# Chemical Characterization of Chert Artifacts from Caution Bay, Papua New Guinea: Exploring archaeological resource use via portable X-Ray Fluorescence

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# Abstract

This thesis investigates the potential for the use of Portable X-Ray Fluorescence Spectrometry (pXRF) to identify chemically distinct groups of chert from an archeological assemblage and explores how this data can be used to explore a range of questions about how chert was selected, used and discarded over time.

The assemblage of chert artifacts used in this research is from Caution Bay, Papua New Guinea (PNG). It includes 2,454 chert artifacts from 12 archaeological sites with pre-Lapita, Lapita, and post-Lapita deposits. The pXRF analysis was conducted using a Niton XL3t GOLDD+ in the factory TestAllGeo mode and collected data from a total of 44 different elements. The data produced by the pXRF instrument were investigated using a variety of different statistical analyses and resulted in the successful identification of four chemically distinct groups of chert in the assemblage. These four groups of chemically distinct chert are interpreted as representing four distinct geological outcrops and are referred to here as Geological Source Groups (GSGs).

Having identified the four GSGs, they were used to explore the archaeological assemblages from the Caution Bay sites. Each GSG is present from the earliest phase of occupation to the most recent; that is, each GSG occurs through the full span of occupation in each site. However, some GSGs are minimally represented in the earliest and most recent deposits, but occur in significant numbers in the middle phases. The Excavation Units with the greatest number of artifacts also have the greatest diversity of GSGs represented. This observation suggests, a correlation between increased lithic material use and more diverse resource use. A difference in the number of GSGs present at contemporaneous sites suggests that activities with different lithic requirements may have taken place. The occurrence of a range of chert colours indicates that specific colours may have been targeted. Cultural and geographic factors were both considered; without known source locations for the GSGs, however, specific source locations for the archaeological chert samples could not be determined. To further develop the archaeological interpretations of chert-use in Caution Bay, future research involving the locating and geochemical fingerprinting of natural chert outcrops in the broader Caution Bay area is recommended.

## Declaration

This thesis contains no material which has been accepted for the award of any other degree or diploma at any university or equivalent institution and that, to the best of my knowledge and belief, this thesis contains no material previously published or written by another person, except where due reference is made in the text of the thesis.

# Acknowledgements

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# Chapter 1: Introduction

Stone is the material most likely to survive in the archaeological record, and in some cases, it is the only artifact type available for study (Torrence 2011:29). Across the globe, the vast majority of ancient tools were made from, and assembled with, organic materials that have not survived in the archaeological record. What have survived are the stone artifacts that would have been used to create or form parts of these tools and the debitage resulting from their shaping and subsequent reshaping/sharpening (Wilson 2007b). Debitage is often the most abundant artifact recovered by archeologists, who have developed many ways of gaining information about past peoples and their cultural practices by weighing, measuring, and analysing such lithic materials (Kardulias and Yerkes 2003; Mahaney 2014; Odell 2004). Complex fields of research, generally focused on the physical characteristics of artifacts (investigating both quantitative and qualitative details) and the locations in which they were found, have been developed (e.g. Andrefsky 1998; Chauhan and Lycett 2010; Eerkens et al. 2007; Hayden 1979; Hiscock 2002; Kardulias and Yerkes 2003; Odell 2004; Perreault et al. 2013; Scerri et al. 2016; Swanson 1975). Quantitative and qualitative data have been used to produce information about the thought patterns, technologies, and cultures of the people who created the artifacts and the assemblages. These data, however, are limited in what they can do, and can only be used to address particular questions so archaeologists regularly look for new ways to investigate lithic artifacts. Comprehensive discussions of the applications and limitations of quantitative and qualitative data in lithics analyses are provided in Andrefsky (1998), Kardulias and Yerkes (2003) and Odell (2004) amongst others.

As other disciplines develop new techniques and new tools, archaeologists tend to find ways to adapt these new technologies to their own research needs and questions. Following developments in nuclear science, chemistry, and geology, a range

of new tools is now available for archaeologists to undertake sophisticated chemical composition analyses of lithic artifacts. The predominant way that archaeologists have used such techniques has been to conduct tests on lithics in the hope of connecting artifact materials back to the geological sources from which they came (Eker et al. 2012; Golitko et al. 2012; Hassler et al. 2013; Nadooshan 2013; Parish et al. 2013; Reepmeyer et al. 2010; Sheppard et al. 2010). The success of such sourcing studies has varied, depending on the techniques used and the materials in question. Successful studies of this sort have resulted in new understandings of ancient trade networks, resource choices, and raw material selection by past peoples. Such studies have taken place across the globe and have provided valuable means of gathering information about past behaviours and social choices (Fortin 2015; Frank et al. 2015; Magnin 2015; McCoy and Carpenter 2014; McCoy and Robles 2015; Tomasso and Porraz 2016).

The research presented here investigates one such chemical characterization technology – portable X-ray Fluorescence Spectrometry (pXRF) – to explore the chemical composition of archaeological chert artifacts from the Caution Bay area of southern Papua New Guinea (PNG). The speed at which items could be tested, the non-invasive nature of the method and the relatively wide range of elements that could be sampled for all contributed to the selection of pXRF for this Research (See Chapter 4). A large assemblage of chert artifacts was tested using pXRF to identify chemically distinct groups. These chemically distinct groups of artifacts were then examined in relation to other available data to explore questions about the use of chert raw material through time and across the archaeological landscape of the broader Caution Bay region.

This research is focused on how chert artifacts with different chemical signatures are spread across the Caution Bay landscape through time, but it is not a sourcing study. A sourcing study would have necessitated access to large numbers of geological source materials, which were not available at the time of study. Without source location information, the data can be produced on chert variability to produce information on similarities and differences in lithic resource use within and between sites across the landscape, allowing also for an exploration of how chert use changed over time (Allen et al. 2011:77). Chemical characterization data allow for the putting forth and investigation

of hypotheses concerning resource access, ownership, and sharing. It also allows for the development of hypotheses about choices people made about lithic material quality, texture, and colour (Evans et al. 2010:1157). Understanding how people used the resources around them is integral to the understanding of culture. This research helps provide a step towards such understandings.

## Main Research Question and Subsidiary Questions

This thesis asks two main research questions:

1. **Can an 'out-of-the-box' pXRF Instrument produce chemical data that can be used to successfully identify chemically distinct groups of archaeological chert artifacts?**

And, if so,

2. **Can chemical data from chert artifacts collected using an 'out-of-the-box' pXRF Instrument in factory settings be used to explore how people in Caution Bay selected and used chert over the past 5,000 years?**

To address these questions, I undertook the following tasks. First, the chemical composition data produced by a pXRF instrument were examined to determine if it was possible to successfully characterise and differentiate different types of chert in the archeological assemblage. This examination was accomplished by means of a variety of statistical tests carried out on the pXRF data to ascertain if statistically distinct groups of chert could be identified from the chemical data (Chapter 9).

Next, the pXRF data were used to chemically compare the lithic artifacts from the Caution Bay sites both between sites and through time. To accomplish this second task, the chemical pXRF data, the original excavation records for each site, and the lithic analyses carried out by Dr. Jerome Mialanes (Monash Indigenous Studies Centre, Monash University) were all considered. These combined sources of data were examined for patterns and trends. The resulting observations were then explored and

tested in relation to other types of data (e.g. environmental, geological, ethnographic, etc.) available for the region (Chapter 10-12).

Accomplishing these goals has the potential to result in information that could be used to develop a comprehensive picture of how people used different chert materials through Caution Bay's occupational history. This research also has the potential to provide additional information useful for the development of, and the inclusion of lithic materials in, cultural chronology for the region.

## Archaeological Framework

The archaeology of the Caution Bay region and surrounding areas of southern PNG is not well developed (see Chapter 2). Before the Caution Bay Project, the cultural chronology accepted by most researchers was based mainly on information from sites that had been excavated by what are now considered coarse-grained methods. Research conducted at Caution Bay, which included relatively fine-grained excavation methods, has produced a large amount of new information that is enabling a refinement and development of the existing chronologies for southern PNG. The location of Caution Bay on the southern coast of PNG, as well other key archeological sites mentioned in the text, are presented in Figure 1.
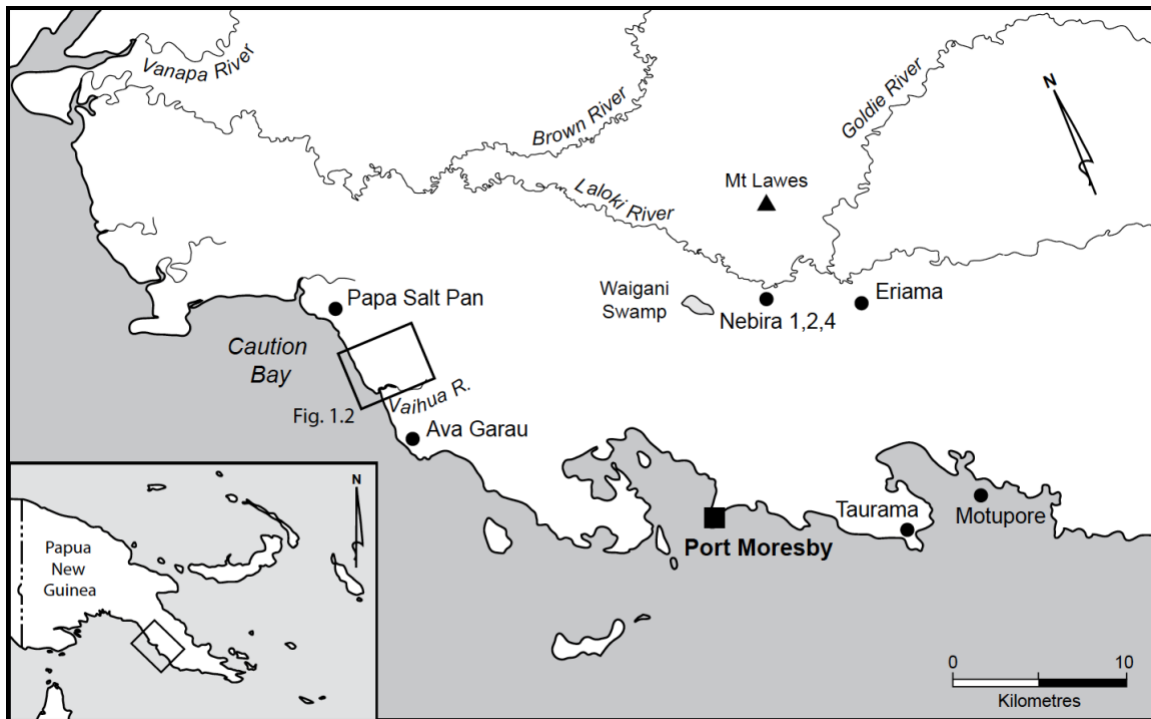
**Figure 1: Location of Caution Bay study area (small rectangle) and other key sites from the greater Port Moresby area (black dots). Reproduced from Richards et al. (2016b:1)**

Much of the research conducted at Caution Bay and in the surrounding region has focused primarily on archaeological ceramics and shell remains. Stone tools, especially flaked tools, have generally not been discussed with the same level of detail as ceramics. Notable studies focused on the lithics in Caution Bay and the surrounding region include Allen et al. (2011), Ford (2011), Mialanes et al. (2016a), Specht (2011), Sutton et al. (2015) and Vanderwal (1976, 1973), among others. Generally, when lithic materials are considered, the research tends to focus not on the relatively abundant chert artifacts, but on rare items such as ground stone tools and artifacts made from rare or imported materials. Ground stone tools such as adzes and axes have been explored in some detail (e.g. Burton 1989; Rhoads 2010), but much of this work has focused on long-distance trade of primarily igneous stones rather than on the exploitation of local resources. There are a number of research projects that have looked at the use and trade of obsidian in coastal sites of PNG (e.g. Summerhayes 2000, 2004; Summerhayes and Allen 2007; Summerhayes et al. 2014; Torrence 2011; Torrence et al. 2013), but the

south coast of PNG rarely features in such endeavours, with the research conducted by Irwin and Holdaway (1996) and Mialanes et al. (2016a) being exceptions. In contrast, the results of my thesis research will provide valuable new information about the exploitation and use of cherts – a locally abundant raw material – and its relationships with local ceramic traditions.

The artifacts investigated for this thesis were collected in 2009 and 2010 as part of a large-scale archaeological salvage project at Caution Bay. The excavations were carried out by an international team of archaeologists led by Associate Professor Bruno David, Professor Ian McNiven, and Dr. Tom Richards from Monash University in Melbourne, Australia. One hundred and twenty-two individual sites were excavated, and the archaeological material from these excavations was plentiful and diverse. Materials recovered included ceramics, lithics, fauna, and other items (David et al. 2011; David et al. 2016a; David et al. 2012b; McNiven et al. 2012b). Research continues to be conducted on the excavated materials, and the resulting list of publications continues to grow. Key examples include David et al. (2011), David et al. (2012a, 2012b), David et al. (2016g), McNiven et al. (2011, 2012a, 2012b), Mialanes et al. (2016a), Petchey et al. (2012, 2013), Richards et al. (2016a, 2016b), Rowe et al. (2013), with many more in press. The research presented here adds another, unique dimension to these ongoing results.

One artifact type that was particularly plentiful in the excavations was expediently-made stone flakes. The variety and volume of relatively simple flaked stone artifacts recovered led to the development of this thesis research. The vast majority of the lithic material was chert, with a small proportion of obsidian (Mialanes et al. 2016a) and other materials also present. I have solely focused on chert artifacts as the number of artifacts made from other materials was very limited. Although expediently-made flakes do not readily provide information that can be used to identify temporal changes of the kind that formal projectile point typologies can, as seen in other parts of the world (e.g. Morrissey 2009), there are still some analyses that can be applied to such tool types. As well as typological approaches, researchers working with lithic artifacts have also commonly incorporated technological approaches when studying lithics (e.g. Sutton

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et al. 2015). Technological analyses are being carried out by Mialanes (2016a-2016K) for all of the sites excavated at Caution Bay. Although technological analyses provide valuable information, they do not allow for the exploration of where the raw materials were acquired, what selection criteria were used, or how the raw materials were accessed by people who probably lived in different villages and through time. Another line of investigation that can be valuable with a lithic assemblage like the one described here are residue and use-wear analyses. Such analyses provide valuable information about how stone tools were used and what materials they were applied on, but not on the exploitation of lithic sources (e.g. Crowther 2005; Kealhofer et al. 1999; Marreiros et al. 2015). To obtain information relating to provenance, source use, and selection, chemical composition data are required. Understanding four stages of engagement with lithic raw materials – acquisition, transport, use, and abandonment – is the key to understanding past engagements with lithic landscapes (Wilson 2007b:391). The chemical information produced by pXRF can provide the required data to address such cultural landscape histories.

This research will demonstrate a method of analysis that can be used on common chert raw materials as a typically overlooked class of artifacts, to provide valuable data that will contribute to better understanding the archaeology of the Caution Bay region. Additionally, chemical characterisation data for chert artifacts analyzed in conjunction with traits such as colour, quality, and texture of the material will also be a valuable resource for future researchers interested in incorporating chert into cultural chronologies (see Arakawa and Miskell-Gerhardt 2009:204). Data such as these have been used successfully in conjunction with raw material source locations by other researchers elsewhere to create a variety of resource use and selection models (Browne and Wilson 2011; Evans et al. 2010; Wilson 2007b).


## Theoretical and Conceptual Framework

The use of pXRF to characterise lithic materials is not new (see Chapter 3). X-Ray Fluorescence Spectrometry (XRF), the more powerful laboratory-based version of

XRF, has been in use for lithic characterisation for many years. XRF and pXRF, however, have recently seen an increase in use by archaeologists interested in chemical sourcing and characterisation of lithic resources, particularly in the Pacific region (e.g. Burley et al. 2011; Golitko et al. 2010; Moore 1977; Sheppard et al. 2011; Sheppard 2010; Sutton et al. 2015). Lab-based benchtop XRF units and their smaller portable pXRF counterparts (see Chapter 4) have been extensively applied, with much success, to obsidian across the Pacific (e.g. Burley et al. 2011; Niknami et al. 2010; Phillips and Speakman 2009; Sheppard et al. 2011) as well as in other parts of the world.

In contrast to its use with obsidian, the use of pXRF with chert artifacts is much less frequent. This is probably due to the higher degree of chemical and geological complexity of chert. Researchers who have conducted chemical analyses of chert have primarily focused on determining chert sources and have generally used large laboratory XRF instruments and destructive high-powered chemical and analytical techniques (e.g. Benge 2016; Elvidge 2013; Gauthier et al. 2012; Olivares et al. 2009; Rafferty et al. 2007; Wurtzburg 1991). These studies (see Chapter 5) have yielded a variety of results, ranging from positive and useful to unsatisfactory. Although not focused on sourcing, the research presented in this thesis provides a valuable new addition to the existing literature about the successful use of pXRF analysis on chert materials. In the Pacific region, chemical analysis of chert without a focus on sourcing is far less common, with the only relevant example being research conducted by Sutton et al. (2015). Sutton et al. (2015) used pXRF to perform a successful chemical characterization of a small sample of chert artifacts from Taurama, near Port Moresby in PNG, which they then used to explore archaeological questions. Their research (see Chapter 5) has demonstrated that chemical data can be valuable and can produce results that will help to strengthen interpretations of past human behaviours even in the absence of source locations. Building on that project's initial success, my thesis provides a detailed methodology for pXRF testing and subsequent analyses that will be valuable to researchers focusing on varied aspects of chert analysis and general lithic resource use, not only in PNG but also in a wide range of contexts on a global scale.

This thesis also provided information that addresses concerns expressed by Davis et al. (2012) and Grave et al. (2012), amongst others, about the use of pXRF and what they identify as a growing use of pXRF instruments by researchers who do not understand the system or who fail to use appropriate techniques in their application of it. Recently, pXRF instruments have become less expensive to acquire and much easier to use. Many users working with these new instruments do not have the extensive chemistry backgrounds that were required to operate older benchtop XRF instruments. These changes to the way pXRF is being used have resulted in discussions about the validity of the interpretations produced (Frahm 2013a, 2013b; Shackley 2011b; Speakman and Shackley 2013; Zhu et al. 2011:167). The two major issues relating to the use of pXRF are 1) researchers not following established laboratory protocols, and 2) the differences in data output between different pXRF and larger more powerful desktop XRF instruments (Frahm 2013a; Grave et al. 2012; Nazaroff et al. 2010). This thesis addresses these issues and provides further support to challenge the additional problem of "silo science" — research that produces results that are only internally consistent and not reproducible with other equipment — that has been presented by Speakman and Shackley (2013) in relation of pXRF based research. All of the methods used herein are presented in detail to ensure that they are clearly understood, and measures have been taken to ensure that other researchers can use the data provided herein for comparison with other pXRF data sets. This thesis presents a methodology to address the issues that have been raised and demonstrates that the use of pXRF instruments in their 'out-of-the-box' settings by non-chemists should not be discounted as long as researchers follow the appropriate methodology and are aware of the limitations of their data.

This thesis is also significant in terms of sample size. It relies on a sample of artifacts that far outnumbers any previous study of archaeological chert geochemistry. To date, Gauthier et al.'s (2012) pXRF testing on 91 chert artifacts and Sutton et al.'s (2015) pXRF testing of 81 chert items have been the largest sample sets to have undergone analysis. This thesis was underpinned by the notion that with a much larger sample size, small differences in the chemical composition of chert would be more apparent and would provide better results for the identification of chemically distinct

groups of chert. Furthermore, even if it had been unsuccessful in its planned application, the pXRF data produced from a collection of this size would provide valuable results for archaeologists interested in chert geochemistry. This large data set would allow for the exploration of other avenues of chert research such as colour range vs chemical composition, texture vs chemical composition, and chert flaking properties vs chemical composition, to name a few. Although, for the reasons detailed above, a large sample set is considered in this case to be more valuable than a small one, it should still be acknowledged that there may still be issues relating the use of the pXRF instruments that cannot be eradicated by the size of the assemblage being tested (see Chapters 4 and 5).

## Thesis Structure

This thesis is comprised of 13 chapters presented in three sections. Section 1 (Chapters 2 to 6) presents the archaeological and geological context of the research and provides the background information required to understand it. Chapter 2 provides an archaeological overview of the Caution Bay area covering nearby sites, significant discoveries, and details of the current cultural chronology for the area. Chapter 3 provides an overview of the geology of Caution Bay including a description of the tectonic setting and a history of the geological development of the area focused on deposits relating to chert. Chapter 3 also introduces the geography of Caution Bay in its broader southern PNG setting, with a discussion of both current and past environmental conditions. Chapter 4 provides a synopsis of the history of chemical characterisation studies in archaeology, a brief history of pXRF, and an explanation of why it was selected for this research. In Chapter 5, chert as a raw material is introduced, and the positive and negative aspects of applying pXRF to it are discussed.

Section 2 (Chapters 7 to 9) introduces the data set used for this research and provides details of the chemical characterisation work conducted. Chapter 7 presents the data set used for this research and includes details of the excavation methodology, artifact handling, and sample selection methods. Chapter 8 outlines the laboratory

procedures used for the preparation and testing of the archaeological artifacts and includes discussion of the quality control systems used. In Chapter 9, the statistical analysis carried out on the data produced by the pXRF instrument for the archaeological assemblages is detailed.

Section 3 (Chapters 10 to 12) explores the results of the chemical analyses in relation to the other available archaeological information and provides the results of a variety of different avenues that were explored in relation to the archaeological evidence and the pXRF analyses. Chapter 10 explores the presence of the four chemical source groups (GSGs) identified in Chapter 9 within the archeological assemblages from each site, collectively and then by cultural phases. In Chapter 11 the use of the GSGs is explored over time. Where applicable, the assemblage for each occupation phase is discussed in relation to chronological change. Chapter 12 explores a range of factors identified in Chapters 10 and 11 that may have affected the use and selection of chert materials and, where possible, tests these factors using the GSG results.

Chapter 13 concludes the thesis with a summary of the significant contributions and findings of this research and details directions for future research.

# Section 1: Background and Context

# Chapter 2: The Archaeology of Caution Bay, PNG

Caution Bay is located on the southeast coast of the island of Papua New Guinea, approximately 20 km northwest of Port Moresby, and between the villages of Boera and Papa (Figure 1). Sites excavated as part of the Caution Bay project are located along a stretch of coastline 3.1 km east-west and 2.8 km north-south (inland), covering an area of about 9 km$^2$ (Richards et al. 2016). This chapter provides an overview of the current understanding of the archaeological history of Caution Bay and highlights locations where pXRF analyses were undertaken as part of this thesis.

## Archaeology of Caution Bay and Surrounding Areas

The archaeological history of the Caution Bay area and surrounding southeastern PNG is not well developed and is predominantly based on research conducted by a small group of archaeologists during the 1970s and early 1980s (Allen 1972a, 1972b, 1977, 1984, 1985; Allen and Rye 1982; Bulmer 1971, 1975, 1978, 1979, 1982; Swadling et al. 1977; Vanderwal 1973, 1978). David et al. (2011:588) noted that before the Caution Bay Project, no new archaeological excavations had taken place in the area since the 1980s and no new detailed site reports had been presented since the 1970s. Though more recent publications concerning the area are available (e.g. Bickler 1997; Summerhayes and Allen 2007, Sutton et al. 2015), some of these works rely heavily on the results of earlier archaeological excavations with data sets that have, in some cases, been called into question due to coarse excavation methods (David et al. 2011:588).

It is of note that published details of the results of archaeological excavations are not prevalent even for the broader area of southern PNG. Table 1 provides a summary of the archaeological sites, not related to the Caution Bay Project, for which published information is available. Only two sites, Ava Garau (Swadling 1980), located to the south of Caution Bay, and Papa Salt Pan (Swadling 1980), located to the north (Figure 1, Chapter 1) had been excavated before the Caution Bay Project began. The locations of

some of the other nearby sites of significance for this research are also presented in Figure 1 (Chapter 1). For the locations of the more distant sites to the southeast and northwest of Caution Bay refer to the original publications.

*Table 1: Sites at which archeological excavations have been conducted, and published information is available, grouped by geographic region.*

| Region | Archaeological Site Names and Authors |
|---|---|
| Caution Bay Vicinity | Ava Garau and Papa Salt Pan (Swadling 1980) |
| Northwest of Caution Bay (Yule Island and area) | Oposisi (Allen et al. 2011; Vanderwal 1978), Urourina and Sirirou (Vanderwal 1973), Abe (Vanderwal 1973), Kukuba Cave (Vanderwal 1973), Apere Venuna (Vanderwal 1971), and others (see Skelly 2014; Skelly and David 2017) |
| South of Caution Bay (Port Moresby area) | Nebira 4 (Allen 1972b; Shaw et al. 2011), Motupore (Allen 1977, 2017), Nebira 1 and 2 (Bulmer 1979; Shaw et al.2011), Eriama (Bulmer 1979), Taurama (Bulmer 1979; Sutton et al. 2015; Vilgalys and Summerhayes 2016) and others (Skelly 2014; Skelly and David 2017) |
| Far northwest of Caution Bay (Kikori River Delta area) | Emo (David et al. 2010), Epe Amoho (McNiven et al. 2010a), Kikiniu and Rupo (Rhoads 1980), Keveoki 1 (David et al. 2009), the Kerema sites (Frankel and Vanderwal 1984), Popo (Rhoads 1994; Urwin et al. 2018), Old Helau, Hopo, Kaveharo, Lui Swamp, Iri kahu, Hivo ancestral village and Opu Hill (Skelly 2014; Skelly and David 2017) |
| Far southeast of Caution Bay (Amazon Bay-Mailu area) | Mailu sites (Irwin 1978), Oraido 1, Oraido 2 and Selai (Irwin 1985) and the Kasasinabwana midden site on Wari Island (Leavy1977; Negishi and Ono 2009) |

## *Chronological Sequence*

In much of the rest of the Western Pacific, cultural chronologies begin with the Lapita Cultural Complex. Lapita is the name given to an archaeological assemblage with distinctive ceramics and other items of material culture. The people who made Lapita objects transported these with them as they moved into the Pacific islands. Their migration into, and colonization of, the Western Pacific has been the source of much archaeological debate. Detailed information about Lapita material culture and its interpretations is available in Bedford et al. (2007), Clark et al. (2001), Gibbons (2001), Kirch (1996, 2000), Sheppard (2011), Specht and Torrence (2007), and Torrence and Swadling (2008), among others, and will not be discussed further here. However, relevant to this discussion are two points: first, prior to the recent excavations at Caution Bay, the time depth of human occupation with ceramics on the southern coast of PNG was thought to be approximately 2,000 years; and second, although some ceramics did appear to have a strong Lapita influence, no Lapita ceramics had ever been recovered *in situ* from mainland PNG (Bulmer 1974:157).

Recent research at Caution Bay has shown that sites in the area have the potential to be much older than regional studies previously indicated; they have also demonstrated that Lapita ceramics are present on mainland PNG (David et al. 2016a; David et al. 2012a, 2012b; McNiven et al. 2012a, 2012b; Petchey et al. 2013). Further, Bogi 1, one of at least nine sites now known to contain Lapita ceramics in this area, has also been shown to contain pre-ceramic cultural deposits dating back to c. 4200 cal BP (David et al. 2011:580). These new findings have forced a re-examination of the commonly accepted cultural sequence proposed by Irwin (1991) by placing a pre-Lapita presence with no associated ceramics as the earliest cultural occupation in the area and Lapita as the earliest ceramic occupation (David et al. 2012b). The cultural sequence for the southeast coast of PNG proposed by Irwin (1991) was defined using cultural material from a large and relatively diverse area and included five broad temporal groupings, Period 1: Pre-ceramic (? –2000 BP), Period 2: Colonization (2000–1600 BP), Period 3: Regional isolation (1600–1000 BP), Period 4: Pottery transformation (1200–800 BP), and Period 5: Interaction, specialization and exchange (800–200 BP). These broad

groupings, specifically Periods 1–3, have been challenged by the results of the Caution Bay Project and can no longer be accepted as accurate . The more recent Periods 4–5, on the other hand, still provide a valuable framework for understanding cultural/temporal changes in the area.

The findings from the Caution Bay Project have provided data which David et al. (2012a and 2012b) have used to produce a ceramic sequence that not only contains a Lapita component, but also pushes the date of the pre-ceramic material much further into the past. As well as research on lithic materials already published by Mialanes et al. (2016a), further research on the faunal and lithic material associated with these ceramic horizons is underway and will be forthcoming (Richards et al. 2016b). Irwin's (1991) regional cultural sequence will be discussed in Chapter 2, in relation to this new ceramic sequence and broader cultural materials from this sequence will be addressed for time periods in which the dates for the two sequences are contemporaneous.

It should also be noted that the cultural sequence presented below is based almost exclusively on ceramic materials excavated from various sites in the region. Ceramics have been the primary focus of researchers interested in chronology for a number of reasons. Ceramic artifacts are generally abundant in the archaeological record, they typically have stylistic changes that are temporally discreet, and there are often noticeable changes in vessel shapes over time. These characteristics combine to make ceramic materials reliable and readily visible markers of cultural change over time.

Although other artifact types commonly identified from sites dating to the time periods outlined below are discussed, these items are generally found in conjunction with the temporally diagnostic ceramics and have not been examined independently themselves for temporal stylistic change. To this end, the research presented in this thesis will independently identify changes in chert raw material selection use over time that may or may not correspond neatly with existing ceramic chronologies.

**Pre-Lapita / Pre-Ceramic Period (c. 4200–2900 cal BP)**

The pre-Lapita/pre-Ceramic Period represents the first evidence of human occupation in the area yet remains poorly understood. This cultural horizon is

represented by a number of sites in the Caution Bay area including Bogi 1 and Tanamu 1 (McNiven et al. 2011:4; Richards et al. 2016) as well as the Kukuba Cave site to the north (Skelly 2014:51; Vanderwal 1973). Common artifacts from this horizon include flaked and ground stone tools such as ground stone adzes, lithic flakes, and debitage, as well as shell grave goods (e.g. McNiven et al. 2011:4). A wide variety of faunal remains from this time have been recovered, providing insight into diet. These remains include a variety of shellfish, reef fish, and marine turtle taxa (McNiven et al. 2011:4). At Bogi 1, a burial associated with grave goods has also been found in association with this period and is the first burial to be recovered from pre-Lapita deposits in the South Pacific (McNiven et al. 2011:4). Irwin's (1991) regional sequence also began with a pre-ceramic period that had a similar set of cultural materials; however, Irwin's dates for this period extended from 2000 BP back to an unknown time in the past. It is possible, that with further research, sites associated with Irwin's pre-ceramic period might be shown to be contemporaneous with the pre-Lapita horizon identified at Caution Bay.

**Lapita Horizon (2900–2600 cal BP)**

The Lapita phase cultural material from the Caution Bay area is in many ways similar to late Lapita assemblages elsewhere in the South Pacific and includes ceramics as well as shell and stone artifacts (McNiven et al. 2011:4). Lapita ceramics found in Caution Bay represent a variety of vessel forms including low-fired, thick-walled, carinated and sometimes collared vessels (David et al. 2012a, 2012b; McNiven et al. 2011:4). A single decorated cylinder stand fragment was noted in this assemblage. Decoration on these vessels includes comb dentate-stamping and red slipping. McNiven et al. (2011:4) note that a common theme in the Caution Bay Lapita ceramic decorations is impressed parallel sets of single-curve impressions made with a narrow tool and repeated in various combinations along the upper part of pots. David et al. (2011:586) note that there is an absence of dentate-stamped faces and flat-bottomed vessels in the Caution Bay Lapita assemblage, distinct Lapita designs which have been noted in Lapita assemblages elsewhere in the southwestern Pacific.

Shell artifacts associated with the Lapita ceramics include ground, narrow, and broad rings made from cone shell (*Conus* sp.) and clam shell (*Tridacna* sp.; McNiven et

al. 2011:4). Stone tools include ground stone adzes and expediently-made flakes, most of which have not been retouched (McNiven et al. 2011:4). Adzes are made from igneous material likely sourced from the mountains to the north (McNiven et al. 2011:4), and the flakes were made from either chert or obsidian. The nearest source of obsidian is West Fergusson Island located 500 km to the southeast, indicating long-distance movement of raw materials during this time period (McNiven et al. 2011; Mialanes et al. 2016a). McNiven et al. (2011:4) suggest that the chert material was likely sourced locally, due to its relative natural abundance in the area.

The faunal remains from this time period are also consistent with other Lapita assemblages. McNiven et al. (2011:4) indicate that the Caution Bay Lapita sites contain over 130 species of shellfish from a wide range of habitats. There is also evidence that many other marine species were exploited, including reef-dwelling rockfish, wrasse, sea urchin, crab, and marine turtle (McNiven et al. 2011:4).

## *New Ceramic Traditions*

David et al. (2012b) use the term 'tradition' to define a consistent set of ceramic design conventions that repeatedly occur within an archaeological assemblage relating to a specific temporal phase. They identify four distinct ceramic traditions that follow chronologically after Lapita (see below). Prior to the Caution Bay Project, the regional sequence proposed by Irwin (1991) saw the first pottery-users as a colonizing group of people making what he refers to as Early Papuan Wares and first appearing in the area around 2000 cal BP (Irwin 1991:503). More recently, Summerhayes and Allen (2007) have presented a ceramic phase they refer to as the Early Papuan Pottery phase (EPP) that corresponds temporally to Irwin's (1991) Early Papuan Wares which include ceramics that have been referred to by various researchers previously as Red Slip pottery (Bulmer 1971), Laloki Style (Bulmer 1999), Initial Ceramic Phase (Vanderwal 1973, 1978), Early Period (Allen 1977; Bickler 1997), and Early Ware (Allen et al. 2011; Irwin 1991; Summerhayes and Allen 2007:100). David et al. (2012b:73) suggest that the four newly identified ceramic traditions identified at Caution Bay provide significant evidence that further examination of the nature, stylistic and chronological integrity, and

timing of the individual ceramic phases purported to occur within the EPP, is needed. The four new Caution Bay traditions will be discussed here with reference to the EPP where applicable.

**Post-Lapita Transformative Tradition (c. 2600–2150 cal BP)**

David et al. (2012b:74) identify a period of simplification of ceramic design immediately following Lapita, consisting mainly of plain body wares, that they refer to as the post-Lapita Transformative Tradition. This tradition is described as having designs that are recognizably similar to those of the Lapita, yet are structurally simplified. Designs include simple linear and geometric dentate-stamped decorations. David et al. (2012b:75) do not provide any information about other archaeological or faunal materials associated with this tradition, but indicate that further research will be forthcoming. Irwin's (1991) cultural sequence does not include a discussion of cultural assemblages that contain ceramic material dating to this time.

**Linear Shell Edge-Impressed Tradition (c. 2150–2100 cal BP)**

The second distinct ceramic tradition is identified as the Linear Shell Edge-Impressed Tradition. This tradition is defined by ceramics with highly standardised shell edge-impressed decorations that mimic the dentate stamping seen in earlier traditions. Decorations that consist of simple linear arrangements, made using the dorsal edges of *Anadara* shell valves, are predominant and this has led to the choice of name (David et al. 2012b:75). David et al. (2012b:75) describe this tradition as having either retained or newly adopted a decorative element reminiscent of Lapita, but made using a different set of implements. They also indicate that this ceramic tradition is chronologically constrained at Caution Bay, and that although it has been identified elsewhere, it has not been isolated properly making accurate identifications challenging. David et al. (2012b:75) do not provide any information about other archaeological or faunal materials associated with this tradition. Irwin's (1991) cultural sequence included ceramics that fit within this tradition, however due to poor isolation, he associated these items with the first pottery use in the area.

**Umbo-Bordered Shell Back Impressed Tradition (c. 2100–1650 cal BP)**

The third tradition identified at Caution Bay by David et al. (2012b:75) is the Umbo-Bordered Shell Back Impressed Tradition. This tradition is characterised by designs created using the dorsal surface of shell valves, including lines of umbo impressions that often delimit the margins of geometric designs. This tradition has already been documented at a number of other locations in the region, and is included in the Colonization Period (2000–1600 BP) of Irwin's (1991) cultural sequence and as part of the EPP. David et al. (2012b:75) do not support the use of the EPP concept and believe that the Umbo Bordered Shell Back Impressed Tradition is distinct. David et al. (2012b:75) do not include information about other archaeological materials associated with this tradition in Caution Bay.

On a regional scale, information about the archaeological assemblage associated with ceramic material from this tradition is provided in the archaeological records from Yule Island at Oposisi (Vanderwal 1973) and in Port Moresby at Nebira 4 (Allen 1972b). Associated lithic artifacts include ground stone tools and flaked stone artifacts predominantly made from obsidian and chert. Obsidian from West Fergusson Island has been noted during this time in a number of sites with quantities diminishing as the distance from the source increases. Ground stone artifacts include two forms of adze, the common lenticular Papuan form and a less common trapezoidal form only found in a few locations (Summerhayes and Allen 2007:107). These adzes are made from a variety of materials and vary widely in size (Vanderwal 1973:129-132).

Regionally, a wide variety of bone and shell artifacts are found in sites from this time period. These include awls, scrapers, gouges, spatulas with handles, tubular bone beads (including some made from human bone), human cranial tablets, pierced animal teeth, pendants, and shell beads and bracelets (Vanderwal 1973).

This faunal material includes both terrestrial and marine resources. A wide variety of shellfish species has been recovered, as well as various fish species (primarily reef fish), turtle, crocodile, and dugong. Terrestrial species present include cassowary, wallaby, pig, and dog (Vanderwal 1973:178, Table VII-23). These faunal assemblages

indicate that people placed a strong emphasis on marine resources (fishing and collecting) and that they supplemented these resources with hunted and gathered terrestrial resources (wallaby and cassowary). The presence of pig remains in these sites also suggests local horticulture (Summerhayes and Allen 2007:104).

**Varied Incised Tradition (c. 1650–1000 cal BP)**

The final tradition identified by David et al. (2012b:73) is the Varied Incised Tradition. Ceramic material that forms part of this tradition has been documented at a number of other locations in the region and is included in the Regional Isolation Period (1600–1000 BP) of Irwin's (1991) cultural sequence. This tradition is defined by pottery with similarities to Bulmer's (1969, 1978) Red Slip Style, Allen's (1972a) Styles F and G, and Vanderwal's (1973) Type E–W. David et al. (2012b:75) indicate that although this tradition has similarities with Bulmer`s (1969, 1978) Red Slip Style, Allen's (1972a) Styles F and G, and Vanderwal's (1973) Type E–W, they have disaggregated it from these because in some cases these styles also included sherds that David et al. (2012b:75) associated with the other traditions.

David et al. (2012b:75) do not provide information about other archaeological or faunal materials associated with this tradition. Cultural material from other archaeological sites in the region that contain this ceramic tradition is presented here to illustrate the range of cultural materials present. Lithic artifacts include both flaked and ground stone tools. The flaked stone artifacts are made from chert and occasionally from obsidian (Irwin and Holdaway 1996). Ground stone artifacts include axe/adzes range widely in size and are made from a variety of materials (Vanderwal 1973:129-132). Rhoads and MacKenzie (1991) argue that by at least 1500 BP, material for these ground stone tools was coming from as far away as the Tapini/Woitape quarry in the Western Owen Stanley Mountain range, supporting the development of long-distance trade and exchange by this time.

Faunal materials indicate continued use of terrestrial and marine resources. Marine resources include a wide variety of shellfish species, various fish species, turtle,

crocodile, and dugong. Terrestrial species include cassowary, wallaby, pig, and dog (Vanderwal 1973:178, Table VII-23).

## *The Past 1,000 Years*

The Caution Bay Project has not yet resulted in any publications documenting significant changes within the past ca. 1,000 years of the cultural sequence provided by Irwin (1991). Irwin's final two periods, Period 4: Pottery Transformation, and Period 5: Interaction, Specialization and Exchange, are described here. It is possible that ongoing research on materials from Caution Bay may produce new information that will also necessitate a rethinking of the integrity of these components of Irwin's sequence. Until such material is published, these two periods continue to provide the best available cultural overview.

### Period 4: Pottery Transformation (1200–800 BP)

This period begins with a period of time termed by some as the "ceramic hiccup" or "Papuan Hiccup" beginning at approximately 1200 BP (Sutton et al. 2015; Vilgalys and Summerhayes 2016). This phase is characterised by a widespread and rapid change in localised ceramic design, accompanied by a change in settlement patterns. Though most researchers accept that previous ceramic traditions changed rapidly after about 1200 BP, there is still much discussion concerning why and how this change occurred (Summerhayes and Allen 2007:101; Sutton et al. 2015; Vilgalys and Summerhayes 2016). Initially, the transformation was attributed to a secondary in-migration of people thought to have come from islands in the Milne Bay province to the east (Allen 1977; Irwin 1985). There is much debate about this in-migration hypothesis, and it is now more commonly accepted that these changes are the result of *in situ* local social re-organization (Irwin 1991; Summerhayes and Allen 2007). Much of the discussion about these changes is due to significant regional differences in the archaeological record from this time (Summerhayes and Allen 2007:101). Regardless of the mechanisms of change, it is broadly accepted that this period saw the beginning of localised cultural traditions and the beginning of new specialised maritime trade networks (Shaw et al. 2011:346; Summerhayes and Allen 2007; Vilgalys and

Summerhayes 2016). Evidence for these new specialisations includes a growing abundance of non-local style pottery recovered from sites across the region (Allen 1977; Vilgalys and Summerhayes 2016) and evidence for more resource-specific settlement patterns such as inhabiting extreme coastal locations (such as Motupore) to maximise opportunities for trade and exchange (Allen et al. 1997:15; White and O'Connell 1982:197). Broad regional descriptions of ceramic vessel types common during this time are not well developed because of the significant regional variation. In some regions, new styles developed; in others, old styles seem to persist, or ceramic use disappeared altogether (Irwin 1991; Summerhayes and Allen 2007). Irwin (1991:507) sums this trend up by highlighting that "this was a widespread transformation expressed everywhere in local terms insofar as all of the replacement ceramic industries were different from one another as well as from what preceded them".

