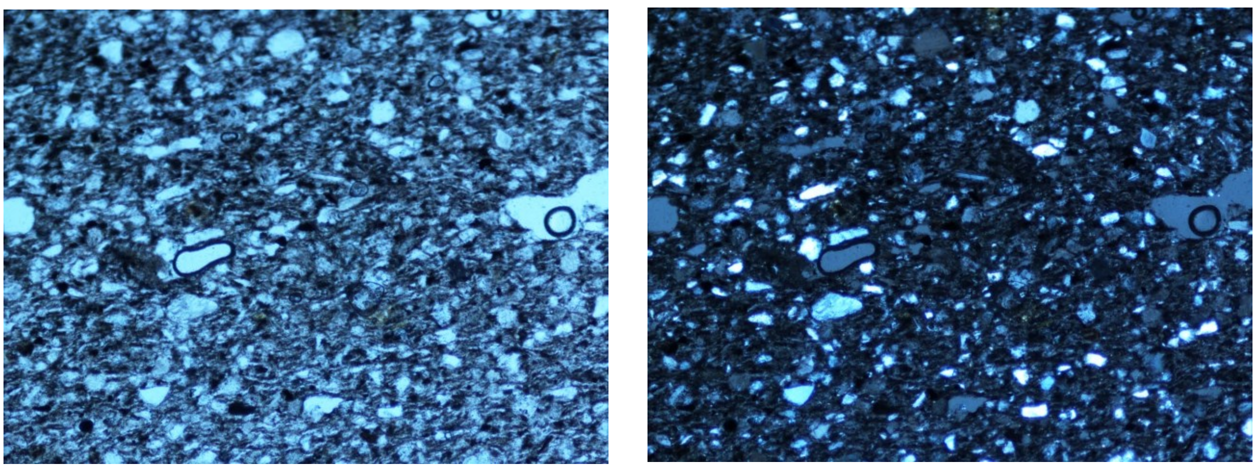


Slide 13, Sample 101



Slide 20, Sample 119


Slide 21, Sample 159


Slide 28, Sample 150

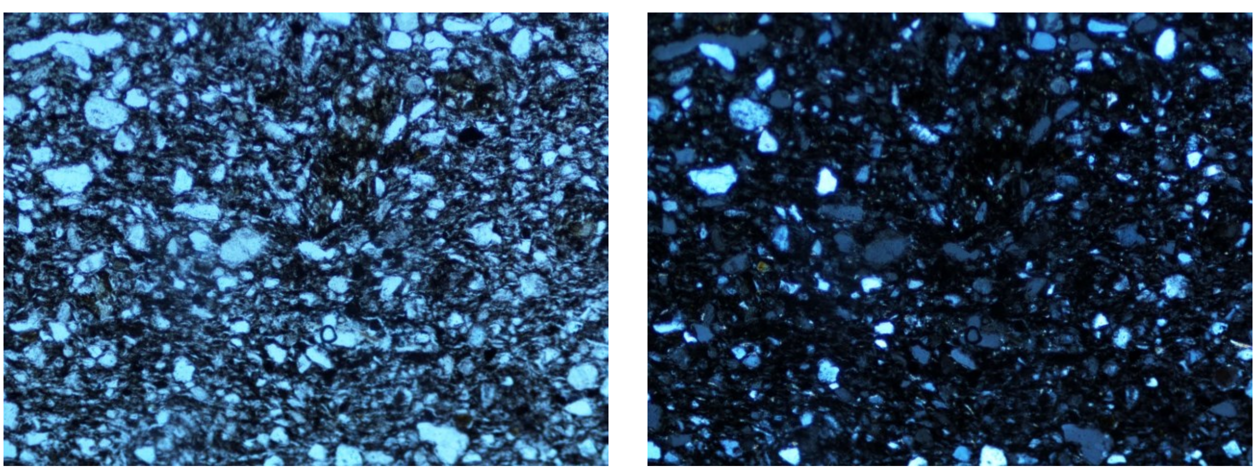
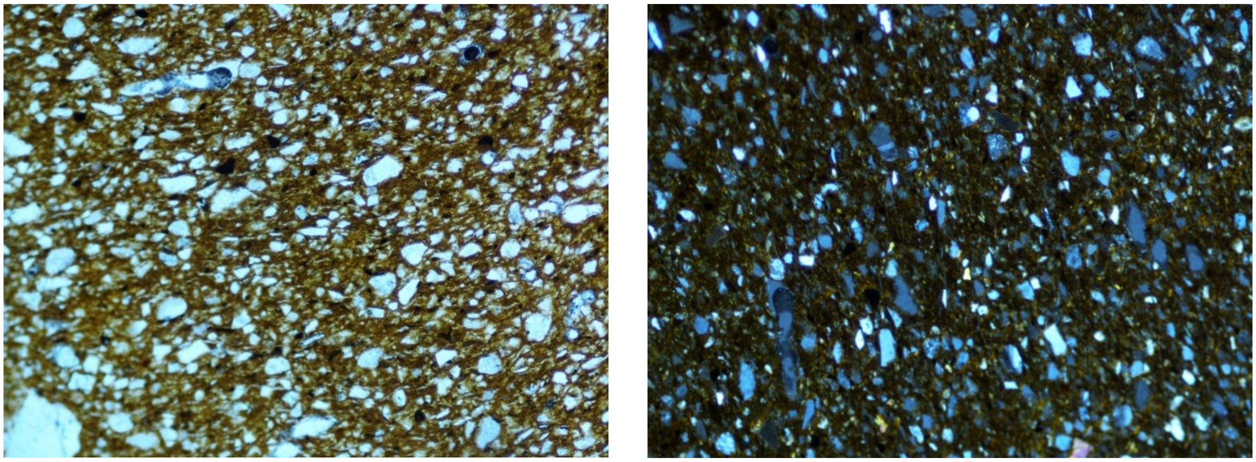
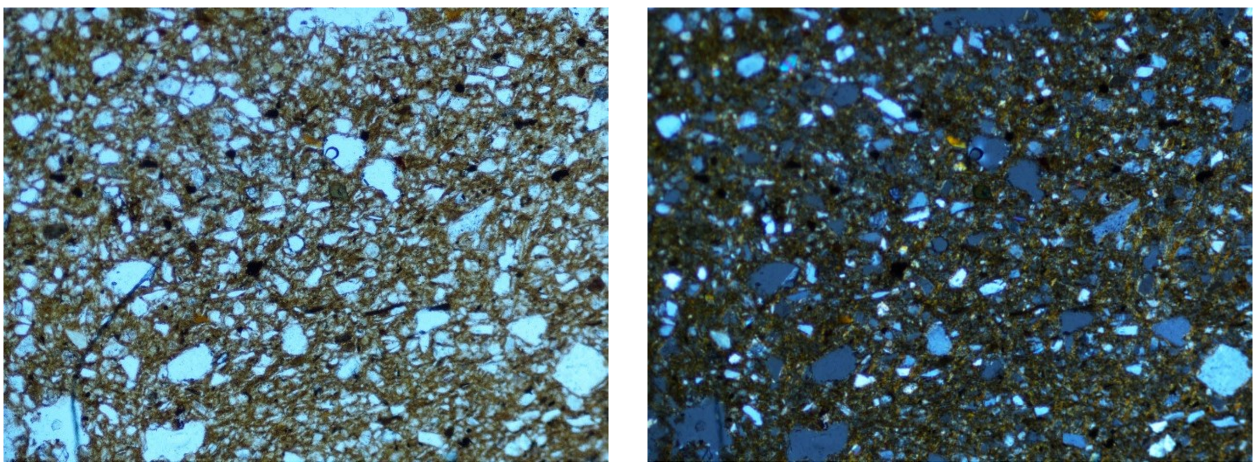