Depending on the locations of their studies, researchers have different interpretations concerning the changes in settlement patterns and in other material culture during this time. Irwin (1991:507) does not see any major change in these two domains, but Bulmer (1979), working in the Port Moresby area, suggests that assemblages of other archaeological materials recovered from this period (e.g. stone, bone, and shell artifacts) also appear to have a degree of regional variation. Expediently-made flaked stone tools, made predominantly from local chert, continued to be the most common stone artifacts during this time, although Irwin (1991:508) indicates that a very small amount of imported obsidian is also present. Irwin and Holdaway (1996:228) point out that the quantities of flaked stone materials of chert and obsidian appear to remain the same, undergoing no significant change during this pottery transformation. Bulmer (1982:121) indicates that although their numbers are generally low, ground stone axes/adzes, grindstones, stone pounders, and stone club heads are all present in the archaeological assemblage during this time, and that most of these are made from exotic stone possibly brought to the area as a result of trade and exchange networks. Rhoads (2010:61) indicates that there are notable similarities in axe/adze forms between those found in the Port Moresby area and those from the Hall Sound area during this time, suggesting some degree of movement of goods or raw materials over longer

distances. Bone and shell artifacts continue to be present, with some common items such as shell rings and perforated shell disks appearing in most sites.

A wide variety of marine and terrestrial faunal remains continue to be present. In sites like Nebira, which is located inland approximately 32 km from the marine shoreline, the presence of quantities of marine shell has been used to indicate some form of coastal interaction (Allen 1972b; Bulmer 1978). The variety in archaeological assemblages from sites across this region has made the development of regional generalisations concerning material culture and resource use difficult for this time period.

## Period 5: Interaction, Specialization and Exchange (800–200 BP)

Irwin (1991) describes a fifth and final period before European contact in the area as a period of interaction, specialization, and exchange. During this period, Irwin (1991:509) sees the development of certain areas into production places where ceramic vessels were being made specifically for trading purposes, while other areas became "middle-men" trading centres. The data presented in David et al. (2016a) provides a good example of this specialised mass production of ceramics occurring at Ruisasi 1 in Caution Bay. In general, however, it appears that by approximately 500 BP, the development of a large-scale maritime trade network is clearly visible in the archaeological record. Through this period, ceramic vessels become more uniform and standardised in size and decoration. Ceramic vessels during this time also took on certain characteristics believed to be related to speedy manufacture for high-volume trade. The thickness and quality of the vessels changed, and both the complexity of the decorations and decorated area diminished (Swadling 1980). The addition of small distinctive decorative markings regarded as "trade marks" also became common (Allen and Rye 1982:105). Also noteworthy is the fact that specific clay resources became commonly used and general vessel thickness diminished (White and O'Connell 1982:209). This archaeological evidence represents the immediate antecedent to the system of specialised exchange networks referred to as the *hiri* that was recorded and described ethnographically (Groves 1960). The *hiri* trade system is characterised by the movement of large numbers of ceramic vessels from the southern coast carried by fleets of large ocean-going sailing vessels (*lagatoi*) and traded for valuable items and food

resources, primarily sago (*Metroxylon sagu*), and large canoe hulls further to the west in the Gulf Province. Annual sailing fleets typically travelled 400 km, carrying around 20,000 pots that were destined to be exchanged for approximately 500 tonnes of locally produced sago (Barton 1910). Further detail about the *hiri* trade system and its impact at archaeological sites along the south coast of PNG are presented in Skelly and David (2017).

Artifact types recovered from archaeological sites representing this period continue to be similar to those from previous periods and include those made from stone, bone, and shell. Pig, dog, and human tooth pendants, shell pendants, disks, and arm bands, as well as bone tubes and beads, are among the artifacts recovered from this time period at the Nebira site (Shaw et al. 2011:349). Once again, the primary stone artifacts associated with this period are expediently-made flaked stone tools made from local chert, although Irwin and Holdaway (1996:227) indicate that at Mailu at least, the presence of obsidian increased again during this period. Other stone artifacts include flaked stone drill points made from local materials (Allen et al. 1997) and polished axes made from non-local green diorite recovered from Motupore (Allen 1977:443-444). Rhoads (2010:61) indicates that for much of this period, the form of axes/adzes generally stays consistent with the forms from the previous period. By the time of European contact, however, Rhoads (2010:61) notes significant changes in axe/adze form, as well as an increase in reshaping of old tools. Rhoads (2010:61) suggests that these changes in form may be directly linked to the development of the *hiri* trade system and the exchange of goods with people in the Papuan Gulf. Bone and shell artifacts, including shell beads in various stages of production, are also common during this time (Anson 1986). A wide variety of marine and terrestrial faunal remains continue to be present at sites in the area, and it is noted that shore sites such as Motupore appear more reliant on marine resources than on terrestrial ones (Allen 1977:444).

# Conclusions

The archaeological record of the Caution Bay is complex and varied. Continued archaeological research in the region is likely to reveal new information that will continue to modify our understanding of cultural change in this area. The ceramic data that has been the primary focus for the creation of this timeline is robust, but as with any scientific work, there is always room for additional data and refinement. The research conducted for this thesis will provide additional data focused on the selection and use of chert raw material in the Caution Bay area that can be used to further refine understandings of the broader integrity and applicability of these largely ceramic-based temporal periods. The addition of data from lithic artifacts to the ceramic-based sequences along the south coast of PNG is not completely new, however, it has not been a focus until recently. Allen et al. (2011) used the chemical characterization of chert artifacts from Oposisi to strengthen their discussions about human mobility on the landscape and the changes in the intensity of human interaction. The research carried out by Allen et al. (2011) did not included any geological chert samples, but was still able to provide valuable data to add to their discussions. More recently, Sutton et al. (2015) used pXRF analysis of chert artifacts, again without known geological sources, to make inferences about access to raw materials and the technological organization of people living at Taurama both prior to, and then after the Papuan Hiccup. This work, although done with a limited sample size, was remarkably successful, and has proven to be an invaluable guide for this research. The pioneering work conducted by Allen et al. (2011) and Sutton et al. (2015) have both demonstrated the value of chemical analysis on chert artifacts and have shown how beneficial the results of these analyses can be to strengthening the chronologies and cultural sequences that have been, until very recently, primarily focused on ceramic materials.

In light of the archaeological overview that has been presented in this chapter and the examples of other research that has included chert chemical characterization, it is valuable at this time to reiterate and further define the research goals that were presented in Chapter 1. The chert artifacts collected for this analysis come from sites with a wide geographical range and significant time depth. The Caution Bay area has a

preceramic component, a Lapita component, a variety of later ceramic traditions and was occupied both before and after the "Papuan Hiccup". Where possible, the chert collection from each of these temporal periods will be investigated to determine what chert resources were being used and to what extent these were being used. These results will be compared where possible from site to site across the Caution Bay landscape to explore if there are similarities or differences in chert use between sites with different occupations densities (as defined by the quantities of all archaeological material being discarded at any given time) that were occupied at the same time. Additionally, these relationships will be explored from one period to the next at all the multiple component sites to assess how or if chert raw material selection is reflected by the changes seen in other parts of the archaeological assemblage – specifically the ceramic artifacts.

Researchers should always be willing to update and revise their theories in light of new evidence. The results of the chert analysis carried out in this research have the potential to provide data that will necessitate some degree of revision of the cultural chronology that has been presented here. As evidence from the Caution Bay Project continues to be analysed, data from other artifact types and faunal analyses will become available, and it is inevitable that if these data are examined in relation the existing cultural chronologies, further changes may also likely be required.

# Chapter 3: The Geology, Geography and Environment of Caution Bay, PNG

This chapter is divided into two sections. The first section introduces the geology of the Caution Bay area. As this thesis focuses on the analysis of chert, an understanding of the underlying geology of the areas is required. This section of the chapter introduces the geology of Caution Bay and southern PNG more broadly with a focus on identifying the types of rock formations present and, where possible, to identify formations that may give rise to chert outcrops. Where appropriate, the potential for the underlying geology to have an effect on the chemical composition of chert is also discussed.

The second section of this chapter introduces the geography and environment of the Caution Bay area. For an effective understanding of the depositional history of the archaeological sites discussed in this thesis, it is important to understand the local geography and environment both as it is currently and how it was in the past. This is particularly beneficial when discussing potential locations of natural outcrops of chert, the visibility of these outcrops, and how and why these may have changed over time. A general overview of the current geography and environmental conditions at Caution Bay is provided and some of the known changes that have occurred in relation to the major periods of occupation identified in Chapter 2 are identified. The detail provided here is not exhaustive and has been tailored to the needs of this thesis, particularly with regards to providing context and background information for the discussion in Chapter 12. To avoid broad generalizations resulting from the use of environmental and geographical data from regions outside of the Caution Bay area, the discussion that follows has been based primarily on the limited sources that focus on Caution Bay.

## Geology of Caution Bay and the Surrounding Area

The details of the entire tectonic history of the island of New Guinea are too complex to be discussed in detail here. A detailed geological timeline of the island of

New Guinea is available in Gradstein et al. (2004). Some framework, however, is required to understand the geological setting of the southern lowlands and the Caution Bay region.

## *General Tectonic Setting of New Guinea*

New Guinea is geologically complex (Figure 2). It is positioned on a tectonic boundary and formed through collision between the large northward-moving Indo-Australian Plate and the extensive westward-moving Pacific Plate. A series of smaller tectonic plates between the Philippines and the Solomon Islands also form a complex network of strike-slip faults and island arcs (Brown et al. 1979; Polhemus 2007). Generally speaking, New Guinea consists of three discrete tectonic provinces that run parallel to each other in a roughly east-west direction. These comprise a south Stable Platform, which consists of the un-deformed Australian continental craton, the central Fold Belt, comprised of the deformed craton margin, and the northern Mobile Belt, a complex mix of accreted arc-terranes and tectonic slivers (Löffler 1977; Polhemus 2007). Of interest to this research is the south Stable Platform province that provides context for the Caution Bay area.

The Stable Platform province, variously referred to as the Stable Platform, Papuan Platform, Australian Shield, Australian Platform, Australian Plate, or Australian Craton, comprises most of the southern half of New Guinea and is an extension of the Australian continental basement. This area is isostatically stable and consists of un-deformed Palaeozoic, peneplained, metamorphic, and minor acidic volcanic rocks. These formations are intruded by late Carboniferous and Permian granitic and dioritic rocks, and overlain by thin, flat-lying, Mesozoic and Cainozoic sequences (Brown et al. 1979; Polhemus 2007). Rifting along the eastern margin of this craton during the middle to late Cretaceous resulted in the development of an elevated ridge in current PNG-Indonesian border areas, extending north to along the west of the modern Sepik Basin. This ancient ridge defines the drainage patterns of modern New Guinea, which flow from this location to the east (Sepik and Fly Rivers) and the west (Mamberamo and Digul Rivers) (Audley-Charles 1991; Brown et al. 1979; Polhemus 2007). The Stable Platform has been further subdivided into three smaller geological regions, the Fly Platform, the

Southern Fold Mountains, and the Eastern Fold Ranges. The Stable Platform also contains the Southern Plains and Lowland geomorphological zones.

The Southern Plains and Lowlands geomorphological zone extends along the southern coast of New Guinea to the foothills of the Eastern Fold Ranges. In the Fly and Digul Rivers area, this zone covers approximately 230,000 km$^2$ and extends over 400 km inland. To the east and west, the zone becomes progressively much narrower, resulting in a small stretch of alluvium to the west and a series of embayments to the east such as the area near Port Moresby. Caution Bay is a good example of one such embayment (Loffler 1982, 1977). The Southern Plains and Lowlands have a distinct geomorphic character that is related to low seasonal rainfall. The minimal rainfall has resulted in a savannah-type morphogenetic regime similar to that of northern Australia and unlike the humid tropical regime dominating most of PNG. Low rainfall is also the reason for regional stability in landforms, surface deposits, and weathering profiles not found elsewhere in New Guinea (Loffler 1982, 1977). The lowland geomorphological zone is dominated by low ridges formed on moderately to steeply sloping limestone, chert, sandstone, siltstone, and mudstone (Loffler 1982, 1977; Mabbutt 1965). The presence of chert in these deposits provides a further indication of locally available lithic raw materials.
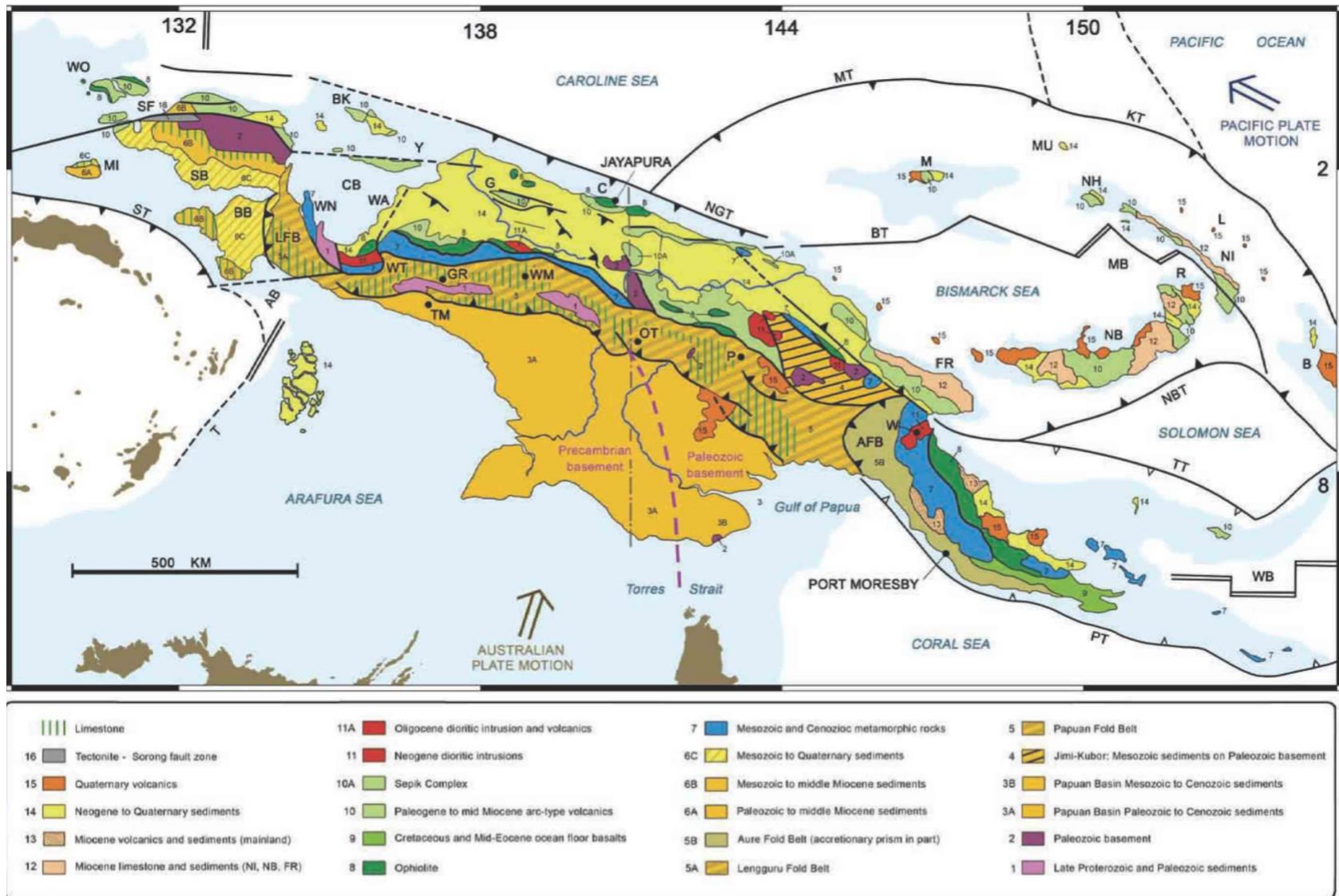
*Figure 2: Geological map of New Guinea drawn by Randall Betuela (from Davies 2012).*

## *Local Geology of the Southern Plains and Caution Bay*

The geology of the Southern Plains and Lowland zone (encompassing Caution Bay) falls into five age brackets, each with a characteristic structure and lithology: Cretaceous-Palaeogene (145–158 million years ago [MYA]), Miocene (23–5.3 MYA), Pliocene (5.3–2.4 MYA), Pleistocene (2.4–0.01 MYA), and recent (<10,000 years). These categories are summarised here, with specific comment on Caution Bay where possible. Descriptions of the various geological formations draw primarily on the work of Speight (1965), Glaessner (1952), Yates and Ferranti (1967), and Rogerson et al. (1981). Also, of relevance to this section are the broad geological maps presented in Shearman and Bryan (2011) as they provide geological context for the broader region.

### Cretaceous-Palaeogene (145–158 MYA)

Rocks from this geological period consist of metamorphosed and un-metamorphosed sediments, and include limestone, sandstone, mudstone, chert, and tuff intruded in various locations by gabbro, dolerite, and serpentine (Speight 1965). Two major classes of rock are associated with this time period, a sedimentary formation and an igneous one. The sedimentary rocks include the Bogoro limestone, a sheared limestone, the Barune sandstone, and a bedded calcareous quartz sandstone, both of which are pink in colour (Glaessner 1952). These formations occur as lenses associated with the Port Moresby geological group and give rise to the ridges of the southern hills. The Port Moresby geological group also includes limestone with silicified lenses, limestone metamorphosed up to garnet-pyroxene grade, and beds of green and red mudstone and calcareous sandstone. Hard chert is also present in this group and can appear either as massive and concretionary or as thin and bedded (Glaessner 1952). In both cases, the chert is found pinching into lenses in mudstone and marl. The Port Moresby group is underlain and intruded by igneous rocks including gabbro and smaller volumes of dolerite and serpentine (Pieters 1982; Speight 1965).

**Miocene (23–5.3 MYA)**

Rocks from the Miocene cover large areas of the central southern plains and lowlands. They form the main foundation of Caution Bay. They are composed of a variety of different rock types, including beds of coral limestone, other marine sediments of considerable thickness, and occasional conglomerates. A number of these geological groups have been formally defined and are presented here. The Boira tuff and limestone group is a coarse bedded sequence with tuffaceous grit, gravelly limestone grit, limestone blocks, and massive limestone. It is known for being richly fossiliferous, containing abundant foraminifera (indicating a lower Miocene age), and is most prominent in Caution Bay near the village of Boera (Rogerson et al.1981). The Siro group consists of beds of pebbly sandstone and coarse boulder conglomerates, notably quartz, igneous rocks, schist, chert (pebbles, cobles and even bolder sized nodules), and feldspar grains (Glaessner 1952, Rogerson et al.1981). The Gidobada geological series is a poorly-defined group of volcanic rocks, including beds of pink coralline limestone which dip moderately to the northwest and contain middle or lower Miocene algae (Pieters 1982; Speight 1965). A further four Miocene formations include the Kaieu greywacke (lower or middle Miocene), Bokama and Diumana limestone (both middle Miocene), and Vanuamai siltstone (upper Miocene). All these sequences are well bedded and contain abundant reef deposits with coral debris. Other Miocene rocks without foundation group names include general coralline and foraminiferal limestone with hard calcareous sandstone and conglomerate overlying mudstone and calcareous tuffs (Speight 1965).

**Pliocene (5.3–2.4 MYA)**

No geology of Pliocene origin occurs within the Caution Bay catchment. Deposits of this age concentrate in the upland zone and plateaus immediately inland (Speight 1965). These are mainly volcanic derived continental deposits (Mabbutt 1965; Speight 1965) and include sheets of thick-bedded andesitic agglomerate, and basaltic to andesitic lava flows with inter-bedded basic tuff. Westward, these grade to tuffaceous sandstone and conglomerate, then into thin-bedded tuffaceous limestone (Glaessner 1952).

**Pleistocene (2.4–0.01 MYA)**

Raised coral reefs of Pleistocene age and consisting of a thin layer of coral covering previously submerged benches, are periodically found throughout the southern plains and lowlands (Loffler 1982). No other Pleistocene material has been identified in this area.

**Recent (<10,000 years)**

Deposits that post-date the last major sea level change cover an estimated 40% of the area surveyed by Speight (1965) and incorporate the Caution Bay area. According to Speight (1965:103), detrital material derived mainly from the mountainous hinterland (e.g. the Southern and Eastern Fold Mountains, and ranging from boulders to clay) was laid down and reworked by fluvial and littoral agents at an undefined "rapid rate". As a result of this rapid deposition, peaty deposits are significant only in the broadest swamps. Apart from river mouth locations, fringing and barrier reefs are present and extend along the coast as far north as Yule Island (Loffler 1982; Speight 1965). Glaessner (1952) notes chert in the form of angular and subangular nodules often comprises a large component of recent scree deposits at the foot of formations with significant chert outcrops.

## *Rocks of Significance for Stone Artifact Raw Material Studies*

Two of the most common rock types used for making flaked stone tools in the region are obsidian and chert. Though there are extrusive igneous deposits, such as lava flows, present in southern PNG, there is no obsidian source in this area (Mialanes et al. 2016a). Chert, on the other hand, occurs in abundance and is found in the Caution Bay area in deposits of Cretaceous-Palaeogene and Miocene age (Glaessner 1952). Additionally, Glaessner (1952) identifies a number of other formations that contain chert outcrops, from an even wider range of time periods, both further east and further west along the coastline from Caution Bay.

In the Caution Bay area, chert from the Cretaceous-Palaeogene and Miocene geological periods can be found both in bedded formations and as nodules, or in some

cases as boulders as noted by Glaessner (1952). The chert from these periods was deposited in a marine environment and contains a variety of fossil marine life, including Radiolaria, sponge spicules, and the silicified casts of worm burrows (Glaessner 1952).

Based on the sedimentary geology of the Caution Bay area, and the abundance of chert in local deposits, it is likely that chert sources would have been present as natural outcrops, visible on the landscape as lenses of nodular chert or as thick beds, in a variety of areas. Furthermore, because of weathering and erosion, it is also likely that chert nodules of various shapes and sizes would be present in depositional deposits from rivers and streams as well as mass wasting events such as landslides, and mudflows and scree slopes. Chert nodules present in these recent sedimentary matrixes would likely be exposed over time by the movement of stream cuts and natural exposures caused by events such as flooding from heavy seasonal rains.

## *Geomorphology of the Southern Lowlands and Caution Bay*

It is difficult to determine the degree of natural exposure of chert in the past due to differences in erosion and deposition cycles. Having a general understanding of some of the geomorphologic processes occurring continually in the Caution Bay area can, however, provide information to help to shed light on this issue.

There are two major geomorphologic systems at work in the Caution Bay area — erosional and depositional. Erosional systems include the foothills and coastal hills. Depositional systems include fluvial plains, swamps, and littoral plains (descriptions following Löffler 1977; Mabbutt 1965; Speight 1965). Erosional systems are the most important in locating chert outcrops, as it is erosion that will eventually remove softer, easily weathered materials, exposing the hard, erosion-resistant chert. In the Caution Bay area there is a lack of significant relief-building rock outcrops, and therefore ridges tend to be the expression of a number of harder and softer beds (Mabbutt 1965). Free rock faces are small, or lacking altogether, and structural benches are insignificant or not visible due to the degree of erosion. Hard rock outcrops are mainly limited to boulder chert bands on ridge crests and the upper slopes of hills. Ridge profiles in Caution Bay therefore tend to be smooth with rounded crests (Mabbutt 1965). In some cases, where

the ridge crest is composed of cherty limestone and underlain by relatively weaker mudstone, slumping can occur and is more significant at steeper valley heads. The valley below typically incorporates thin stony fill derived from slope wash (Mabbutt 1965). All these erosional processes can lead to the exposure of chert outcrops. A further source of chert exposure is the erosional and depositional nature of watercourses. In Caution Bay, lowland watercourses are ephemeral, mainly small, and originate in the above-described landscape (Löffler 1977; Mabbutt 1965). Drainage patterns are dendritic on the open plains and subparallel on foot slopes, and generally indicative of high run-off. Much of the run-off occurs as sheet flow from long gentle slopes on relatively impermeable rock (Mabbutt 1965). The only structured watercourse with its own drainage pattern is that of the Vaihua River, which traverses the southeastern portion of the catchment (Pain and Swadling 1980). Sources of chert would likely be identified in the exposures resulting from sheet flow, as well as in minor adjustments relating to seasonal flooding in the structured drainage of the Vaihua River. Though chert nodules might be carried downstream on occasions of high water or seasonal flooding, the predominant sediment moved in these various drainage systems is fine dark clay (Löffler 1977; Mabbutt 1965).

## Current Geography and Environment of Caution Bay

The geography and vegetation of the approximately 9 km$^2$ area of Caution Bay that contains the recently excavated archaeological sites have been described in detail by Aplin et al. (2016) and Rowe et al. (2013). They are also discussed by McNiven et al. (2012a) in relation to the Edubu 1 archaeological site excavated as part of the Caution Bay Project. Beginning on the shoreward side of the project area, Aplin et al. (2016) and Rowe et al. (2013) describe the landscape as a littoral plains complex consisting of plains, spits, barrier beaches, and tidal flats ranging up to 1 km inland. Vegetation in these areas consists mainly of mangrove communities with a variety of different species. Landward from the littoral zone, vegetation is mixed scrub and evergreen-deciduous thicket (shrubs and low trees) that grades into grassland. The grassland area is gently undulating, and although it is generally level, it continually slopes gently upward away

from the shore. The grasslands are dense, with greater concentrations of sedge and broadleaf herbs noted in *Pandanus* depressions. With increased distance from the shore, the ground cover becomes drier and lower in height. The drier areas are dominated by sparse tree cover with very little underbrush. These treed areas are associated with the more pronounced elevation gains and are located on the edges of pronounced slopes and gentle hills in the more inland portions of the project area. Other features of note include a line of raised sand dunes paralleling the shoreline and marking the break between the littoral zone and the grassland. An area of vegetated salt marsh and bare high-inner tidal salt flats is located immediately inland from this sand feature. A variety of sediment types are present across the area including sand dunes near the shore, clay-rich mud in the swampy depressions, and developed soils on the raised areas (see Aplin et al. 2016 and Rowe et al. 2013). Additional information about the current environmental conditions and geographic features in Caution Bay, including detailed maps can be found in Aplin et al. (2016).

## Past Geography and Environment of Caution Bay

The past geography and environment of Caution Bay played a role in structuring the location and length of occupation of the archaeological sites in the Caution Bay area. The following section will briefly outline the current understanding of the environment that likely existed during the major periods of human occupations identified at Caution Bay detailed in Chapter 2. Where possible, references to changes in local geography will also be detailed.

The pollen records published by Rowe et al. (2013) only provide data for the last 2000 years in the Caution Bay area. Mangrove forests first occurred in this area approximately 2000 years cal BP. It is also during this time that sea levels dropped approximately 1–3 m to reach levels close to those of modern times. These initial mangrove forests were much larger than present day, with modern dimensions and diversity being reached at approximately 1000 cal BP, presumably connected to stable sea levels through this time.

Prior to this time, there is evidence that suggests sea levels were up to 3 m higher (Lewis et al. 2012; Perry and Smithers 2011; Sloss et al. 2007). Data from neighbouring northern Australia also places sea level as 1–2 m above present until 2000 cal. BP (Nott 1996; Woodroffe 2009). Rowe et al. (2013) indicate that for a majority of the mid to late Holocene, a large proportion of the Caution Bay littoral zone sat well below increased sea levels and associated high-tide reach. As the sea-level receded to that of the present day, sedimentation would have been occurring. However, as noted by Rowe et al. (2013) this sedimentation was not occurring at a rate that was fast enough to keep up with the changes in sea level until the eventual sea-level stabilized approximately 2000 years ago.

During the first four phases of human occupation at Caution Bay: pre-Lapita / pre-Ceramic Period (c. 4200–2900 cal BP), the Lapita Horizon (2900–2600 cal BP), the Post-Lapita Transformative Tradition (c. 2600–2150 cal BP) and the Linear Shell Edge-Impressed Tradition (c. 2150–2100 cal BP), the pollen records provided by Rowe et al. (2013) are of limited value as they only cover the past 2000 years. However, Rowe et al.'s (2013) discussion of sedimentation rates is highly relevant to this research. Rowe et al. (2013:1138) describe a small, slow sediment supply throughout this early period that effected change on the mangroves by slow sediment infilling rather than shoreline regression. This interpretation is supported by the thin core depths that were recovered and the c. 2000 cal BP date for the growth of extensive mangroves in the area. It is likely that this slow, steady sedimentation reflected a relatively stable environment in the Caution Bay area during the period of occupation from c. 4200 to c.2000 cal BP. Rain and flooding events were likely infrequent and terrestrial vegetation would have likely seen limited change. It is of note that the falling sea-levels during this time would have exposed a significant quantity of newly dry and accessible land. Terrestrial flora would quickly have covered this newly exposed land and would provide new habitat for local Fauna. Humans would most likely have moved into these areas as well, to take advantage of the new resources they provided.

Additional evidence for the environmental conditions of Caution Bay prior to 2000 years ago is presented by McNiven et al. (2012a) and they rely on the presence of

specific fauna, namely the wallaby, as an indicator of local vegetation patterns. The archaeological evidence at Edubu 1 suggests that the Caution Bay area was largely savannah and grassland as early as 2600 years ago. It is further suggested by McNiven et al. (2012a:145) that this savannah and grassland is due in some part to anthropogenic firing of the landscape, a process they suggest began with the initial Lapita settlement of the area. They (2012:147) also infer rapid sedimentation at Edubu 1 between approximately 2350 cal BP and 2650 cal BP. Over a period of up to 300 years, a rapid accumulation of 90 cm of sediment was deposited at this site suggesting increased erosion and sedimentation. McNiven et al. (2012a) suggest that the increased erosion was due to human landscape disturbances including burning and cultivating gardens. Additionally, using Osborn et al.'s (1993) evidence from Waigani Lake, east of Caution Bay, McNiven et al. (2012a) discuss the possibility that increased erosion and deposition were also associated with increased precipitation in the area. Regardless of the exact mechanisms at play it is likely that increased erosion and sedimentation combined with a gently receding sea level played an important role in shaping the shoreline of Caution Bay during the period of initial human occupation (c. 4200 cal BP), to the time of shoreline stabilization and the onset of coastal mangroves c. 2000 cal BP.

The gentle and slow rate of sedimentation suggested by Rowe et al. (2013) between c. 4200 to c.2000 cal BP contrasts with the more rapid sedimentation identified by McNiven et al. (2012a) at Edubu 1 between c. 2350 cal BP and 2650 cal BP. It should be noted however that these two interpretations come from distinctly different environments – Rowe et al. (2013) is focusing on marine sediments over a larger area and in a specific environment (i.e. coring was done in the mangroves intertidal zone). McNiven et al. (2012a) on the other hand, looked at inland terrestrial sediments and focused on only one site. It is possible that both increased erosion and deposition are occurring on the land, but that due to the rate of sea level decline they are not happening at a rate that is significant enough to be identified as rapid along an entire coastline.

During the period of occupation at Caution Bay associated with the Umbo-Bordered Shell Back Impressed Tradition (c. 2100–1650 cal BP) and those periods following – the Varied Incised Tradition (c. 1650–1000 cal BP), Period 4: Pottery

Transformation (1200–800 BP), and Period 5: Interaction, Specialization and Exchange (800–200 BP) – the pollen records published by Rowe et al. (2013) become more relevant. These records indicate that during the occupation associated with the Umbo-Bordered Shell Back Impressed Tradition the environment at Caution Bay was likely becoming more stable and that the sea level had stopped fluctuating. These observations are supported by the onset of mangrove growth in the area between 2000-1700 cal BP (Rowe et al. 2013:1137). The development of mangroves on stable mud flats occurs rapidly, and as it does, it stabilizes a greater area, encouraging more extensive growth. Rowe et al. (2013:1137) identify a well-established mangrove forest, with openings housing a variety of other species, including ferns and palms, covering an area much larger than that present in Caution Bay today and covering much of the coastal region during this time. Following the initial rapid growth of mangroves in the Caution Bay area, Rowe et al. (2013) document that a period of change occurred within the coastal mangroves. During the period between c.2000 cal BP and 1300-1000 cal BP, associated with the occupation of people making ceramics associated with the Varied Incised Tradition, Rowe et al. (2013:1137) identify a change in the species present and in their growing locations. By 1000 cal BP, Rowe et al. (2013) identify a division of mangrove species with *Rhizophora* being dominant to seaward and *Avicennia* encompassing the landward margin. There is also evidence of a central unvegetated mud flat occurring concurrently.

The pollen records published by Rowe et al. (2013) also provide insights into the nature of plants landward of the intertidal mangrove and mudflat zone over the past c. 2000 cal BP years. Throughout this period, the mangrove zone from which these pollen cores were taken was backed by a littoral sand dune and rolling plains. A variety of plants were present on these landforms, including coastal thickets, and mixed evergreen and deciduous trees. Rowe et al. (2013) note that there is a greater diversity of taxa present during the deep, early portion of the cores (c.2000-1740 cal BP) compared to more recent times. This diversity suggests a wetter ecosystem in the area and is also used to support the idea that the coastal dune system would have been stable through this time (Rowe et al. 2013:1138). Landward of the coastal dune system Rowe et al. (2013) identify a variety of *Pandanus,* swamp grasses and sedges, ferns and aquatic

herbs filling and living in the various low-lying depressions and swale-like features and undergoing varying degrees of freshwater flooding. Of the species identified, only *Pandanus* is identified as having any change in distribution over time. Rowe et al. (2013) note that *Pandanus* increases in distribution after c.1000 cal BP and suggest that this may be the result of it expanding to other cross-mosaic communities or possibly due to disturbances (see Prebble et al. 2005).

After 1740 cal. BP, Rowe et al. (2013) note a change to the inland vegetation and discuss first the shift from coastal thicket towards coastal scrub ecosystems as well as an increase in coastal woodlands. In the coastal scrub areas, they note an overall decrease in tree cover and a decrease in general canopy diversity. In the coastal woodlands, an initial dominance of *Barringtonia* is followed by a dominance of *Casuarina* with a variety of other plants, including palms, incorporated. Both tree species form an open canopy forest and are considered secondary forest indicators (Rowe et al. 2013:1138).

The observations made by Rowe et al. (2013) suggest a level of stability in the environment from c. 2000 cal BP to 1740 cal BP. Evidence for paleoclimate trends from Port Moresby and the Central Province developed by Osborne et al. (1993) indicate periodically wetter conditions and wet-dry phasing commencing c. 2500 BP, increasing through 1700–1200 yrs. BP and becoming predominant from 1000 to 700 yrs. BP. Rowe et al. (2013:1139) also suggest that an increased occurrence of fire, possibly anthropogenic in origin, may have played a significant role in the changes in species that occurred at Caution Bay c. 1740-1300 cal BP. The wet-dry trends and the evidence for anthropogenic burning of the landscape inferred by Rowe et al. (2013) during the past 2000 years, and by McNiven et al (2012) for the period of time before that, are both of significance for this thesis, as both have the potential to affect the rate of erosion and deposition occurring over the Caution Bay landscape, which in turn may have affected the visibility of and access to sources of chert.

# Conclusions

The geology of the Caution Bay region and the surrounding area is varied and complex. The overview that has been presented here provides details about the types of rock present, the geological strata and associated time lines for their formation, and a brief description of the erosional environment in which they are now located. The erosional and deposition environments of these rocks are important for this thesis as they will used later in the discussion of raw material source availability.

Of special note is the frequency of chert identified in the formations described here. Not only is chert recorded in banded thick formations within the greater area (Glaessner 1952:66), but it is also noted in a number of other forms including boulders, cobbles, and integrated materials in other rock formations (Glaessner 1952). The abundance of chert in the geological material of the Caution Bay region and the surrounding area suggests that the potential number of sources of chert in the landscape may have been quite numerous at any given time. The geology of the area, though complex, indicates that similar rock formations exist over large areas and in these cases, it may be possible that numerous visible sources of the same chert formation would have been visible on the landscape. These ideas will be revisited later in this thesis in the discussion of how people may have been selecting discrete raw materials on the landscape.

Understanding the history of geographic and environmental changes that have occurred during the human occupation in Caution Bay is a challenge. It is, however, a challenge that is well worth undertaking as it provides valuable information that can be used to understand when, and for how long, sites in particular areas may have been occupied and what potential ecological or environmental factors may have influenced both their initial occupation and their final abandonment. Most critical in terms of this thesis, environmental and geographical factors have the potential to play a significant role in the visibility of lithic resources on the landscape. For example, periods of increased rainfall have the potential to cause increased erosion and deposition.

# Chapter 4: Chemical Characterization of Lithic Materials and X-Ray Fluorescence Spectrometry

This chapter is divided into two sections. The first section provides a brief background to chemical characterisation studies in archaeology on a global scale and then specifically in the Southwest Pacific region and the Caution Bay area. It introduces the various tools used for chemical characterisation studies in archaeology and the variety of materials on which these studies have focused. The second section introduces X-Ray Fluorescence Spectrometry (XRF) and includes a brief history of XRF technology, a description of what it is, how it works, and its limitations. This section also explains why this particular technique was selected for use in this research by highlighting a variety of successful and unsuccessful applications of XRF to archaeological research questions.

## History of Chemical Characterization in Archaeology

Chemical characterisation studies have been employed in archaeological research since the early 1960s (Tykot 2003:64). As advances in chemistry provide new or better means of examining the chemical composition of a material or object, archaeologists have found a way to apply these new technologies to archaeological questions. Understanding the chemistry of an object can provide information that will help answer questions about the source and origin of objects and the connections between objects that otherwise could not be answered or would be far more challenging to address.

Some of the earliest chemical characterisation studies were conducted by Cann and Renfrew (1964,1967), and Renfrew et al. (1965). These studies focused on obsidian raw materials from the Aegean and used spectroscopic analysis of trace elements. Other commonly used chemical characterisation techniques include the following, adapted from Tykot (2003):

**Elemental Methods:**

- Neutron Activation Analysis (NAA)
- X-Ray Fluorescence (XRF)
- Electron microprobe with wavelength-dispersive spectrometers
- Scanning Electron Microscope with X-Ray Analyser (SEM-EDS)
- Atomic Absorption Spectroscopy (OES)
- Proton-Induced X-Ray-Gamma Ray Emission (PIXE-PIGME)
- Inductively Coupled Plasma Spectroscopy (ICP-S)
- Raman Spectroscopy

**Isotopic methods:**

- Thermal Ionisation Mass Spectrometry (TIMS)
- Stable Isotope Ratio Analysis (SIRA)
- Inductively Coupled Plasma–Mass Spectrometry (ICP-MS)
- Multicollector–Inductively Coupled Plasma Mass Spectrometry (MC-ICPMS)
- Laser Ablation–Inductively Coupled Plasma–Mass Spectrometry (LA-ICP-MS)

Descriptions of each of these methods and a brief discussion of the positive and negative aspects of each are presented in Renfrew and Bahn (2016:365-371) and Tykot (2003). These methods have been applied to materials ranging from ceramic objects (e.g. Arnold et al. 1991; Renson et al. 2013; Speakman et al. 2011; Tong and Williams 1970), stone tools (e.g. Foradas 2003; Gauthier et al. 2012; Malyk-Selivanova et al. 1998; Moore 1977; Parish et al. 2013; Rafferty et al. 2007), metal objects (e.g. Bayard 1972; Charlton 2015), paints (e.g. Centeno et al. 2012; Clarke 2004; Moffatt et al. 1997; Osticioli et al. 2009), ochres (e.g. Huntley et al. 2014a, 2014b; Scott and Hyder 1993; Vila and Centeno 2013), faunal material (e.g. Locock et al. 1992; Price et al. 1986), and human remains (e.g. Drasch 1982; Kniewald et al. 1994; Runia 1987). More detailed information about these techniques and their various applications is available in Glascock et al. (2007), Stos-Gale (1992), and Tykot (2003), among others.