Slide 5, Sample 2

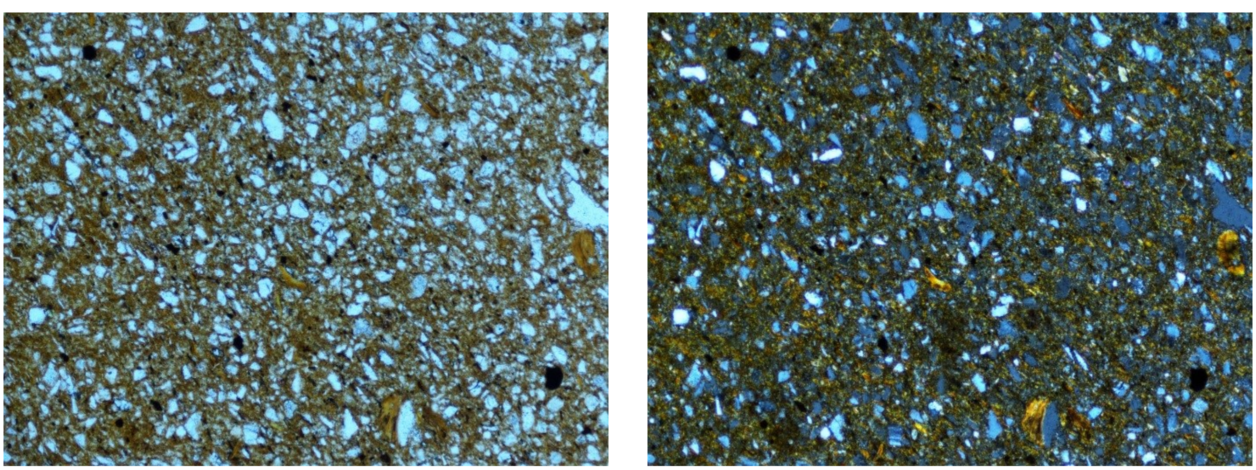
Figure 13.11 Petrographic Group 11



Slide 8, Sample 6

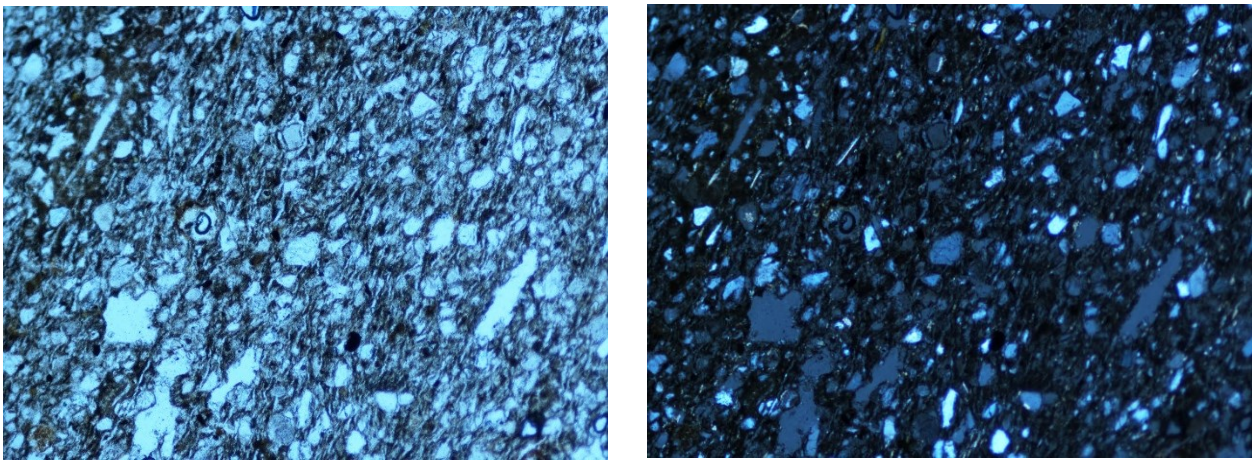


Slide 10, Sample 10

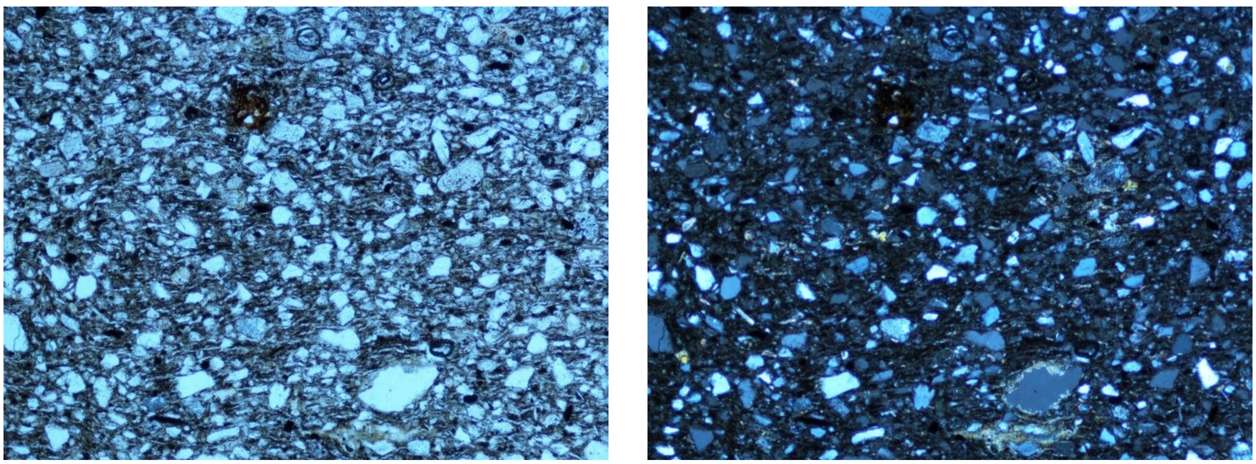


Slide 40 Sample 8

Figure 13.12 Petrographic Group 12

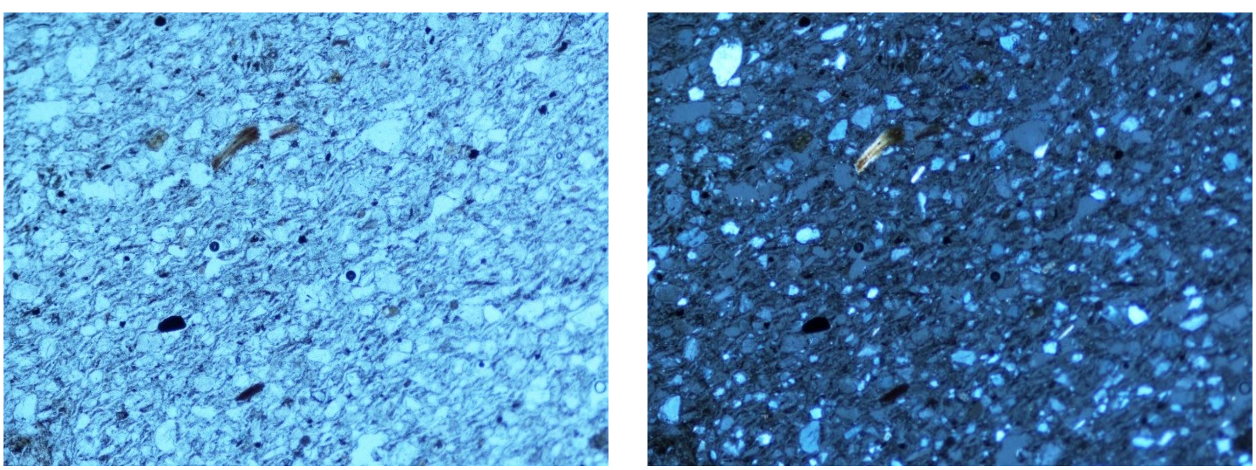