# Chemical Characterization in the Southwest Pacific

Identifying the chemical composition (and subsequently the potential or known origin) of archaeological materials presents an excellent opportunity to better explore migration and mobility patterns, settlement histories, and exchange systems across the Pacific. In the Pacific region, chemical characterisation research has primarily focused on two materials: obsidian and ceramics. Ceramics have tended to be a focus simply due to their significant presence within archaeological assemblages and changing styles through time. Examples of ceramic-focused studies include Bickler (1999), Buhring et al. (2015), Cochrane et al. (2013), Golitko and Terrell (2012), and Robb and Nunn (2012), with works by Summerhayes (2000), Summerhayes and Allen (2007), and Irwin (1991) being among the most influential due to their wider regional focus. Obsidian, on the other hand, is less common, but has been the focus of sourcing studies for two reasons. First, obsidian is relatively regionally isolated, with only a few source locations available (Golitko et al. 2012:151; Summerhayes et al. 2014:238). Second, the chemical composition of obsidian has been shown to be very homogenous from location to location and sources can be identified with pXRF (and other tools) by focusing on a relatively small number (n=8) of trace elements. Examples include the use of Ti, Fe, Mn, Zn, Rb, Sr. Zr, and Pb by Sheppard et al. (2011:48) and the use of Na, Mg, Al, Si, Ca, K, Ti, Mn, and Fe by Summerhayes et al. (2014:243) to characterize obsidian sources from New Zealand and PNG respectively. Examples of obsidian sourcing studies include Ambrose et al. (1981), Burley et al. (2011), Carter et al. (2009), Golitko et al. (2010), Green and Bird (1989), Sheppard et al. (2011), and White et al. (2006).

Published literature about chemical characterisation research along the southern coast of PNG is limited. Studies include chemical characterisation of ceramics (Bickler 1999; Sutton 2016), human remains (Shaw et al. 2011), and lithic materials (Allen et al. 2011; Mialanes et al. 2016a; Skelly et al. 2016; and Sutton et al. 2015). Allen et al. (2011) use of PIXE-PIGME for the chemical characterisation of 97 chert artifacts (and a selection of obsidian artifacts) from Oposisi, and that of Sutton et al. (2015) using pXRF for the chemical characterisation of 81 chert artifacts from Taurama, are the only previous studies on this raw material type of direct relevance to this thesis.

## Choosing a Chemical Characterization Tool for this Research

As technology continues to improve, the number of analytical techniques and instruments capable of conducting chemical characterisation similarly develops. The most commonly used techniques in archaeology include XRF, pXRF, PIXE-PIGME, and Raman spectroscopy. Each of these techniques has inherent negative and positive attributes that significantly affect their ability to answer research questions. Some instruments require specialised training or are very large and non-portable; some instruments can only test for selected elements or can only test an object invasively or destructively (Huntley et al. 2016). Each researcher must select the tool that will not only provide the targeted data but also do it in a way that is affordable, timely, applicable to the materials tested, and ethically. Glascock et al. (2007) present a discussion of the variety of chemical characterisation techniques currently in use in archaeology and their potential applications and limitations. Based on factors that will be addressed below, portable X-Ray Fluorescence (pXRF) was selected as the most appropriate analytical technique for this research project.

## Introduction to X-Ray Fluorescence (XRF)

X-Ray Fluorescence Spectrometry is a scanning technology used to determine the chemical composition of an object. XRF machines, as large laboratory-based instruments, have been around since the 1950s, and have been used extensively for geological and environmental applications as well as for archaeological studies. Although discussions of the archeological use of XRF first appeared in the literature nearly 60 years ago (Hall 1960), these early studies were often limited in their sample size and in the number of elements included. More recently archaeologists have begun to explore the applications of this technology in its portable 'hand held' form, and although the number of studies is rapidly on the rise, Phillips and Speakman noted in 2009 that relatively few archaeological research projects using pXRF have been published at that time (Phillips and Speakman 2009:1258). When first developed, XRF

equipment was limited to chemistry laboratories. Original instruments were bulky, non-portable, complicated to use, and would potentially have been dependent on radioactive isotopes as a source for excitation (Phillips and Speakman 2009:6). In many cases, these instruments were assembled by chemists and physicists from a variety of independent components and would have required constant attention from qualified personnel to produce reliable data (Olvera 2010). With continued advances in technology, chemistry and engineering, all the components required can now be made to fit into a hand-held device that contains no radioactive material, is battery operated, and is completely portable. These modern portable X-Ray Fluorescence handheld instruments, commonly referred to as pXRF, often come with manufacturer-set sampling protocols and proprietary software for conducting data analysis (Phillips and Speakman 2009). These technological advances have allowed a reduced cost of testing, a reduced time for testing, a greater range of applications, and an increased number of users. Because these instruments are much easier to use than their lab-based counterparts, many of the new users do not need to have the same extensive chemistry backgrounds required to operate the older benchtop instruments. This has resulted in discussions about the validity of the interpretations being produced by users without chemistry backgrounds (Frahm 2013a, 2013b; Shackley 2011b; Speakman and Shackley 2013; Zhu et al. 2011:167). To understand these issues, it is important to understand what XRF (both conventional and portable) is and how it works.

*Figure 3: Portable X-Ray Fluorescence analyser used in this research.*

## How X-Ray Fluorescence Works

A complex overview of the operational theory of XRF and pXRF technology can be found in Potts and West (2008) and Zhu et al. (2011). A simplified description of the chemistry involved adapted from Shackley (2011a), Jones et al. (1997), and Weindorf et al. (2012) is presented here.

Regardless of the type of XRF instrument, the first step involved in the analytical process is the bombardment of the sample by high-energy X-ray photons (Bachor 2011), photons being a particle that represents a quantum of light radiation (Shackley 2011a). The mechanism that produces the X-ray photons can range from radioactive isotopes used for excitation (these are common in laboratory instruments and some older pXRF instruments; Weindorf et al. 2012) to a variety of X-ray tubes, common in portable instruments (Phillips and Speakman 2009:6). The depth of X-ray penetration and the size of the surface area being bombarded by the X-rays can vary depending on the brand and model of the XRF instrument. In most modern instruments, the surface area

under bombardment is often less than 25 mm in diameter and the penetration depth is usually not more than 3 mm (Jones et al. 1997:929; Weindorf et al. 2012:268).

X-ray bombardment causes the forcible ejection of electrons from the inner shells of an atom, the K and L orbitals (Figure 4). The ejection of these electrons causes instability in the inner shells that result in a "cascade" of electrons from the outer, higher energy orbitals (the N and M orbitals; Figure 4) down to these inner orbitals, filling the voids left by the ejected elections. This movement of electrons down the various shells causes a secondary energy emission that is termed X-ray fluorescence.
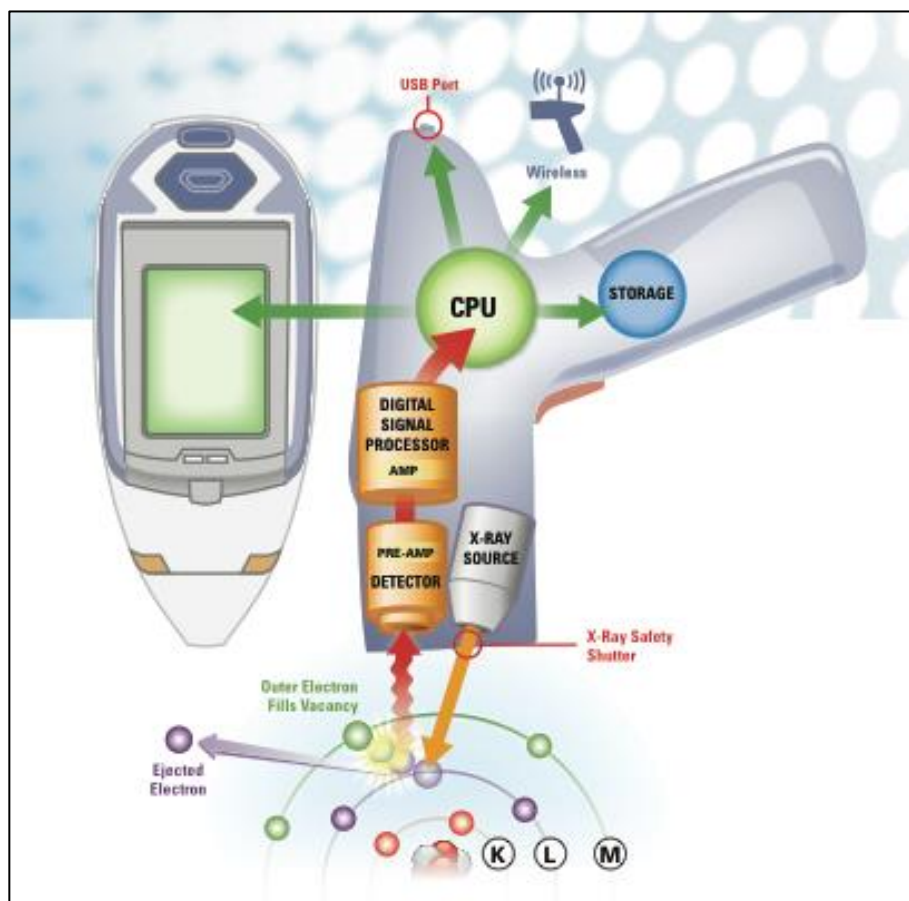
*Figure 4: Schematic of the pXRF instrument and electron cascade illustrating the basic technique of X-ray Fluorescence spectrometry (adapted from p.42 of the Portable Analytical Solutions Ltd. Radiation Safety Course – HH and pXRF handbook).*

The energy emitted by fluorescence has discrete wavelengths that are specific to each element. With the use of a detector that can record these characteristic X-rays and the number produced over a given time, it is possible to determine the element from which they are produced (Olvera 2010). When a specimen that is composed of more than one element is examined, this process goes a step further. The fluorescence (or secondary X-ray spectrum) generated in this case consists of a large number of discrete, high-intensity spectral lines that are superimposed upon a background of low-intensity X-ray radiation. The intensity of each of these individual spectral lines is primarily related to the concentration of the corresponding element in the specimen (Wurtzburg 1991:93). With the appropriate equipment, calibration, and analysis, these energy signatures can be used to identify the elements present in a sample, and their respective quantities (Jones et al. 1997:930; Lundblad et al. 2008:2; Olvera 2010).

## A Brief History of XRF and Some of its Applications

From its origin as large complex multi-component units, XRF and has been continually improved and refined, with smaller, more accurate, and easier to use units being developed regularly. Over the past 20 years, XRF has developed into greatly improved, highly accurate, portable instruments available from several different manufacturers (Bachor 2011:107; Phillips and Speakman 2009). Early XRF testing required that the sample to be analysed was homogenised to ensure accurate results. This homogenisation involved one of two methods. The first method involved grinding the sample down to a fine powder and mixing it with a chemical flux before heating in a crucible to produce a glass button (Potts and West 2008; Zhu et al. 2011). The second method also required that the specimen to be analysed was first ground into a fine powder, but instead of being heated, it would be mixed with a binding agent and pressed into a pellet using a high-pressure hydraulic press (Gauthier et al. 2012:2442). Both these methods were used to create artificial homogeneity within the specimen to get the most accurate results possible. While both methods continue to be used with large laboratory-based XRF and some pXRF instruments (e.g. Jones et al. 1997; Lundblad et al. 2008), in most cases they are not applicable to archaeological artifacts because of

ethical concerns over sample destruction. Although there are a variety of projects that have used these destructive methods with archaeological materials (e.g. Jones et al. 1997; Stevenson and Klimkiewicz 1990), the use of XRF as an archaeological tool did not begin to flourish until the advent of the modern pXRF instruments (Gauthier et al. 2012:2442). These pXRF instruments enable non-destructive sampling of artifacts, produce results that are comparable (although not exactly the same) to those produced by laboratory benchtop XRF instruments (Frahm 2013a:1444), and can be taken to archaeological materials in the field, the lab, or a museum anywhere in the world. All of these issues are significant factors when considering rare and precious archaeological artifacts and when a researcher wishes to work with artifacts that cannot be moved across political boundaries or out of specific museum collections.

Although all the items listed above make pXRF an ideal tool for archaeologists. There are still a number of issues relating to the accuracy of pXRF and the ability of the system to produce accurate data. As this thesis is not focused on testing the pXRF instrument, however, the intricacies of pXRF processing and recording abilities and the potential problems associated with these will not be discussed in detail here. One major issue that should be addressed however is result accuracy. A major issue being discussed is the demonstrated difference in the accuracy of the results provided by a pXRF unit used to take readings on samples that have not been homogenised when compared to the results of a modern, high powered bench-top XRF units taking readings on homogenized samples (Frahm 2013b; Liritzis and Zacharias 2011; Orfanou and Rehren 2014; Shugar 2013). Another issue relating to the function and use of pXRF that has been addressed is the problem of "signal to noise" or how much of the signal non-destructive pXRF is missing or misinterpreting (Brouwer 2010; Ernst et al. 2014; Gauthier and Burke 2011). Due to all the additional variables associated with pXRF units in general, and in the ability to test almost any surface in any conditions, the potential for errors and inaccurate data is much higher. Depending on the nature of the research being conducted and the questions being asked of the pXRF data the issues noted here can have a significant negative impact on the results (Shugar 2013). If a researcher requires the most accurate elemental data and is working on samples that can be destroyed, bench-top XRF units are still being produced and should be used if possible.

Alternately, as in the case of this research, considering the potential issues with pXRF when developing a methodology allows for a researcher to mitigate or work with these issues and still provide valid and useful pXRF data (Shugar 2013). Although archaeologists should be aware of the shortcomings of the tools they use, it should be chemists who are testing and perfecting the accuracy of the pXRF, and archaeologists using the tool to see what questions can be addressed by the data it provides. The issue of pXRF unit accuracy is addressed further in Chapter 8 as it pertains to the testing carried out for this research.

Obsidian was one of the first archaeological materials to be analysed in detail using pXRF technology to answer archaeological research questions about lithic sources (Grave et al. 2012; Rafferty et al. 2007:168). The physical properties of obsidian, such as its smooth surface texture and homogenous composition, combined with its geological formation, made it an excellent candidate for the application of pXRF technology (Eerkens et al. 2007:585). Goodale et al. (2012) note that there are two dozen articles using pXRF for obsidian sourcing and Frahm and Doonan (2013:1430) note that 45% of pXRF archaeology publications concern obsidian. As the technology has become more advanced, and as more and more people have access to pXRF equipment, the technology is increasingly being applied to other materials. There are currently several papers documenting the use of XRF and/or pXRF on metal objects (Cesareo et al. 1982; Hanson 1973), other stone materials (Bachor 2011; Frahm 2013a; Gauthier et al. 2012; Grave et al. 2012; Jones et al. 1997; Malyk-Selivanova et al. 1998), ceramic materials (Bickler 1999; Forster et al. 2011; Freeland 2013; Hall et al. 1973; Picon et al. 1972; Yap and Tang 1984), pigments in rock paintings (Huntley 2012; Huntley et al. 2014a; Kriznar et al. 2008), and even direct analysis of *in situ* archaeological sediments (Davis et al. 2012) to name only a few examples.

While it is clear that the use of pXRF technology is becoming increasingly commonplace, it is also true that there are researchers who have concerns about its application. Davis et al. (2012) and Grave et al. (2012), amongst others, have expressed concerns about what they see as the prolific use of pXRF by researchers who ignore standard protocol or have a poor understanding of the chemistry involved, resulting in

data that are not reliable and/or accurate enough to be compared. The two major problems that have been noted are: 1) researchers using pXRF are not always following the long-established laboratory XRF protocols such as sample preparation and instrument setup and calibration, and 2) although pXRF instruments produce valuable data, they do not produce results that match exactly with those produced by other pXRF instruments or lab-based instruments (Frahm 2013a; Grave et al. 2012; Nazaroff et al. 2010). This second problem potentially leads to what Speakman and Shackley (2013) refer to as "silo science" — research that produces results that are only internally consistent and not reproducible with other equipment. An ongoing debate exists in the literature between Speakman and Shackley (2013) and Frahm (2013a; 2013b) regarding these matters. In this debate, Speakman and Shackley, both much experienced with conventional XRF and pXRF, attest that more formalization and standardization is required before pXRF can be an accepted means of conducting research. The main point that Speakman and Shackley (2013) make is that internally consistent measurements, such as those published by Frahm (2013a), are not acceptable as they fail to acknowledge some of the fundamental issues of reliability and validity in the pXRF measurements. Speakman and Shackley feel that this oversight on the part of many researchers leads to something they term "silo science" and they caution against this liberal and un-scientific application of the technology. Frahm (2013a, 2013b), on the other hand, takes the stance that even if the results produced by one pXRF instrument do not replicate those produced by another; they can still be used to answer archaeological questions successfully. Frahm advocates for the use of pXRF by archaeologist working with specific research questions and with well-defined parameters regardless to where the result they produce can be replicated identically by another researcher using a different technique or pXRF instrument. Frahm suggests that the prime concern of Speakman and Shackley (2013) is "an artificial crisis triggered by specialists' concerns about a hitherto restricted technique becoming available to a wider community" (Frahm 2013b:1444). Frahm's approach is supported by other research, such as that conducted by Nazaroff et al. (2010) and Gauthier et al. (2012), in which pXRF data are used to successfully answer archaeological research questions. Gauthier et al. (2012:2442) even state explicitly that their data set "will not be used to elucidate

chert pathogenesis or to define chemical, mineralogical and geological models". Frahm (2013a; 2013b) provides a solid argument in support of the use of pXRF by non-chemists and promotes the idea that new researchers might expand the current understanding of what is and is not possible with this technology. This thesis aligns with the arguments and conclusions put forward by Frahm (2013a; 2013b). Many pXRF units that are available today are designed by their manufactures to be used in their 'out-of-the-box' settings. As long as a researcher is aware of the potential limitations this may have to whatever research questions the units are being used to address, the data produced by the pXRF unit is just as valid and valuable as data produced by bench-top XRF units operated by chemists.

## Why Use pXRF Technology?

As the merits of pXRF and XRF continue to be debated in the archaeological literature (see above), it is necessary to explain why this technique was selected over others. Like many other chemical analytical techniques, pXRF is not a technology without constraints and limitations and these should be understood in advance of developing a pXRF based research project. One common challenge associated with the use of pXRF instruments include samples size. The minimum samples size required for pXRF testing is larger than that required for many other methods, >10 mm in smallest dimension and >2-mm thick are optimal (Shackley 2011:9). Another common challenge when using pXRF instruments is elemental range. Although pXRF instruments can test a wide range of elements, they do have more restricted range then some other analytical techniques, with a range generally limited to the mid-Z X-ray region, the best portion including elements Ti-Nb (Shackley 2011:10). Portable XRF is simply not a technology that is well suited for testing the extreme ends of the elemental spectrum. A third shortcoming of the technology is that pXRF is a mass analysis technique. This means that every component in the item being tested is included in the analysis and as such, the system cannot characterize small components of a larger item (Shackley 2011:10). Because of both the large size of the artifact collection and the wide range of artifact shapes present in it the size restraints of pXRF were not an issue for this research.

Additionally, because of the inquisitive nature of the primary research question posed here, neither the restricted elemental range of pXRF nor the inability to single out components were considered to be a hindrance to the use of pXRF technology.

The major problems associated with using pXRF as a chemical characterization tool were, therefore, not considered to be an issue for this research. The benefits of using pXRF technology, on the other hand, were considered to be much greater than the potential benefits associated with any of the other commonly used geochemical characterisation instruments and systems. As previously mentioned, a wide variety of other chemical composition techniques from geology and environmental science have made their way into archaeological research. In most of these, however, two major problems exist when related to archaeological materials. First is the amount of destruction and/or preparation that an artifact must undergo, and second is the time and the associated costs required to carry out the tests.

Portable XRF was selected because of its ability to satisfy both these constraints. Although there are challenges related to the use of pXRF (see Frahm 2013a, 2013b; Orfanou and Rehren 2014; Shackley 2011; Shugar 2014; and Speakman and Shackley 2013), it has been shown in other research (e.g. Burley et al. 2011; Grave et al. 2012; Nazaroff et al. 2010; Sheppard et al. 2011; Williams-Thorpe 2008) that pXRF can be used successfully on lithic materials without requiring any sample preparation other than simple washing. Although Frahm (2013b) has produced positive results using lithic materials with adhering sediment matrix, this work has caused some controversy (see above; Speakman and Shackley 2013).

Regarding the second issue, other techniques such as PIXE-PIGME and LA/ICPMS require a designated laboratory and trained staff. Both of these requirements can be costly and are difficult for most archaeologists to overcome. A pXRF instrument, although initially expensive to purchase, has no further costs associated with its use beyond general maintenance. In most cases, universities or large archaeological consulting firms can purchase the necessary instrument and make it available to those willing to take the time to learn how to use it. Usually, manufacturers of pXRF equipment

include some degree of training on the instrument as part of the purchase price, and the software and interfaces are now designed so that even someone with no prior experience in chemistry would be able to learn to use the instruments quickly and effectively.

The final issue to discuss is the time it takes to carry out a test. Systems such as PIXE-PIGME take up to 40 minutes to run a single test (Rainer Siegele, ANSTO, pers. comm. 2014). A pXRF instrument, on the other hand, can produce results that are both accurate and precise in as little as five seconds of live run time on certain types of materials (Thermo Fisher Scientific Inc. 2011). The tests undertaken for this thesis only required 180 live seconds of testing per artifact. This small amount of time required for testing allows a much greater number of items to be processed, which in turn provides a more robust number of samples on which to perform further analyses.

When all the above factors are taken into consideration, it becomes apparent that even with the few negative aspects of this instrument, the benefits offered by the pXRF system of analysis make it the most appropriate instrument for this form of analysis. It should be reiterated that although pXRF results may be slightly less accurate than those from other chemical analytical systems, these differences are not significant enough to warrant discontinuing the application of the instrument to archaeological research questions.

## The pXRF Equipment Used in This Research

The primary pXRF data used for this thesis was produced using a 2012 model Thermo Scientific Niton* XL3t GOLDD+ XRF Analyzer. This device is equipped with a thermoelectrically cooled miniature Au anode 6–50 kV, 0–200 uA (maximum) X-ray tube and kapton emission window to excite and measure existing elements of the periodic table from magnesium (Mg) through to uranium (U). Backscattered X-rays are sensed by a proprietary "Geometrically Optimized Large Area Drift Detector" (GOLDD) detector with 180,000 throughput counts per second (cps) and a resolution of <185 eV @ 60,000 cps @ 4μ sec shaping time and are corrected via Compton Normalization and translated

by a 533 MHz ARM 11 CPU and a 300 MHz dedicated math coprocessor into elemental composition and concentration (for further details on the instrument and its internal workings, refer to the Thermo Scientific Niton Web site, http://www.niton.com/en). The Thermo Scientific Niton* XL3t GOLDD+ XRF Analyzer is currently marketed as one of the most effective and reliable pXRF instruments on the market.

The range of pXRF instruments currently available is quite large and included instruments that have a wide range of features and functions. On one side of the spectrum, there are very simple units with minimal features and simple interfaces that test for only a few elements and are designed primarily for use in the metal recycling industry. On the other end, there are instruments that can test for a very wide range of elements, but are accompanied by complex user-driven interfaces in which almost all of the analytical settings must be selected and modified by the user. These units have been heavily marketed to universities because of their adaptability to different materials and research questions, however, they require a lot more chemistry background and often are accompanied by a very steep user learning curve. The Niton unit used here was selected as it is a unit that falls between these two extremes. It can test for a very wide range of elements with no additional pieces, or programs while still having a simple, user-friendly interface that does not require a significant understanding of the involved chemistry by the user. This Niton pXRF instrument was used in its 'out-of-the-box' configuration for the research presented here. This means that no additional user modifications were made to the analytical settings, data processing systems or data output from the instrument. There is ongoing debate concerning the use of pXRF instruments by individuals without significant chemistry back ground using pXRF instruments in their 'out-of-the-box' setting. The research conducted herein, and the conclusions presented provide support for the side of the debate in support of a wider use of pXRF and an acceptance of the use of manufacture provided analytical settings.

Finally, it bears mentioning that although the pXRF instrument used for this research was designed to be portable, it was not used in this manner. Because it was possible to bring the artifacts to the laboratory, the pXRF unit was used in its benchtop configuration instead of its portable one. This bench-top set up did not change the

workings of the pXRF unit in any way, but because the unit was stable and not being held by hand in the field it was possible to test the same location on the test specimen for the entire 180 seconds, providing the best possible reading results for each sample tested.

# Chapter 5: An Introduction to Chert and its Characterisation Using pXRF

This chapter introduces chert, the material undergoing chemical analysis for this research. The chapter examines chert as a raw material, including a chemical description of the stone, and an introduction to how it forms and where it is found. This chapter also provides a discussion of previous XRF analyses of chert in archaeological research.

## What is Chert?

As a geological term, 'chert' refers to a chemically precipitated microcrystalline sedimentary rock that is primarily made from the mineral quartz. Other terms such as flint, jasper, and chalcedony have also been used to refer to various forms of chert, usually based on the colour of the material or its depositional environment. Chert is formed by the precipitation of silica in solution through various geological matrices and its subsequent re-crystallization into rock (Ward and Smith 1974:282). Regardless of colour or origin, chert is almost entirely composed of microcrystalline or chalcedonic quartz, making them essentially monomineralic rocks (Frahm 2013a). Quartz is a mineral composed of silicon and oxygen ($SiO_2$). It follows, therefore, that for any given piece of chert the chemical content can be at least 90–95% pure silica (Ward and Smith 1974:282). The remaining elemental composition includes major, rare, and trace elements (Luedtke 1979:746), which can reflect minor constituents that have come from the surrounding geology as the chert was formed. These constituents can include, but are not limited to, volcanic detritus, terrigenous clasts, and hydrothermal precipitates (Eker et al. 2012:167). The formation process of chert results in the potential for a wide degree of chemical variability within an outcrop as well as between different outcrops. Unlike obsidian, which is the result of one homogenous flow of magma, the chemistry of chert deposits can be significantly affected by the regional geology of the location in which it formed.

Chert is found across the world in a variety of sedimentary deposits. It is most commonly found as nodules or as seams embedded in other sedimentary matrices such as limestone and chalk (Eker et al. 2012:167). Chert nodules typically vary greatly in size and shape, ranging from small pebbles to boulders. Chert can also be found as bedded seams ranging from quite thin (50 mm thick) and localised (Specht 2011:55) to 10 m thick, extensive deposits (Eker et al. 2012:17, Figure 5).
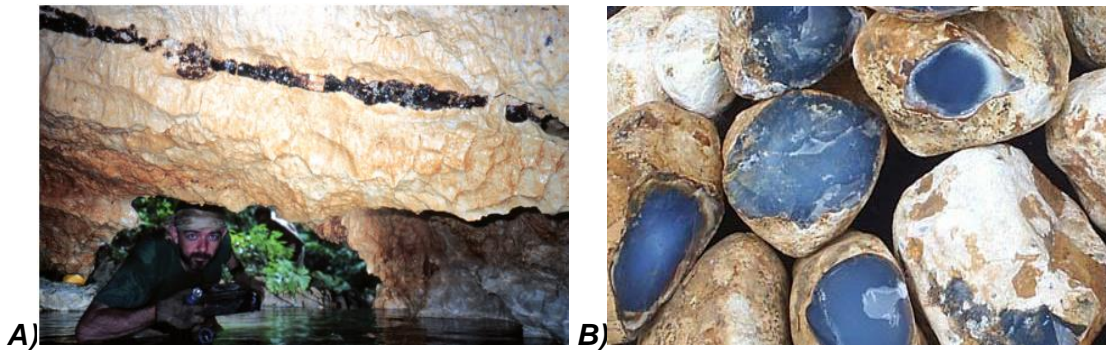


*Figure 5: A) Image of bedded chert formation reproduced from (Specht 2011), and B) Image of chert nodules (from http://paleoplanet69529.yuku.com/topic/54347).*

Due to its fine microscopic matrix, the un-weathered surface of a piece of chert usually appears to have a smooth vitreous texture. Observations about these unweathered surfaces, such as texture, colour, and lustre are often used to describe chert types (Browne and Wilson 2011:599) but can also be unreliable (Rafferty et al. 2007). Most chert nodules exhibit one of two forms of white rind on their surfaces — cortex or weathering patina. Cortex often appears porous, rough, and irregular, and is usually white or cream coloured. Cortex is the material that formed the original boundary between the chert and the surrounding chalk or limestone of the host rock (Graetsch and Grunberg 2012:22). Patina, on the other hand, is caused when weathering takes place on a cortex-free surface. This process can leach some silica from the stone and enlarge the porosity of the surface material. Subsequent refilling of these surface pores by silica-containing solution from the soil can create the white patina often seen on the surface of very old chert artifacts (Graetsch and Grunberg 2012:23).

Chert ranges extensively in colour, from black through to white, with varieties of browns, oranges, reds, and even bluish-greys (Luedtke 1992; Rafferty et al. 2007; Specht 2011). Chert from different geological formations and different geological areas can be visually identical. On the other hand, it has also been noted that there can be a wide range of physical properties (colour, lustre etc.) within a single chert formation (Eker et al. 2012:171). In general, chemical differences between chert outcrops are greater than the differences within outcrops (Luedtke 1978). It is clear, however, that "visual identification alone is inadequate for any rigorous study of chert material types and their correlations; clearly defined objective (qualitative and quantifiable) criteria must be found" (Malyk-Selivanova et al. 1998:676).

Archaeologically, chert has been used as a tool stone in many parts of the world and for hundreds of thousands of years. It is considered to be the most used mineral resource in prehistory (Malyk-Selivanova et al. 1998:676). As it forms from a precipitate, chert is a very fine-grained stone, and this means it can be broken in a predictable manner. It has been worked in many ways, from the simple production of informal and expediently-made cutting edges, right up to the production of formal, complex tools. Because of its chemical composition (predominantly quartz), chert is also very strong, and much less brittle than other tool stone materials, such as obsidian. These characteristics highlight why chert was so heavily used by stone-using cultures, but they are also relevant to why chert is so important to archaeological investigations. The fine-grained nature of chert with their primarily quartz matrix provides a material that is highly resistant to weathering (Eker et al. 2012:167; Olivares et al. 2009:492), meaning that chert artifacts often will appear in archaeological contexts as they appeared during their original manufacture and use. This observation is supported by Graetsch and Grunberg (2012:34) who indicate that "leaching of flint [chert] in the course of patination does not lead to alterations or structural defects in the microstructure of the flint". As minor weathering does not appear to have a significant effect on the chemical composition of chert artifacts (Evans et al. 2010:1162), it is not expected that weathering will adversely impact pXRF chemical characterisation analyses. It should be noted that even though the references presented here indicate that weathering should not affect the results of research such as those presented in this thesis, no artifacts with visible weathering were

included in this research, with every effort being made to avoid testing surfaces of artifacts exhibiting cortex. To avoid potential problems associated with chemical residues on the artifacts tested, each item was cleaned prior to testing (see Artifact Preparation, below).

A large portion of the artifacts in the assemblage that were selected for pXRF testing for this research display evidence of heating or burning. As discussed later in the thesis, the artifacts from Caution Bay were not heat-treated, but were, rather, disposed of in fires or burned naturally. Though the process of heat treatment and the effects of heat on the physical properties of chert have been well studied (e.g. Corkill 1997; Domanski et al. 1994; Domanski and Webb 1992; Flenniken and White 1983; Speer 2010), the possibility of chemical changes taking place in chert as a result of purposeful heat treatment or accidental burning has not been adequately addressed in the academic literature. It cannot be ruled out, therefore, that elemental changes related to thermal alteration may have occurred in artifacts that were included in this research. Though experiments to test this are beyond the scope of this thesis, the issue is addressed in Chapter 10.

## Analysing Chert with pXRF: A Brief History

In comparison to the use of pXRF or XRF with obsidian, very few archaeological studies have applied pXRF or XRF technology to chert materials. Presumably, this is due to the chemical and geological complexity of chert. Notable studies that have applied XRF or pXRF to chert include Benge (2016), Elvidge (2013), Gauthier et al. (2012), Olivares et al. (2009), Rafferty et al. (2007), Sutton et al. (2015), and Wurtzburg (1991) among others. Among the studies listed here, the authors have produced mixed results, some studies have produced data that successfully addressed the research questions, and others have had less success. A review of the successes, challenges, and shortcomings of each of these previously studies has been completed (Table 3) and some more notable examples of both the successful and the unsuccessful application of pXRF to chert are discussed here.

*Table 2: Summary data of pXRF applications to chert*

| Researcher | Equipment | Sample size | Elements range | Statistical Analysis Method | Outcome |
|---|---|---|---|---|---|
| Benge (2016) | Thermal Scientific Niton XRF model number XL3t900S | 63 geological samples | Mo, Zr, Sr, U, Rb, Th, Pb, Au, Se, As, Hg, Zn, Cu, Ni, Co, Fe, Mn, Cr, V, Ti, Sc, Ca, K, S, Ba, Sb, Sn, Cd, Cs, Te, Al, P, Si, Cl, Mg | MANOVA and Linear discriminant analysis | Successfully identified chemical differences between outcrops. |
| Elvidge (2013) | Bruker AXS Handheld Tracer III-V + Portable XRF Analyzer | 43 artifacts | Ca, Cu, K, Nb, Ni, Rb, Si, Sr, Ti, V, Y, Zn, Zr | Principle Component Analysis | Too much overlap in the chemical ranges to identify groups. |
| Gauthier et al. (2012) | PANalytical Epsilon 5 XRF analyzer | 43 artifacts | S, Cl, V, Cr, Co, Ni, Cu. Zn. As, Rb, Sr, Y, Zr, Nb, Cs, Ba, La, Ce, Pb, Th, U | Principle Component Analysis and normalized spider diagrams | Successfully identified chemically distinct groups |
| Olivares et al. (2009) | Röntec ArtTAX -ED-XRF | 7 items | Si, Fe, Ca, Ba, Sr, | Used as part of other techniques | XRF usual in combination with other techniques |
| Rafferty et al. (2007) | Custom built energy dispersive XRF | 65 artifacts and 24 debitage samples | Ti, Fe, Cu, Zn, Rb, Sr, Y, Zr, Sn, Ba | Principle Component Analysis | Close match between sources and tools |
| Sutton et al. (2015) | Bruker AXS Tracer III-V Portable Energy Dispersive XRF | 81 artifacts | Mn, Fe, Rb, Sr, Y, Zr, Na, Mg, Si, Al, K, P | Principle Component Analysis | Identified four Chemical Composition Reference Units (CCRUs) |
| Wurtzburg (1991) | Custom built XRF unit | 88 tests on less than 88 artifacts. | Not provided | Not provided | System not able to define chert groups. |

Wurtzburg (1991) conducted an initial XRF characterisation of chert focusing on an assemblage of chert artifacts from Sayil in the Yucatan Peninsula. Using a benchtop XRF instrument, a sample of chert artifacts was analysed with the hope of identifying chemical groupings that could be used to relate back to source areas. Analyses yielded homogenous chemical results that did not allow separation into different source groups. Wurtzburg (1991) put forward two possible explanations for this result. First, it was possible that this assemblage of chert had all come from the same location and

therefore the sample was chemically homogeneous. Second, the XRF instrument used was not refined enough to identify the potentially subtle differences in the chemical composition of these cherts.

The analysis of chert artifacts from northeastern North America by Gauthier et al. (2012) involved the use of a high-energy laboratory-based XRF instrument and focused on an assemblage of 38 geological samples and 42 archaeological artifacts. Information was collected based on whole rock chemistry, for which 31 elements were tested. After preliminary analysis of the bulk data, the elemental data was further broken down based on concentration yields. This process ensured that only those elements that provided the most valuable data were included in the analysis (six major and nine trace elements were used). Gauthier et al. (2012) were able to demonstrate that chert collected from different source locations did have chemical fingerprints that were discernible from one another using XRF. They were also able to demonstrate that archaeological samples, even ones with a small degree of weathering, can be chemically related to each other and to known sources using non-destructive XRF.

More recently, and relevant to the area of this research, Sutton et al. (2015) successfully conducted a pXRF analysis of 81 chert artifacts from Taurama on the southern coast of PNG. They were able to identify six chemically distinct groups of chert in their assemblage, which they refer to as Chemical Compositional Reference Units (CCRUs). The success of their research, with its relatively small sample size, provided valuable support for the feasibility of this research.

## Analysing Chert with pXRF: Potential Problems and Possible Solutions

The successful application of laboratory XRF equipment to chert conducted by Gauthier et al. (2012) and Sutton et al. (2015) provided a sound baseline upon which to model the research undertaken for this thesis. At the same time, the less successful experiment conducted by Wurtzburg (1991) provided a cautionary lesson. Due to the lack of previous research of this sort in the Caution Bay area and the limited research of

this sort on chert in general, it was not possible to be sure that the results of the pXRF analysis would produce data indicating a range of chemically distinct chert types, or data indicating that all artifacts were made from a chemically homogeneous material. The potential for the existence of different types of chert at Caution Bay was supported by both Sutton et al. (2015) using pXRF on chert artifacts from Taurama and Allen et al. (2011) using PIXE-PIGME analysis on chert artifacts from Oposisi further to the west along the coast on Yule Island. It was still important to consider, however, that the chemical groupings produced by these researchers might not be reflected in the data from Caution Bay. To address this issue, the primary means of ensuring that the pXRF analysis did not result in artificially homogeneous results were twofold: first, to gather information about as many elements as possible (Grave et al. 2012:1676), and second, to include as many specimens as possible. Following both of these procedures increased the statistical probability that if distinct chemical markers and distinct chemically similar groups of artifacts were present within the Caution Bay assemblage, they could and would be identified successfully.

Although, as previously noted, one portion of the potential solution to the problem of not having a known source group was to gather information about as many elements as possible, there are still some potential issues related to this approach. Unlike obsidian where the important trace elements for differentiating sources are within the high energy K region of the pXRF spectrum and readily measured, there is no preconceived idea of what elements should be examined for in this work, and therefore no limit was applied to the spectrum from which the pXRF unit records data. Because the pXRF unit was set up to collect data for as many elements as possible, the unit will take data from lower energy regions of the pXRF spectrum for some of the elements on the high and low range of its capabilities and this data has been known to be unsurprisingly slightly less accurate (Liritzis and Zacharias 2011, Orfanou and Rehren 2014 and Shugar 2013). Researchers concerned with getting the most accurate chemical data for sourcing or for building chemical descriptions, neither of which are pursued here, have typically addressed these measurement limitations and uncertainties associated with non-destructive pXRF by including one or multiple, independent validation techniques (e.g. Reepmeyer et al. 2010). By testing some of the samples on any of the conventional

multi-elemental destructive techniques (e.g. XRF, ICP-MS, or NAA) researchers can establish a baseline for elemental (or isotopic) range/concentrations and structure in a data set. Then, using the same sample set the results of non-destructive pXRF can be compared to establish how well the pXRF results can reproduce data structure. Although this may have proven valuable for the research presented in this thesis, it was not conducted for the simple reason that none of the artifacts being tested could be destroyed or altered. In order to address the issue of pXRF accuracy and to provide a means of making the data set collected for this research useable for further research, periodic testing was conducted on a range of Certified Standards Reference Materials (CSRMs), and these were used to provide a key for the transposing of data and to illustrate the degree of accuracy of the data provided. Descriptions of these CSRMs and the methods used to test them and analyze the results are presented in Chapter 9.

It bears repeating that this research is not attempting to determine the accuracy of the results of the pXRF unit used for this testing, nor is it attempting to acquire chemical characterization data that will be directly comparable to any existing chert research. This research is also not attempting to develop an exact chemical composition of the chert being tested. Questions such as those would be better addressed by geologists and chemists. This research is instead focused on using the data provided by the pXRF unit, as it comes, to explore questions about the use of chert material over time as illustrated by the archeological record. Because of this focus, the accuracy of the pXRF results for individual elements is of less importance than the constancy of the results. Although this statement and ones like it by other researchers is what has given rise to the ideas of Speakman and Shackley (2013) concerning the issues related to "silo science" in pXRF testing, great lengths have been taken here to ensure that other researches will be able to use this data by providing details of the CSRMs used and allowing for a mechanism to transpose this data to match data collected on other machines.

An additional source of potential problems present in the collection of artifacts used for this research is the effects of heat alteration on chert. As discussed in Chapter 7, Mialanes in his analyses of the lithic artifacts from the various Caution Bay sites

regularly notes that many of the chert artifacts bear the signs of some degree of heating, including discoloration and potlid scars. Mialanes (2016a-2016K) suggests that this heating was not the result of purposeful heat treatment of the items, but more likely a result of accidental burning or purposeful disposal of the artifacts into a hearth. Regardless of the cause, heat altered items were present in the collection of artifacts from Caution Bay, and due to their high number, it was decided that to have a large enough sample for each site the heat altered artifacts should be included in the testing with the less common, un-heat-treated artifacts.

Literature about the effects of the application of heat to chert is predominantly focused on the changes in the various flaking properties of chert (e.g. Borradaile et al. 1993; Corkill 1997; Domanski and Webb 1992; Domanski et al. 1994; Speer 2010). Although the question of how to identify heat treatment that is not readily visible on the surface of an artifact has been explored (e.g.: Borradaile et al. 1993; Robins, et al. 1981; Salomon et al. 2015; Schmidt et al. 2013; Schmidt et al. 2011), there is no research currently available that addresses the potential for changes in the over-all chemical composition of chert because of heat treating.

Some researchers have addressed the identification of heat treatment using chemistry, but not in a way that is comparable to the data produced by a pXRF unit. One example is the work of Schmidt et al. (2011; 2013) using infrared spectroscopic measurement of the strength of H-bonds formed between SiOH on the surface of the artifacts and H2O molecules held in open pores of the samples. In this research, the authors successfully determined if an artifact had been heated or not, and to what temperature it was heated even when no visual indicators of heat treatment are present. Another study that focused on the changes in chemistry associated with the heating of chert was conducted by Weiner et al. (2014). This research indicates that flint artifacts that have been heated have broader peaks on specific portions of the infrared spectrum than chert samples that have come directly from the same geological sources as the artifacts. Once again, the study indicates that there are changes occurring to the heat-treated chert that effect far more than the visual appearance and fracture predictability. Unfortunately, in both these cases, the type of chemical analysis that was conducted is

not something that can be assessed with the pXRF instrument being used in this research and is therefore not something that can be adequately addressed at this time.

Given the extremely limited data about the possible changes that heat might have to the chemical composition of chert artifacts, it was decided that heat impacted artifacts would not be excluded from this research. Therefore, all artifacts that fit this testing criterion, irrespective of whether they were heat impacted or not, were included in this research.

# Section 2: The Data Set, pXRF Methods, and Statistical Analysis

# Chapter 6: The Data Set

This chapter introduces the data set used for this research. As previously noted this thesis is focused entirely on expediently-made and used flaked chert artifacts. Artifacts discussed are either flakes, flake fragments, retouched flakes, flaked pieces, or cores.

Before introducing the data set from each of the sites included in this research, it is important to note that information about various materials recovered from some of these sites, as well as the details of some of the excavations, have not yet been published. For some sites, therefore, important data is either not available or is available only in draft form. A number of references to Mialanes work on the lithic materials from these sites are from drafts that have yet to be published.

As each site is presented below, the site description (the details of which have been obtained by lead members of the excavation team) is accompanied by a synopsis of associated lithic analyses carried out by Mialanes and where applicable references to published works.

## Excavation and Processing Methods Used During the Caution Bay Project

The archaeological materials used in this research came from large-scale excavations undertaken at Caution Bay in 2009 and 2010 (see David et al. 2011, 2012a, 2012b; Richards et al. 2016b; McNiven et al. 2012b, 2011). The excavation methodology described herein was used to recover all of the archaeological material included in this research and is documented in detail in David et al. (2016f). Figure 6 shows the location of excavated sites analysed in this thesis.
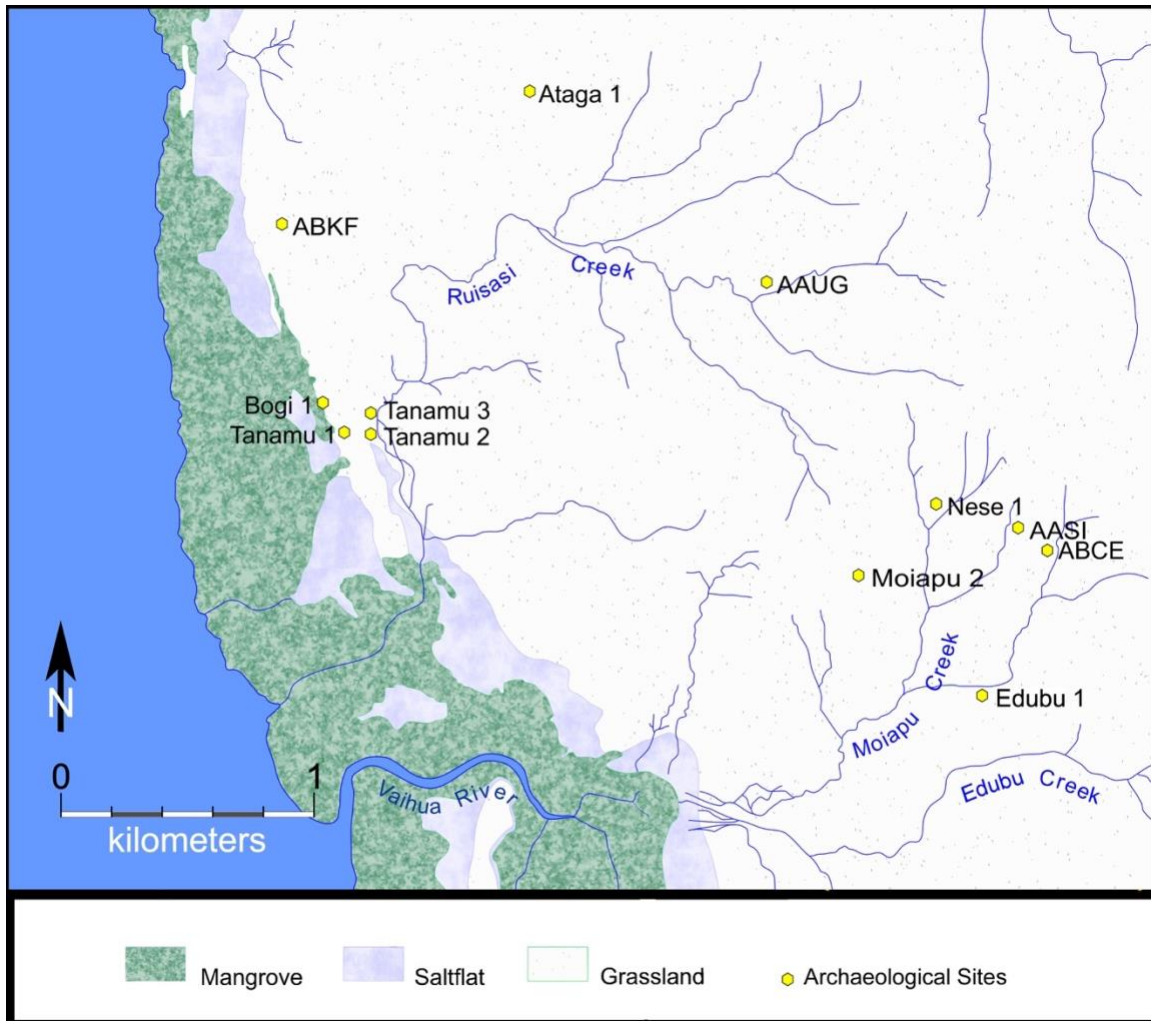
***Figure 6: Map of Caution Bay showing the location of archaeological sites
included in this research.***

Excavations were carried out in 1 m by 1 m units referred to as 'squares'. The number of squares excavated at each site was primarily based on the estimated surface area of that site, and typically ranged from one to six. Depending on the topography and visible surface deposits at each site, squares were excavated either contiguously, providing a larger continuous profile, or independently of each other, providing stratigraphic information for a larger area of a site (David et al. 2016f:146).

Each square was excavated in arbitrary excavation units (XUs) ranging from 2–5 cm depth following the stratigraphy. When sediment changes (such as features) were

encountered in an XU, it would be subdivided into sub-units with letter designations (David et al. 2016f:149). All excavated materials were placed into plastic bags and labelled with pertinent provenance information (David et al. 2016f:149). A small bulk sediment sample was also collected for each XU. All the excavated materials were processed in a specialised lab where they were wet sieved through 2.1 mm mesh (David et al. 2016f:153).

Excavation information such as sediment type, colour, texture, moisture, and archaeological content was recorded on custom XU forms. Photographs were taken at the end of each XU showing the base of the excavation as well as the profiles. At the end of each XU, the locations of rocks, features, and artifacts were all recorded in a sketch map. Artifacts of significant size such as large diagnostic ceramic sherds (e.g. rim sherds and sherds with decoration), worked shell and bone items, ground stone tools, and large pieces of flaked stone material were recorded in three dimensions and were bagged individually and assigned unique find numbers (David et al. 2016f:149-150).

A total of 122 sites were excavated (David et al. 2016f:146), and surface collections were gathered from a further 26 sites. A minimum of one square was hand excavated at each site, with up to six being excavated at others. Some of the deeper excavations (e.g. Bogi 1 and Tanamu 1) required the excavation of "stepping out squares" to provide safe access to the main hand excavations (David et al. 2016f:152). Stepping out squares were excavated using a different methodology and are not included in this discussion. In total, 211 squares (not including the stepping out squares) were excavated by hand over the course of the project (David et al. 2016f:146). These hand excavated squares ranged in depth from 21 cm below the surface at AK58 (Richards et al. 2011: Appendix C page 188) to 331 cm at Bogi 1 (McNiven et al. 2010b:10). These sites featured stratigraphy that ranged from varied to homogeneous.

## *Processing the Artifacts*

Following wet sieving and air-drying, excavated materials were sorted, and the various archaeological material (e.g. ceramics, lithics, charcoal, faunal remains) and natural materials (e.g. coral fragments, rocks and pebbles, roots and other vegetal

material, insects) were separated. Much of the material was sorted at the sorting laboratory on site in PNG. Remaining unsorted materials were processed in the Monash Indigenous Centre Archaeology Laboratory quarantine facility at Monash University's Clayton campus (David et al. 2016f:154).

A technological analysis of excavated lithic artifacts has been undertaken by Dr. Mialanes (David et al. 2016f:160-163) and his work is heavily referenced in this research. Faunal assemblages (e.g. bone and shell) were sent off to other institutions for specialist analyses (David et al. 2016f).


# Selection of Sites, Squares and Artifacts

As the goal of this research was to use the results of pXRF testing to examine the way chert was used and selected over the length of human occupation at Caution Bay it was important to select sites that would provide the most relevant data. To that end, limiting the analysis to sites with large quantities of chert artifacts that had been recovered from well-defined time periods would have been ideal. Unfortunately, this was not possible as limited analysis had been completed for most of the sites at the time this thesis commenced. As such site selection was based on the following criteria: depth and stratigraphic complexity (both associated with antiquity), geographic location, and the total number of squares excavated at a site. Details on each of these selection criteria are discussed below.

## *Depth*

The sites excavated ranged in maximum depth from 21 cm to 331 cm (McNiven et al. 2010b:10; Richards et al. 2011: Appendix C page 188). To obtain the broadest range of data, sites with the greatest excavated depth were assigned high research priority. Although published dates were available for some of the Caution Bay sites before this selection process, they were not available for all sites. Therefore, all sites with a depth greater than 70 cm were automatically considered for inclusion in the project given the potentially greater length of time these deposits might represent. The

few sites with depths less than 70 cm that were considered for inclusion were chosen based on the other factors discussed below.

### Stratigraphic Complexity

Sites with complex stratigraphy were, in most cases, ranked as more valuable for this research than those with simple stratigraphy. Many of the deeper sites and some of the shallower sites at Caution Bay had more than one stratigraphic unit. Sites with more than one stratigraphic unit were considered to have a higher potential for revealing chronological changes in raw material choice over time. Sites featuring a single stratigraphic unit were considered for inclusion in this research if they met the geographic location criteria and the criteria for the number of squares that are detailed below.

### Geographic Location

It was considered important that the sites selected provided coverage of the whole project area and also represented the various local environmental zones and associated sediment types. This geographical spread would pick up potential spatial variations in site usage patterns and chert use. Following this reasoning, in cases where a group of deep sites were all located very close together, only one was chosen to allow for the inclusion of what may have been a slightly less deep site in a different location and environment.

### Number of Squares Excavated

One important part of the methodology for pXRF testing used in this research was the need to wash artifacts prior to analysis. However, there was a concern that washing the artifacts would remove or alter potential future research, such as residue analysis. As such, only sites with more than one excavation square were included in this research. This criterion would allow artifacts from one square to be washed (for this research) and artifacts from remaining squares to be left unwashed for potential residue analyses etc.

# Sites Selected for Analysis

After careful consideration of the selection criteria, 12 sites were selected for analysis: Edubu 1, ABCE, Bogi 1, Ataga 1, AAUG, AASI, Tanamu 1, Tanamu 2, Tanamu 3, ABKF, AAWA, and Moiapu 2. Figure 6 presents the location of each of the sites included in this research. A description of the location, topography, and stratigraphy of each site is provided later in this chapter.

## *Selecting Squares*

In most cases, the square with the greatest number of lithics was selected for analysis. There were, however, a few exceptions. In a few cases, the chert material from one square, although less abundant, revealed greater colour diversity compared to other squares. In these cases, the square with the greatest diversity of material was selected. A greater diversity of colour was considered likely to maximise the potential for discerning the range of chert sources exploited and therefore be more valuable to this research.

## *Selecting Artifacts*

Artifacts were selected based on a number of physical characteristics. These characteristics were determined based on those used in similar published studies (Lundblad et al. 2008:7; Nazaroff et al. 2010:4-5) and on the requirements of the pXRF equipment used for this research. Each artifact had to have at least one surface that was relatively flat. This flat surface had to have dimensions of at least 12 mm by 6 mm, with a thickness greater than 2 mm (after Shackley 2011b:9). Although the length and width requirements listed herein are similar to those used in other studies, they were, in this case, influenced by the particular aperture size on the pXRF instrument employed. The length measurement had to be long enough to hold the artifact on the testing surface of the pXRF instrument without falling into the sensor, and the width measure had to be wide enough to provide a surface on which to test the artifact without allowing the X-rays to miss the target.

The artifacts that were included in this research were all flakes, fragments of flakes, flaked pieces, and cores. Although a few flakes displayed limited unifacial retouching, no formal flaked implement types were recovered from any of the sites excavated at Caution Bay. Information about the quantities of flaked artifacts recovered at each site is provided in the lithic analyses carried out by Mialanes (2016a-2016k).

As the sieving methods used for the Caution Bay Project (David et al. 2016f) included the use of screens with a mesh size of 2.1 mm, a large number of very small chert flakes, flake fragments, and flaked pieces (shatter) were present in many of the collections. Although some artifacts were not included in this research because they had surface inconsistencies (rough surface texture, inclusions or cortex present), or were not flat enough to facilitate accurate testing, these were uncommon. On average from the 12 sites included in this research, 77.5% of the total collection of chert artifacts were not suitable for pXRF testing largely due to morphological issues.

Due to the requirements of the pXRF instrument used in this research, it was not possible to analyse a random sample of chert artifacts from a site. To keep the collection of artifacts tested from each site as large as possible everything that met the requirements of the pXRF instrument was included. Although this methodology provided the largest collection of artifacts for testing, it does have some potential sample bias consequences for this analysis and the interpretation of the results. For example, it is possible that chert artifacts large enough to be tested with the pXRF instrument do not accurately reflect the total diversity of the chert material being used throughout the history of occupation in Caution Bay. For example, it is possible that the most preferred materials would be used and reduced to a relatively greater degree, resulting in a relatively higher proportion of small artifacts (especially scatter) compared to less popular and less reduced varieties of chert. The only way to test this hypothesis would have been to find a way to test the smaller fragments on the pXRF instrument, and that was not possible with the current instrument.

The range of colours present in the collection of chert artifacts analysed is addressed in Chapter 13. It should be noted that although black coloured chert was

present in some collections, it was generally not included in this research. Because of this resemblance to obsidian, most of the black chert fragments had been sent away for analysis elsewhere and were not available for while this research was being conducted. The few pieces of black chert that were still available were included here in the same fashion as all the other items.

## Sampling Bias

Using the methods that have been detailed here, a total of 2,454 artifacts from 12 sites was selected for analysis. In some cases, the collection of artifacts to undergo testing from a single site was very large (Bogi 1 with >900 samples) and in others, it was quite small. Seven sites have more than 130 sampled artifacts, and five sites have from 90-15 samples. This range of different quantities of artifacts from each site is affected by the site selection processes detailed herein. As previously discussed the technological analysis by Mialanes was not complete for all sites at the time that the pXRF testing was being conducted. This analysis, in some cases, the only metrics available were total artifact counts. The sites that were selected all met the requirements for testing, but in doing so ended up providing a wide variety of sample sizes. Most of the sites in Caution Bay were not as deep or as prolific at Bogi 1, however, the collection of artifacts from this site and the clear stratigraphy it presented made it an Integral part of this research. In the same way, some of the much smaller sites in Caution Bay that were shallower and produced fewer artifacts still had well-defined stratigraphy and were located at the geographical margins of the project area, thus providing invaluable data with which to explore the use of chert over time and across the Caution Bay landscape.

The decision to retain even the smallest sites in the analysis was made in an effort to provide the widest possible array of data from which to develop interpretations. One method of working with such diverse groupings is to change the counts of artifacts for those items being compared from actual counts to percentages. Percentages allow more uniformity for comparison but also have the potential to make data that is not similar appear so. In order to keep as much data from as many sites as possible,

percentages were considered a necessity for this work despite the issues. This analysis and discussion in Section 3 of this thesis was conducted with the understanding that the wide range in quantity of artifacts from each site could have unidentified consequences that may skew or cause biases in the discussion.

As well as the sampling biases that arise from the site selection methodology, there are also some challenges that need to be addressed in relation to the artifact selection process. Because the pXRF instrument had specific requirements for each artifact that was to undergo testing, it limited what artifacts from each site were, or were not, included in this research. As a result, only a specific, non-random, sample of artifacts from each site underwent testing. Because this sample was not random and was a result of the testing methodology, a number of potential biases were introduced to this research at this stage: 1) Is the sampled collection chemically representative of the whole? 2) Does it represent all the colours and textures of material present in the whole?, and 3) How might the reduction strategies used by the people who created these artifacts affect the size of flakes and debitage made from materials from different chert sources? None of these concerns are easy to address, and each may have significant impacts on the interpretations generated by this research. For example, it is possible that only a particular source material was regularly discarded in fragments large enough to meet the requirements of the pXRF instrument, and that other source materials were all worked until only very small un-testable fragments remained. These issues will be addressed in additional detail in Section 3 when the topics to which they are related are explored in detail.

## Overview and Description of Included Sites

### Edubu 1 — Square A

McNiven et al. (2012a) provide details on the excavation of Edubu 1. The site is located approximately 1 km inland from the southern end of Caution Bay and 20 km northwest of Port Moresby. It is located on a flat to gently sloping area of elevated ground 19 m above sea level (asl). The ground drops away to the northwest to an

ephemeral waterway known locally as Moiapu Creek. The site was identified by a surface scatter of ceramics, lithics, and marine shells. It is approximately 30 m in length and up to 20 m in width. Three squares (Squares A, B, and C) were excavated and ranged in depth from 67 cm to 90 cm. Stratigraphic units (SUs) refer to the individual sediment layers. The arbitrary Excavation units (XUs) were assigned to specific SUs in the lab after completion of excavation.

Four SUs were identified at Edubu 1, the upper three of which contained most of the cultural material. The three major concentrations of human activity at the site were SUs 1 (XU 1–16) and 2 (XU 16–23) in the top levels of the site and SU 3 (XU 27–32) in the lower levels of the site (McNiven et al. 2012a:124). Cultural materials included a wide variety of marine and terrestrial fauna, ceramics, lithics, and wood charcoal. AMS radiocarbon dates indicate that the earliest levels at the site date to 2600–2650 cal BP (McNiven et al. 2012a:124). The significant finds at Edubu 1 included the presence of terminal/transforming Lapita ceramics. The wide variety of both marine and terrestrial faunal material is also significant as it indicates generalised subsistence patterns. Square A was selected for this research.

A total of 2,983 stone artifacts from 40 XUs were recovered from Square A. Based on the criteria discussed above, 298 chert artifacts from 29 XUs were selected for pXRF analysis (Table 3). Mialanes' (2016a) analysis of the lithic material from the site indicates that eight types of raw material were present. The raw material was predominantly chert (97.8%), with much smaller portions of chalcedony (0.7%), obsidian (0.5%), and limited igneous materials. Stone artifacts were recovered from every XU and ranged from one (XU 34) to 201 (XU 2) artifacts per XU. Larger quantities of artifacts were present closer to the surface with nearly half of the stone artifact assemblage (49.2%) recovered from XU 2 to XU 6 (Mialanes 2016a:5). There was evidence for post-depositional heat alteration in the form of potlid scarring and reddish discoloration on 57.5% of the artifacts. Most of this heat alteration is limited to artifacts recovered from the first 11 XUs, however, heat-altered artifacts were present throughout the site (Mialanes 2016a:5). Based on observed surface characteristics, Mialanes (2016a:5) indicates that heat alteration was not purposefully carried out on cores in order to

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produce better flaking qualities, but rather, was more likely to have occurred either due to purposeful burning of the flakes themselves, through disposal into a fire pit, and/or accidental burning, as a by-product of controlled and/or wild fires in the landscape. Mialanes (2016a:23) concludes that the generally small size of flakes recovered from Edubu 1 indicates that in situ knapping was occurring. Based on the lack of cortex recovered from the site it is likely that the initial reduction stages took place elsewhere (Mialanes 2016a:24).

***Table 3: Lithic artifacts, temporal sequence and selections for pXRF testing from the Edubu 1 collection***

| Edubu 1, Square A, Stone Artifact Numbers | | | | | | | |
|---|---|---|---|---|---|---|---|
| XU | Chronological Period | Total Stone Artifacts | Not Chert | % Not Chert | Chert | % Chert | Chert Items Tested | % of Chert Items Tested |
| 1 | Upper Cultural concentration (ca. 2350 cal BP)(SU1, XU 1-16) | 92 | 0 | 0 | 92 | 100 | 17 | 18 |
| 2 | | 201 | 3 | 1 | 198 | 102 | 25 | 13 |
| 3 | | 175 | 8 | 5 | 167 | 105 | 27 | 16 |
| 4 | | 333 | 4 | 1 | 329 | 101 | 31 | 9 |
| 5 | | 253 | 5 | 2 | 248 | 102 | 19 | 8 |
| 6 | | 313 | 2 | 1 | 311 | 101 | 43 | 14 |
| 7 | | 70 | 1 | 1 | 69 | 101 | 11 | 16 |
| 8 | | 108 | 0 | 0 | 108 | 100 | 15 | 14 |
| 9 | | 167 | 5 | 3 | 162 | 103 | 19 | 12 |
| 10 | | 123 | 4 | 3 | 119 | 103 | 13 | 11 |
| 11 | | 125 | 6 | 5 | 119 | 105 | 11 | 9 |
| 12 | | 51 | 2 | 4 | 49 | 104 | 12 | 24 |
| 13 | | 59 | 0 | 0 | 59 | 100 | 3 | 5 |
| 14 | | 67 | 1 | 1 | 66 | 102 | 2 | 3 |
| 15 | | 53 | 1 | 2 | 52 | 102 | 9 | 17 |
| 16 | Middle Cultural concentration (ca. 2500 cal BP) (SU2, XU 16-23) | 27 | 0 | 0 | 27 | 100 | 4 | 15 |
| 17 | | 56 | 2 | 4 | 54 | 104 | 0 | 0 |
| 18 | | 85 | 2 | 2 | 83 | 102 | 5 | 6 |
| 19 | | 40 | 1 | 3 | 39 | 103 | 9 | 23 |
| 20 | | 25 | 2 | 8 | 23 | 109 | 8 | 35 |
| 21 | | 2 | 0 | 0 | 2 | 100 | 1 | 50 |
| 22 | | 21 | 0 | 0 | 21 | 100 | 2 | 10 |
| 23 | | 26 | 2 | 8 | 24 | 108 | 0 | 0 |
| 24 | | 14 | 0 | 0 | 14 | 100 | 2 | 14 |
| 25 | | 17 | 1 | 6 | 16 | 106 | 0 | 0 |
| 26 | | 10 | 0 | 0 | 10 | 100 | 1 | 10 |
| 27 | Lower Cultural concentration (ca. 2500-2750 cal BP) (SU3, XU 27-32) | 20 | 0 | 0 | 20 | 100 | 2 | 10 |
| 28 | | 18 | 0 | 0 | 18 | 100 | 3 | 17 |
| 29 | | 14 | 0 | 0 | 14 | 100 | 2 | 14 |
| 30 | | 10 | 0 | 0 | 10 | 100 | 0 | 0 |
| 31 | | 6 | 0 | 0 | 6 | 100 | 1 | 17 |
| 32 | | 11 | 0 | 0 | 11 | 100 | 1 | 9 |
| 34 | | 1 | 0 | 0 | 1 | 100 | 0 | 0 |
| **Totals** | | **2593** | **52** | **0** | **2541** | **0** | **298** | **12** |

### *ABCE — Square C*

The overview for this site has not yet been completed. The information about this site is limited to the lithic analysis carried out by Mialanes (2016 f), data relating to obsidian at the site in Mialanes et al. (2016a), and information in a personal email from Tom Richards. This site was originally identified as a surface scatter of ceramic and lithic artifacts in 2008 and was excavated in 2009 (Richards et al. 2016b:2). Site records indicate that nine squares (Squares A–I) were excavated to varying depths.

Four occupation levels were identified. The earliest occupation, Occupation 1, is dated to 2390–1910 cal BP and was identified in Squares A–H but was not present in Square I. Occupation 1 is associated with XUs 7–18 in Squares B and D and is present in all XUs of the other squares. Occupation 2 dates to 1600–1420 cal BP and is associated with XUs 1–5 in Square D. Cultural materials from this period are mixed with material from Occupation 1 due to an associated human burial. Occupation 3 is present only in Square B and is associated with XUs 1–9. No radiocarbon dates are available for this occupation phase; however, it is believed to date to sometime before 2390–2200 cal BP based on dates from overlying XUs. A final occupation (Occupation 4) is present only in Square I, and dates to 280–140 cal BP.

Square C was selected for this research project. All of the cultural material from Square C is dated to 2390–1910 cal BP and is associated with plain ware ceramics associated with the Post-Lapita Transformative Tradition (c. 2600–2150 cal BP) and with shell-impressed Wares associated with the Linear Shell Edge-Impressed Tradition (c. 2150–2100 cal BP) and the Umbo-Bordered Shell Back Impressed Tradition (c. 2100–1650 cal BP, Mialanes et al. 2016a:252). This square contained 1,078 stone artifacts (Mialanes et al. 2016a:253) from 18 XUs (Mialanes 2016b:1) of which 169 artifacts from 15 XUs were selected for pXRF analysis (Table 4). This table also includes available temporal data. Seven types of raw material were present at the site. Artifacts were predominantly chert (94.3%), followed by obsidian (4.7%, Mialanes et al. 2016a:253) and chalcedony (0.7%; Mialanes 2016b:2). Stone artifacts were recovered from every XU, but increased in quantity towards the surface of the site with the greatest amount of lithic material present in XUs 3 and 4. The artifacts that were not included in this analysis

either did not meet the testing criteria, or were not readily identified as chert. Almost half of the chert artifacts were heat altered. Mialanes (2016b:3) suggests that the fire alteration was not related to purposeful heat treatment of cores, but more likely was due to either purposeful burning of the flakes themselves, as a result of disposal into fire pits, and/or accidental burning, as a by-product of controlled/wild fires in the landscape. Mialanes (2016b:13) concludes that both the number of artifacts and the generally small size of flakes indicates limited lithic manufacturing activities at the site such as retooling/resharpening activities.

***Table 4: Lithic artifacts, temporal sequence and selections for pXRF testing from the ABCE collection.***

| ABCE, Square C, Stone Artifact Numbers | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| XU | Chronological Period | Total Stone Artifacts | Not Chert | % Not Chert | Chert | % Chert | Chert Items Tested | % of Chert Items Tested |
| 1 | Occupation 1, c. 2390-1910 call BP, XU 1-18 | 136 | 5 | 4 | 131 | 96 | 14 | 11 |
| 2 | | 100 | 3 | 3 | 97 | 97 | 18 | 19 |
| 3 | | 127 | 9 | 7 | 118 | 93 | 24 | 20 |
| 4 | | 201 | 7 | 3 | 194 | 97 | 27 | 14 |
| 5 | | 112 | 6 | 5 | 106 | 95 | 16 | 15 |
| 6 | | 148 | 10 | 7 | 138 | 93 | 17 | 12 |
| 7 | | 74 | 9 | 12 | 65 | 88 | 15 | 23 |
| 8 | | 51 | 4 | 8 | 47 | 92 | 13 | 28 |
| 9 | Jerome's lithic break point (no date available) | 41 | 4 | 10 | 37 | 90 | 5 | 14 |
| 10 | | 19 | 0 | 0 | 19 | 100 | 3 | 16 |
| 11 | | 22 | 0 | 0 | 22 | 100 | 6 | 27 |
| 12 | | 13 | 0 | 0 | 13 | 100 | 1 | 8 |
| 13 | | 11 | 3 | 27 | 8 | 73 | 1 | 13 |
| 14 | | 18 | 2 | 11 | 16 | 89 | 1 | 6 |
| 15 | | 1 | 0 | 0 | 1 | 100 | 0 | 0 |
| 16 | | 1 | 0 | 0 | 1 | 100 | 0 | 0 |
| 18 | | 3 | 0 | 0 | 3 | 100 | 1 | 33 |
| Totals | | 1078 | 62 | | 1016 | | 162 | 16 |

## Bogi 1 — Square C

McNiven et al. (2011) provide details on the excavation of Bogi 1. It is located approximately 20 km northwest of Port Moresby and midway along a 2 km-long dune complex that parallels the shoreline (McNiven et al. 2010b:1). Bogi 1 is located 45 m east and 4 m above the current high tide mark (David et al. 2012b:75). The site was identified on the basis of a surface scatter of lithic and ceramic material. Two squares (Squares C and D) were excavated systematically to a depth of 3.5 m. Radiocarbon

dates indicate occupation from 4550 cal BP to 1450 cal BP. A total of 10 SUs were identified. Artifacts were found in most XUs, with three major concentrations that represent occupation episodes and referred to as 'phases'. Phase I is a pre-ceramic occupation that occurred between 3900 and >4500 cal BP (McNiven et al. 2011:4; Mialanes 2016c:13) and corresponds to the upper portion of SU 8 (XUs 79–149; Mialanes 2016c: Table X.22). Phase II covers the Lapita occupation at Bogi 1 dating to 2600–2900 cal BP (McNiven et al. 2012b:21; Mialanes 2016c:13) and corresponds to SU 7a and b, including XUs 48-69 (Mialanes 2016c: Table X.22). The most recent occupation of the site is Phase III, a post-Lapita occupation that spans the period 2000–2200 cal BP (McNiven et al. 2012b:21; Mialanes 2016c:13) and is present in SU 5–6 (XUs 5–35a; Mialanes 2016c:Table X.22).

Among the many significant results of the excavation of Bogi 1 is the age of the site. The dates from this site indicate human occupation as early as 4550 cal BP, which represents some of the earliest known evidence of human settlement on the southern coast of PNG (McNiven et al. 2011:2). Other significant finds associated with Bogi 1 include ceramic material dating back to 2900 cal BP (the earliest presence of pottery at the site), the earliest comb dentate-stamped Lapita pottery on mainland PNG, a variety of ground shell and stone tools, and the first complete human burial recovered from beneath Lapita levels in the Pacific (McNiven et al. 2011:4).

Square C was selected for pXRF analysis. A total of 5,969 stone artifacts from 144 XUs was recovered from Square C (Mialanes 2016a:13). Of these, 935 artifacts from 77 XUs were selected for analysis (Table 5). Mialanes' (2016c) lithic analysis identified six types of raw material, predominantly chert (90.6%) followed by obsidian (9.1%) and chalcedony (0.2%). Stone artifacts were recovered from most XUs and increased in quantity towards the surface. The greatest amount of lithic material was discarded between 2000 and 2200 cal BP with the largest assemblage of artifacts present in XU 7 (Mialanes 2016c:13). Mialanes' (2016c) analysis focused on the three phases of occupation. The majority of chert artifacts at Bogi 1 were small complete flakes, broken flakes, and flaked pieces.

Mialanes (2016a:14) concludes that the large number of artifacts and the generally small size of flakes indicate lithic manufacturing activities at this site. Due to much lower occurrences of chert artifacts in Phases I and II compared to Phase III, Mialanes (2016a:14) suggests that different activities were performed with regards to chert reduction at the site through time. Though there is evidence for heat-alteration of flakes, Mialanes (2016b:15) again associates heat alteration with disposal into fire pits, or accidental burning as a by-product of controlled/wild fires in the landscape and not the purposeful treatment of cores to produce better flaking qualities. There is a limited amount of cortex in the Bogi 1 lithic assemblage which Mialanes (2016c:16) associates with partial decortication prior to bringing cores to the site. Of interest to this research, Mialanes (2016c:Figure X.12) notes that, from 4550–2900 cal BP, chert assigned to colours #10 (5YR 5/4), #16 (N3), and #22 (N1) are common (representing nearly 40% of the assemblage) but that these colours decrease significantly (down to only 10%) after this. No potential explanations for this trend are provided, but Mialanes notes that this would be worth examining in more detail. This trend will be addressed from a chemical analysis standpoint in Chapter 10.

**Table 5: Lithic artifacts, temporal sequence and selections for pXRF testing from the Bogi 1 collection.**

| Bogi 1, Square C, Stone Artifact Numbers | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| XU | Chronological Period | Total Stone Artifacts | Not Chert | % Not Chert | Chert | % Chert | Chert Items Tested | % of Chert Items Tested |
| 1 | | 21 | 6 | 29 | 15 | 71 | 2 | 13 |
| 2 | | 217 | 32 | 15 | 185 | 85 | 23 | 12 |
| 3 | | 295 | 30 | 10 | 265 | 90 | 50 | 19 |
| 4 | | 316 | 41 | 13 | 275 | 87 | 67 | 24 |
| 5 | Phase 3- | 372 | 51 | 14 | 321 | 86 | 65 | 20 |
| 6 | c.2000-2150 | 457 | 71 | 16 | 386 | 84 | 45 | 12 |
| 7 | cal BP, XUs 5- | 480 | 54 | 11 | 426 | 89 | 63 | 15 |
| 8 | 35a | 314 | 53 | 17 | 261 | 83 | 41 | 16 |
| 9 | | 34 | 0 | 0 | 34 | 100 | 5 | 15 |
| 10 | | n/a | n/a | n/a | n/a | n/a | 21 | n/a |
| 11 | | 247 | 29 | 12 | 218 | 88 | 35 | 16 |
| 12 | | 320 | 25 | 8 | 295 | 92 | 32 | 11 |
| 13 | | 238 | 15 | 6 | 223 | 94 | 37 | 17 |
| 14 | | 249 | 18 | 7 | 231 | 93 | 54 | 23 |
| 15 | | 314 | 27 | 9 | 287 | 91 | 58 | 20 |
| 16 | | 310 | 19 | 6 | 291 | 94 | 43 | 15 |
| 17 | | 266 | 25 | 9 | 241 | 91 | 44 | 18 |
| 18 | | 117 | 5 | 4 | 112 | 96 | 22 | 20 |

| | | Bogi 1, Square C, Stone Artifact Numbers | | | | | | |
|---|---|---|---|---|---|---|---|---|
| XU | Chronological Period | Total Stone Artifacts | Not Chert | % Not Chert | Chert | % Chert | Chert Items Tested | % of Chert Items Tested |
| 19 | | 95 | 7 | 7 | 88 | 93 | 10 | 11 |
| 20 | | 111 | 7 | 6 | 104 | 94 | 13 | 13 |
| 21 | | 85 | 4 | 5 | 81 | 95 | 20 | 25 |
| 22 | | 67 | 5 | 7 | 62 | 93 | 8 | 13 |
| 23 | | 52 | 1 | 2 | 51 | 98 | 13 | 25 |
| 24 | | 48 | 4 | 8 | 44 | 92 | 9 | 20 |
| 25 | | 29 | 2 | 7 | 27 | 93 | 9 | 33 |
| 26 | | 50 | 1 | 2 | 49 | 98 | 11 | 22 |
| 27 | | 46 | 2 | 4 | 44 | 96 | 5 | 11 |
| 28 | | 38 | 1 | 3 | 37 | 97 | 7 | 19 |
| 29 | | 61 | 6 | 10 | 55 | 90 | 12 | 22 |
| 30 | | 32 | 3 | 9 | 29 | 91 | 6 | 21 |
| 31 | | 7 | 1 | 14 | 6 | 86 | 3 | 50 |
| 32 | | 43 | 3 | 7 | 40 | 93 | 4 | 10 |
| 33 | | 23 | 2 | 9 | 21 | 91 | 2 | 10 |
| 34 | | 20 | 0 | 0 | 20 | 100 | 5 | 25 |
| 35 | | 10 | 1 | 10 | 9 | 90 | 4 | 44 |
| 36 | | 18 | 2 | 11 | 16 | 89 | 2 | 13 |
| 37 | | 20 | 1 | 5 | 19 | 95 | 3 | 16 |
| 38 | | 17 | 0 | 0 | 17 | 100 | 0 | 0 |
| 39 | | 10 | 1 | 10 | 9 | 90 | 1 | 11 |
| 40 | | 12 | 0 | 0 | 12 | 100 | 0 | 0 |
| 41 | | 13 | 0 | 0 | 13 | 100 | 0 | 0 |
| 42 | | 19 | 0 | 0 | 19 | 100 | 1 | 5 |
| 43 | | 13 | 0 | 0 | 13 | 100 | 1 | 8 |
| 44 | | 3 | 0 | 0 | 3 | 100 | 0 | 0 |
| 45 | | 10 | 0 | 0 | 10 | 100 | 1 | 10 |
| 46 | | 6 | 0 | 0 | 6 | 100 | 0 | 0 |
| 47 | | 10 | 0 | 0 | 10 | 100 | 1 | 10 |
| 48 | Phase 2-c.2600-2900 cal BP, XUs 48-69 | 20 | 0 | 0 | 20 | 100 | 2 | 10 |
| 50 | | 8 | 0 | 0 | 8 | 100 | 0 | 0 |
| 51 | | 11 | 0 | 0 | 11 | 100 | 0 | 0 |
| 52 | | 4 | 0 | 0 | 4 | 100 | 2 | 50 |
| 53 | | 9 | 1 | 11 | 8 | 89 | 3 | 38 |
| 54 | | 6 | 0 | 0 | 6 | 100 | 0 | 0 |
| 55 | | 14 | 0 | 0 | 14 | 100 | 1 | 7 |
| 56 | | 4 | 0 | 0 | 4 | 100 | 0 | 0 |
| 57 | | 7 | 0 | 0 | 7 | 100 | 0 | 0 |
| 58 | | 11 | 0 | 0 | 11 | 100 | 0 | 0 |
| 59 | | 16 | 0 | 0 | 16 | 100 | 4 | 25 |
| 60 | | 12 | 0 | 0 | 12 | 100 | 0 | 0 |
| 61 | | 13 | 0 | 0 | 13 | 100 | 2 | 15 |
| 62 | | 11 | 2 | 18 | 9 | 82 | 1 | 11 |
| 63 | | 7 | 0 | 0 | 7 | 100 | 2 | 29 |
| 64 | | 15 | 1 | 7 | 14 | 93 | 1 | 7 |
| 65 | | 21 | 0 | 0 | 21 | 100 | 2 | 10 |
| 66 | | 12 | 0 | 0 | 12 | 100 | 1 | 8 |
| 67 | | 13 | 0 | 0 | 13 | 100 | 1 | 8 |
| 68 | | 4 | 0 | 0 | 4 | 100 | 0 | 0 |
| 69 | | 18 | 0 | 0 | 18 | 100 | 2 | 11 |
| 70 | | 16 | 0 | 0 | 16 | 100 | 3 | 19 |
| 71 | | 7 | 0 | 0 | 7 | 100 | 0 | 0 |

| Bogi 1, Square C, Stone Artifact Numbers | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| XU | Chronological Period | Total Stone Artifacts | Not Chert | % Not Chert | Chert | % Chert | Chert Items Tested | % of Chert Items Tested |
| 72 | | 4 | 0 | 0 | 4 | 100 | 0 | 0 |
| 73 | | 9 | 0 | 0 | 9 | 100 | 0 | 0 |
| 74 | | 5 | 0 | 0 | 5 | 100 | 0 | 0 |
| 75 | | 4 | 0 | 0 | 4 | 100 | 3 | 75 |
| 76 | | 6 | 0 | 0 | 6 | 100 | 1 | 17 |
| 77 | | 5 | 0 | 0 | 5 | 100 | 0 | 0 |
| 78 | | 4 | 0 | 0 | 4 | 100 | 1 | 25 |
| 79 | Phase 1-c. >3000-4200 cal BP, XUs 79-149 | 6 | 0 | 0 | 6 | 100 | 1 | 17 |
| 80 | | 7 | 0 | 0 | 7 | 100 | 1 | 14 |
| 81 | | 10 | 0 | 0 | 10 | 100 | 1 | 10 |
| 82 | | 5 | 1 | 20 | 4 | 80 | 0 | 0 |
| 83 | | 1 | 0 | 0 | 1 | 100 | 0 | 0 |
| 84 | | 11 | 1 | 9 | 10 | 91 | 1 | 10 |
| 85 | | 1 | 0 | 0 | 1 | 100 | 0 | 0 |
| 86 | | 2 | 0 | 0 | 2 | 100 | 0 | 0 |
| 87 | | 8 | 2 | 25 | 6 | 75 | 0 | 0 |
| 88 | | 1 | 0 | 0 | 1 | 100 | 1 | 100 |
| 89 | | 3 | 0 | 0 | 3 | 100 | 0 | 0 |
| 90 | | 2 | 0 | 0 | 2 | 100 | 0 | 0 |
| 91 | | 7 | 1 | 14 | 6 | 86 | 3 | 50 |
| 92 | | 4 | 0 | 0 | 4 | 100 | 0 | 0 |
| 93 | | 3 | 0 | 0 | 3 | 100 | 1 | 33 |
| 94 | | 1 | 0 | 0 | 1 | 100 | 0 | 0 |
| 96 | | 2 | 0 | 0 | 2 | 100 | 1 | 50 |
| 97 | | 1 | 0 | 0 | 1 | 100 | 1 | 100 |
| 98 | | 4 | 0 | 0 | 4 | 100 | 1 | 25 |
| 99 | | 6 | 0 | 0 | 6 | 100 | 0 | 0 |
| 100 | | 4 | 0 | 0 | 4 | 100 | 1 | 25 |
| 101 | | 3 | 0 | 0 | 3 | 100 | 1 | 33 |
| 102 | | 4 | 0 | 0 | 4 | 100 | 1 | 25 |
| 103 | | 4 | 0 | 0 | 4 | 100 | 0 | 0 |
| 104 | | 3 | 0 | 0 | 3 | 100 | 0 | 0 |
| 108 | | 1 | 0 | 0 | 1 | 100 | 1 | 100 |
| 109 | | 4 | 0 | 0 | 4 | 100 | 0 | 0 |
| 111 | | 1 | 0 | 0 | 1 | 100 | 0 | 0 |
| 112 | | 1 | 0 | 0 | 1 | 100 | 0 | 0 |
| 113 | | 2 | 0 | 0 | 2 | 100 | 0 | 0 |
| 114 | | 2 | 1 | 50 | 1 | 50 | 0 | 0 |
| 122 | | 1 | 0 | 0 | 1 | 100 | 1 | 100 |
| 129 | | 1 | 0 | 0 | 1 | 100 | 0 | 0 |
| 138 | | 3 | 0 | 0 | 3 | 100 | 0 | 0 |
| 140 | | 1 | 0 | 0 | 1 | 100 | 0 | 0 |
| 141 | | 5 | 0 | 0 | 5 | 100 | 1 | 20 |
| 143 | | 4 | 0 | 0 | 4 | 100 | 0 | 0 |
| 144 | | 2 | 0 | 0 | 2 | 100 | 1 | 50 |
| 145 | | 3 | 0 | 0 | 3 | 100 | 0 | 0 |
| 146 | | 3 | 0 | 0 | 3 | 100 | 0 | 0 |
| 147 | | 3 | 0 | 0 | 3 | 100 | 0 | 0 |
| Totals | | 5971 | 565 | | 5406 | | 909 | 17 |

### *Ataga 1 — Square A*

A site overview for Ataga 1 is not yet available, the information is limited to the lithic analysis carried out by Mialanes (2016f). This site was identified by a surface scatter of ceramic and lithic artifacts in 2008 and was excavated in 2009 (Richards et al. 2016b:2). Site records indicate that two squares (Squares A and B) were excavated to varying depths. Radiocarbon dates for the two squares indicate occupation during the transition associated with the end of the Lapita period at Caution Bay (Mialanes 2016f:1). Radiocarbon dates from Square B reveal that occupation began 2771–2711 cal BP and ended 2699–2566 cal BP. Occupation of Square A, on the other hand, started at 2648–2540 cal BP and ended at 2558–2448 cal BP. The largest quantities of cultural material were present in both squares in XUs 1–18, with peaks for various materials, present between XUs 4 and 14. Artifacts recovered from below XU 18 are not *in situ*, due to taphonomic processes, and do not represent earlier occupation at the site (Mialanes 2016f:1).