Slide 3, Sample 103

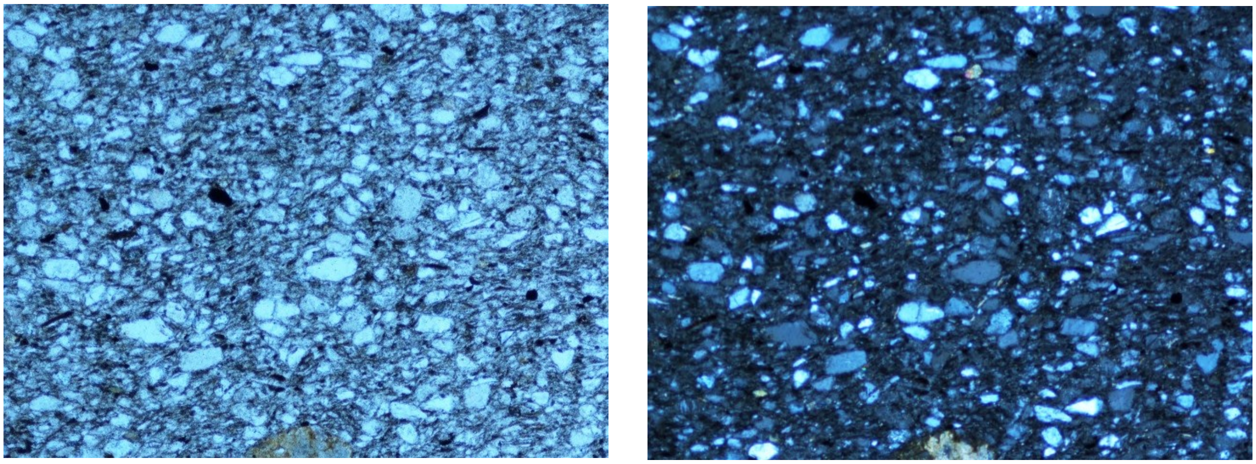


Slide 38, Sample 187

Figure 13.13 Petrographic Group 13



Slide 19, Sample 105



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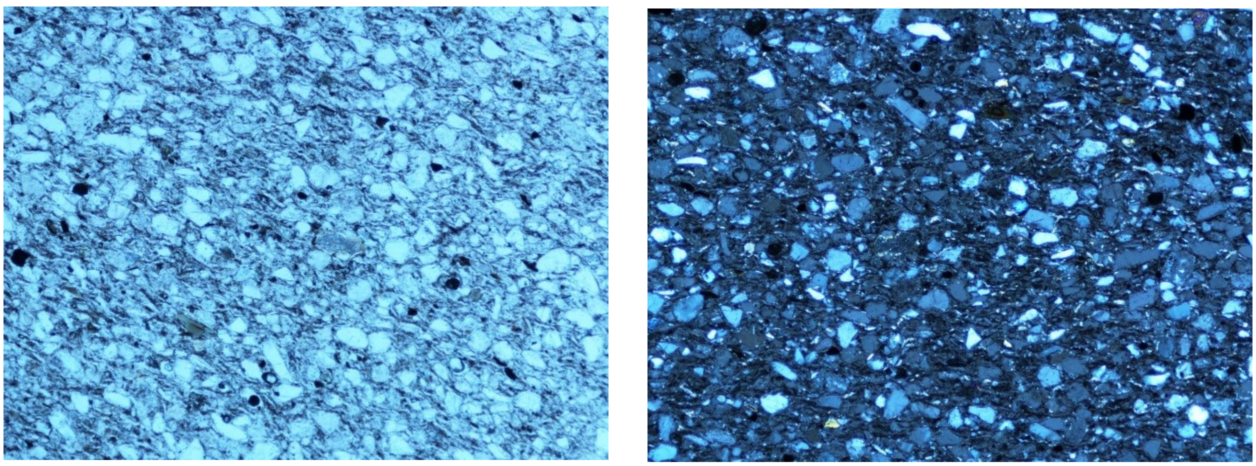
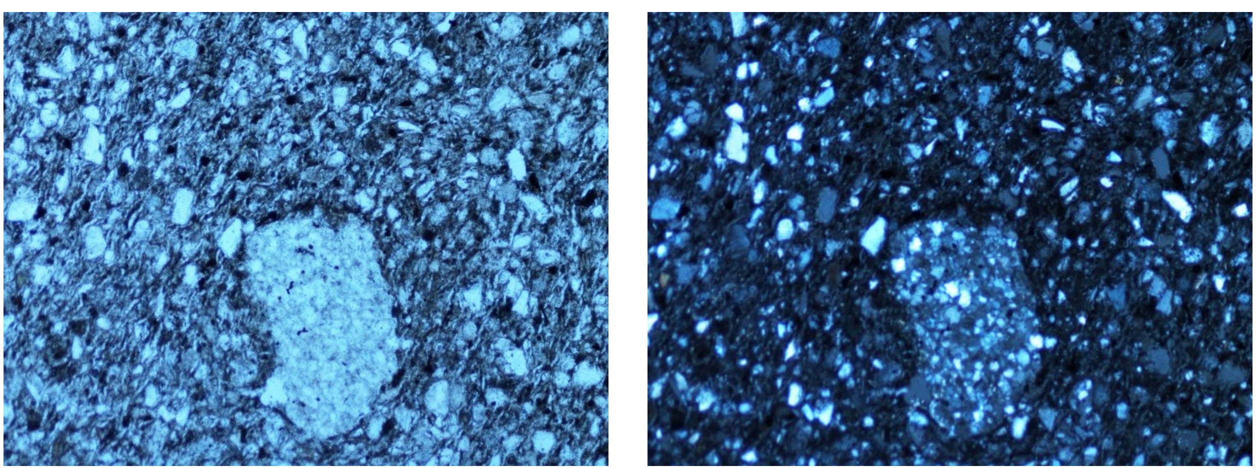
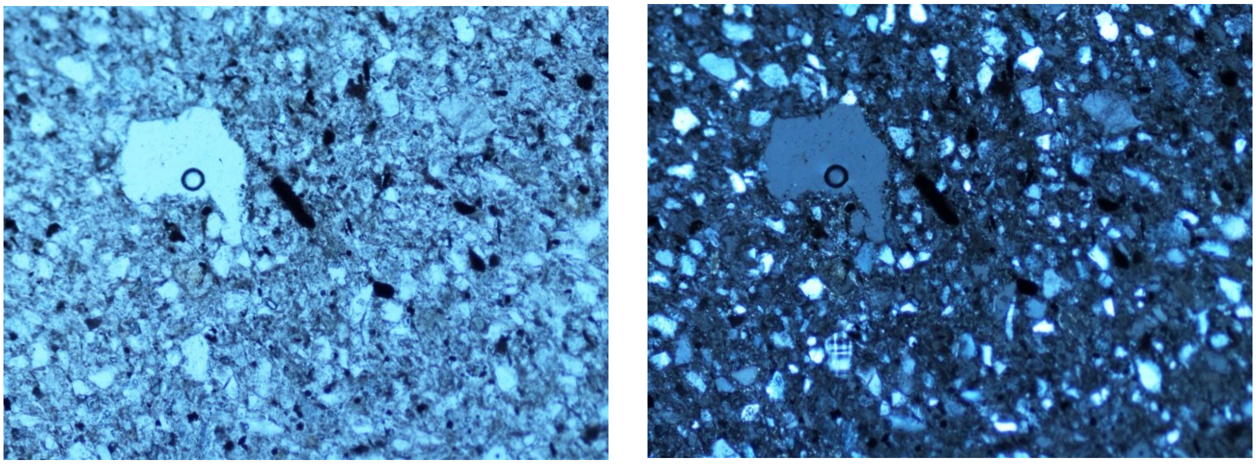


Slide 25, Sample 186

Figure 13.14 Petrographic Group 14

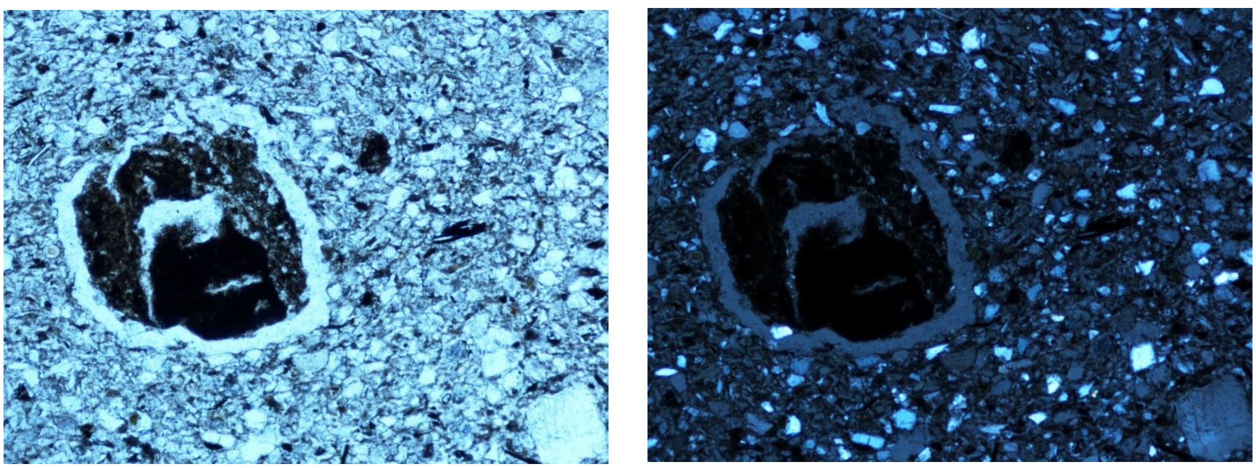


Slide 6, Sample 100

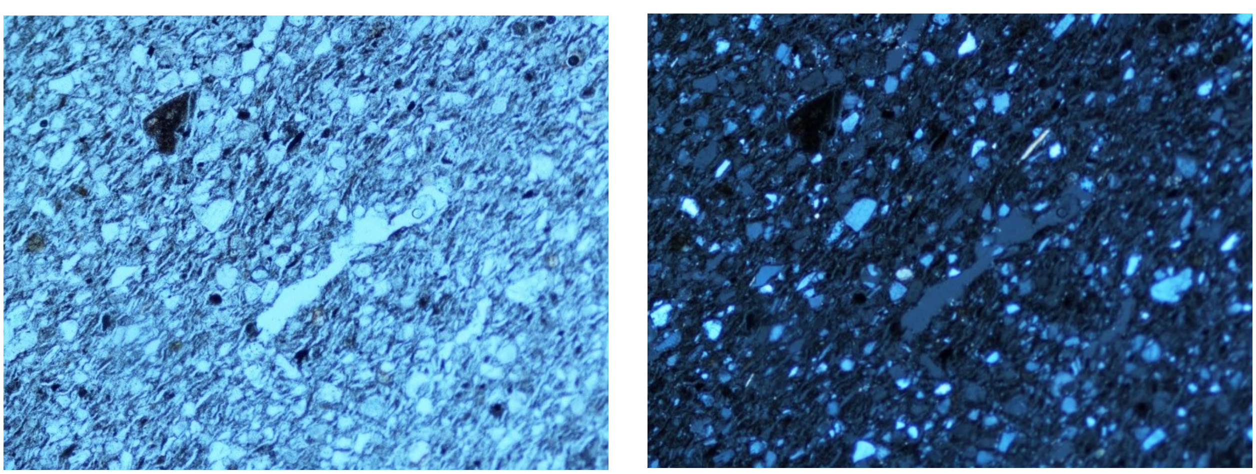


Slide 11, Sample 165

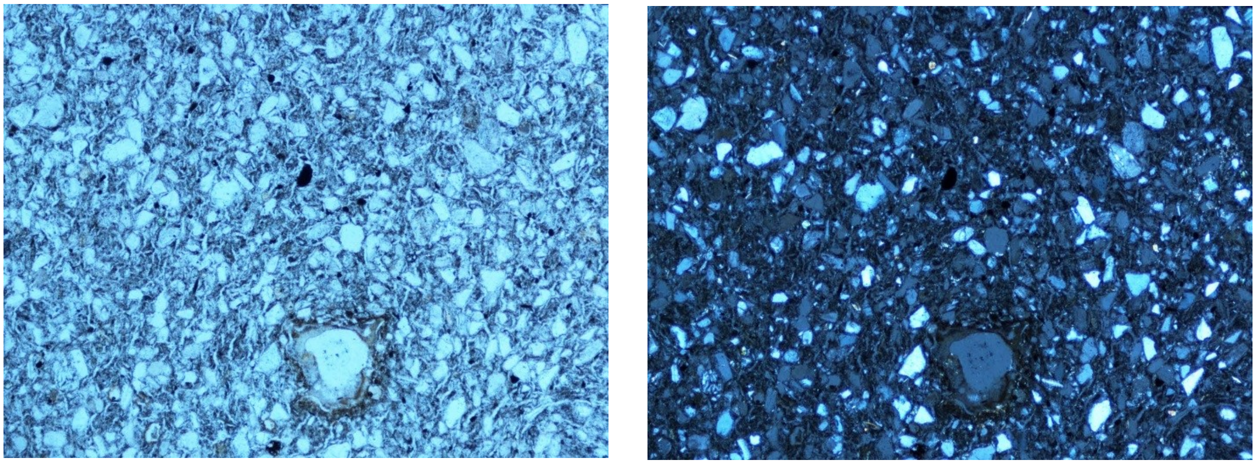
Figure 13.15 Petrographic Group 15



Slide 1, Sample 9

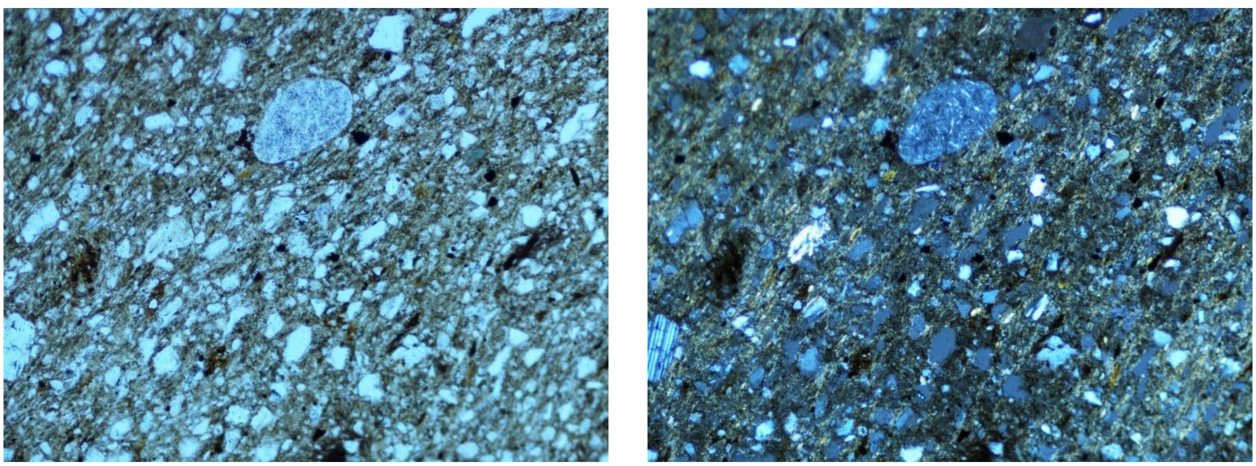


Slide 4, Sample 168