Square A was selected for this project. A total of 1,002 artifacts from 40 XUs was recovered from Square A (Mialanes 2016f:1). Of these, 202 artifacts from 23 XUs were selected for pXRF analysis (Table 6). Mialanes (2016f:2) identifies four types of raw material, predominantly chert (98.1%) followed by basalt (1.5%), chalcedony (0.2%), and obsidian (0.2%). Stone artifacts were recovered from all XUs down to XU 20 and then sporadically to XU 26. The quantity of stone artifacts increased towards the surface of the site, with highest densities recorded in XU 11. The majority of chert artifacts were broken flakes, with significantly fewer complete flakes and flake pieces. Cores were rare in relation to the high number of flakes and Mialanes (2016f:5) suggests a variety of possible explanations for this pattern, including core discard off-site. The high numbers and generally small size of flakes and flake pieces indicated secondary lithic manufacturing activities at the site. A lack of cortical material and limited primary reduction flakes suggests off-site preparation of cores (Mialanes 2016f:12). Heat-altered flakes were present, and Mialanes (2016f:4) suggests that this may have contributed to the small and fragmented nature of this lithic assemblage. Mialanes (2016f:3) indicates that the heat alteration is not related to purposeful heat treatment because none of the

flakes with evidence of heating have any further modifications and because potlid scars are present on the ventral surfaces of some flakes. Mialanes (2016f) suggests that the heat alteration is evidence of purposeful burning of the flakes themselves, as a result of disposal into fire pits, and accidental burning as a by-product of landscape fires.

**Table 6: Lithic artifacts, temporal sequence and selections for pXRF testing from the Ataga 1 collection.**

| | | Ataga 1, Square A, Stone Artifact Numbers | | | | | | |
|---|---|---|---|---|---|---|---|---|
| XU | Chronological Period | Total Stone Artifacts | Not Chert | % Not Chert | Chert | % Chert | Chert Items Tested | % of Chert Items Tested |
| 1 | Major cultural level, 2648-2540 cal BP to 2558-2448 cal BP, XU 1-18. | n/a | n/a | n/a | n/a | n/a | 10 | n/a |
| 2 | | 110 | 0 | 0 | 110 | 100 | 19 | 17 |
| 3 | | 68 | 3 | 4 | 65 | 96 | 13 | 20 |
| 4 | | 47 | 1 | 2 | 46 | 98 | 14 | 30 |
| 5 | | 53 | 1 | 2 | 52 | 98 | 7 | 13 |
| 6 | | 57 | 0 | 0 | 57 | 100 | 16 | 28 |
| 7 | | 66 | 0 | 0 | 66 | 100 | 8 | 12 |
| 8 | | 63 | 0 | 0 | 63 | 100 | 6 | 10 |
| 9 | | 34 | 0 | 0 | 34 | 100 | 15 | 44 |
| 10 | | 141 | 4 | 3 | 137 | 97 | 17 | 12 |
| 11 | | 86 | 3 | 3 | 83 | 97 | 18 | 22 |
| 12 | | 53 | 1 | 2 | 52 | 98 | 10 | 19 |
| 13 | | 82 | 0 | 0 | 82 | 100 | 4 | 5 |
| 14 | | 33 | 3 | 9 | 30 | 91 | 7 | 23 |
| 15 | | 10 | 2 | 20 | 8 | 80 | 2 | 25 |
| 16 | | 51 | 0 | 0 | 51 | 100 | 6 | 12 |
| 17 | | 16 | 0 | 0 | 16 | 100 | 3 | 19 |
| 18 | | 4 | 0 | 0 | 4 | 100 | 1 | 25 |
| 19 | | 5 | 0 | 0 | 5 | 100 | 1 | 20 |
| 20 | | 7 | 0 | 0 | 7 | 100 | 2 | 29 |
| 22 | | 4 | 0 | 0 | 4 | 100 | 1 | 25 |
| 23 | | 4 | 0 | 0 | 4 | 100 | 1 | 25 |
| 24 | | 3 | 0 | 0 | 3 | 100 | 1 | 33 |
| 25 | | 3 | 0 | 0 | 3 | 100 | 0 | 0 |
| **Totals** | | **1000** | **18** | | **982** | | **182** | **19** |

## AAUG — Square D

Richards et al. (2016c) provide details of the excavation of AAUG in 2009. The site is located 26.5 m asl on a low rocky outcrop rising above the surrounding undulating open plain. Ruisasi Creek is located 190 m to the south-southwest, and an unnamed tributary creek is located 160 m to the north-northwest. The site was identified by a large (73 m x 75 m), low-density surface scatter of ceramics, shells, and lithic artifacts (including ground stone adze/axe blades; David et al. 2016f). A total of five squares

located approximately 10–15 m apart were excavated across the site, to a maximum depth of 49.1 cm in Square A. Analysis of squares from this site is ongoing, so the discussion that follows focuses primarily on Square A. A total of four SUs were identified in Square A.

SU 4 corresponds to XUs 14–22 and indicates a minor early occupation dated (in Squares C and D) to 2400–2600 cal BP (Richards et al. 2016c:4). Radiocarbon dates indicate that the dominant phase of occupation occurred during SUs 2 and 3 that date to 2331–1916 cal BP. SU 3 corresponds to XU 10–18. SU 2 corresponds to XU 6–13. These two SUs contained the largest collection of cultural material (Richards et al. 2016c:2). SU 1 corresponds to XUs 1–9 and represents a minor occupation that occurred between 1270 and 1488 cal BP.

Square D was selected to be used in this research. It contains a total of 1,662 stone artifacts from 18 XUs (Mialanes 2016g:19), of which 269 from 14 XUs were selected for pXRF analysis (Table 7). The number of lithic artifacts varied greatly between the five squares, with the most significant number of artifacts recovered from Squares A and D (Mialanes 2016g). The most common raw material present was chert, with obsidian and other materials present in much smaller quantities. Five types of lithic material were recovered from Square D (Mialanes 2016g:19), including chert (95.3%), limited amounts of obsidian (4.5%), igneous materials (0.1%), chalcedony (<0.1%), and quartz (<0.1%). Stone artifacts were recovered from almost all XUs of Square D with approximately 68% of the lithic material found between XUs 5 and 10 and associated with the first major occupation period at the site (Mialanes 2016g:19). The chert artifact assemblage from Square D is heavily fragmented, and the predominant artifact types were broken flakes (71.5%) and flaked pieces (18.8%) with significantly fewer complete flakes (Mialanes 2016g:19). Cores were rare in relation to the high number of flakes and were generally small, averaging 20 g in weight with a mean length of 40.5 mm. Mialanes (2016g:29) concludes that the number and classes of artifacts combined with the generally small size of flakes indicate secondary lithic manufacturing activities at the site. An almost complete lack of cortex and large primary reduction flakes in this assemblage points to the off-site preparation of cores. Retouching is rare suggesting that unmodified

flakes were the predominant tool type used at AAUG (Mialanes 2016g:30). Heat-altered flakes were present, and it is suggested that heat alteration may have contributed to the very small and fragmented nature of the lithic assemblage (Mialanes 2016g:28). Mialanes (2016g:29) indicates that the heat alteration is not likely related to purposeful heat treatment as none of the flakes showing evidence of burning have any further modifications. This pattern is supported by the presence of potlid scarring on the ventral side of many flakes, which indicates heat alteration after flake production. Mialanes (2016g:29) suggests that heat alteration was instead evidence of purposeful burning of the flakes themselves and accidental burning as a by-product of landscape fires.

**Table 7: Lithic artifacts, temporal sequence and selections for pXRF testing from the AAUG collection.**

| AAUG, Square D, Stone Artifact Numbers | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| XU | Chronological Period | Total Stone Artifacts | Not Chert | % Not Chert | Chert | % Chert | Chert Items Tested | % of Chert Items Tested |
| 1 | | 5 | 0 | 0 | 5 | 100 | 5 | 100 |
| 2 | | 2 | 0 | 0 | 2 | 100 | 5 | 250 |
| 3 | | 97 | 3 | 3 | 94 | 97 | 15 | 16 |
| 4 | | 51 | 2 | 4 | 29 | 57 | 6 | 21 |
| 5 | | 155 | 13 | 8 | 142 | 92 | 20 | 14 |
| 6 | Major occupation 2350-1950 cal BP, XU6-14. | 176 | 12 | 7 | 164 | 93 | 26 | 16 |
| 7 | | 230 | 9 | 4 | 221 | 96 | 22 | 10 |
| 8 | | 215 | 8 | 4 | 207 | 96 | 36 | 17 |
| 9 | | 205 | 12 | 6 | 193 | 94 | 49 | 25 |
| 10 | | 205 | 6 | 3 | 199 | 97 | 30 | 15 |
| 11 | | 86 | 1 | 1 | 85 | 99 | 9 | 11 |
| 12 | | 58 | 7 | 12 | 51 | 88 | 10 | 20 |
| 13 | | 158 | 10 | 6 | 148 | 94 | 19 | 13 |
| 14 | | 57 | 1 | 2 | 56 | 98 | 13 | 23 |
| 15 | | 9 | 2 | 22 | 7 | 78 | 0 | 0 |
| 16 | | 1 | 0 | 0 | 1 | 100 | 0 | 0 |
| 17 | | 5 | 0 | 0 | 5 | 100 | 0 | 0 |
| 18 | | 2 | 0 | 0 | 2 | 100 | 0 | 0 |
| 20 | | 1 | 0 | 0 | 1 | 100 | 0 | 0 |
| Totals | | 1718 | 86 | | 1612 | | 265 | 16 |

## AASI — Square A

This site was investigated by Sutherland et al. (2016) in 2009. The site is located 37.2 – 38.2 m asl on the western slope of a small hill close to the head of a small valley and 20 m east-southeast of an unnamed creek junction. The site was identified as a medium-sized (20 m in diameter) lithic scatter concentrated around a cluster of quartzite

boulders. Shell and ceramic materials were also noted on the surface in much smaller quantities compared to the lithic material. Two squares located 5 m apart were excavated. Square A reached a depth of 53.5 cm, and Square B reached a depth of 70.2 cm. Excavation data from Square A is not available due to data management issues. Therefore, the following discussion of the SUs at this site relies on data from Square B which was located in close proximity and had similar stratigraphy (Sutherland et al. 2016:5). Three SUs were identified (Sutherland et al. 2016:5). SU 3 is the deepest SU and corresponds to XU 8–22. SU 3 contained little cultural material. It is suggested that the limited quantity of cultural material in SU 3 is related to taphonomic processes and is not an indication of a lack of human occupation during this time (Sutherland et al. 2016:4). SU 2 overlaps SU 1 in areas, corresponding to XUs 1–11 due to dipping stratigraphy. SU 1 generally corresponds to XUs 1–6. The vast majority of the cultural material was recovered from SUs 1 and 2, and they are thought to represent a single occupation phase. Radiocarbon dates were taken for both squares and generally indicate that the cultural material present in SUs 1 and 2 dates to 1564–1415 cal BP.

Square A was selected for this research. It contained 102 lithic artifacts recovered from 13 XUs (Mialanes 2016h:2), of which 31 artifacts from 9 XUs were selected for pXRF analysis (Table 8). Mialanes' (2016h:8) analysis indicates that only two phases of knapping took place, and these involved a variety of raw materials. Stone artifacts were recovered from almost all XUs of Square A, with the majority recovered from XUs 1 to 4 (Mialanes 2016h:2). Four different raw material types were present, including chert (93.1%), chalcedony (3.9%), quartz (2.0%), and unidentified igneous materials (1.0%). The chert artifact assemblage was heavily fragmented, and the predominant artifact types were broken flakes (60.0%) and flaked pieces (23.2%) with significantly fewer complete flakes and cores (Mialanes 2016h:2). Cores indicate free-hand unipolar reduction (Mialanes 2016h:3). Mialanes (2016h:8) concludes that the number and classes of artifacts combined with the generally small size of flakes indicate secondary lithic manufacturing activities at the site. An almost complete lack of cortex and large primary reduction flakes points to the off-site preparation of the cores. Retouching is rare, suggesting that flakes were predominantly used and discarded unmodified (Mialanes 2016h:9). Heat altered flakes were present, and Mialanes

(2016h:8) indicates that heat alteration is likely not related to purposeful heat treatment as none of the flakes showing evidence of burning have any further modifications. This inference is further supported by the presence of potlid scarring on the ventral side of many flakes. It is concluded that heat alteration is evidence of purposeful burning of flakes themselves and accidental burning due to wild/controlled fires in the landscape (Mialanes 2016h:8).

**Table 8: Lithic artifacts, temporal sequence and selections for pXRF testing from the AASI collection.**

| AASI, Square A, Stone Artifact Numbers | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| XU | Chronological Period | Total Stone Artifacts | Not Chert | % Not Chert | Chert | % Chert | Chert Items Tested | % of Chert Items Tested |
| 1 | One Occupation phase, c. 1564-1415 cal BP, XU1-11. | 80 | 7 | 9 | 73 | 91 | 16 | 22 |
| 2 | | 36 | 1 | 3 | 35 | 97 | 4 | 11 |
| 3 | | 11 | 1 | 9 | 10 | 91 | 1 | 10 |
| 4 | | 17 | 0 | 0 | 17 | 100 | 4 | 24 |
| 5 | | 6 | 0 | 0 | 6 | 100 | 1 | 17 |
| 6 | | 7 | 0 | 0 | 7 | 100 | 1 | 14 |
| 7 | | 3 | 0 | 0 | 3 | 100 | 0 | 0 |
| 8 | | 4 | 0 | 0 | 4 | 100 | 1 | 25 |
| 9 | | 4 | 0 | 0 | 4 | 100 | 1 | 25 |
| 10 | | 3 | 0 | 0 | 3 | 100 | 0 | 0 |
| 13 | | 1 | 0 | 0 | 1 | 100 | 1 | 100 |
| Totals | | 172 | 9 | | 163 | | 30 | 18 |

## Tanamu 1 — Square A

David et al. (2016e) provide excavation details for Tanamu 1. The site was excavated in 2009 (Richards et al. 2016b:2) and is located on the edge of an exposed coastal sand dune forming a low, northwest-to-southeast-trending 'peninsula'. The peninsula is grass covered and is flanked by open tidal mudflats to the east and extensive inter-tidal mangrove forest to the west. The site is located 5 m above the present high-water mark and was identified from a low-density surface scatter of shell, ceramic material, and lithic artifacts over an area of 20 m by 13 m. Two squares were excavated to a total depth of 284 cm. Seven distinct SUs were identified, including three dense occupational horizons (David et al. 2016e:5). The oldest cultural material forms the Lower Horizon (4350–4050 cal BP), a dense pre-ceramic occupation level containing faunal remains, stone artifacts, and large amounts of shell (David et al. 2016e). Although

in situ cultural material is present below this Horizon, likely representing episodic minor occupation as early as c.5,000 cal BP (David et al. 2016e:16) these short-term occupations are poorly understood and are represented by an extremely small amounts of cultural material. Discussion of the artifacts from this time has not been included here. The second major occupation at Tanamu 1 is the Middle Horizon (2800–2750 cal BP), which consists of a dense Lapita occupation. Lapita ceramics are the first ceramics present and include collared and carinated vessels predominantly decorated with curvilinear comb dentate-stamped tools. The third cultural horizon has been labelled the Upper Horizon B and was deposited immediately prior to the ethnographic period (c. 200–100 cal BP). This horizon contains dense deposits of undecorated pottery and cultural materials.

Square A was selected for this research. It contained 1,056 artifacts from 134 XUs (Mialanes, Ford, et al. 2016:2), of which 160 from 55 XUs were selected for pXRF analysis (Table 9). Five types of raw material are present, predominantly chert (98.6%), followed by unidentified igneous material (0.7%), and chalcedony (0.6%) (Mialanes, Ford, et al. 2016:3). Stone artifacts were recovered from most XUs, but increased in quantity towards the surface of the site. The greatest amount of lithic material was present between XUs 2 and 23, corresponding to the two most recent phases (Mialanes, Ford, et al. 2016:2). The second most intensive period of occupation occurred during the Lapita phase dating to 2800–2750 cal BP (Mialanes, Ford, et al. 2016:4). The majority of chert artifacts were broken flakes and flaked pieces, and many were very small. Mialanes et al. (2016b:19) concludes that both the number of artifacts and the generally small size of the individual flakes confirm that secondary lithic manufacturing activities were occurring at the site. A lack of cortex and primary reduction flakes in this assemblage points to the off-site preparation of the cores prior to their arrival at the site (Mialanes, Ford, et al. 2016:11). There is evidence for fire-altered flakes; however, based on the apparent lack of flake use after burning, Mialanes et al. (2016b:7) concludes that heat alteration is not related to heat treatment and is instead evidence of purposeful burning or a result of disposal into fire pits and/or accidental burning as a by-product of fires in the landscape. Mialanes et al. (2016b:9) suggest that the increased use of this site, as indicated by the volume of other cultural materials, supports an

interpretation of increased local fires for pottery manufacture. These cultural fires are considered to be a more likely cause for heat alterations than the possibility of wild fires in the area. Mialanes et al. (2016b:18) identify no major changes in the use and manufacture of lithics at Tanamu 1 over the approximately 5,000 years of occupation.

***Table 9: Lithic artifacts, temporal sequence and selections for pXRF testing from the Tanamu 1 collection.***

| Tanamu 1, Square A, Stone Artifact Numbers | | | | | | | |
|---|---|---|---|---|---|---|---|
| XU | Chronological Period | Total Stone Artifacts | Not Chert | % Not Chert | Chert | % Chert | Chert Items Tested | % of Chert Items Tested |
| 1 | Upper Horizon B- c.100-200 cal BP, XU1-6 | 6 | 0 | 0 | 6 | 100 | 2 | 33 |
| 2 | | 22 | 0 | 0 | 22 | 100 | 7 | 32 |
| 3 | | 69 | 0 | 0 | 69 | 100 | 19 | 28 |
| 4 | | 68 | 0 | 0 | 68 | 100 | 14 | 21 |
| 5 | | 45 | 0 | 0 | 45 | 100 | 14 | 31 |
| 6 | | 25 | 0 | 0 | 25 | 100 | 0 | 0 |
| 7 | | 18 | 0 | 0 | 18 | 100 | 1 | 6 |
| 8 | | 23 | 0 | 0 | 23 | 100 | 0 | 0 |
| 9+10 | | 23 | 0 | 0 | 23 | 100 | 0 | 0 |
| 11 | | 24 | 0 | 0 | 24 | 100 | 0 | 0 |
| 12 | | 9 | 0 | 0 | 9 | 100 | 1 | 11 |
| 13 | | 12 | 0 | 0 | 12 | 100 | 0 | 0 |
| 14 | | 39 | 0 | 0 | 39 | 100 | 5 | 13 |
| 15 | | 20 | 0 | 0 | 20 | 100 | 1 | 5 |
| 16 | | 11 | 0 | 0 | 11 | 100 | 3 | 27 |
| 17 | | 4 | 0 | 0 | 4 | 100 | 0 | 0 |
| 18 | | 15 | 0 | 0 | 15 | 100 | 3 | 20 |
| 19 | | 32 | 0 | 0 | 32 | 100 | 5 | 16 |
| 20 | | 16 | 0 | 0 | 16 | 100 | 2 | 13 |
| 21 | | 13 | 0 | 0 | 13 | 100 | 4 | 31 |
| 22 | | 8 | 0 | 0 | 8 | 100 | 0 | 0 |
| 23 | | 12 | 0 | 0 | 12 | 100 | 1 | 8 |
| 25 | Middle Horizon- c.2800-2750 cal BP, XU 24-34 | 10 | 0 | 0 | 10 | 100 | 2 | 20 |
| 26 | | 9 | 1 | 11 | 8 | 89 | 1 | 13 |
| 27 | | 6 | 1 | 17 | 5 | 83 | 1 | 20 |
| 28 | | 3 | 0 | 0 | 3 | 100 | 0 | 0 |
| 29 | | 6 | 0 | 0 | 6 | 100 | 2 | 33 |
| 30 | | 8 | 0 | 0 | 8 | 100 | 0 | 0 |
| 31 | | 12 | 0 | 0 | 12 | 100 | 4 | 33 |
| 32 | | 6 | 0 | 0 | 6 | 100 | 1 | 17 |
| 33 | | 8 | 1 | 13 | 7 | 88 | 0 | 0 |
| 34 | | 2 | 0 | 0 | 2 | 100 | 1 | 50 |
| 36 | | 11 | 0 | 0 | 11 | 100 | 1 | 9 |
| 37 | | 2 | 0 | 0 | 2 | 100 | | 0 |
| 38 | | 4 | 0 | 0 | 4 | 100 | 1 | 25 |
| 39 | | 5 | 0 | 0 | 5 | 100 | 2 | 40 |
| 40 | | 8 | 0 | 0 | 8 | 100 | 1 | 13 |
| 43 | | 12 | 0 | 0 | 12 | 100 | 4 | 33 |
| 44 | | 11 | 0 | 0 | 11 | 100 | 3 | 27 |
| 45 | | 12 | 0 | 0 | 12 | 100 | 0 | 0 |
| 46 | | 3 | 0 | 0 | 3 | 100 | 0 | 0 |

| Tanamu 1, Square A, Stone Artifact Numbers | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| XU | Chronological Period | Total Stone Artifacts | Not Chert | % Not Chert | Chert | % Chert | Chert Items Tested | % of Chert Items Tested |
| 47 | | 3 | 0 | 0 | 3 | 100 | 1 | 33 |
| 48 | | 5 | 0 | 0 | 5 | 100 | 0 | 0 |
| 49 | | 10 | 0 | 0 | 10 | 100 | 0 | 0 |
| 50 | | 10 | 0 | 0 | 10 | 100 | 0 | 0 |
| 51 | Lower Horison- c.4350-4050 cal BP, XU48-69 | 6 | 0 | 0 | 6 | 100 | 1 | 17 |
| 52 | | 12 | 0 | 0 | 12 | 100 | 0 | 0 |
| 53 | | 4 | 0 | 0 | 4 | 100 | 1 | 25 |
| 54 | | 5 | 0 | 0 | 5 | 100 | 1 | 20 |
| 55 | | 13 | 0 | 0 | 13 | 100 | 7 | 54 |
| 56 | | 5 | 0 | 0 | 5 | 100 | 3 | 60 |
| 57 | | 13 | 0 | 0 | 13 | 100 | 0 | 0 |
| 58 | | 9 | 1 | 11 | 8 | 89 | 1 | 13 |
| 59 | | 10 | 0 | 0 | 10 | 100 | 0 | 0 |
| 60 | | 8 | 0 | 0 | 8 | 100 | 3 | 38 |
| 61 | | 10 | 0 | 0 | 10 | 100 | 0 | 0 |
| 63 | | 7 | 0 | 0 | 7 | 100 | 2 | 29 |
| 64 | | 10 | 1 | 10 | 9 | 90 | 3 | 33 |
| 65 | | 5 | 0 | 0 | 5 | 100 | 0 | 0 |
| 66 | | 11 | 0 | 0 | 11 | 100 | 2 | 18 |
| 67 | | 6 | 0 | 0 | 6 | 100 | 2 | 33 |
| 68 | | 1 | 0 | 0 | 1 | 100 | | 0 |
| 69 | | 3 | 0 | 0 | 3 | 100 | | 0 |
| 70 | SU 6 and 7, intermittent, occupation, very limited materials. | 5 | 0 | 0 | 5 | 100 | 1 | 20 |
| 71 | | 2 | 0 | 0 | 2 | 100 | 1 | 50 |
| 72 | | 4 | 0 | 0 | 4 | 100 | 1 | 25 |
| 73 | | 6 | 0 | 0 | 6 | 100 | 0 | 0 |
| 74 | | 2 | 0 | 0 | 2 | 100 | 1 | 50 |
| 75 | | 3 | 0 | 0 | 3 | 100 | 1 | 33 |
| 76 | | 3 | 0 | 0 | 3 | 100 | 0 | 0 |
| 77 | | 3 | 0 | 0 | 3 | 100 | 0 | 0 |
| 78 | | 5 | 0 | 0 | 5 | 100 | 0 | 0 |
| 79 | | 6 | 0 | 0 | 6 | 100 | 1 | 17 |
| 80 | | 5 | 0 | 0 | 5 | 100 | 0 | 0 |
| 81 | | 3 | 0 | 0 | 3 | 100 | 3 | 100 |
| 82 | | 7 | 0 | 0 | 7 | 100 | 3 | 43 |
| 83 | | 3 | 0 | 0 | 3 | 100 | 1 | 33 |
| 84 | | 1 | 0 | 0 | 1 | 100 | 0 | 0 |
| 85 | | 8 | 0 | 0 | 8 | 100 | 0 | 0 |
| 86 | | 2 | 1 | 50 | 1 | 50 | 0 | 0 |
| 87 | | 5 | 0 | 0 | 5 | 100 | 0 | 0 |
| 88 | | 2 | 0 | 0 | 2 | 100 | 0 | 0 |
| 89 | | 5 | 0 | 0 | 5 | 100 | 0 | 0 |
| 90 | | 3 | 0 | 0 | 3 | 100 | 0 | 0 |
| 91 | | 4 | 0 | 0 | 4 | 100 | 1 | 25 |
| 92 | | 1 | 0 | 0 | 1 | 100 | 0 | 0 |
| 93 | | 2 | 0 | 0 | 2 | 100 | 1 | 50 |
| 94 | | 2 | 0 | 0 | 2 | 100 | 0 | 0 |
| 95 | | 2 | 0 | 0 | 2 | 100 | 0 | 0 |
| 96 | | 2 | 0 | 0 | 2 | 100 | 0 | 0 |
| 97 | | 5 | 0 | 0 | 5 | 100 | 0 | 0 |
| 98 | | 5 | 0 | 0 | 5 | 100 | 0 | 0 |
| 99 | | 8 | 1 | 13 | 7 | 88 | 1 | 14 |
| 100 | | 5 | 0 | 0 | 5 | 100 | 0 | 0 |

| Tanamu 1, Square A, Stone Artifact Numbers | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| XU | Chronological Period | Total Stone Artifacts | Not Chert | % Not Chert | Chert | % Chert | Chert Items Tested | % of Chert Items Tested |
| 101 | | 2 | 0 | 0 | 2 | 100 | 0 | 0 |
| 102 | | 6 | 0 | 0 | 6 | 100 | 0 | 0 |
| 103 | | 2 | 0 | 0 | 2 | 100 | 0 | 0 |
| 104 | | 3 | 0 | 0 | 3 | 100 | 0 | 0 |
| 105 | | 4 | 0 | 0 | 4 | 100 | 0 | 0 |
| 106 | | 2 | 0 | 0 | 2 | 100 | 0 | 0 |
| 108 | | 1 | 0 | 0 | 1 | 100 | 0 | 0 |
| 109 | | 4 | 0 | 0 | 4 | 100 | 0 | 0 |
| 110 | | 4 | 0 | 0 | 4 | 100 | 1 | 25 |
| 111 | | 5 | 0 | 0 | 5 | 100 | 0 | 0 |
| 112 | | 1 | 0 | 0 | 1 | 100 | 0 | 0 |
| 113 | | 2 | 0 | 0 | 2 | 100 | 1 | 50 |
| 117 | | 2 | 0 | 0 | 2 | 100 | 0 | 0 |
| 118 | | 2 | 0 | 0 | 2 | 100 | 0 | 0 |
| 119 | | 1 | 0 | 0 | 1 | 100 | 0 | 0 |
| 120 | | 2 | 0 | 0 | 2 | 100 | 0 | 0 |
| 121 | | 1 | 0 | 0 | 1 | 100 | 0 | 0 |
| 122 | | 1 | 0 | 0 | 1 | 100 | 0 | 0 |
| 123 | | 1 | 0 | 0 | 1 | 100 | 0 | 0 |
| 124 | | 2 | 0 | 0 | 2 | 100 | 0 | 0 |
| 125 | | 1 | 0 | 0 | 1 | 100 | 0 | 0 |
| 126 | | 3 | 0 | 0 | 3 | 100 | 0 | 0 |
| 127 | | 1 | 0 | 0 | 1 | 100 | 0 | 0 |
| 128 | | 1 | 0 | 0 | 1 | 100 | 0 | 0 |
| 129 | | 6 | 0 | 0 | 6 | 100 | 0 | 0 |
| 132 | | 3 | 0 | 0 | 3 | 100 | 0 | 0 |
| 133 | | 4 | 0 | 0 | 4 | 100 | 0 | 0 |
| Totals | | 1004 | 7 | | 997 | | 151 | 15 |

## Tanamu 2 — Square A

This site was excavated in 2009 (Richards et al. 2016b:2) with details provided in David et al. (2016d:1). The site is located on the eastern edge of a slightly raised sandy spit approximately 3.4–3.7 m asl. The spit runs north-south parallel to the mangrove-fringed marine shore located approximately 110 m to the west. Directly adjacent, and to the east of this site, runs the meandering tidal Ruisasi Creek. The site was originally identified and recorded as a dense scatter of pottery sherds, stone artifacts, and shell eroding along a 19 m long and 4 m wide erosional creek embankment. Two squares were excavated and ranged in depth from 111 cm (Square A) to 118 cm (Square B). Three distinct stratigraphic units were identified. The deepest is SU 3 which encompassed XUs 48–55 and was determined to be culturally sterile. The earliest radiocarbon date from this site came from wood charcoal in SU 3 of Square A and

yielded a radiocarbon age of 6490–6808 cal BP (David et al. 2016d:5). This date is interpreted as an indication that occasional cultural activity was occurring on a landscape surface which saw very limited sedimentation spanning from c. 6940 to 2715 cal BP (David et al. 2016d:9). It represents the earliest evidence of human activity on the southern coast of PNG. SU 2a, encompassing XUs 3–16, and SU 2b, encompassing XUs 12–50, both contained rich cultural materials, but to slightly different degrees. SU 1, encompassing XUs 1–9, was a cultural layer but contained very few cultural materials. The ages of the major occupation period of this site have been determined as 2504–2414 cal BP (David et al. 2016d:8).

Square A was selected for this research. It contained 369 stone artifacts from 54 XUs (Mialanes 2016i:1), of which 95 from 26 XUs were selected for pXRF analysis (Table 10) Of the raw material types identified by Mialanes (2016i:1), chert (95.0%) predominated, followed by obsidian (2.0%) and unidentified igneous materials (1.0%). Stone artifacts were recovered from most XUs, but increased in quantity towards the surface of the site (Mialanes 2016i:1). The greatest amount of lithic material was present in SU 2a, corresponding to the major period of occupation (David et al. 2016d:11). The majority of chert artifacts are broken flakes and flaked pieces, with a small number of complete flakes also present (Mialanes 2016i:2). Cores are only present in the most recent phase, and a lack of cortex and primary reduction flakes points to the off-site preparation of cores. The low number of artifacts and the generally small size of flakes most likely indicate limited secondary lithic manufacturing activities were occurring at the site. There is evidence for heat-altered flakes, and Mialanes (2016i:3) suggests that this contributed significantly to the small and fragmented nature of this lithic assemblage. Based on flake taphonomy, Mialanes (2016i:3) notes that fire alteration was not related to purposeful heat treatment, but was a by-product of the purposeful burning of flakes as a result of disposal into fire pits and accidental burning due to fires in the landscape.

**Table 10: Lithic artifacts, temporal sequence and selections for pXRF testing from the Tanamu 2 collection.**

| XU | Chronological Period | Total Stone Artifacts | Not Chert | % Not Chert | Chert | % Chert | Chert Items Tested | % of Chert Items Tested |
|---|---|---|---|---|---|---|---|---|
| | **Tanamu 2, Square A, Stone Artifact Numbers** | | | | | | | |
| 1 | very minor occupation, no date available. | 4 | 2 | 50 | 2 | 50 | 0 | 0 |
| 2 | | 10 | 2 | 20 | 8 | 80 | 3 | 38 |
| 4 | | 7 | 1 | 14 | 6 | 86 | 1 | 17 |
| 5 | | 89 | 4 | 4 | 85 | 96 | 4 | 5 |
| 6 | PHASE 2 – Main occupation period, c. 2504-2414 cal BP, XU 6-50. | 57 | 3 | 5 | 54 | 95 | 14 | 26 |
| 7 | | 43 | 0 | 0 | 43 | 100 | 8 | 19 |
| 8 | | 24 | 2 | 8 | 22 | 92 | 4 | 18 |
| 9 | | 21 | 1 | 5 | 20 | 95 | 8 | 40 |
| 10 | | 6 | 2 | 33 | 4 | 67 | 6 | 150 |
| 11 | | 5 | 0 | 0 | 5 | 100 | 3 | 60 |
| 12 | | 8 | 0 | 0 | 8 | 100 | 1 | 13 |
| 13 | | 8 | 0 | 0 | 8 | 100 | 6 | 75 |
| 14 | | 3 | 0 | 0 | 3 | 100 | 1 | 33 |
| 15 | | 1 | 0 | 0 | 1 | 100 | 0 | 0 |
| 16 | | 4 | 0 | 0 | 4 | 100 | 2 | 50 |
| 17 | | 6 | 0 | 0 | 6 | 100 | 1 | 17 |
| 19 | | 2 | 0 | 0 | 2 | 100 | 1 | 50 |
| 20 | | 1 | 0 | 0 | 1 | 100 | 0 | 0 |
| 22 | | 2 | 0 | 0 | 2 | 100 | 1 | 50 |
| 24 | | 3 | 0 | 0 | 3 | 100 | 1 | 33 |
| 25 | | 1 | 1 | 100 | 0 | 0 | 0 | 0 |
| 26 | | 4 | 0 | 0 | 4 | 100 | 0 | 0 |
| 27 | | 2 | 0 | 0 | 2 | 100 | 0 | 0 |
| 29 | | 2 | 0 | 0 | 2 | 100 | 1 | 50 |
| 30 | | 1 | 0 | 0 | 1 | 100 | 0 | 0 |
| 31 | | 1 | 0 | 0 | 1 | 100 | 1 | 100 |
| 32 | | 12 | 0 | 0 | 12 | 100 | 1 | 8 |
| 33 | | 1 | 0 | 0 | 1 | 100 | 1 | 100 |
| 34 | | 1 | 1 | 100 | 0 | 0 | 0 | 0 |
| 35 | | 3 | 0 | 0 | 3 | 100 | 1 | 33 |
| 36 | | 1 | 0 | 0 | 1 | 100 | 0 | 0 |
| 38 | | 3 | 0 | 0 | 3 | 100 | 0 | 0 |
| 39 | | 2 | 0 | 0 | 2 | 100 | 2 | 100 |
| 40 | | 1 | 0 | 0 | 1 | 100 | 0 | 0 |
| 42 | | 2 | 0 | 0 | 2 | 100 | 0 | 0 |
| 45 | | 4 | 0 | 0 | 4 | 100 | 0 | 0 |
| 47 | | 4 | 0 | 0 | 4 | 100 | 1 | 25 |
| 48 | | 18 | 0 | 0 | 18 | 100 | 2 | 11 |
| 50 | | 2 | 0 | 0 | 2 | 100 | 0 | 0 |
| **Totals** | | **369** | **19** | | **350** | | **75** | **21** |

## Tanamu 3 — Square B

Tanamu 3 was excavated in 2009 (Richards et al. 2016b:2) with the excavation process detailed in David et al. (2016b:4). It is located on a gentle slope on the eastern

edge of a northwest-to-southwest trending sand dune near to the western end of a tidal salt flat. Ruisasi Creek runs along a drainage channel to the landward side of the dune on which the site is located, and to seaward the dune feature is bordered by tidal mudflats. The site was originally identified as a low-density surface scatter of shell, lithics, and ceramic materials. A total of five squares was excavated, and these ranged in depth from 19.9 cm (Square A) to 115 cm (Square D). David et al. (2016b:16) note that the stratigraphy of the five squares is different enough to warrant division of these squares into two groups for discussion. Squares A, B, and E form one group and Squares C and D another. As material from Square B was used in this research, the site synopsis presented here will focus on the first group of squares.

Three main phases of occupation have been identified at Tanamu 3. The earliest phase, Phase A, was present in Squares B and E and is dated to 2889–3196 cal BP and is represented by XUs 18–32. Phase A features low quantities of cultural materials and is not believed to indicate continuous occupation of the site at this time. The middle phase, Phase B, was present in all five squares and is dated to 2265–2737 cal BP. It is represented variably by XUs 1–20 in Squares A, B, and E and by XUs 1–48 in Squares C and D. Phase B represents the major period of occupation in all excavated squares at Tanamu 3 as evidenced by high amounts of cultural material. The final and most recent phase, Phase C, was present only in Square B (XUs 1–7) and dates within 1800–1891 cal BP. This phase is not considered to represent an occupation due to a lack of associated cultural martial.

Square B was selected for this research. It contained a total of 146 stone artifacts from 34 XUs (Mialanes 2016d:2) of which 32 artifacts from 15 XUs were selected for pXRF analysis (Table 11). Three types of raw material were present in Square B. Raw material was predominantly chert (95.8%), with four obsidian flakes and one basalt flake (Mialanes 2016d:2). Stone artifacts were recovered from most XUs but increased in quantity towards the surface of the site. The majority of chert artifacts were broken flakes and flaked pieces with a small number of complete flakes also present (Mialanes 2016d:3). The high proportion of small flakes suggests predominantly secondary lithic manufacturing activities. There is evidence for heat alteration on chert artifacts, but none

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of the flakes showing evidence of burning had any further modifications. Mialanes (2016d:4) concludes that the heat alteration was either due to the purposeful burning of the flakes from disposal into fire pits or accidental burning from wild or controlled fires and is not evidence of purposeful heat treatment.