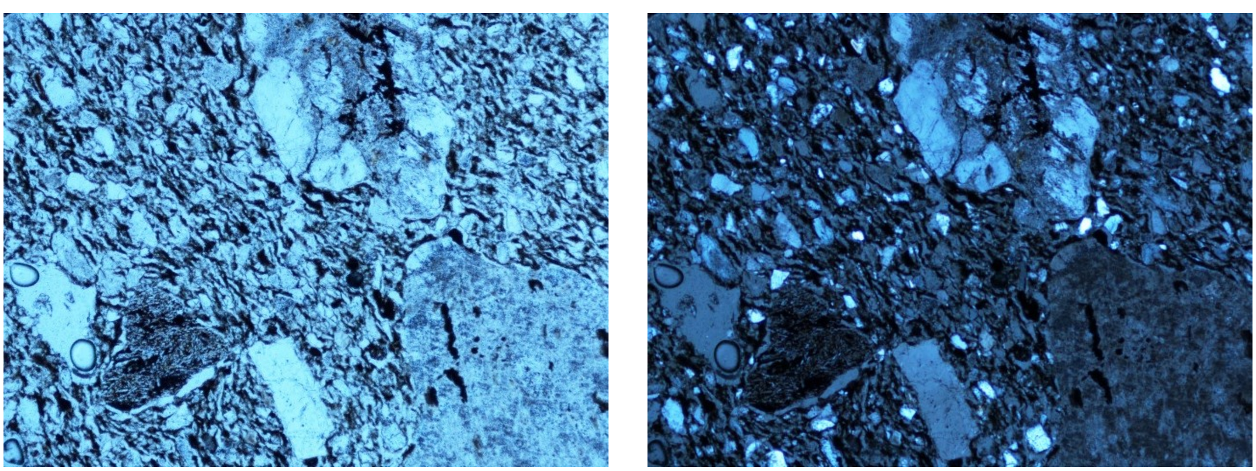
Slide 42, Sample 110

Figure 13.16 Petrographic Group 16



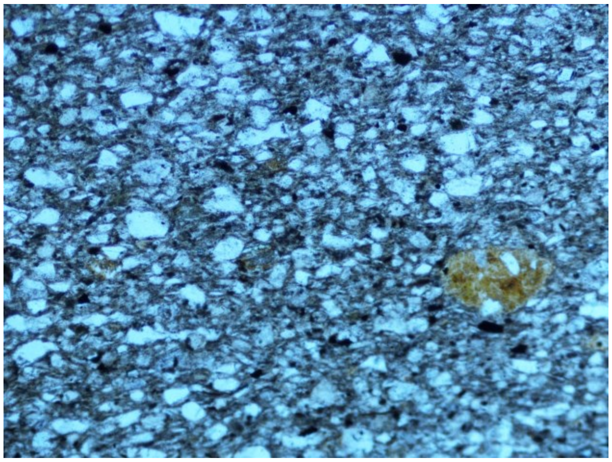
Slide 18, Sample 7

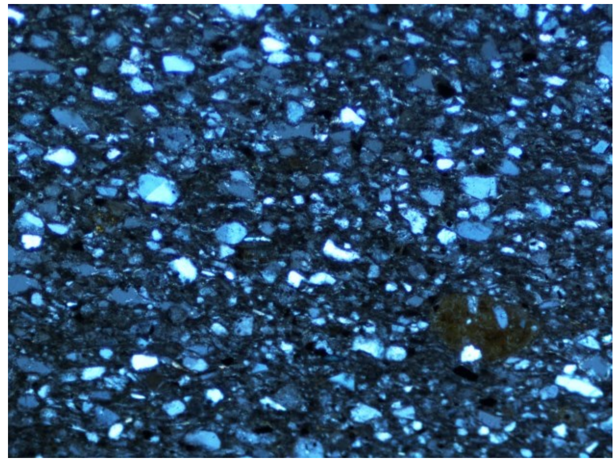
Figure 13.17 Petrographic Group 19



Slide 27, Sample 5

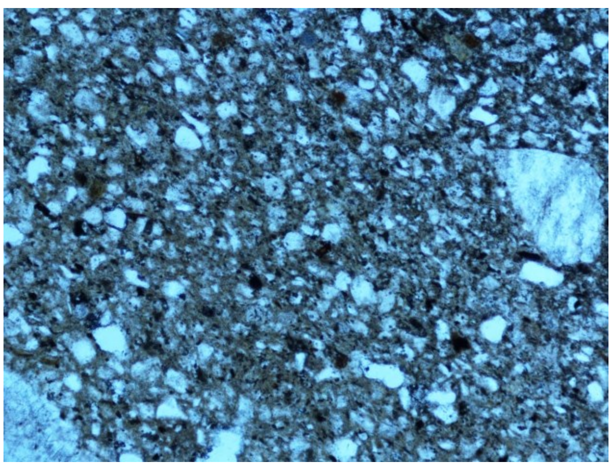
Figure 13.18 Petrographic Group 20

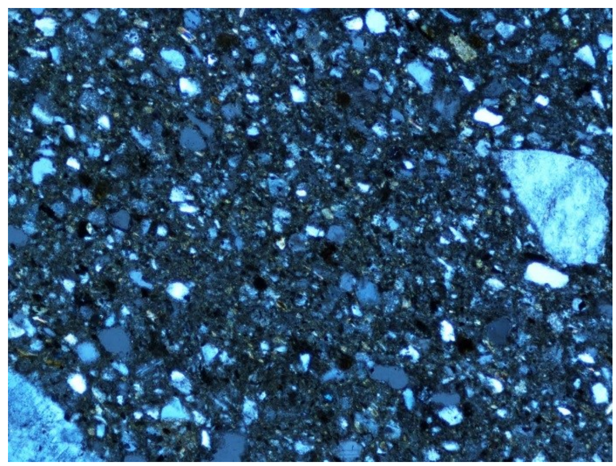