**Table 11: Lithic artifacts, temporal sequence and selections for pXRF testing from the Tanamu 3 collection.**

| Tanamu 3, Square B, Stone Artifact Numbers | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| XU | Chronological Period | Total Stone Artifacts | Not Chert | % Not Chert | Chert | % Chert | Chert Items Tested | % of Chert Items Tested |
| 2 | Phase C (XU 1-7) c.1800-1891 cal BP – not cultural? | 12 | 0 | 0 | 12 | 100 | 2 | 17 |
| 3 | | 9 | 0 | 0 | 9 | 100 | 3 | 33 |
| 4 | | 17 | 0 | 0 | 17 | 100 | 3 | 18 |
| 5 | | 14 | 0 | 0 | 14 | 100 | 1 | 7 |
| 6 | | 7 | 1 | 14 | 6 | 86 | 1 | 17 |
| 7 | | 5 | 0 | 0 | 5 | 100 | 1 | 20 |
| 8 | Phase B (XU 8-19) – 2265-2545 cal BP – major occupation | 2 | 0 | 0 | 2 | 100 | 1 | 50 |
| 9 | | 3 | 1 | 33 | 2 | 67 | 0 | 0 |
| 10 | | 8 | 0 | 0 | 8 | 100 | 1 | 13 |
| 11 | | 2 | 0 | 0 | 2 | 100 | 0 | 0 |
| 12 | | 9 | 0 | 0 | 9 | 100 | 0 | 0 |
| 13 | | 8 | 0 | 0 | 8 | 100 | 4 | 50 |
| 14 | | 9 | 1 | 11 | 8 | 89 | 2 | 25 |
| 15 | | 8 | 1 | 13 | 7 | 88 | 2 | 29 |
| 16 | | 11 | 1 | 9 | 10 | 91 | 5 | 50 |
| 17 | | 11 | 1 | 9 | 10 | 91 | 2 | 20 |
| 19 | | 5 | 0 | 0 | 5 | 100 | 0 | 0 |
| 21 | Phase A (XU 19-32) – 3046-3173 cal BP – minor occupation | 2 | 0 | 0 | 2 | 100 | 1 | 50 |
| 28 | | 1 | 0 | 0 | 1 | 100 | 0 | 0 |
| 29 | | 1 | 0 | 0 | 1 | 100 | 0 | 0 |
| 30 | | 1 | 0 | 0 | 1 | 100 | 0 | 0 |
| 31 | | 1 | 0 | 0 | 1 | 100 | 1 | 100 |
| Totals | | 146 | 6 | | 140 | | 30 | 21 |

## ABKF — Square C

The site overview for ABKF has not been completed with information currently limited to the lithic analysis carried out by Mialanes (2016j:4). This site was originally identified from a surface scatter of ceramic and lithic artifacts in 2008 and was excavated in 2009 (Richards et al. 2016b:2). Site records indicate that 18 XUs were excavated at three squares and reached depths of 30 cm to 44 cm below the surface. Square C was selected for this research. It contains a total of 50 lithic artifacts from 18 XUs of which 20 artifacts from 12 XUs were selected for pXRF analysis (Table 12). All three squares from

this site yielded a relatively small and heavily fragmented assemblage of artifacts with the largest assemblage recovered from Square C. Mialanes (2016j:5) indicates that it is likely that only a single knapping event took place in Square C and this was focused on chert. Though the assemblage of artifacts from Square C is predominantly chert (96.0%), single flakes of both chalcedony (2.0%) and quartz (2.0%) were also recovered from this square. Stone artifacts were recovered from nearly all XUs of Square C, the majority from XUs 11 to 15 (Mialanes 2016j:4). The chert artifact assemblage from Square C was heavily fragmented, and the predominant artifact types were broken flakes (45.9%) and flaked pieces (39.6%). Mialanes (2016j: Table 3) indicates significantly fewer complete flakes (2.1%) and cores (2.1%) present in this assemblage. One small core was obtained from this square, and it was reduced using free-hand unipolar reduction. Mialanes (2016j:5) concludes that the number and classes of artifacts combined with the generally small size of flakes indicate secondary lithic manufacturing activities at the site. This conclusion is supported by an almost complete lack of cortex and primary reduction flakes in the assemblage, both of which point to the off-site preparation of cores. Retouching was absent from all squares indicating that all flakes were used and discarded unmodified. Heat-altered flakes comprise approximately 30% of this assemblage. Though Mialanes (2016j) makes no statements about the origin of these heat-altered items, the location of potlid scars and artifact discoloration both indicate that the heat alteration is more likely a by-product of accidental (wild fires) or purposeful (disposal into fire pits) burning and should not be taken to indicate purposeful heat treatment. No temporal data is currently available for this site, so a further discussion GSG quantities in relation to SUs or occupation periods is not possible. Although the data from ABKF will not be included in the discussions focusing on chert use during the various ceramic traditions and periods discussed in Chapter 11. The data from this site is still of value for discussions of GSG quantities base on XU as presented in Chapter 10. This site has been retained in the data set, because even with a lack of temporal data and a very small sample it still gives provided data that is of use in discussion of the chert use and distributions in the wider Caution Bay area that would not be available otherwise.

**Table 12: Lithic artifacts, and selections for pXRF testing from the ABKF collection.**

| XU | Total Stone Artifacts | Not Chert | % Not Chert | Chert | % Chert | Chert Items Tested | % of Chert Items Tested |
|---|---|---|---|---|---|---|---|
| 1 | 2 | 0 | 0 | 2 | 100 | 0 | 0 |
| 2 | 4 | 0 | 0 | 4 | 100 | 0 | 0 |
| 3 | 6 | 0 | 0 | 6 | 100 | 1 | 17 |
| 5 | 5 | 0 | 0 | 5 | 100 | 2 | 40 |
| 7 | 3 | 0 | 0 | 3 | 100 | 0 | 0 |
| 8 | 2 | 0 | 0 | 2 | 100 | 0 | 0 |
| 9 | 2 | 0 | 0 | 2 | 100 | 1 | 50 |
| 10 | 1 | 0 | 0 | 1 | 100 | 1 | 100 |
| 11 | 4 | 0 | 0 | 4 | 100 | 2 | 50 |
| 12 | 3 | 1 | 33 | 2 | 67 | 2 | 100 |
| 13 | 4 | 0 | 0 | 4 | 100 | 1 | 25 |
| 14 | 3 | 0 | 0 | 3 | 100 | 3 | 100 |
| 15 | 8 | 0 | 0 | 8 | 100 | 1 | 13 |
| 17 | 2 | 0 | 0 | 2 | 100 | 0 | 0 |
| 18 | 1 | 1 | 100 | 0 | 0 | 0 | 0 |
| **Totals** | **50** | **2** | | **48** | | **14** | **29** |

No temporal data is currently available for this site, so a further discussion GSG quantities in relation to SUs or occupation periods is not possible. Although the data from ABKF will not be included in the discussions focusing on chert use during the various ceramic traditions and periods discussed in Chapter 11. The data from this site is still of value for discussions of GSG quantities base on XU as presented in Chapter 10. This site has been retained in the data set, because even with a lack of temporal data and a very small sample, it still provided data that is of use in discussion of the chert use and distributions in the wider Caution Bay area that would not be available otherwise.

## Nese 1 — Square C

The site overview for Nese 1 has not been completed with available information limited to the lithic analysis carried out by (Mialanes 2016k:12). This site was identified from a surface scatter of ceramic and lithic artifacts in 2008 and was excavated in 2009 (Richards et al. 2016b:2). Five squares were excavated to varying depths at this site. Square C was selected for this research. It contained a total of 556 stone artifacts from 32 XUs of which 105 artifacts from 7 XUs were selected for pXRF analysis (Table 13). The cultural material from all of the squares was associated with one major period of

occupation radiocarbon dated to between 2730–2530 cal BP (Mialanes 2016k:1). Lithic materials were recovered from all squares, and in most of the squares, a variety of materials were present. All the lithic material from Square C was chert (Mialanes 2016k:12). Stone artifacts were recovered from almost all XUs of Square C, with the majority of the artifacts recovered from XUs 2 to 13 (Mialanes 2016k:12). This assemblage is generally small and heavily fragmented, with the predominant artifact types being broken flakes (80.6%), followed by complete flakes (10.1%), flaked pieces (7.9%), cores (0.7%), and potlids (0.7%). No major changes in fracture type proportions over time were noted in this square, but Mialanes (2016k:12) notes a greater number of cores during the major occupation period. Both unipolar and bipolar cores are present in this assemblage indicating that two modes of reduction were employed. Based on the presence of cores and the generally small size of the flakes, it is concluded that the artifacts from this square represent a late reduction stage. The limited amount of cortex indicates that small nodules of raw material were used for tool production or that initial reduction took place off-site. Two artifacts revealed fine retouching along their dorsal lateral right margin. Seventy-one artifacts with potlid scars, as well as some potlids themselves, provide evidence of heat alteration. The presence of potlid scars on the ventral side of many flakes as well as the lack of evidence that any of the heat altered flakes had been used after burning indicates that heating was not purposeful heat treatment. Mialanes (2016k:13) suggests that these items underwent heat alteration as a by-product of purposeful burning as a result of disposal into fire pits and accidental burning from fires in the landscape. Although a date range is provided in the preliminary report produced by Mialanes (2016k:12), no other cultural data are provided making it difficult to confidently assigned the occupation at this site to any of the ceramic traditions identified in Caution Bay. Based on the dates presented, the occupation commenced during the Lapita period and continued into the Post Lapita Transformative Tradition. It is currently unknown if ceramic artifacts support this observation.

***Table 13: Lithic artifacts, temporal sequence and selections for pXRF testing from the Nese 1 collection.***

| | | Nese 1, Square C, Stone Artifact Numbers | | | | | | |
|---|---|---|---|---|---|---|---|---|
| XU | Chronological Period | Total Stone Artifacts | Not Chert | % Not Chert | Chert | % Chert | Chert Items Tested | % of Chert Items Tested |
| 2 | | 9 | 0 | 0 | 9 | 100 | 0 | 0 |
| 3 | | 14 | 0 | 0 | 14 | 100 | 0 | 0 |
| 4 | | 14 | 0 | 0 | 14 | 100 | 0 | 0 |
| 5 | | 26 | 0 | 0 | 26 | 100 | 0 | 0 |
| 6 | | 36 | 0 | 0 | 36 | 100 | 9 | 25 |
| 7 | | 93 | 0 | 0 | 93 | 100 | 13 | 14 |
| 8 | | 77 | 0 | 0 | 77 | 100 | 15 | 19 |
| 9 | | 42 | 0 | 0 | 42 | 100 | 13 | 31 |
| 10 | | 41 | 0 | 0 | 41 | 100 | 17 | 41 |
| 11 | | 84 | 0 | 0 | 84 | 100 | 22 | 26 |
| 12 | | 38 | 0 | 0 | 38 | 100 | 1 | 3 |
| 13 | Major Occupation (XU 2-33) 2730-2530 cal BP | 27 | 0 | 0 | 27 | 100 | 0 | 0 |
| 14 | | 6 | 0 | 0 | 6 | 100 | 0 | 0 |
| 15 | | 4 | 0 | 0 | 4 | 100 | 0 | 0 |
| 16 | | 4 | 0 | 0 | 4 | 100 | 0 | 0 |
| 17 | | 6 | 0 | 0 | 6 | 100 | 0 | 0 |
| 18 | | 1 | 0 | 0 | 1 | 100 | 0 | 0 |
| 19 | | 3 | 0 | 0 | 3 | 100 | 0 | 0 |
| 20 | | 5 | 0 | 0 | 5 | 100 | 0 | 0 |
| 21 | | 3 | 0 | 0 | 3 | 100 | 0 | 0 |
| 22 | | 3 | 0 | 0 | 3 | 100 | 0 | 0 |
| 23 | | 4 | 0 | 0 | 4 | 100 | 0 | 0 |
| 25 | | 6 | 0 | 0 | 6 | 100 | 0 | 0 |
| 27 | | 2 | 0 | 0 | 2 | 100 | 0 | 0 |
| 29 | | 2 | 0 | 0 | 2 | 100 | 0 | 0 |
| 31 | | 5 | 0 | 0 | 5 | 100 | 0 | 0 |
| 33 | | 1 | 0 | 0 | 1 | 100 | 0 | 0 |
| Totals | | 556 | 0 | | 556 | | 90 | 16 |

## Moiapu 2 — Square C

Moiapu 2 was excavated in 2009 (Richards et al. 2016b:2) and the results are presented in David et al. (2016c:1). It is located 1.3 km inland from the shore of Caution Bay in an area of undulating hinterland hills. The site is located on a relatively flat section of the hill with steep slopes to the east and gentle slopes to the north and west. Moiapu 2 was identified from a surface scatter of lithics, ceramics, and shell spread over an area of 35 m by 35 m. A total of five squares was excavated, ranging in depth from 65 cm to 105 cm. Three distinct SUs were noted at Moiapu 2, including SU 1, SU 2 (a, b and c) and SU 3, with most cultural material occurring in SU 2 and less in SU 1. Radiocarbon determinations indicated that the oldest part of this site dates to 2700–2570 cal BP and the most recent dates to 1750–1540 cal BP. Cultural material at the site indicated one

period of intense human activity (SU 2) present in all squares that ranged from 2660–2230 cal BP with a second, less intense period of occupation during terminal Lapita times, dating to 2720–2530 cal BP. There was limited evidence for deposition of cultural materials in levels dating to 1700–1590 cal BP. Cultural materials included a wide variety of marine and terrestrial faunal remains as well as a variety of lithics and ceramics.

Square C was selected for this research. It contained 324 stone artifacts recovered from 23 XUs (Mialanes 2016e) of which 129 artifacts from 11 XUs were selected for pXRF analysis (Table 14). Five types of raw material were present, including chert, obsidian, quartz, chalcedony, and unidentified igneous material. Only three of these raw materials were recovered from Square C, including chert (98.3%), obsidian (1.0%), and unidentified igneous material (0.6%). The artifacts that were not included in this analysis either did not meet the testing criteria, or were not readily identified as chert. Stone artifacts were recovered from most XUs, but were present in largest numbers between XUs 6 and 7. The majority of chert artifacts at Moiapu 2 were broken flakes (74.1%), followed by complete flakes (13.2%), flaked pieces (11.5%), potlids (0.6%), and unipolar cores (0.6%). There was a high proportion of small flakes, averaging 0.8 g in weight and 10.5 mm in length. All flakes appeared to be the result of unipolar free-hand percussion and Mialanes (2016e:19) concludes that multiple knapping events likely took place. The rarity of artifacts displaying cortex suggests that initial reduction stages took place off-site. The presence of small complete flakes, however, confirms that chert reduction also occurred *in situ* at all five squares. There was evidence for heat alteration on chert artifacts, but none of the flakes showing evidence of burning have any further modifications. Mialanes (2016e:33) concludes that the heat alteration was either due to the purposeful burning of the flakes from disposal into fire pits or accidental burning from wild or controlled fires and is not evidence of purposeful heat treatment.

***Table 14: Lithic artifacts, temporal sequence and selections for pXRF testing from the Moiapu 2 collection.***

| Moiapu 2, Square C, Stone Artifact Numbers | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| XU | Chronological Period | Total Stone Artifacts | Not Chert | % Not Chert | Chert | % Chert | Chert Items Tested | % of Chert Items Tested |
| 1 | | 4 | 0 | 0 | 4 | 100 | 2 | 50 |
| 2 | | 11 | 1 | 6 | 10 | 91 | 0 | 0 |
| 3 | Major Cultural material (XU 3 to 12) c.2720-2530 call BP | 16 | 0 | 0 | 16 | 100 | 2 | 13 |
| 4 | | 28 | 1 | 1 | 27 | 96 | 7 | 26 |
| 5 | | 70 | 0 | 0 | 70 | 100 | 15 | 21 |
| 6 | | 123 | 2 | 2 | 121 | 98 | 35 | 29 |
| 7 | | 109 | 1 | 2 | 108 | 99 | 38 | 35 |
| 8 | | 62 | 0 | 0 | 62 | 100 | 11 | 18 |
| 9 | | 55 | 1 | 8 | 54 | 98 | 11 | 20 |
| 10 | | 12 | 1 | 33 | 11 | 92 | 5 | 45 |
| 11 | | 3 | 0 | 0 | 3 | 100 | 1 | 33 |
| 13 | | 21 | 2 | 200 | 19 | 90 | 0 | 0 |
| 16 | | 1 | 0 | 0 | 1 | 100 | 1 | 100 |
| **Totals** | | **515** | **9** | | **506** | | **128** | **25** |

# Conclusions

This chapter has provided an introduction to the data set used for this research. In total, 12 squares from 12 different sites were chosen for analysis. A total of 2,454 artifacts were selected for pXRF analysis. The criteria by which artifacts were selected were influenced by the analytical method, and this has potentially introduced an unquantifiable bias to the sample. The potential for sampling bias is acknowledged, and its possible effects on the results of this research will be discussed in later chapters.

# Chapter 7: Laboratory Procedures for pXRF Analysis of Caution Bay Chert Artifacts

Before conducting the Caution Bay pXRF analyses, an extensive literature review was conducted to determine best practice in laboratory applications of pXRF and XRF equipment (e.g. Frahm 2013b; Frahm and Doonan 2013; Goodale et al. 2012; Grave et al. 2012; Sheppard et al. 2011; Speakman et al. 2011). While variability exists in the methods used by previous researchers due to the range of research questions investigated, certain commonalities exist. Some of these common practices, such as cleaning artifact surfaces before testing (Sheppard et al. 2011:48), the length of testing time, and pXRF instrument settings (Davis et al. 2012), were easily incorporated into the methodology for this research. Others, such as mechanically preparing a testing surface by grinding it smooth or turning the test artifact into a homogenous powder for testing (Stevenson and Klimkiewicz 1990), were avoided due to the requirement to maintain artifact integrity. Not conducting invasive surface preparation or powderedized testing likely introduced an unquantifiable bias to the results. As it was not possible to damage the artifacts, these additional sample preparation methods were simply unavailable.

As the number of pXRF instrument manufactures increases, the affordability of pXRF instruments also increases. More affordable pXRF instrumentation means more institutions and organizations can purchase these instruments. This results in an increased number of archaeologists experimenting with pXRF and testing the methods associated and application of the technology. As the research presented here is attempting a novel way of using pXRF to explore the relationships between chert artifacts it was determined that the entire methodology used for each step of the testing process should be documented and included in the thesis. The methodology is presented in detail here in the body of the thesis to ensure that readers are aware of the methods employed during testing and how these methods may enhance or limit the quality of data produced.

Along with the literature review, a variety of simple tests were carried out with the pXRF instrument to establish the best methods to process the artifacts and to determine

the parameters of the instrument. These preliminary tests involved using different settings on the instrument, different degrees of sample preparation, and discussions with a statistician about which methods were providing the most valuable data. Although they will not be presented as part of this research, the results of these early explorations provided the basis for the development of a formal data collection strategy and protocol designed to produce the largest quantity of reliable data in the most efficient way possible. A detailed description of the pXRF data collection methods employed for this research follows.

## Artifact Preparation

All artifacts were washed using distilled water and an ultrasonic bath before analysis (Lundblad et al. 2008:4). This was done to eliminate the possibility of surface contamination when taking readings with the pXRF instrument. The ultrasonic bath used for this research was a Power Sonic 405" made by HWASHIN Technology Co. and located in what was then the School of Geography and Environmental Science (now Monash Indigenous Studies Centre) quarantine laboratory at Monash University. Each artifact was washed in this bath for between 10 and 30 minutes. Artifacts that received longer cleaning times all had hard sand concretions. If these concretions had not been removed after 30 minutes, the artifact was excluded from the research. After washing, the artifacts were placed in aluminum laboratory trays to dry at room temperature for a minimum of 24 hours. This drying also took place in a restricted access quarantine laboratory to minimise the potential for subsequent contamination by dust or foreign materials.

## The pXRF Analysis Procedure

Once dried, artifacts were ready to undergo pXRF testing. Although the pXRF instrument used for this research was designed to be portable, it can be set up in a test stand with a shielded hood to protect the user from stray X-ray radiation (Thermo Fisher Scientific 2011). When this stand is used, an attached laptop computer can operate the instrument remotely, enabling repeated testing using the same parameters and test times. Each artifact was placed on this test stand with its flattest surface parallel to the

testing aperture on the pXRF instrument. The testing aperture on the instrument is a circular opening 8 mm in diameter and is located on the centre of the rectangular nose of the instrument. With long, thin artifacts, the longest axis of the artifact was oriented parallel to the longest axis of the nose of the instrument. If the artifact undergoing testing did not cover the entire aperture or if the artifact appeared to bow up from the underlying aperture (concave surface) or bend down into the aperture (convex surface), then these observations were noted along with the artifact's chemical data reading. These extra observations were recorded in order to have further avenues of exploration in the case of anomalous results.

Once an artifact had been positioned, the shield hood was closed, and testing was initiated. Each artifact was tested for a minimum of 180 live seconds using the factory designated *TestAllGeo mode* setting. This setting was chosen as it provided results for the greatest number of elements. Up to 44 elements could be detected in this setting, covering a range from Magnesium (Mg) to Uranium (U). The *TestAllGeo mode* makes use of four different filters within the instrument and measures elements from the heavy metals all the way up to the light elements. These filters are referred to as the Low, Main, High, and Light filters, and each corresponds to the weights of the elements they can record. On some of the preliminary artifacts, a second or third 180-second test was conducted using alternative settings (the factory designated *Soils* and *Metals modes*) as an additional means of testing the accuracy of the instrument. The results of this additional testing will not be discussed in relation to the artifacts.
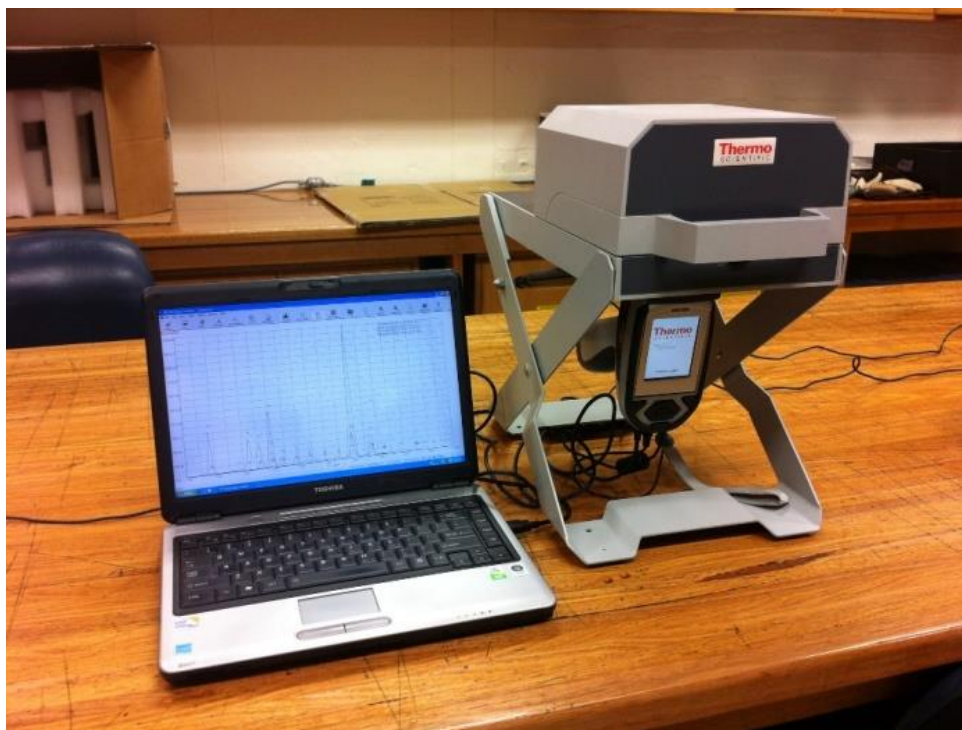
***Figure 7: Niton pXRF instrument used in this research shown in shielded test stand and connected to a PC.***

The total time required to process each artifact was approximately five minutes. This time included placing the artifact on the pXRF instrument, taking the reading, and entering the relevant artifact identification information in the pXRF instrument and a complimentary backup database. This additional database contained all the artifact number information from the pXRF instrument and a variety of further observations about the artifacts. In addition to the information about how the artifact appeared while being tested, as discussed above, notes about the visual appearance of each artifact were entered into this database. These included, but were not limited to, the texture, colour, and presence/absence of inclusions and cortex on the surface being tested. Although efforts were made to test artifacts with no cortex present on the testing surface, this proved to be a challenge due to limitations of the sizes of artifacts in the various site assemblages. Therefore, to maintain adequate sample sizes, occasional artifacts that contained cortex or inclusions on a remote portion of their flattest surface but still contained an area as large as the testing window on the pXRF instrument were included

in the research. Inclusions, cortex, and colour differences that were not located on the tested surface were not recorded. The washing, drying, and subsequent pXRF testing of artifacts took place from September 2012 to April 2013.

In total, 2,545 artifacts from 12 different sites were analysed using the *TestAllGeo mode* setting. Of these, 766 artifacts, all from the Bogi 1 site, were also tested using the *Soils mode* and *Metals mode.*

In order to ensure that the instrument was functioning properly, an internal system test was conducted at the beginning of each day's testing, and these results were recorded within the instrument's database (see Appendix 1). In order to assess the consistency and accuracy of the instrument and to provide a means of facilitating the comparison of the pXRF data collected here to other chemical testing systems and/or other XRF equipment, a series of CSRMs were also tested at the beginning of each testing event (Davis et al. 2012:668; Lundblad et al. 2008:5). The CSRMs used were provided with the instrument and included a Silicon Oxide blank (99.9% $SiO_2$) and a variety of other geological CSRMs including NIST 2780 (hard rock mine waste), CCRMP TILL-4PP (geological till sample), and RCRApp (laboratory metal standard). A detailed description of each of these CSRMs is provided in Chapter 5. Known chemical composition and factory-produced quality control data were provided with these CSRMs. Records of each of these tests were made in order to monitor instrument drift (Drake et al. 2009:14) and ensure reading quality over the duration of the research (see Appendix 2). The results of these internal and CSRMs tests are also discussed in detail in Chapter 5.

## Conclusions

This chapter has presented in detail the methods used for each step of the testing process. The methods employed represent best practices as noted by the relevant literature and by direction from the pXRF manufacturer (Niton). It bears repeating that these procedures have been documented in detail here to provide an explanation of what methods were used to collect the data. Although this may seem

trivial, there is an over-abundance of published research relating to the use of pXRF and its application to a wide variety of materials in which the testing procedures are not adequately documented. Information about the pXRF instrument, its settings, and the length of time for each test are often included, but other details such as those provided here are not. With the wider use of pXRF as a multi-purpose tool by the archaeological community, it is imperative that this information is included when publishing research relating to pXRF.

# Chapter 8: Assessing the Function of the pXRF Instrument

Before conducting any experiment, it is imperative to ensure that the equipment that is being used is functioning as it should be. As discussed in Chapter 5, it is commonly assumed that each pXRF unit made by any manufacturer will have some variability. The potential variability between instruments made by different manufacturers is even greater. In addition, some pXRF instruments have far more options for changing, adjusting and manipulating internal testing settings than others. The data gathered for this thesis was collected using an 'out-of-the-box' pXRF instrument in factory settings, and no additional adjustments were made to the instrument. It was very important to access not only the functioning of the instrument, but also to establish a baseline with which to allow future comparisons of the data collected for this research using different instruments.

This chapter addresses the procedures conducted to ensure the pXRF instrument used for the analyses operated in an accurate, consistent, and reliable manner throughout all of the testing. These methods included both the built-in controls that came with the pXRF instrument, and the comprehensive testing carried out on a set of CSRMs. This chapter also addresses the most common concerns raised in the academic literature in reference to pXRF studies – the issues of comparing data from one pXRF instrument to data collected by another – and will provide details how these concerns were addressed in this research. The following discussion will rely on the scientific element name abbreviations; a periodic table of elements is provided in Appendix 5 for reference.

It should be reiterated here that this thesis is not attempting to provide details about the exact chemical composition of geological samples of chert; that is a task that is arguably still beyond the abilities of most pXRF instruments. This thesis is instead applying a tool (pXRF) to a collection of otherwise generally neglected artifacts to see if the data that is generated (geochemical information) is sufficient to be used to identify chemically distinct groups of chert that can then be used in discussions of how chert

artifacts can be added to the archaeological interpretations of cultural changes. The chemical results have been produced using a single pXRF instrument and for the research carried out here, it was not a requirement that the data be comparable with chemical data produced by other means. It was understood before commencing this work that pXRF testing would likely have some limitations when applied to a relatively unstudied material such as chert. The methodology, analysis, and presentation of results that follow have been presented in detail to ensure that any future researchers that may use the data set will be able to do so knowing each step of the methodology (and any associated limitations).

## Built-in Controls

The first and most important control that was used to ensure consistency in the data collection was the built-in control of the Niton pXRF instrument. Following the instrument manual, prior to each day's testing the internal systems check was run. The built-in systems check conducts a set of tests on a titanium blank housed within the testing aperture of the instrument. The readings taken during this process are compared to the factory-tested settings that have been programmed into the instrument to ensure that the instrument consistently reads at the factory-defined accuracy level. This internal system check also examines various other settings and conditions necessary for optimum functioning of the instrument, including items such as instrument temperature, instrument pressure, and software glitches. All of these tests and checks are conducted internally by the instrument. The only results of these tests accessible to the user are a Pass/Fail report that is provided on the screen of the instrument and a blank "System Check" entry in the data output log. The Niton user manual (Thermo Fisher Scientific Inc. 2011) directs the user to contact the manufacturer if a fail report is produced. During testing for this research, no fail reports were received. These results demonstrate internal consistency for this pXRF instrument and suggest that all results produced by this instrument were reliable.

# External Controls: CSRMs

A second set of tests was conducted to ensure that no unidentified software problems were occurring within the pXRF instrument. This second step involved daily testing of a selection of certified scientific standard material samples. This step was conducted in order to ensure that the pXRF instrument was reading consistently and accurately over the duration of the project. The results of this test are also valuable for inter-instrument data comparisons and are presented in Appendix 2.

CSRMs come in many forms, including powders, solids, liquids, and gases. Each standard sample has been tested at and by an International Standards Organization (ISO) accredited laboratory and is certified to contain a specific amount of one or more elements. CSRMs are typically given internationally recognised ISO name codes. Each standard sample is provided to the end user with a document identifying the element(s) present and certifying the quantity of the element(s) present.

Four CSRMs were selected for use in this research, all of which were provided with the pXRF instrument by the instrument manufacturer. The four CSRMs are NISP 2780, RCRA, TILL 4, and SiO2. Three of these CSRMs, NISP 2780, RCRA, and TILL 4 are geological standard materials containing a variety of elements in varying quantities. The fourth, SiO2, is a blank and contains only one element, Si. A brief description of each of the CSRMs follows, and the certified values for each as provided by the manufacturer are presented in CANMET (1995), Hach Company (2014), High Purity Standards (2013), and National Institute of Standards and Technology (2012). A copy of the pXRF instrument manufacturer's Certificate of Calibration is provided in Thermo Fisher Scientific Inc. (2010). The Certificate of Calibration contains the certified quantity values for each of the elements included in the certification along with other valuable data about the standard that was recorded with the pXRF instrument at the time of manufacture.

### NISP 2780

This chemical standard is a geological rock sample from an abandoned hard rock mine waste pile located near Silverton, Colorado, USA. The standard was certified by the National Institute of Standards and Technology (NIST) of the United States of America Department of Commerce in 2012 (National Institute of Standards and Technology 2012). This standard is provided as a loose powder and is used in a compressed plastic canister with a very fine membrane of ¼ mil (0.0064 mm thick) polypropylene film covering the testing portion of the canister. This covering is designed in such a way as to have no effect on the readings of the pXRF instrument (Thermo Fisher Scientific Inc. 2011). The standard is guaranteed to contain certified quantities (Certified Mass Fractions) of the following major elements:

- Al
- Pb
- Na
- As
- Ca
- Mg
- S
- Cd
- Fe
- K
- Zn
- Hg

Of these, the Niton instrument was certified to accurately access Fe, Pb, K, S, and Zn. This standard was also certified to contain the following elements in reliably consistent quantities (Reference Mass Fractions): Ti, Ba, Cu, Mn, P, Sr, and V. Of these, the Niton instrument was certified to accurately measure Ti, Ba, Cu, Mn, and Sr in parts per million (ppm). Further information about this standard is provided in the NIST Certificate provided in National Institute of Standards and Technology (2012) and the 'Thermo Fisher Scientific Certificate of Calibration' (Thermo Fisher Scientific Inc. 2010).

### RCRA

The complete name of this standard is ICP-RCRA-1, and it is a metals standard. This standard is created in a laboratory by combining various single element solutions that are ISO Guide 34 certified. The physical standard used for this research was created by High-Purity Standards in their laboratory located in North Charleston, South Carolina (High Purity Standards 2013). The standard is certified after its creation for a year from the purchase date. As with the previous standard, RCRA is provided as a loose powder and is tested in a compressed form in a plastic canister with a

polypropylene film window. The standard is guaranteed to contain certified quantities (Certified Mass Fractions) of the following major elements: As, Ba, Cd, Cr, Cu, Pb, Ni, and Zn. Of these, the Niton instrument was certified to accurately measure As, Ba, Cd, Cr, and Pb. Further information about this standard is provided in the 'High-Purity Standards Certificate of Analysis' High Purity Standards (2013) and the 'Thermo Fisher Scientific Certificate of Calibration' provided in Thermo Fisher Scientific Inc. (2010).

## *TILL-4*

This standard is a mix of geological samples taken from two locations. The first material comes from a glacial till horizon sourced from a surface mine near Scission's Brook, New Brunswick, Canada. The second material comes from a natural geological molybdenite occurrence near Hull Quebec, Canada. The standard was certified by the Canadian Certified Reference Materials Project (CCRMP) Mining and Mineral Sciences Laboratories in Ottawa, Canada in 1995 (CANMET 1995). As with the previous CSRMs, this one is provided as a loose powder and comes in a compressed plastic canister with a polypropylene testing window. The standard is guaranteed to contain certified quantities (Certified Mass Fractions) of the following major elements:

- As
- Au
- Ba
- Be
- Bi
- Br
- Ce
- Co
- Cr
- Cs
- Cu
- Eu
- Er
- Fe
- Hf
- La
- Li
- Mo
- Nb
- Ni
- P
- Y
- Yb
- Pb
- Rb
- S
- Sb
- Zn
- Zr
- Sr
- Ta
- Tb
- Th
- Ti
- U
- V
- W

Of these, The Niton instrument was certified to accurately access Sr, Rb, W, Cu, Fe, Ti, and Ba. Further information about this standard is provided in the CCRMP Certificate (CANMET 1995) and the Thermo Fisher Scientific Certificate of Calibration (Thermo Fisher Scientific Inc. 2010).

### SiO₂

This chemical standard is a single element blank produced in a laboratory and is available from many different manufacturers in accordance with ISO Guide 34:2009 and ISO/IEC 17025:2005 (Hatch Company 2014). This standard can originate from quartz deposits in many parts of the world, and the location is typically only provided with the original purchase of the standard. This standard is provided as a very fine quartz powder and like the previously discussed CSRMs, is provided in a compressed plastic canister with a polypropylene testing window. As this standard was provided by Niton, no certificate is available for it. Further information is provided in the Thermo Fisher Scientific Certificate of Calibration document (Thermo Fisher Scientific Inc. 2010).

Of the four CSRMs, initially, only three, RCRA, Till4, and SiO₂ were tested. Midway through the testing, the fourth standard (NISP) was added as it was identified as a standard more commonly used in North America than other parts of the world. It was hoped that by including it in this research, future comparisons between the data presented herein and work being conducted in North America would be facilitated and encouraged.

Regardless of when the standard was added to the research methodology, the testing procedure was the same. Each of the CSRMs was tested every morning prior to testing any of the artifacts, and directly after conducting the internal system calibration test. Through the course of the testing, all of the CSRMs were tested using both the Soils mode and the *TestAllGeo* mode. The Soils mode was used predominantly due to the recommendations provided in the Thermo Fisher Scientific Niton XL3 Analyzer users guide.pdf (Thermo Fisher Scientific Inc. 2011) but also because this mode is specifically designed to test for a smaller range of elements that includes all of the certified elements in the CSRMs. The results for this mode will, therefore, produce slightly more accurate data for the certified elements while also providing less peripheral data. The *TestAllGeo* mode was used in order to ensure that the mode being used for the main research data would provide results comparable to as many other data sets as possible. As has been explained earlier, due to the built-in factory calibrations, the two modes used on the

pXRF instrument provided slightly different readings for certain elements in the CSRMs. These two modes tested for different ranges of elements as well, resulting in the *TestAllGeo* mode producing results for elements not tested for in the Soils mode.

The results of each of these tests were recorded along with the results of each day's testing. These were then compared to the published data for each of the CSRMs on a daily basis. Though there were some differences noted between the results of the two testing modes, the majority of the results for the elements in all CSRMs were within the appropriate quantities for all the testing modes.

The comparisons previously mentioned for daily laboratory purposes simply involved comparing each day's results to the certified values of the elements present in the standard. Upon completion of the data collection, the results for each standard were analysed using exploratory statistics to investigate the range of the readings and the degree to which each of the calibration modes changed. The results for this more complete analysis and testing of the pXRF results for each of these CSRMs are provided and discussed here.

## Descriptive Statistics for CSRMs

Descriptive statistics for each standard were calculated, first for the results using the *Soils mode*, and then for the *TestAllGeo mode*. For each element, the mean, standard error of mean, median, standard deviation, minimum, maximum, and range were calculated. For ease of comparison, all the elements tested were included in this step of the analysis even if very few or no (nil) readings were provided for that element. There are two possible explanations for a nil result for an element. The element was not tested for in that particular mode, or the element was tested for, but was not present in a quantity large enough for the instrument to detect and measure. Appendix 3 provides all of the descriptive statistical information from the testing of the four standard materials during the course of the data collection for this research.

The standard deviation measurement is the most valuable descriptive statistic, as it provides information about the distribution of the readings. The vast majority of the results for the elements in these four CSRMs have values that are within the two standard deviation limit and are therefore normally distributed. This result indicates that the instrument was reading consistently on a daily basis. To provide further support for this conclusion a set of standardized value frequency graphs were generated for each of these readings. These graphs are presented in Appendix 3 Section 3, and a discussion of the results for each of the CSRMs is presented here.

## Results of Standard Testing – Discussion

### SiO$_2$

The SiO$_2$ is considered to be a blank, and it was expected that it would have been below the level of detection (<LOD) or zero ppm readings for all of the elements being examined with the exception of Si. The reading for Si was expected to be 99.8%, the same as the certified value. Though many of the elements tested for did produce results that were the expected <LOD or zero ppm readings, a number of elements did not. The presence of measurable quantities of elements in this standard was unexpected based on the certified standard value. The Certificate of Calibration provided with the Niton instrument (Thermo Fisher Scientific Inc. 2010), however, indicates that such a result is in line with the appropriate factory settings for the instrument. This certification document indicates a wide range in the expected quantity of certain elements in this standard. It also indicates that Hg and Fe should have readings greater than the instrument's LOD. Based on the factory Certificate of Calibration results, the test results for this standard indicate that the pXRF instrument was working as expected during the entire testing program.

### Soils Mode Results

The *Soils mode* tests indicated that Ca, Cr, Fe, Hg, K, S, and V all had quantities that were measurable and present in this sample. Silicon was not tested in this mode. All of the elements that produced results were well within the ranges specified on the manufacturers supplied Certificate of Calibration (Thermo Fisher Scientific Inc. 2010).

The standard deviation for the various readings for each of these elements varies, but so do the measured values. Table 3-1 in Appendix 3 provides the results of the CSRMs analysis for each of the elements for which calibration data was provided. This table indicates consistency of the readings based on the statistically normal distribution of the resulting values. The results for this standard indicate that the pXRF instrument was always functioning correctly.

### *TestAllGeo Mode Results*

*TestAllGeo mode* tested for Si and showed the expected quantities. This mode also indicated that Al, Ca, Cl, Cr, Hg, Pd, P, K, Ag, and V were present in detectable and measurable quantities in this standard. The manufacturer does not provide expected results for Al or P. All of the other elements produced results that were within the ranges specified on the manufacturer's supplied Certificate of Calibration (Thermo Fisher Scientific Inc. 2010). Overall, results are within the expected range of values, but in some cases, elements had unexpectedly high result values. It was not possible to discern the cause of these higher than expected results, but it could relate to both the natural variation in the sample readings and the programming of the pXRF instrument. This standard is designed to be used with the *Soils mode,* so it is possible that the high standard deviations found in the *TestAllGeo mode* relate directly to the internal pXRF processing software. Table 3-1 in Appendix 3 provide the results of the CSRMs analysis for each of the elements for which calibration data was provided. All the elements except for Cl and P have consistently cohesive results.

### Till-4

The Till-4 standard was expected to have known quantities of Sr, Rb, W, Cu, Fe, and Ti. Expected element ranges for Till-4 were less than those of the $SiO_2$ standard, but once again, the Certificate of Calibration provided with the Niton instrument (Thermo Fisher Scientific Inc. 2010) indicates a wide range of expected readings for the elements in this standard. Although there is some variation within the individual reading results for the Till-4 standard, the calculated mean results for both testing modes fall within the expected range provided by the manufacturer. Again, these results indicate that the instrument was working correctly for the duration of the testing.

**Soils Mode Results**

The six elements that were expected to be present in the Till-4 standard are tested for also in *Soils mode.* For all six of these elements, the mean measurements were within the expected error margin provided by the manufacturer, and in many cases, they were close to the certified values for that standard. A large number of other elements for which certified values were not provided were present in this standard. These non-certified elements provided values that fit well within the error range provided in the manufacturer's Certificate of Calibration (Thermo Fisher Scientific Inc. 2010). Table 3-2 in Appendix 3 provides the results of the CSRMs analysis for each of the elements for which calibration data was provided. The data indicate that most of the elements from this standard provided consistent results. Elements that do not show this consistent result include Co, Au, Hg, Sc, Te, and Sn. It is likely that these results reflect the internal pXRF processing software and the choice of analysis mode.

***TestAllGeo Mode Results***

The *TestAllGeo mode* tests for all of the six elements certified to be present in the Till-4 sample. As with the results for the *Soils mode*, the means for all six of these elements were well within the expected error margin provided by the manufacturer's Certificate of Calibration and, in many cases, they were also very close to the certified values. Again, a large number of other elements were present in this sample that do not have certified values. As with the *Soils mode* results, the values for these elements fit well within the ranges provided in the manufacturer's Certificate of Calibration (Thermo Fisher Scientific Inc. 2010). Table 3-2 in Appendix 3 provides the results of the CSRMs analysis for each of the elements for which calibration data was provided. All the elements except for Mg, Hg, Tin, Cl, and U have the expected consistent results. Again, it is likely that the inconsistent results are a result of the internal pXRF processing software and the choice of analysis mode.

**RCRA**

The RCRA standard was expected to contain certified quantities of Pb, Se, As, Cr, Cd, and Ag. The Certificate of Calibration provided with the Niton instrument

(Thermo Fisher Scientific Inc. 2010) indicated a range of expected readings for these elements. Of the six certified elements, only one, Pb, fell within the expected certified range. Even though the Pb results fell within the certified range, they were lower than expected. The other five certified elements were all present but in quantities that were much lower than the results provided in the manufacturer's Certificate of Calibration for this standard. These results indicate that the pXRF instrument was reading consistently, but was getting different values for the selected elements, a result that is most likely associated with the testing mode. This is a metal standard and testing it with an instrument mode designed for metals instead of general element analysis may have resulted in different values, possibly ones that would be closer to the certified values.

### Soils Mode Results

The six elements that were expected to be present in the RCRA standard were tested for in the *Soils mode*. For all six of these elements, the means were within the expected ranges, with all but Pb falling on the low side of the range. A large number of other elements were also present in this sample, and although they were not elements for which certified values are present, they provided results that were consistent with the others. The results from testing this standard provided values that are generally lower than those certified. Even though these results are different than expected, the ranges of these values and the standard deviations indicate that all the readings provided very similar, if consistently low, results. Table 3-3 in Appendix 3 provides the results of the CSRMs analysis for each of the elements for which calibration data was provided. The data shows that the majority of the elements in this standard provided reliable results when tested in this mode. These results indicate consistency in the pXRF instrument reading but an inaccuracy in the reading value. As with the other CSRMs, the differences in these results were interpreted as a result of the internal pXRF processing software and likely would have been different if tested using a metals-focused mode.

### TestAllGeo Mode Results

Four of the six elements that were expected to be present in the RCRA standard were tested for in this mode, with the exclusion of Cd and Ag. As with the results for *Soils mode*, all elements tested for in this mode provided values below those expected.

In particular, the values for Pb were much lower than expected. As with *Soils mode*, a number of other non-certified elements were present in this sample. The results for these elements indicated that there was more variety in these results than those for the *Soils mode* tests. Some of these elements have values that are lower than expected and others have values very close to the expected quantities. Element values for this standard were generally different from the expected values. The range of values and the standard deviations, however, indicated that the readings were all similar to each other and similar between modes. This similarity indicates consistency of the pXRF instrument's readings regardless of the inaccurate quantity result. Table 3-3 in Appendix 3 provides the results of the CSRMs analysis for each of the elements for which calibration data was provided. The data indicates that most of the elements in this standard provide results that are consistent and cohesive. RCRA is a metal-based standard, and it is presumed that the Metals mode would have provided equally consistent but more accurate reading if it had been used. The range of results from the *TestAllGeo mode* on this standard is attributed to the internal pXRF processing software and the choice of analysis mode.

**NISP 2780**

The NISP 2780 standard was expected to have known quantities of Sr, Pb, Zn, Cu, Fe, Mg, Ti, K, and S. The mean of the values of the readings from almost all of these elements was well within the ranges provided by the Certificate of Calibration provided with the Niton instrument (Thermo Fisher Scientific Inc. 2010). The two elements that had mean readings that did not fall within the range of certified values were K and S. The results for K in the readings from the two modes were very similar, and both were just over the high end of the range provided in the Certificate of Calibration. The mean results for S were low, and within the certified range in the *Soils mode*, but were greater than the high end of the range in *TestAllGeo mode*. These results were unexpected and not easily explained. It is assumed that the difference in results for S between the two modes is the result of the instrument's internal operating system. Though there is some variation within the results for other elements, the calculated mean for both modes is generally within the range provided by the manufacturer and the readings for all

elements, with the exception of As, Co, Hg, Ni, and U in the *TestAllGeo mode* results which were closely grouped and indicated consistent readings and results from the pXRF instrument.

### Soils Mode Results

The nine elements that were expected to be present in the NISP 2780 standard were tested in *Soils mode*. For eight of these elements, the mean measurements were well within the expected error margin, and in many cases, they were very close to the certified values, fluctuating slightly higher or lower than the actual certified value. K was the only element that had a mean value that was outside the range of certified values, and the measured value was greater than the certified range. A number of other elements were also present in this sample and although these were not elements for which certified values are present, they once again fit well within the error ranges provided in the manufacturer's Certificate of Calibration. Table 3-4 in Appendix 3 provides the results of the CSRMs analysis for each of the elements for which calibration data was provided. The results for the various elements in this standard were all accurate and consistent.

### TestAllGeo Mode Results

The *TestAllGeo mode* also tests for all nine of the elements certified to be present in the NISP 2780 sample. The results for this mode were more varied than those for *Soils mode*. Seven elements produced mean values that fell within the certified range of values and two produced mean values that were outside this range. Both K and S have mean values higher than the certified range. Although these values were outside of the certified range, they still clustered together tightly, indicating consistency in the readings. Non-certified elements were present in this sample, and the mean values for these elements fell well within the error ranges provided in the Certificate of Calibration. Table 3-4 in Appendix 3 provides the results of the CSRMs analysis for each of the elements for which calibration data was provided. The values for this standard appear to have the least cohesive range of results for all the standard and mode combinations. This result is likely related to the very small number of readings taken on this standard.

# Results and Conclusions of Standard Testing

Two important observations can be made from an analysis of the results of the pXRF testing on the four CSRMs. The first observation is that the measured values for each of the certified elements in the CSRMs were not consistently the same as the certified values. This observation was initially a cause for concern, as these results can be interpreted as an indication that if a certified value is not reproducible, then the pXRF instrument is not functioning at a level that can provide data suitable for research. This is not the case, however, as the few anomalous results can be explained by other factors. All of the CSRMs used for this research were provided with the pXRF instrument, and they are generic CSRMs. Future research of this sort would benefit from the selection of CSRMs that were specifically selected for the testing mode being used and representative of the materials being tested. Thermo Scientific, the pXRF instrument manufacturer, indicates on their website (http://www.thermoscientific.com/en/product/niton-xl3t-ultra-analyzer.html) that if a researcher is looking for a specific element within a sample, a factory recalibration can be conducted that will heighten the sensitivity of the instrument for that element or range of elements. In the future, researchers applying pXRF to chert in the Caution Bay area would benefit from having their instruments calibrated to look for the elements shown to be valuable for chemical characterization herein (see Chapter 10).

The second, and more important, observation is that for most of the elements tested in all of the CSRMs and with both of the modes that were used, the results were generally consistent even if the values were not what were expected. The relationship between the standard deviation and the mean values for all the measured elements in both testing modes indicated that the results were all consistently similar. This observation is supported by the patterns displayed in the frequency graphs presented for each mode and standard. With these observations, it is possible to conclude that the results of testing these CSRMs indicate that the pXRF instrument was functioning consistently and reliably on a day-to-day basis. The data indicate that the results of the daily testing on archaeological specimens were as accurate as possible and did not have any inconsistencies that can be attributed to the pXRF testing methodology.

The discussion of the CSRMs data and the conclusions drawn from it provide a solid foundation for the analysis of archaeological artifacts that follows. It has been pointed out by Speakman and Shackley (2013) that internally consistent results, such as those presented here, can be interpreted as "silo science". It is true that the data provided here might be different from data provided by an alternative pXRF instrument; however, the tools required to compare this data set to data collected by another instrument have been provided by the addition of the CSRMs testing in this research. Future researchers who wish to compare their results to those provided herein can make the appropriate calculations to transpose these results so that the readings from two different pXRF instruments on the CSRMs listed here are the same. Using the results of the CSRMs as a key, the readings from two different PXRF instruments will be comparable. All of the results from the raw data output from the pXRF instrument have been provided in Appendices 1 and 2, to facilitate the possibility of future research relating to this assemblage. In addition, details of all the statistical analysis conducted for this work are provided in Appendix 3.

This chapter has presented the methodology used to ensure that the pXRF instrument used for this research was working properly and to the best of its abilities and has also provided the data needed to make accurate comparisons between the data collected by the pXRF instrument for this work and that from future research. Although the information provided in this chapter can be used to some degree as such, it was not intended to be an experiment to determine the potential to use pXRF to build an accurate chemical profile for chert. This research has been conducted using a pXRF instrument that came pre-programmed from the manufacturer to generate data. For the purposes of this research, it was assumed that the manufacturer settings were accurate and more than appropriate for the exploratory nature of the questions being asked. It is understandable that older pXRF units may have a wide range of inconsistencies depending on when, where, and how they were made, and have made archaeologists nervous about using the data that has been produced by them at face value. The methods described in this chapter, and the results they produced, suggest that as long as a researcher is aware of the limitations of the pXRF unit for the work in question, it is time to start trusting the manufacturers of these instruments. It is time to move the

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debate from "does pXRF provide accurate results?" to "what do the results that pXRF provide tell us about the item being studied?". That is the overall question that is addressed in this thesis.

# Chapter 9: Identifying Chemically Similar Clusters of Artifacts – The Statistical Analysis of the pXRF Data

This chapter presents details of the statistical analysis that was conducted on the results of the pXRF tests. Statistical analysis, and the intricacies of statistical software were not skills that the author possessed when embarking on this research. To ensure that the statistical analysis was done correctly and that the appropriate interpretations and conclusions were extrapolated from the results it was determined that a statistician should be hired to assist with this work. The statistical analyses for this research was carried out under contract by a third-party statistician under the guidance and with constant and continual feedback from the author.

Doug Talling, a statistician from Vancouver, BC, Canada, was hired to conduct these analyses. Throughout the analysis and interpretation, the author worked closely with Talling to ensure that the methods that he was suggesting, and making use of, were the most appropriate for the work being conducted and that they were either in line with other published archaeological sources working with pXRF, or in cases when they were not, their use was justified. Over the course of this analysis the author was able to make use of, and learn from Talling's skills, however, this still did not provide the necessary skills to be considered proficient at statistical analyses. Talling assisted greatly in determining the best ways in which to tackle the large data collection to produce results that would allow for the identification and exploration of chemically smaller groups of chert. The process was highly collaborative and involved considerable communication back and forth. While the data and the questions posed were provided by the author, Talling developed the methodology to use. As each new step in the process was conducted, the results would be investigated together with the author asking questions about the result and Talling providing answers where possible, or more often, solutions and suggestions for the use of other analytical techniques. Talling produced an independent report detailing all the methodology that we used and the conclusions that we made based on the results of these analyses. This chapter presents the authors own

review of the statistical analyses and is based on the report produced by Talling. In addition, the tables provided in this chapter have been adapted from Talling's report. Readers looking for detail beyond that provided here are directed to Appendix 3, where Talling's statistical analysis report is presented in its entirety.

In order to ensure clarity for future researchers who may wish to use this research for other questions, thorough details have been provided for each step of the data analysis. This includes the methods used for data management and the preparation of the raw data for analysis. It was determined that the presentation of this information is important to this sort of research. It is far too common that the details of data preparations and cleaning are not discussed in published sources, and it is not inconceivable that these steps have effects on the results of an analysis.

## Preparing the Artifact pXRF Data for Analysis

Each artifact included in this research was tested with the pXRF unit following the procedures outlined in Chapters 7 and 8. The data collected by the pXRF instrument was compiled in a spreadsheet along with all of the data and notes taken while the pXRF testing was taking place. This combined data file of raw data formed the basis for the statistical analysis that followed.

Before conducting any complex statistical analyses, the data provided by the pXRF instrument for each of the artifact's tests was explored in its entirety to identify and address any potential errors that might have been made during the recording and testing process. This quality control exploration was carried out in three parts. The first step was to compare the automatic testing record generated by the pXRF instrument to the independent testing records that were created by the individuals doing the testing each day. The second step was to read through all the recording notes taken during the testing process to ensure that only readings that were documented as occurring accurately were incorporated into the final analysis. The third step of data exploration was to provide descriptive statistics for the entire data set to examine the range of values the data presented and to examine the data for outliers and other potential

problems with the pXRF reading values. A detailed discussion of each of these steps follows.

## Step 1: Transcription Errors

The Niton pXRF instrument is provided with a proprietary software program called NDT. This program allows the user to retain all of the data associated with a reading. A large amount of descriptive and identifying data is provided for each reading, including an automatically generated test number, information about the machine, the setting that was used for each reading, time of day, temperature of the instrument, test results for the reading and finally the user assigned reading name. NDT also stores the spectra generated from the various filters in the instrument and a photograph of the area tested for each reading.

While each pXRF test was conducted, a second external spreadsheet was also created by the pXRF instrument operator. This auxiliary spreadsheet contained information and observations about the artifact and notes about the pXRF reading, including observations relating to the shape, texture, and matrix of the surface being tested. This list also provided a means to track potential errors in labelling or data entry that might occur and that were not recorded in the automatically generated list produced by the pXRF instrument. Once the testing was complete, these two lists were compared, and a few small problems were noted. Either the problem was fixed, or the associated reading was removed from the data set. These problems included items such as mislabelled readings, multiple readings on the same artifact, and incomplete or void readings.

## Step 2: Spreadsheet Comparisons

After the first step was completed, the notes associated with each reading were also re-visited. The original recording and testing procedure should have ensured that all the artifacts tested, and the location of the test on each artifact, were appropriate for this research. As undergraduate volunteers had undertaken some of the pXRF recordings, the possibility for individual interpretation of what was a good or bad reading was ever

present. For this reason, the photo and notes taken for each of the readings were inspected to ensure that no major source of potential error (e.g. a large inclusion in the testing area on the artifact, or a rough testing surface) had inadvertently been included in the data set. Again, a small number of tests were found to have problems and were removed from the data set.

The final data set for statistical analysis consisted of 2,271 pXRF readings from 2,263 individual artifacts. The discrepancy between these two numbers is because eight artifacts had two readings, each reading was taken on two distinct colours present on each artifact. The reading numbers for these artifacts were noted so that they could be removed from the statistical analysis to avoid altering results inadvertently.

### Step 3: Preliminary Descriptive Statistics and Outliers

When the initial cleaning of the data was completed, the data was ready to undergo preliminary, descriptive analysis. Descriptive statistics do not provide detail about the potential for chemically distinct groups of chert in the data set, but they are valuable to the analysis for other reasons. Descriptive statistics can identify problems that might be present in the data, such as extreme outlying values and unexpected ranges of values. The results of this analysis are presented here.

# Descriptive Statistics

The first step of any statistical analysis is to examine the data and to look at general descriptive statistics such as mean, median, and mode. The exploratory nature of this research necessitated the inclusion of descriptive statistics. The first step of the analysis was to plot descriptive statistics for each element for which data had been recorded. Although looking at the amount of any particular element for each of the readings taken by the pXRF instrument does not provide information that can be used to answer the bigger questions being examined, it does provide valuable data about the distribution of the results and quality of the data set as a whole. The results of the descriptive analysis are provided in Table 15 in the form of standardised values (z-

scores) for each element. The use of standardised values for this portion of the analysis was selected to provide a uniform scale on which to compare the various results.

***Table 15: Descriptive statistics for standardized values for each element tested by the pXRF instrument***

| Element (Symbol) | Valid N | % Valid | <LOD | Mean | Min. | Percentiles | | | Maximum | Range |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 25th | 50th | 75th | | |
| Aluminium (Al) | 2329 | 0.997 | 6 | 3981.8 | 509.2 | 2480.5 | 3268 | 4442.8 | 33959.3 | 33450.1 |
| Antimony (Sb) | 440 | 0.188 | 1895 | 19.3 | 10.3 | 14.5 | 18.8 | 22.7 | 43.5 | 33.2 |
| Arsenic (As) | 113 | 0.048 | 2222 | 4.9 | 3.1 | 3.6 | 4.1 | 5.6 | 15.4 | 12.3 |
| Barium (Ba) | 706 | 0.302 | 1629 | 203.9 | 36 | 116.1 | 180.2 | 261.3 | 894.4 | 858.4 |
| Bismuth (Bi) | 0 | 0 | 2335 | | | | | | | |
| Cadmium (Cd) | 238 | 0.102 | 2097 | 10.4 | 5.8 | 8.9 | 10 | 11.9 | 20.3 | 14.5 |
| Caesium (Cs) | 521 | 0.223 | 1814 | 53 | 13.8 | 33.1 | 49.4 | 71.7 | 117.3 | 103.5 |
| Calcium (Ca) | 2335 | 1 | 0 | 2740.4 | 84.1 | 710.5 | 1035.1 | 1674.6 | 136311.2 | 136227 |
| Chlorine (Cl) | 923 | 0.395 | 1412 | 283.4 | 24.8 | 92.9 | 201.6 | 370.2 | 2082 | 2057.3 |
| Chromium (Cr) | 4 | 0.002 | 2331 | 53.4 | 15.8 | 17.6 | 28.4 | 114.1 | 141.1 | 125.3 |
| Cobalt (Co) | 0 | 0 | 2335 | | | | | | | |
| Copper (Cu) | 242 | 0.104 | 2093 | 17.7 | 10.2 | 12.7 | 14.9 | 19.9 | 55.4 | 45.2 |
| Gold (Au) | 0 | 0 | 2335 | | | | | | | |
| Iron (Fe) | 2335 | 0.01 | 0 | 2028.3 | 56.1 | 1159 | 1618 | 2187.7 | 75085.6 | 75029.5 |
| Lead (Pb) | 2 | 0.001 | 2333 | 11 | 8.5 | 8.5 | 11 | N/A | 13.5 | 5 |
| Magnesium (Mg) | 17 | 0.007 | 2318 | 5081.2 | 3905.2 | 4155 | 4638.1 | 5674.4 | 8359.4 | 4454.3 |
| Manganese (Mn) | 465 | 0.199 | 1870 | 117.1 | 39 | 52.5 | 68.3 | 98.2 | 2338.6 | 2299.7 |
| Mercury (Hg) | 1003 | 0.43 | 1332 | 6.9 | 4.6 | 5.8 | 6.6 | 7.7 | 15.2 | 10.6 |
| Molybdenum (Mo) | 585 | 0.251 | 1750 | 3.9 | 1.7 | 2.5 | 3.6 | 4.8 | 10.2 | 8.5 |
| Nickel (Ni) | 409 | 0.175 | 1926 | 29.4 | 17.6 | 22.8 | 27.6 | 34.5 | 64.6 | 47 |
| Niobium (Nb) | 738 | 0.316 | 1597 | 3.7 | 1.5 | 2.2 | 3.2 | 4.7 | 24 | 22.5 |
| Palladium (Pd) | 213 | 0.091 | 2122 | 5.2 | 3.1 | 3.8 | 4.6 | 6.1 | 14.3 | 11.2 |
| Phosphorus (P) | 2334 | 0.01 | 1 | 2523.9 | 303.2 | 2051.5 | 2363.2 | 2794.8 | 12019.5 | 11716.3 |
| Potassium (K) | 2335 | 0.01 | 0 | 1445.8 | 166.8 | 1107.4 | 1370.9 | 1666.4 | 6210.7 | 6043.9 |
| Rubidium (Rb) | 2092 | 0.896 | 243 | 3 | 1.2 | 2.1 | 2.8 | 3.6 | 14.8 | 13.6 |
| Scandium (Sc) | 42 | 0.018 | 2293 | 23.6 | 4.9 | 7.6 | 13.6 | 25.8 | 148.6 | 143.7 |
| Selenium (Se) | 1 | 0.001 | 2334 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 0 |
| Silicon (Si) | 2335 | 0.01 | 0 | 524144.7 | 254400.8 | 499815.5 | 521177.6 | 546506 | 705434.1 | 451033.4 |
| Silver (Ag) | 162 | 0.069 | 2173 | 5.9 | 3.1 | 4.4 | 5.9 | 7 | 12.4 | 9.3 |
| Strontium (Sr) | 2323 | 0.995 | 12 | 23 | 1.1 | 10.7 | 17.5 | 27.4 | 225.9 | 224.8 |
| Sulfur (S) | 464 | 0.199 | 1871 | 255.5 | 65.6 | 111.9 | 145.5 | 311.6 | 1395.2 | 1329.6 |
| Tellurium (Te) | 481 | 0.206 | 1854 | 63.9 | 26.9 | 45.2 | 62.4 | 81 | 131.7 | 104.8 |
| Thorium (Th) | 0 | 0 | 2335 | | | | | | | |
| Tin (Sn) | 279 | 0.119 | 2056 | 11.7 | 13.7 | 7.8 | 21.6 | 9.5 | 11.1 | 13.4 |
| Titanium (Ti) | 2318 | 0.993 | 17 | 230.9 | 1590.4 | 18.9 | 1609.3 | 147.5 | 203.5 | 277.8 |
| Tungsten (W) | 382 | 0.164 | 1953 | 59.9 | 21 | 33.2 | 47.5 | 71.9 | 265.2 | 244.2 |
| Uranium (U) | 694 | 0.297 | 1641 | 5 | 2.8 | 3.5 | 4.5 | 5.9 | 16 | 13.2 |
| Vanadium (V) | 2005 | 0.859 | 330 | 18.8 | 7.1 | 13.3 | 16.7 | 21 | 372.6 | 365.6 |
| Zinc (Zn) | 426 | 0.182 | 1909 | 7.5 | 5 | 6 | 6.7 | 8.3 | 28.4 | 23.4 |
| Zirconium (Zr) | 1331 | 0.57 | 1004 | 6.1 | 2.7 | 4.7 | 5.7 | 7.1 | 23.5 | 20.8 |
| Legend: | | Missing Reading | | | | | | | | |
| | | Factor score outlier | | | | | | | | |
| | | Element removed, correlation > 0.9 | | | | | | | | |

The descriptive statistical analysis identified two notable trends. One obvious trend is that, except for Ca and Si, all the elements tested have at least one reading with a value of zero. Due to the way the NDT program provides its data output these zero readings may not actually indicate a zero concentration of the element being tested. In some cases, it is possible that the zero values indicate that this element was present in the sample but in quantities that fell below the level of detection for the instrument. It became apparent that elements with zero readings fall into two categories, those where zero is part of the statistically normal range of that element's concentration and those where it is not. This pattern is further highlighted by the various exploratory methods discussed here, and is especially visible in frequency graphs, an example of which is provided in Figure 8. Frequency graphs for all elements tested are presented in Figures 2-1 to 2-40 of Appendix 3. Another trend that is apparent in the table of descriptive statistics (Table 15) is that many elements have a very wide range of reading values. Many of the elements with wide ranges of values also have large numbers of zero, or very low readings and the occasional much higher value reading.

**Aluminium**
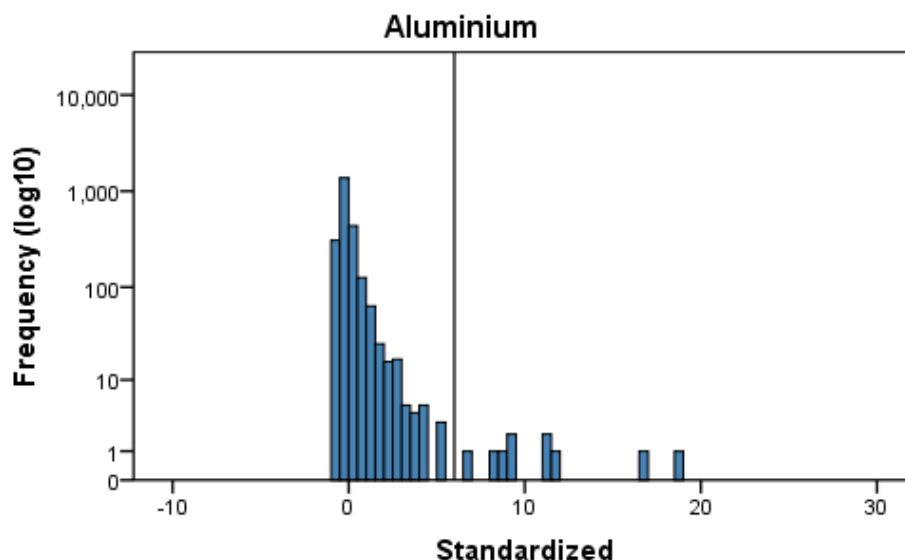
Values greater than reference line are outliers.

***Figure 8: Frequency graphs for standardised values for aluminum (Adapted from Talling 2018)***

The results of the exploratory analysis indicate that most of the data do not have a normal distribution of values. This distribution is due in large part to the great number of readings in which the element was either not present in a specimen or was below the level of detection (LOD) for the instrument. To explore this relationship further, box plots were generated for each element in the data set. The range of values for many of the elements has the same skewed appearance when rendered as a box plot as they did in the frequency graphs. It is again evident that these results were caused by the majority of readings for most elements being very low, with only the occasional higher value readings.

Examination of the box plots indicates that only two elements, P and Si, have something close to a normal distribution. Based on these results, it is apparent that these two elements have different characteristics to other elements tested. Again, due to broad-spectrum element testing, it is not possible to identify if this difference is due to the actual chemical composition of the chert artifacts or due to the pXRF test mode. The

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results for Si appear to be what would be expected from an element that is known to be present in every artifact and P likely simply follows the same pattern.

The range of readings for Si also requires further exploration. The Si readings on the low end of the scale indicate exceptionally low amounts of Si, and that is not what is expected from a material that should be composed of up to 90% of that element. This result should be examined further as no explanation is currently available. This apparent anomalous trend in Si values provides support for the need for a formal characterisation of chert and a more in-depth analysis than the comparative characterisation conducted herein. Though the low readings for Si seem out of place, there is no such preconceived notion connected to the readings for P, which has the same general distribution. As will be seen, P and Si are both used to provide valuable data in the principal component analysis section of this research.

Due to the experimental nature of this research, it is not possible to determine if the elemental compositions presented are the result of testing chert using a setting that includes a broad range of elements in the pXRF instrument or if these values represent the true nature of chert as a raw material, consistent in certain elements, but drastically varied in others. Frequently in research using chemical composition data with a focus on connecting artifacts back to their source materials (which is primarily done with obsidian), researchers rely on only a few elements known to separate the previously identified sources (e.g. Burley et al. 2011; Mialanes et al. 2016a: and Summerhayes et al.2014). The use of only Rb, Sr, Y, and Nb by Mialanes et al. (2016a:251) is a prime example. Such a method was not possible for this research for two reasons. No work has been done to locate or sample geological sources, and, as noted by Sutton et el (2015:8), the archaeological literature concerning the chemical composition of chert and what elements might best be used to identify different outcrops is almost non-existent at this time.

An additional reason that it is not possible to determine if the elemental compositions presented are the result of testing chert using a setting that includes a broad range of elements in the pXRF instrument or the fact that these values represent

the true nature of chert as a raw material is the pXRF instruments testing function itself. Because it had been determined that data for the greatest number of elements would be the most appropriate approach to the exploratory analysis of chert, the *TestAllGeo* setting was selected on the pXRF instrument. This setting gathers data for as many elements as possible, but to do so will take readings from different energy lines of an atom. Some of the elements for which data were recorded are, therefore, based on readings from high energy K shells, while others come from lower energy L shells depending on the element in question. Readings from these lower energy shells are based on a much weaker excitation energy and are also prone to spectral interferences in the X-ray spectrum. Because of the limits of excitation energy produced by a pXRF instrument element values that are identified from the weaker excitation energy signatures are more prone to producing unreliable results. Although this does provide some problems when developing interpretations based on the data collected for this research, it was not within the scope of this project to explore this issue further. The most appropriate way to address these issues would be to conduct destructive testing on samples of geological chert from the project area. This testing should also be done using a high-powered lab-based XRF instrument. Although the level of investigation required for the analysis mentioned above was beyond the scope of this research, the importance of doing this research should not be underestimated. A detailed description of chert sources along the southeast coast of PNG does not yet exist in the literature and would be an asset to this type of research.

## Identification and Removal of Outliers

As the elemental data collected from the artifacts do not have a normal distribution, it was necessary to identify and examine all the test results that contained outliers. This additional step was carried out to explore the potential cause of this degree of skewness. Possible explanations for what caused the data to present in this manner include: a) the natural variability of the elemental composition of chert, b) a possible problem with the pXRF readings, and c) testing the artifact on an uneven or inconsistently coloured surface. As discussed in Chapter 8, the laboratory procedure of

testing CSRMs daily indicates that the pXRF instrument was always functioning within the manufacturer's settings, so a problem with the pXRF instrument's readings can be discounted. Examination of the pXRF instrument's photos of each tested surface allows for the elimination of another possibility. There are no visible issues identified in any of the photos, and it is therefore unlikely that an uneven or inconsistently coloured surface was affecting the results of the test. Although the possibility exists that these readings are inaccurate because of the *TestAllGeo* setting used on the pXRF instrument, testing this was beyond the scope of this research. Building on the discussion of the function of the pXRF unit presented in Chapter 8 it was concluded that even if some of these outlying readings were a result of the pXRF instruments internal processes, each of these readings was taken under the same conditions and could, therefore, be assumed to be as accurate as the next. Each of these readings was as accurate as the pXRF instrument in question could provide, and if they were not accurate, for a specific element, it could safely be assumed that for each artifact tested the result for a particular element would have the same degree of inaccuracy. It was concluded, therefore, that although the possibility for inaccuracy in the elemental data remained, the data set would be treated as internally and consistently accurate for the research presented herein and would be treated as if it represented the actual chemical variation of these chert materials.

To investigate the outlying values, frequency graphs of the standardised values were plotted for each element. The standardised values were used instead of actual values to provide consistency for comparison of the various graphs. The Y-axes of these graphs were plotted in parts-per-million (ppm) using a Log 10 transformation to reduce the size of these axes and highlight the presence of single high outlying values. An example of the frequency graphs that were produced for Aluminium is presented in Figure 8. Frequency graphs of standardised values for this and all the other elements for which data was collected are presented in Appendix 3, Figure 2-1 to 2-40. The frequency graphs were all inspected visually to identify element values that were extremely high and significantly different from the remainder of the values for that element. During this investigation, the value for each element remained linked to the original pXRF test reading number. This linking made it possible to return to the original

laboratory notes about the reading to further investigate possible analytical reasons for extreme readings. The graphed results of the standardised values for each element were examined for natural breaks in the graphs, and specific values were chosen as the low end of the spectrum of values that should be investigated for each element. The standardised values that were selected to be the cut-off point were different for different elements. These lines were plotted on each of the frequency graphs (e.g. Figure 8) to provide a visual distinction between the outlying readings and the remainder. All readings with values higher than these cut-off values were investigated by returning to the notes taken at the time of the pXRF test to assess if any issues that may have resulted in problems with the pXRF test results could be identified.

In some cases, it was possible to associate the extremely high values for a particular element with the testing process. For example, testing an artifact in such a way that surface inconsistencies such as cortex or inclusions were present within the pXRF instrument's testing window and had been recorded by the instrument's operator but were not included in the test area photo may have contributed to the uncharacteristic results. In these cases, the artifact in question was excluded from further analysis. Fifty-three artifacts were removed from further analysis due to potential concerns about the quality of their test results.

In other cases, the high value readings could not be linked to any issues in the testing procedure. It remains possible that these high values are errors and are by-products of the complex calculations being carried out by the NDT software. As discussed this is considered unlikely based on the results of the tests carried out on the CSRMs material (refer to Chapter 8). It was concluded, therefore, that these high readings represented actual element quantities present in the artifacts and these test results remained in the data set. Upon completion of this process, the data were free of potential errors and ready to be used for the more complex statistics that would produce the results required for the remainder of the research.

# Complex Analysis of the Clean Elemental Data

The following section presents the process used to examine the elemental data provided by the pXRF instrument and to ascertain if it was possible to statistically identify chemically similar cluster groupings of chert from the collection of artifacts tested. As discussed in chapter 8, the statistical analysis for this research was conducted under contract by a professional statistician (Talling) who carried out the technical parts of this analysis under close supervision and in constant discussion with myself. The discussion that follows presents the analytical program that was conducted. At each stage of the analysis, the author met with the statistician to discuss the results and determine the best directions for the next steps. The following discussion is presented using language intended to be clear for other researchers who are unfamiliar with the intricacies of the technical language of statistics (for further details, see Appendix 3).

## *Data Transformation*

Factor analysis does not require the data to be multivariate normal (Johnson and Wichern 1982). Many other multivariate statistical analysis methods, including principal components analysis (PCA) and cluster analysis, are designed in such a way that they assume the data input has a normal distribution. As shown by the summary statistics (Table 15), and standardised value graphs (Figure 8) that have already been discussed, the data in question did not have a normal distribution and was instead heavily skewed. It was therefore considered necessary to address the skewed nature of the data prior to continuing with any additional analysis. It was decided that the data would be subjected to a data transformation. A data transformation would assist in dealing with the large quantity of >LOD or zero readings present in the data that were contributing to the skewed results. The first step of this transformation was to address the large number of >LOD or zero readings. These were addressed by changing the inputted values from zero to a value equal to one-half of the minimum value recorded for that element. This was then followed by a log10 (x+0.5) transformation of the entire data set. A variety of transformations were carried out on the data to identify one that would provide the best end distribution, and the log10 transformation provided the most consistent results. The

log10 transformation was not able to provide a normal distribution for all elements, but it did improve the distribution significantly and made the data set into something that would work with a wider variety of analyses.

## Selecting Elements for Input Into the Analysis

### Preliminary Element Selection

Previously published literature on the selection of certain elements used successfully for chert characterisation was used as a guide to narrow the number of elements for this analyses. This step was conducted before the pXRF analysis was carried out. The results of this step are presented in Chapter 4, Table 1. This review failed to identify a specific range of elements that should be focused on and resulted in the selection of the *TestAllGeo* mode (a mode that tested for the widest range of elements) on the pXRF instrument. As previously noted there is very limited research using pXRF on chert available and results of this review indicated that there was not yet any consensus in the literature about what elements would be most valuable to include for a statistical analysis.

The results for each of the elements tested for with the pXRF instrument ranged widely, and it was considered inappropriate to use all the elements in the data set for the final analysis. Three elements that had been tested for produced no data and were therefore considered not to be present in any of the chert materials tested. As such, the three elements — Hf, Re, and Ta — were removed from the data set. The remainder of the elements were kept in the data set and submitted for analysis.

### Complex Element Selection

After removing Hf, Re, and Ta, the data set still included many elements, and this large number had the potential to result in multiple possible solutions when being processed in the cluster analysis that followed. Data reduction is an appropriate method to reduce the number of cluster inputs to a manageable number. Statistical methods were, therefore, employed to further reduce the data set by removing those elements contributing the least to the cluster analysis.

Principal component analysis (PCA) was identified in the literature as the most common means of data reduction for cluster analysis. PCA has been used by a variety of researchers (e.g. Bulmer 1975; Carter et al. 2009; Parish et al. 2013; Sutton et al. 2015) to identify the elements that would contribute the most to the identification of chemically distinct groups of artifacts. PCA was carried out as a preliminary exploratory tool for this analysis, but as a tool, its basic purpose is for data reduction and interpretation that provides results that are frequently used to serve as inputs into cluster analyses (Johnson and Wichern 1982:356-7). PCA creates a single component for each variable and can often lead to situations where a small number of components has as much variability as all other variables. In other words, PCA tends to create a first principal component whose variance overwhelms the remaining components and makes the data difficult to interpret in cases like this, with so many unknown variables.

Having run the PCA on the entire data set, the components were examined. Those components that have eigenvalues (a measure of the variance accounted for by a component) that were greater than or equal to one were selected as input for the cluster analysis. The PCA identified ten components that met the minimum eigenvalue criteria for inclusion into a cluster analysis (Table 16). These ten components account for 67.7% of the total variance of the 33 original variables, a moderate amount considering the number of variables with which the analysis started. These ten components were retained and were used for the cluster analysis that follows.

Although the PCA results were valuable, it was decided that due to the way that PCA functions and due to the exploratory nature of this research, that PCA alone was likely, not focused or detailed enough for this analysis. It was decided that additional methods of data reduction should also be carried out.

**Table 16: Results of Principal Component Analysis, showing 10 components retained for further analysis**

| Principal Component Analysis Total Variance Explained | | | |
|---|---|---|---|
| Component | Initial Eigenvalues | | |
| | Total | % of Variance | Cumulative % |
| 1 | 6.943 | 21.04 | 21.04 |
| 2 | 3.976 | 12.047 | 33.087 |
| 3 | 2.713 | 8.221 | 41.308 |
| 4 | 1.717 | 5.202 | 46.509 |
| 5 | 1.407 | 4.264 | 50.773 |
| 6 | 1.221 | 3.701 | 54.475 |
| 7 | 1.188 | 3.599 | 58.074 |
| 8 | 1.088 | 3.297 | 61.371 |
| 9 | 1.083 | 3.282 | 64.653 |
| 10 | 1.008 | 3.054 | 67.707 |

Factor analysis in combination with varimax rotation was chosen as the next step for data reduction. This type of factor analysis, which can be considered an extension of PCA, is a tool designed to identify a small number of underlying and typically unobservable quantities in a data set that can highlight and magnify the inputs contributing most to the differentiation of the data. Factor analysis rotates the factors within a three-dimensional area so that the maximum amount of variance is explained by each factor. The primary question in factor analysis is whether the data are consistent with a prescribed structure. Having conducted the factor analysis, it was demonstrated that three factors were able to account for 82.4% of the total variance within the assemblage (Table 17-green highlight). These three factors were extracted from the data and were used in the cluster analysis that follows.

**Table 17: Factor analysis with Varimax Rotation (highlighted rows indicate components that were retained for further analysis)**

| Factor | Initial Eigenvalues | | | Extraction Sums of Squared Loadings | | | Rotation Sums of Squared Loadings | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % |
| 1 | 3.706 | 46.328 | 46.328 | 3.706 | 46.328 | 46.328 | 3.089 | 38.618 | 38.618 |
| 2 | 1.857 | 23.212 | 69.54 | 1.857 | 23.212 | 69.54 | 2.453 | 30.657 | 69.275 |
| 3 | 1.028 | 12.844 | 82.384 | 1.028 | 12.844 | 82.384 | 1.049 | 13.109 | 82.384 |
| 4 | 0.467 | 5.833 | 88.217 | | | | | | |
| 5 | 0.397 | 4.967 | 93.183 | | | | | | |
| 6 | 0.299 | 3.736 | 96.92 | | | | | | |
| 7 | 0.141 | 1.76 | 98.68 | | | | | | |
| 8 | 0.106 | 1.32 | 100 | | | | | | |

Extraction Method: Principal Component Analysis.

To be certain that the cluster analysis would be using the best set of data, a third form of data reduction was carried out using another form of factor analysis known as exploratory factor analysis. Exploratory factor analysis works by identifying representative elements in the data. In this system, rather than selecting factors, the procedure selects a subset of elements from all those imputed that is representative of the entire data set. Each exploratory factor analysis involved the removal of element data based on the percentage of valid values present within the readings for that element to find the most robust and stable solution. The results of each run are examined to select a set of elements using the guidelines in Hair et al. (2010:103-4). This procedure is then repeated, removing the results for the element contributing the least to the solution, until the results stabilise and no longer change with the removal of a variable from the data set. This exploratory factor analysis was conducted on the data set to identify if specific elements' characteristics led to the creation of stable clusters.

As each of the steps that have been discussed here were conducted, elements were removed from the analysis. The goal was the reduction of the data down to the smallest subset of elements that were still representative of all the diversity within the entire data set – essentially surrogate elements. The exploratory factor analysis, which provided the best overall results, identified eight elements – Sb, Nb, Ba, Sn, Mo, W, Ni, and V – as representing the entire elemental data set (Table 18). It was these eight

elements and the three factors with which they were associated that were retained for use in the cluster analysis that follows.

*Table 18: Exploratory Factor Analysis – Rotated Factor Loading Matrix showing three components and the eight associated elements.*

| Exploratory Factor Analysis, Rotated Factor-Loading Matrix[a] | | | |
|---|---|---|---|
| Elements | Factors | | |
| | 1 | 2 | 3 |
| Antimony (Sb) | 0.929 | | |
| Tin (Sn) | 0.857 | | |
| Barium (Ba) | 0.857 | | |
| Nickel (Ni) | 0.83 | | |
| Molybdenum (Mo) | | 0.927 | |
| Niobium (Nb) | | 0.919 | |
| Tungsten (W) | | 0.807 | |
| Vanadium (V) | | | 0.981 |

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.[a]
a. Rotation converged in 4 iterations.