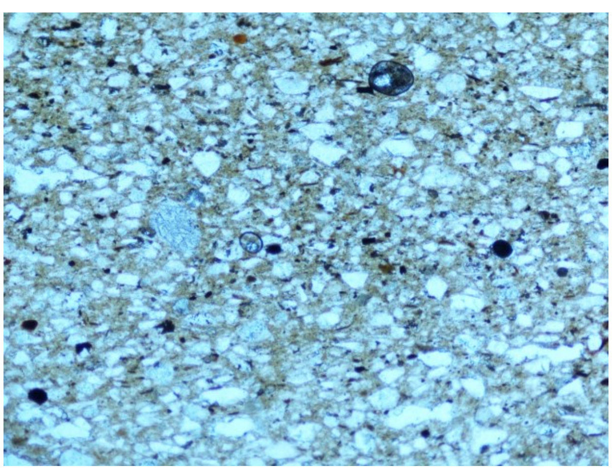
Slide 14, Sample 111

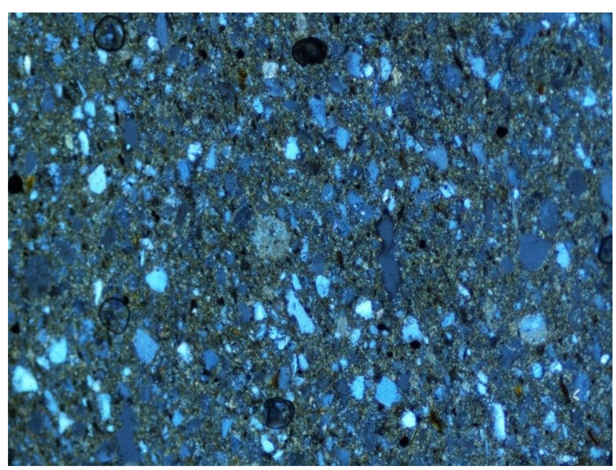
Figure 13.19 Petrographic Group 21



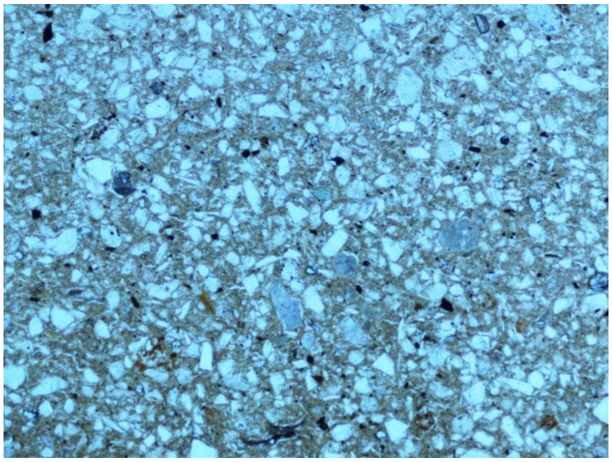
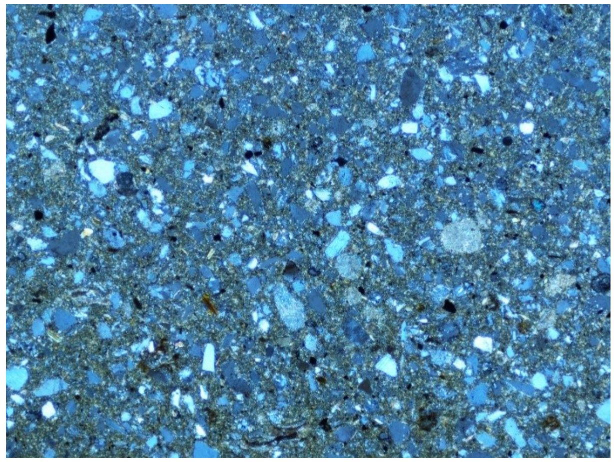


Slide 43, Sample 160

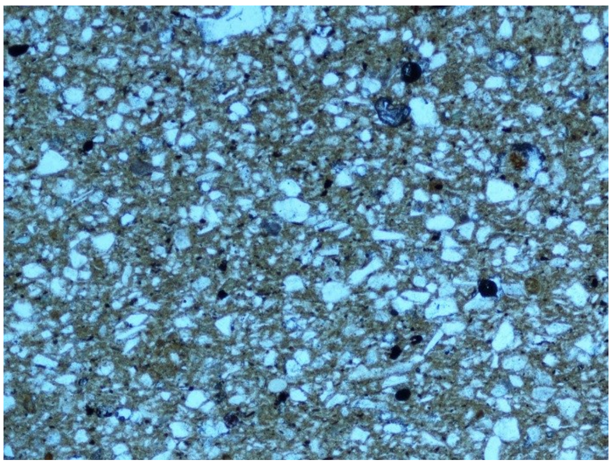
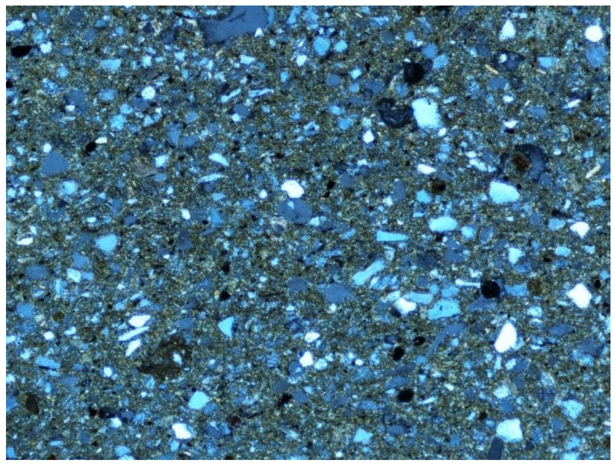




Slide 2, Sample 158

Slide 12, Sample 171

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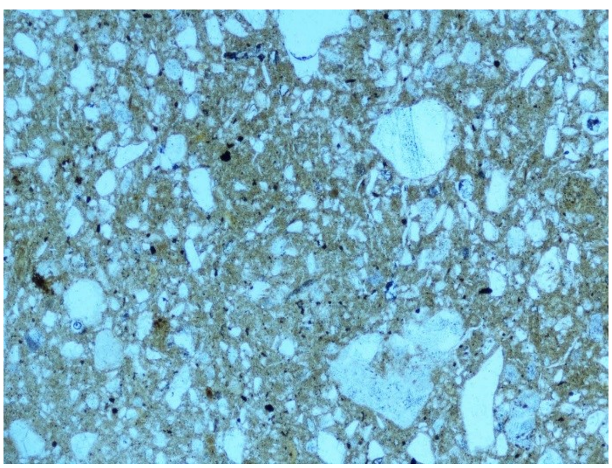
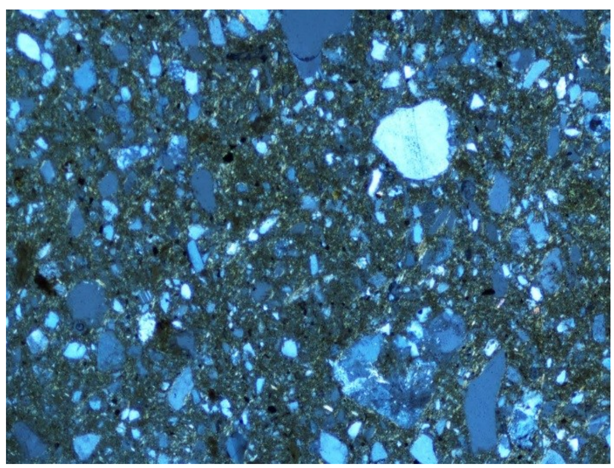
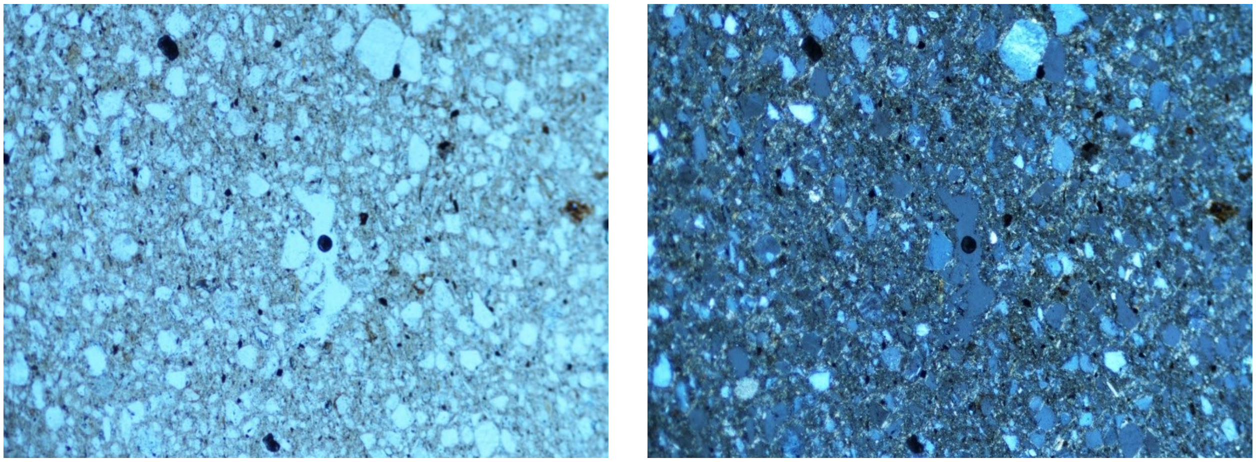
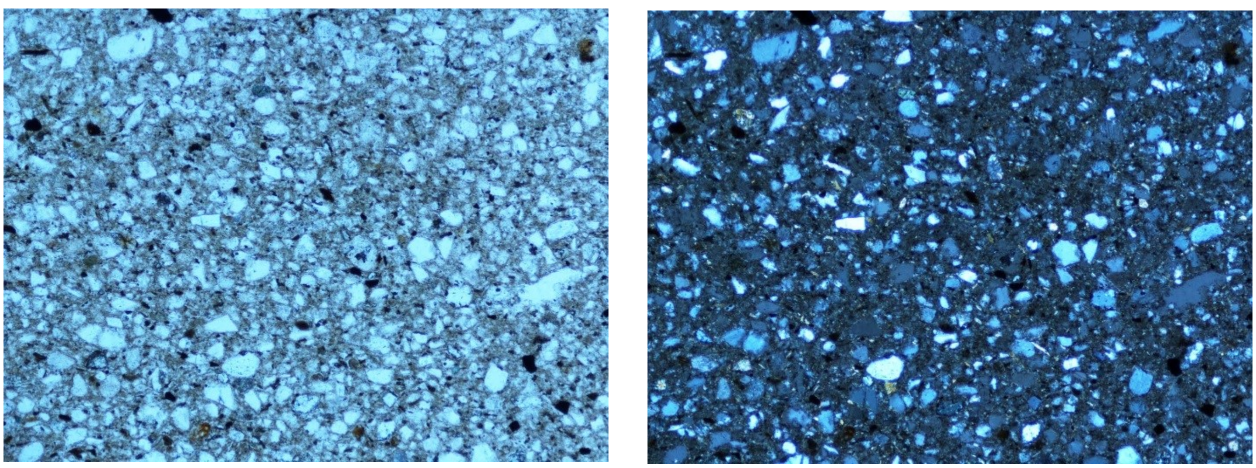



Slide 34, Sample 3

Figure 13.20 Petrographic Group 22

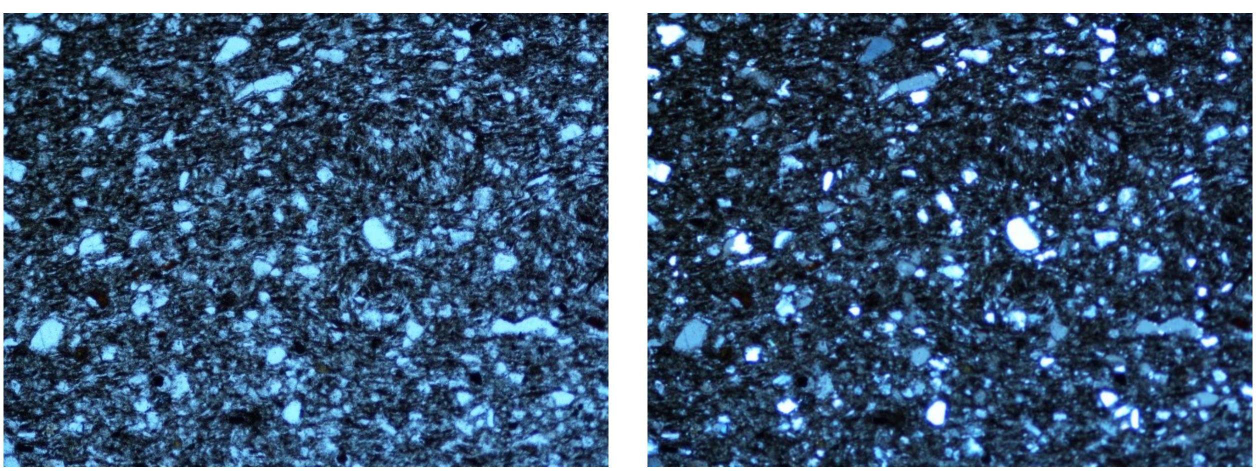


Slide 16, Sample 124



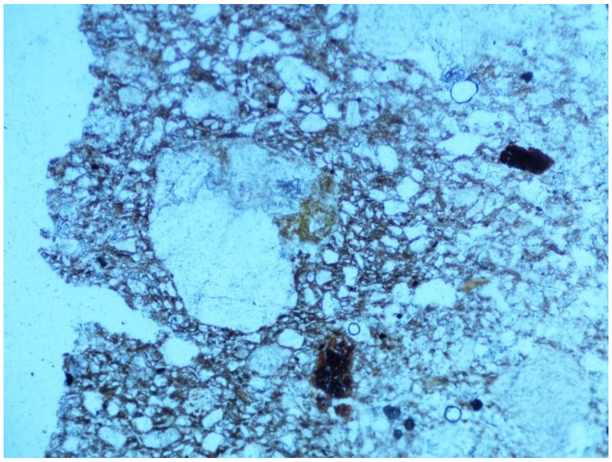
Slide 31, Sample 176

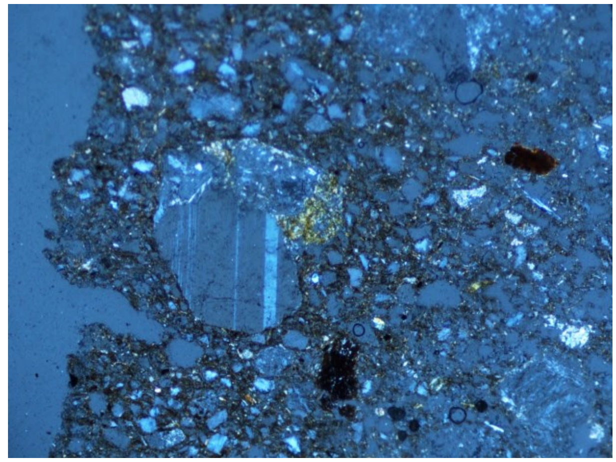
Figure 13.21 Petrographic Group 23



Slide 9, Sample 113

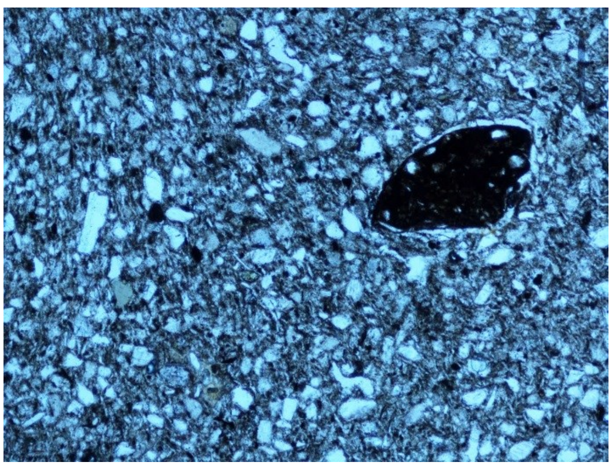
Figure 13.22 Petrographic Group 24

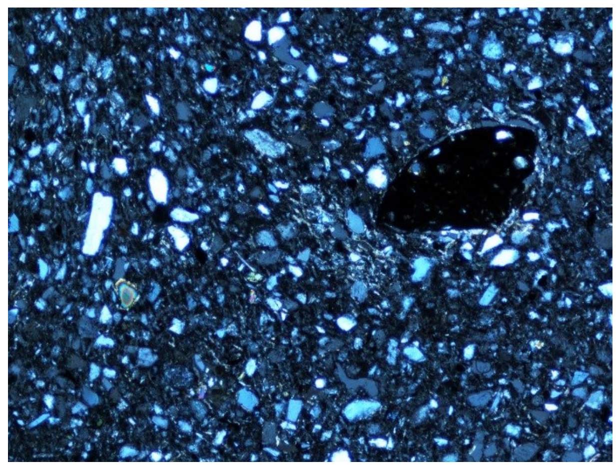




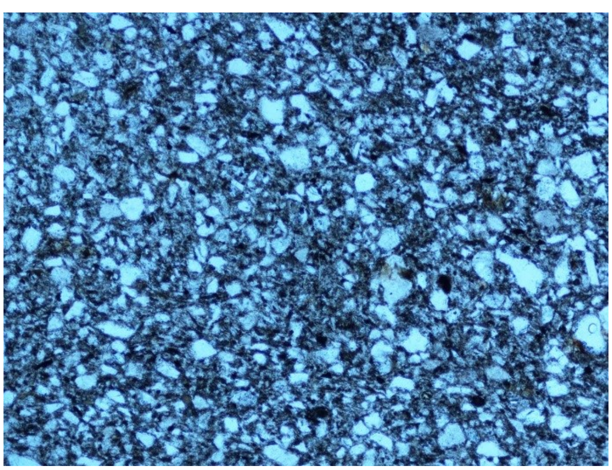
Slide 15, Sample 175

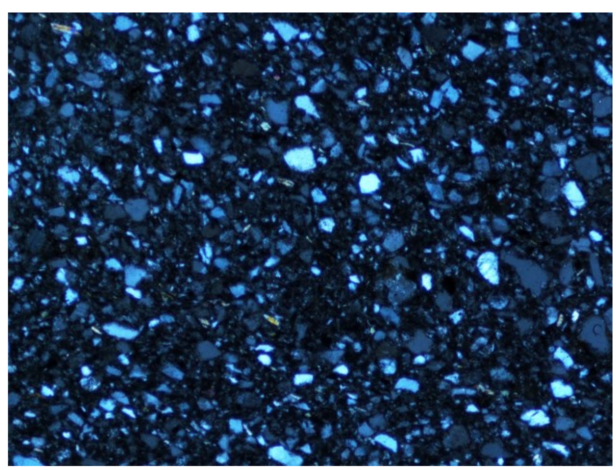
Figure 13.23 Petrographic Group 26





Slide 30, Sample 125





Slide 32, Sample 112