During this portion of the analysis a variety of other "tests" of the data were introduced. These included a test of the correlation of the elements in the data set. This examined the number of correlations greater than 0.30 to identify if there were sufficient correlations within the elemental data to indicate the existence of factors in the data. It was determined that there were. Another test that was conducted to examine the data was Bartlett's test of sphericity and the measure of sampling adequacy (MSA). This is another test designed to identify if there was a sufficient number of correlations between the elements being tested. In this test, the MSA value must exceed 0.50 for the overall data set and for individual variables. Variables with MSA values less than 0.50 were removed one at a time, the analysis re-run, the MSA value re-inspected, and, if necessary, an element removed. This procedure was repeated until all MSA values exceeded 0.50 and resulted in the removal of some additional elements that were not contributing in any significant degree to the correlation between the elements in the data set. The results of the analysis that have been presented here suggest that the data can be successfully reduced in several ways. It is also clear that certain elements contribute more than others to the correlation and interpretation of patterns in the data.

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### *Cluster Analysis*

As noted throughout this thesis, the focus of the project is chemical characterisation research and not a sourcing study. The goal of this analysis, therefore, was to identify chemically distinct groups of chert within the archaeological assemblage without having any geological samples for comparison. Cluster analysis was conducted using the Two-step Cluster Analysis procedure found in the Statistical Package for the Social Sciences (SPSS) software, Version 22. This procedure is different from any other existing methods. As well as being designed to remove operator bias by letting the SPSS program decide on the optimum number of cluster groupings, this system has been shown to be more effective than Bayesian information criterion (BIC) or distance changes alone (SPSS Inc. 2001). A study conducted by Bacher et al. (2004) indicated that the SPSS Two-Step Cluster Component performs well if all variables are continuous, do not overlap extensively, and are coming from large data sets. Each of these conditions are met by the data that was produced from the pXRF testing. The program determines first which variables, in this case, what elements, are contributing the most to the creation of clusters and once this is completed it determines what combinations of clusters provide the best results, primarily based on the following three characteristics: tight cluster groups, wide spreads between cluster groups, and the use of all data for each element in the analysis.

In total three cluster analyses were run, and each was run using the result from one of the inputs detailed above, PCA, factor analysis (with varimax), and exploratory factor analysis. The purpose of conducting all three of these cluster analyses was to be able to compare the results of the three different data input methods to determine if there were differences between them that may have affected the cluster analyses, and to access which of them would be the most accurate.

The first cluster analysis was done using the results of the PCA and included ten principal components. Several runs were conducted removing components whose importance was too low to produce acceptable cluster quality. The final run, using only four of the original ten components and resulting in four clusters, was the best fit solution

as each component was shown to be contributing a maximum importance and these results remained stable for all additional runs.

The second cluster analysis was run using the three factors identified by the factor analysis with varimax rotation. In this case, after only one run, four clusters were formed, and each of the three input factors was shown to have the highest level of importance. These results were maintained for all subsequent test runs.

The third cluster analysis was run on the eight surrogate elements extracted from the exploratory factor analysis. As the various revisions of the cluster analysis were run the quality of each cluster was tested to ensure that the number and the quality of the clusters was consistent. During this procedure, it was found that of the eight elements that had been used initially, V and W were not contributing significantly to the clusters and these two elements were removed from the analyses. Examination of the Auto-Clustering output produced by SPSS provides a *Ratio of Distance Measures* with a value that represents the two-step procedure to calculate the ratios of the current number of clusters against the previous number. The higher the values are, the more likely that the number of clusters is accurate. In this case, the highest value was 3.360, and indicates that four clusters is the best solution (Table 19, yellow high-lighted row).

**Table 19: Cluster analysis results using imputes from the exploratory factor analysis.**

| Two-Step Auto-Clustering | | | | |
|---|---|---|---|---|
| Number of Clusters | Schwarz's Bayesian Criterion (BIC) | BIC Change[a] | Ratio of BIC Changes[b] | Ratio of Distance Measures[c] |
| 1 | 9801.061 | | | |
| 2 | 5454.995 | -4346.066 | 1 | 2.358 |
| 3 | 3665.612 | -1789.383 | 0.412 | 1.593 |
| 4 | 2576.659 | -1088.953 | 0.251 | 3.36 |
| 5 | 2317.91 | -258.749 | 0.06 | 1.419 |
| 6 | 2163.108 | -154.802 | 0.036 | 1.131 |
| 7 | 2036.96 | -126.148 | 0.029 | 1.078 |
| 8 | 1926.763 | -110.197 | 0.025 | 1.003 |
| 9 | 1817.193 | -109.569 | 0.025 | 1.491 |
| 10 | 1774.356 | -42.838 | 0.01 | 2.073 |

a. The changes are from the previous number of clusters in the table.
b. The ratios of changes are relative to the change for the two-cluster solution.
c. The ratios of distance measures are based on the current number of clusters against the previous number of clusters.

The cluster analysis was run with each of the three different inputs, and in each solution, four clusters were identified. This result strongly suggests that four chemically distinct groups do exist in the data and that the results are unlikely to be the result of artificial partitioning resulting from the cluster analysis.

The final step of the analysis was to ascertain which of the three inputs used in the cluster analysis was the most valid. The cluster distributions for each input data method is shown in Table 20.

*Table 20: Cluster distributions for each input data method*

| Two-Step Cluster Distributions | | | |
|---|---|---|---|
| PCA Clusters | Frequency | Percent | Cumulative Percent |
| 1 | 840 | 36 | 36 |
| 2 | 627 | 26.9 | 62.9 |
| 3 | 434 | 18.6 | 81.5 |
| 4 | 434 | 18.6 | 100 |
| FA Clusters | Frequency | Percent | Cumulative Percent |
| 1 | 1173 | 50.2 | 50.2 |
| 2 | 488 | 20.9 | 71.1 |
| 3 | 419 | 17.9 | 89 |
| 4 | 255 | 10.9 | 100 |
| Surrogate Element clusters | Frequency | Percent | Cumulative Percent |
| 1 | 1032 | 44.2 | 44.2 |
| 2 | 623 | 26.7 | 70.9 |
| 3 | 406 | 17.4 | 88.3 |
| 4 | 274 | 11.7 | 100 |

The three inputs were examined and compared to determine which had performed the best at the highest quality. A testing procedure was developed based on methods provided in SPSS Inc. (2001) (Bacher et al. 2004; Schiopu 2010). This procedure was run repeatedly for ten iterations to ensure that the results it produced were stable. After ten iterations, the input with the lowest quality was removed and the procedure re-run. This method was repeated until only one set of inputs remained, and the Cluster Quality and the Input Qualities were maximized. This procedure was tested by examining the Silhouette measure of cohesion and separation produced by each of these inputs. The higher the value of the Silhouette measure of cohesion and separation, the greater the accuracy of clusters being generated. The input/output comparisons for each input method are provided in Table 21 along with the value of the

Silhouette measure of cohesion and separation. The input that produced the highest value was the Exploratory factor analysis and the group of surrogate elements that it identified.

*Table 21: Input/output comparisons for each input method*

| Table 4-11 Comparison of Two-Step Cluster Analysis Methods | | | |
|---|---|---|---|
| Method | Number and Type of Input | Number of Clusters | Silhouette measure of cohesion and separation |
| 1 Principal Components Analysis | 10 principal components | 4 | 0.52 |
| 2 Factor Analysis (varimax rotation) | 3 factors | 4 | 0.6 |
| 3 Factor Analysis (varimax rotation) | 6 surrogate elements | 4 | 0.68 |

The two-step cluster analysis using six of the eight surrogate elements identified in the exploratory factor analysis was able to produce the most accurate results. It was the most representative of the actual chemical groupings present within this assemblage of artifacts. The four clusters identified were formed relying on only six elements (Sb, Nb, Ba, Sn, Mo, and Ni) and were shown to form 'good quality' clusters (Figure 9).

| Algorithm | TwoStep |
|---|---|
| Inputs | 6 |
| Clusters | 4 |

**Cluster Quality**

Poor    Fair    Good

-1.0    -0.5    0.0    0.5    1.0

**Silhouette measure of cohesion and separation**

(Value = 0.68)
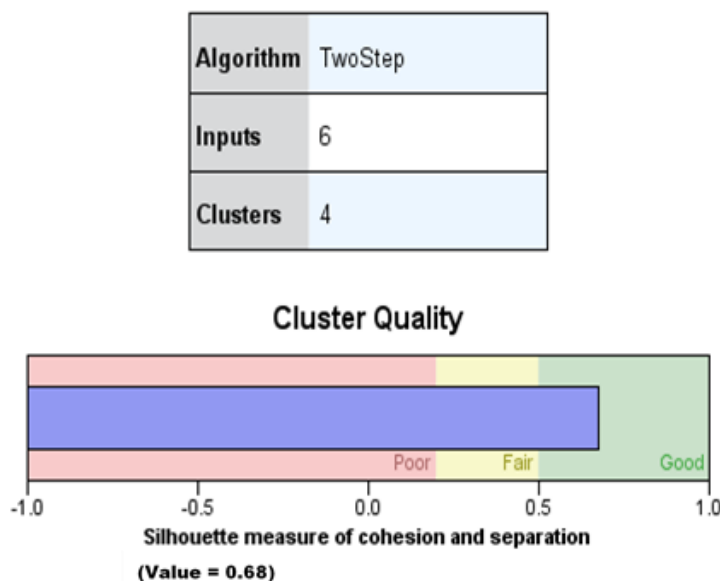
*Figure 9: Two-step cluster analysis model summary – six surrogate elements*

The four clusters that were produced ranged in size. The largest collection of artifacts is associated with Cluster 1 which made up of 44.2% of the collection of chert artifact that were included in this analysis. Cluster 2 is represented by 26.7% of the collection. Cluster 3 and Cluster 4 comprised 17.3%, and 11.7% of the collection respectably (Figure 10).
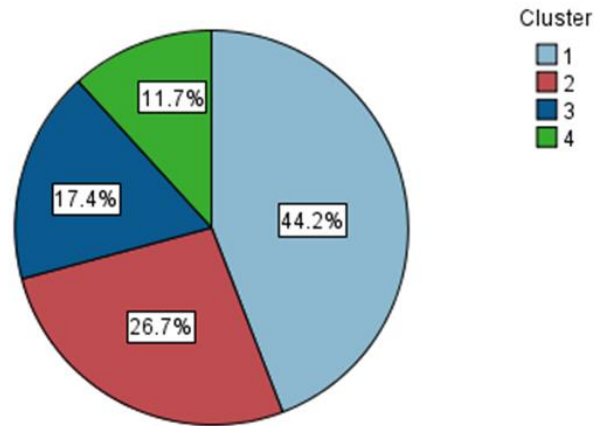


**Figure 10: Pie chart of cluster sizes – six surrogate elements**

To further review and test the results of the cluster analysis, a number of other analytical figures were produced (Figures 11-12). Each of these figures provides an output that allows for a visual assessment of the cluster groupings and provides data with which to refute or support the accuracy of these clusters. Figure 11 and Figure 12 are cluster profiles. Figure 11 presents the distribution of each element by its overall importance to the generation of each cluster. The distributions for the element within the cluster are shown in dark red overlaying the total distribution of that element in light red. This figure illustrates the differences between clusters by presenting the element distributions and the importance of the elements in each cluster, each element having different distributions in each cluster. It can be noted that the absence of Ba is the most important element in Cluster 2, its presence in larger quantities in the other three clusters being so pronounced. Likewise, very limited quantities of Mo are present in Clusters 3, 4, and 1 but an abundance of these elements is important for Cluster 2. Similar distributions are displayed for Ni. The lack of Ni and Sb is important to Clusters 1

and 2, and its presence is important to a similar degree for Clusters 3 and 4. The presence of Sn is an important part of Cluster 4.
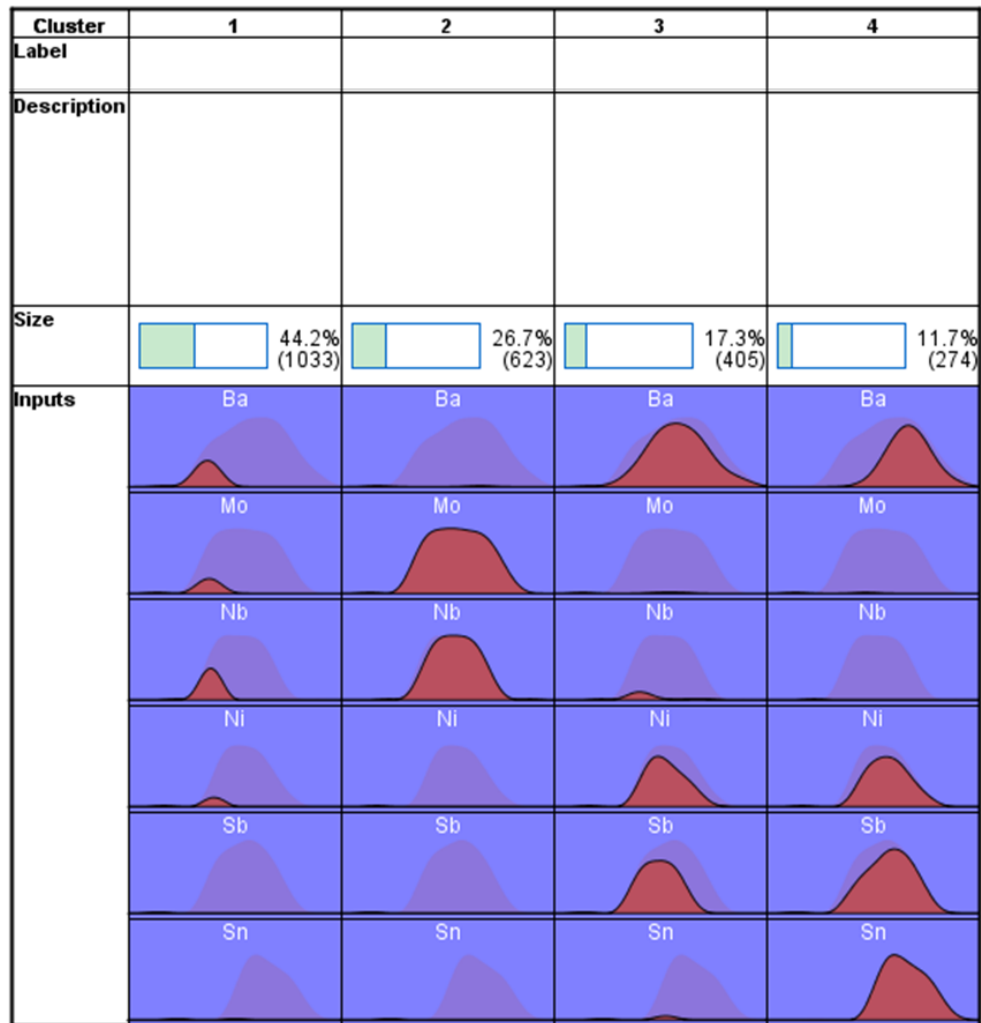


*Figure 11: Absolute cluster distributions, elements by overall importance. Element within cluster shown in dark red and total distribution of that element in shadow red (clusters sorted by size, all elements have input predictor importance of 1.0).*

Figure 12 presents boxplots of the element values for each of the clusters. The white portion of the boxplot contains 50% of the observations for the element in each cluster, and the absence of a box indicates that the element(s) had only inputted values. The box plots generally confirm what is seen in the clusters view in Figure 11. The Ba

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boxplot indicates that there are likely statistically significant differences between Cluster Groups 1 and 3 and that there is some overlap in the values of Ba for Cluster Groups 2 and 4. The distributions for each element shown by the boxplots further support that the four clusters are separate from each other based on the amounts of each of the included elements.
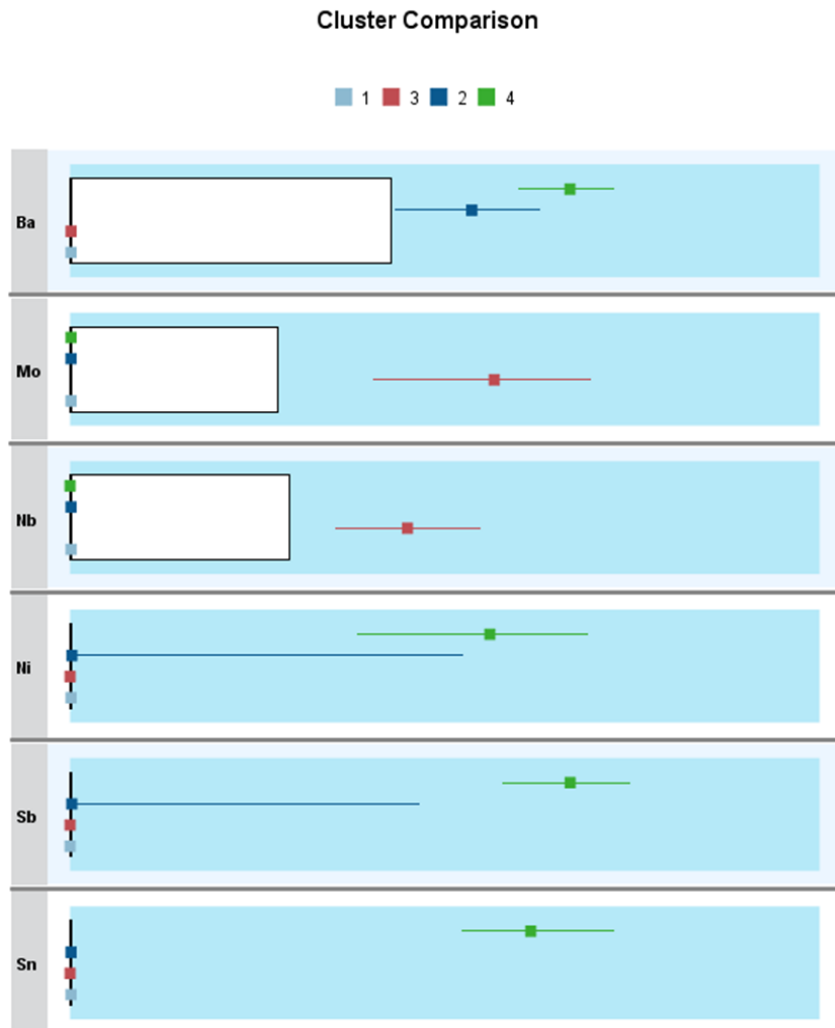


***Figure 12: Element boxplots for four clusters. Clusters of a particular element are represented by the four colours listed at the top of the figure. The boxes represent 50% of the observations for the element, and the whiskers indicate the range of values in each cluster.***

Figures 11 and 12 provide data that confirms good separation between the identified clusters and supports the accuracy of the four-cluster conclusion. It should be noted that although these results indicate that these four clusters are statistically different and distinguishable, they also indicate that they are not extremely different or extremely separated and therefore not drastically different from one another. This result is not unexpected, considering the generally homogeneous nature of chert.

## Conclusions

This chapter has described in detail the statistical analysis of a large amount of chemical data produced by pXRF from the assemblage of Caution Bay chert artifacts. The data were reduced using a variety of methods and then underwent a Two-Step Custer analysis. With each of the data inputs that were used in the cluster analysis, four clusters were identified. The results of each of these analyses were compared, and it was determined that the best data reduction method for use with the cluster analyses was the Exploratory factor analysis which resulted in the selection of eight surrogate elements (later refined to six) that were representative of the entire elemental data set. This set of inputs provided the highest level of separation and cohesion of the four generated clusters. The four clusters that were identified by this statistical analysis program have been shown to be statistically distinct based on their chemical compositions. These four chemically distinct groups of chert are believed to represent different (as of yet unidentified in the field) geological chert formations present within the landscape surrounding Caution Bay. These four clusters will, therefore, be referred to hereafter as chemical Source Groups (GSGs) 1–4. Allen et al. (2011) and Sutton et al. (2015) have both conducted similar chemical characterization studies on chert artifacts and have used the term Chemical Compositional Reference Units (CCRUs) to refer to the groups that they identified. Their terminology has not been used here for two reasons. First, this research used a different pXRF instrument than Sutton et al. (2015) and a completely different chemical analytical technique than Allen et al. (2011). Second, this research used a different statistical analysis procedure to identify the four chemical groups. By using a different terminology when discussing the chemical groups,

it was intended that any potential confusion for future researchers who may attempt to compare these various data sets directly might be avoided.

Although the analysis presented here demonstrates that these four groups of chert are chemically distinct, it also demonstrates that there is not a high degree of separation between these groups. It is unlikely that this result is a by-product of the methods used for this analysis. Methods were tested and checked at each stage of the analysis to ensure that the results being produced were representative of the data. A common concern expressed when interpreting the results of normal cluster analysis is the concept of partitioning. Partitioning occurs when otherwise contiguous data are split into groups artificially based on the analytical process, and it often produces a breakdown of groups with a similar pattern of ever smaller cluster sizes like that seen here. The SPSS Inc. (2001) documentation for the Two-Step Cluster analysis that was used for this research is designed to prevent this problem, and it is therefore not considered to be a problem here. The use of three different methods of data reduction, including PCA and two forms of factor analysis, was also important to ensure that the results reflected the data. The similar result that each of these inputs produced when used in the cluster analysis strongly suggests that the four cluster solution is truly representative of the data.

It is important also to point out that a result showing that multiple groups of chemically distinct chert are present, but that they are not extremely different in their chemical composition, is not entirely unexpected. Due to the nature of chert, as described in Chapter 5, it is highly probable that chert formations over relatively large regions may be chemically similar. As well as being comprised primarily of one element (Si), chert deposits that were formed in similar contexts by materials eroding from similar rock formation elements would likely have many elemental similarities and overlaps. The best way to address this possibility and to explore it in detail would be to locate and test geological sources of chert in the vicinity of Caution Bay. Although research of this sort was beyond the scope of the current thesis, it will be integral to further explore the results of the research carried out here.

The results of this statistical analysis have demonstrated that data collected by a pXRF instrument using its 'out-of-the-box' settings can provide data that is valuable in identifying chert artifacts with similar chemical characteristics. Although this research was conducted using a testing mode that searched for the widest variety of elemental data it turned out that information from only six elements was needed to determine chemically distinct groups of artifacts. There are some known issues with the quality of readings produced by pXRF instruments in the extreme ranges of their power spectrums and reducing the number of elements being examined in future research would be a valuable step for reducing the degree of possible inaccuracy in the pXRF results. It is likely that further research – specifically research focused on chemical samples rather than artifacts – will make it possible to create a testing mode specific to chert that does not test for elements that are not likely to be present in chert, and instead provides increasingly accurate data about those elements that are present in meaningful proportions. The results of the analysis carried out here also provide support for continued use of pXRF analysis on chert materials. The pXRF data produced for this research was collected in a generalized manner using a broad-spectrum test setting on the pXRF instrument, and the statistics that were carried out were necessarily exploratory and experimental. The results produced with these methods, however, were positive and can be used to address and explore several questions about human use of chert. At the least, the research carried out to this point has demonstrated that pXRF does provide valuable data from chert and that chert materials have chemical variability that can be demonstrated statistically. With further work, it will surely be possible to develop a chert characterisation key like those developed for obsidian research. This key will identify the elements most common in chert formations as well as those that are most commonly identified as source indicators.

# *Section 3: Applying the Chemical Analysis Results to Archaeological Questions*

# Chapter 10: Preliminary Investigations – Geochemical Source Groups (GSGs) and General Site Stratigraphy

The history of stone artifact use encompassed by the 12 sites included in this research covers the past 4,500 years and more (McNiven et al. 2011). This chapter provides a preliminary investigation into the way that the four GSGs identified in Chapter 9 are represented stratigraphically at each of these sites. In addition, data will be explored at an arbitrary spatial scale of resolution using XUs. Exploring XU data for each site links to one of the main focuses of this research (detailed in Chapters 1 and 2); namely, to what extent chronological changes in use of GSGs track or map onto stratigraphic unit changes and associated cultural phase chronologies. As stated in Chapter 9, for the purpose of this discussion, the four GSG are treated as geological source groups. It is inferred that these four groups of artifacts originated in different geological formations and therefore represent different geographical locations, without determining where these geographical source locations actually are, across the landscape (because the latter information is not available). Determining these source locations is left for future research independent of this thesis.

## Archaeological Site Assemblages and GSGs

The first step of this investigation involved an examination of how the GSGs were represented by the entire assemblage of artifacts at each of the 12 archaeological sites. Although this examination provides no data about temporal changes per se, it does allow identification of potential major differences relating to GSG abundance between the sites. Table 22 presents the results of site assemblages in terms of the relative proportions of the four GSGs. Although a comparison using percentage values provides a simple means of carrying out comparisons of the quantities of GSG groups from sites with vastly different collection sizes, it is not free of potential sampling bias problems. Even though the sites included in this research that are represented by small

assemblages (e.g. AASI, Tanamu 2, and ABKF) are not comparable to the sites with very large assemblages (e.g. Edubu1, Bogi 1, and AAUG) in terms of sample size, for the purpose of this exploratory investigation percentage comparisons was the only option available. The analysis presented in the later portion of this chapter and those that follow will, wherever possible, avoid making comparisons between sites with extremely different sample sizes.

***Table 22: Cross-validation table showing sites and GSGs.***

| Site | | Geological Source Group (GSG) | | | | Total |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | |
| Edubu 1 | Count | 144 | 68 | 52 | 34 | 298 |
| | % within Site | 48.3% | 22.8% | 17.4% | 11.4% | 100.0% |
| ABCE | Count | 73 | 44 | 28 | 17 | 162 |
| | % within Site | 45.1% | 27.2% | 17.3% | 10.5% | 100.0% |
| Bogi 1 | Count | 434 | 191 | 177 | 107 | 909 |
| | % within Site | 47.7% | 21.0% | 19.5% | 11.8% | 100.0% |
| Ataga 1 | Count | 68 | 85 | 17 | 12 | 182 |
| | % within Site | 37.4% | 46.7% | 9.3% | 6.6% | 100.0% |
| AAUG | Count | 148 | 68 | 30 | 19 | 265 |
| | % within Site | 55.8% | 25.7% | 11.3% | 7.2% | 100.0% |
| AASI | Count | 15 | 6 | 7 | 2 | 30 |
| | % within Site | 50.0% | 20.0% | 23.3% | 6.7% | 100.0% |
| Tanamu 1 | Count | 65 | 28 | 29 | 29 | 151 |
| | % within Site | 43.0% | 18.5% | 19.2% | 19.2% | 100.0% |
| Tanamu 2 | Count | 18 | 14 | 24 | 19 | 75 |
| | % within Site | 24.0% | 18.7% | 32.0% | 25.3% | 100.0% |
| Tanamu 3 | Count | 11 | 8 | 6 | 5 | 30 |
| | % within Site | 36.7% | 26.7% | 20.0% | 16.7% | 100.0% |
| ABKF | Count | 5 | 4 | 2 | 4 | 15 |
| | % within Site | 33.3% | 26.7% | 13.3% | 26.7% | 100.0% |
| Nese 1 | Count | 49 | 19 | 11 | 11 | 90 |
| | % within Site | 54.4% | 21.1% | 12.2% | 12.2% | 100.0% |
| Moiapu 2 | Count | 56 | 33 | 24 | 15 | 128 |
| | % within Site | 43.8% | 25.8% | 18.8% | 11.7% | 100.0% |
| **Total** | **Count** | **1086** | **568** | **407** | **274** | **2335** |
| | % within Site | 46.5% | 24.3% | 17.4% | 11.7% | 100.0% |

The assemblage of analysed artifacts from Edubu 1 included 298 artifacts from 29 XUs (Table 2, Chapter 6) and contains items that have been classified to all four GSGs (Table 22). GSG 1 is represented by the largest number of artifacts (n=144) and

makes up 48.3% of the assemblage. Artifacts associated with GSGs 2 and 3 make up 22.8% and 17.4% of the assemblage respectively. GSG 4 is represented by the smallest number of artifacts (n=34) and constitutes 11.4% of the assemblage. These relative percentages are broadly similar to that seen at other sites.

The assemblage of analysed chert artifacts from ABCE included 169 artifacts from 15 XUs (Table 4, Chapter 6) and represent all four GSGs (Table 22). The largest number of artifacts is associated with GSG 1, representing 45.1% of the assemblage. GSG 2 represents 27.2% of the assemblage with GSG 3 and 4 comprising progressively smaller portions of the assemblage at 17.3% and 10.5% respectively.

The assemblage of analysed artifacts from Bogi 1 included 935 artifacts from 77 XUs (Table 5, Chapter 6) and contains artifacts from all four GSGs (Table 22). The artifacts from Bogi 1 have the same pattern as the sites mentioned above with GSG 1 (47.7%) comprising the largest number of artifacts and GSG 4 (11.8%) the smallest. Unlike the previous sites discussed, GSGs 2 and 3 make up similar portions of the assemblage at 21% and 19.5% respectively.

The analysed artifact assemblage from Ataga 1 included 202 artifacts from 23 XUs (Table 6, Chapter 6) and features all four GSGs (Table 22). Unlike the previously discussed sites, GSG 2 represents the largest number of artifacts and makes up 46.7% of this assemblage. GSG 1 makes up the second largest group at 37.4%. GSGs 3 and 4 make up small percentages of this assemblage at 9.3% and 6.6% respectively. Ataga 1 is the first site discussed in which the predominant material is not GSG 1. The only other site where GSG 1 did not predominate is Tanamu 2 (see below).

The analysed assemblage of artifacts from AAUG includes 269 artifacts from 14 XUs (Table 7, Chapter 6) and all four GSGs (Table 22). GSG 1 makes up more than half of this assemblage at 55.8% and GSGs 2, 3, and 4 make up progressively smaller portions (25.7%, 11.3%, and 7.2%) of the assemblage. This result is similar to that seen at Edubu 1, ABCE, and Bogi 1.

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The analysed artifact assemblage from AASI was relatively small and included only 31 artifacts from 9 XUs (Table 8, Chapter 6). Despite the small sample size, it features all four GSGs (Table 22). GSG 1 represents the largest number of artifacts and makes up 50% of the assemblage. The second largest group of artifacts is GSG 3 (23.3%) followed by GSG 2 (20%) and GSG 4 (6.7%). Although GSG 3 is more common than GSG 2, it is only different by one artifact, which is not significant. This is the first of the sites with a smaller assemblage of artifacts and the problems associated with using percentages to compare sites with vastly different sized assemblages begins to be apparent. At this site, one artifact is contributing to a pronounced difference between the percentage values for each GSG in the collection.

The analysed assemblage of artifacts from Tanamu 1 included 151 artifacts from 54 XUs (Table 9, Chapter 6) and all four GSGs (Table 22). GSG 1 features the largest number of artifacts, making up 43% of the assemblage. Unlike the other sites discussed so far, GSGs 3 and 4 make up the next largest groups within this assemblage, having the same number of artifacts and comprising 19.2% of the assemblage. The smallest group of artifacts is associated with GSG 2 (18.5%).

The analysed assemblage of artifacts from Tanamu 2 contains 95 artifacts from 26 XUs (Table 10, Chapter 6) and all four GSGs (Table 22). Of these, GSG 3 is represented by the largest number of artifacts (32%), followed by GSG 4 (25.3%), GSG 1 (24%), and GSG 2 (18.7%). When examined together, the numbers suggest that even though GSG 3 material played the most significant role at this site, the other three GSGs were also exploited to a significant degree.

The Tanamu 3 analysed assemblage of artifacts is very small with 30 artifacts from 15 XUs (Table 11, Chapter 6), yet all four GSGs are represented (Table 22). The largest number of artifacts is associated with GSG 1 (36.7%), followed by GSG 2 (26.6%), GSG 3 (20.0%), and GSG 4 (16.7%).

The assemblage of artifacts from ABKF is the smallest analysed and included only 20 artifacts from 12 XUs (Table 12, Chapter 6). Five of these were removed from the pXRF analysis due to issues with the readings, leaving only 15 to be included in this

research. All four GSGs are represented in this assemblage (Table 22) which is interesting considering the small number of artifacts tested. The material with the largest number of artifacts is from GSG 1 (33.3%), followed by GSGs 2 and 4 (both 26.7%) and GSG 3 (13.3%). GSG 1 has only one more artifact assigned to it than GSGs 2 and 4. The data suggest that even though GSG 1 material played the most significant role at this site, the other three GSGs were also exploited regularly.

The analysed assemblage of artifacts from Nese 1 contains items from all four GSGs (Table 22) and is represented by 90 artifacts from 7 XUs (Table 13, Chapter 6). The material with the largest number of associated artifacts is GSG 1, making up more than half of the assemblage (54.4%), followed by GSG 2 (21.1%) and GSGs 3 and 4 (both 12.2%).

The analysed assemblage of artifacts from Moiapu 2 included 129 artifacts from 11 XUs (Table 14, Chapter 6) and all four GSGs (Table 22). The artifacts from Moiapu 2 have the same pattern as many of the previously mentioned sites, with the largest number of artifacts associated with GSG 1 (43.8%), and the smallest number associated with GSG 4 (11.7%). GSGs 2 and 3 represent 25.8% and 18.8% respectively. The data suggest that even though GSG 1 material played the most significant role at this site, the other three GSGs were all exploited regularly.

When examined as percentages, the GSGs contribute similar proportions in the larger assemblages but not of, the smaller ones. Of the seven sites with assemblages that included more than 100 artifacts, only one (Ataga 1) does not have GSG 1 as the most common material. All other larger assemblages are dominated by GSG 1 with progressively smaller quantities of GSG 3, GSG2, and GSG 4 (Figure 13). The other exception to this is a pattern is Tanamu 1 which is primarily composed of GSG 1 but has almost identical numbers for the other three GSGs (18.5%, 19.2%, and 19.2% respectively). Sites with less than 100 artifacts have more variability in the way the four GSGs are represented (Figure 14). This observation suggests that there is an apparent relationship between sample size and GSG representation. Although it is possible that these differences are a result of the actual artifact distributions from each of these sites,

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it is also possible that these results are a product of the sample sizes. The results indicate that future research of this sort should ensure that the number of items in assemblages being compared to one and other should be as large as possible and at a minimum, should include more than 100 items.
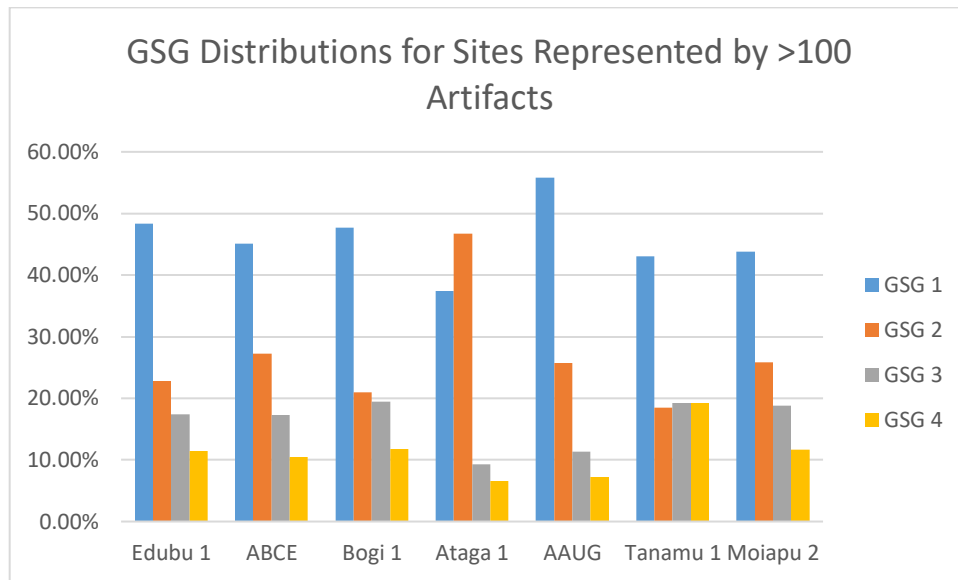


**Figure 13: Site assemblage by GSG of sites with over 100 artifacts tested**
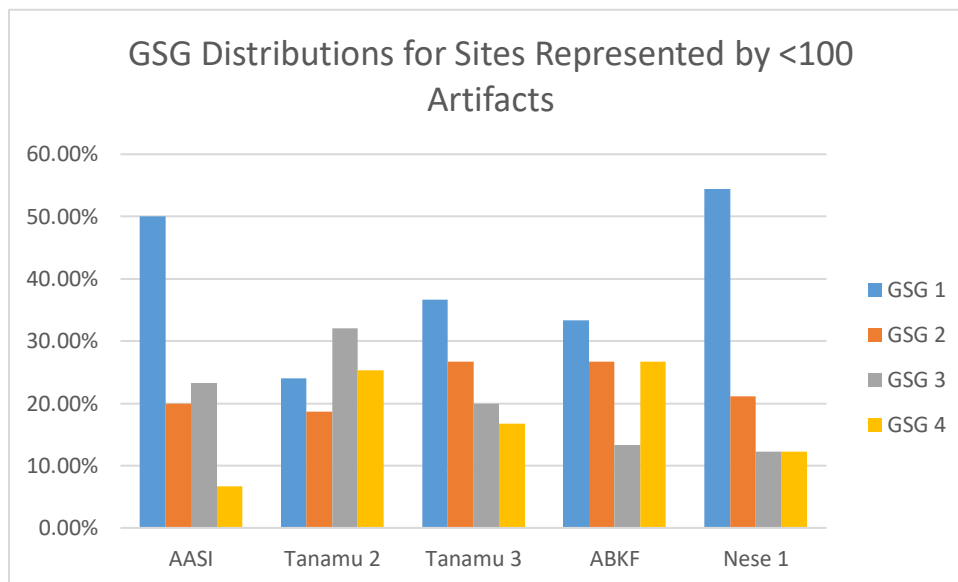


**Figure 14: Site assemblage by GSG of sites with less than 100 artifacts tested**

*Summary*

The point of examining the entire collection of artifacts, site by site, regardless of temporal associations was to identify if there were any obvious overarching trends in the data that would suggest that material was being selected in different ways at different sites. Taken as a whole the chert assemblages from each of these 12 sites are generally very similar. With the exception of Ataga 1 and Tanamu 2, assemblages are dominated by GSG 1. GSG 4 is, with the exception of Tanamu 1, Tanamu 2, and ABKF, is the least represented GSG. Two conclusions are drawn from this broad-scale analysis. First, each of the four GSGs is present at each site during at least some portion of its history of occupation. Second, as GSG 1 is generally the most commonly employed GSG, it is likely that this material was readily available in the Caution Bay area for much, if not all, of the occupation history of the area.

# Archaeological Sites, XU, SUs, and GSGs

The second avenue of preliminary exploration is investigating the relationship between the four GSGs and XUs and where possible SUs at each site. In the following section, each site will be explored first in relation to the quantities of each of the GSGs in each XU and then, where applicable, the SU.

As with the overall site data, the discussion will refer to percentage values in order to facilitate inter-site comparisons. The challenges associated with using percentage values for comparisons that were discussed in the previous section are of less concern here. In the discussion that follows the percentage values will only be used to examine the difference between the various XUs from an individual site. Although the assemblages from various XUs will be different, the range in total numbers form XU to XU is much less than the ranges of the entire assemblages from site to site. Actual counts for the number of artifacts associated with each of the four GSGs from XUs and SUs are provided in Appendix 4, Tables 1–12.

### *Edubu 1*

Artifacts from 28 of the 48 XUs excavated are included in this research. The number of artifacts from each XU classified to each of the GSGs is presented in Appendix 4, Table 1. Not every XU contains artifacts from each of the GSGs (Figure 15). Through much of the site, all four GSGs are present to varying degrees, with only the occasional XU not containing artifacts from one or two of the GSGs. The exception to this pattern is XU14, which contains only artifacts from GSG 1. GSG 4 is almost completely absent below XU20 but is present in most XUs above XU13, often represented by more than one artifact. All four GSGs are represented in the large assemblage of artifacts between XUs 2 and 6.

Edubu 1 contains three SUs each representing major concentrations of human activity (McNiven et al. 2012a:124). The top levels are represented by SU1 (XUs 1–16) which is dated to ca. 2350 cal BP and SU2 (XUs 16–23) which is dated to ca. 2500 cal BP. Both SU1 and SU2 are associated with the Post-Lapita Transformative Tradition. The lower levels of the site are represented by SU3 (XUs 27–32) and are dated to ca. 2500-2750 cal BP (McNiven et al. 2012a:124). This date range includes the end of the Lapita period and the beginning of the Post-Lapita Transformative Tradition and is referred to by McNiven et al. (2012a:124) as a terminal Lapita occupation.

When the chert data is examined by SU, another set of observations can be made. During the Post-Lapita Transformative Tradition (SUs 1 and 2) the assemblages contain large numbers of artifacts and contain materials from all four GSGs. The more recent Post-Lapita Transformative Tradition (SU1) also contains the greatest number of artifacts associated with each of the GSGs. In contrast, the terminal Lapita occupation (SU3) contains far fewer artifacts and has almost no GSG 4 artifacts. This pattern suggests that material from GSG 4 did not play a significant role in the Lapita occupation of the site. During the two Post-Lapita Transformative Tradition occupations of the site far more cultural material was discarded, and chert from all four GSGs was exploited. Possible explanations for these changes will be presented in Chapter 12.

| Edudu 1 | | | | | |
| --- | --- | --- | --- | --- | --- |
| Strtigraphic Data | GSG 1 | GSG 2 | GSG 3 | GSG 4 | Number of Artifacts |

| SU | XU | GSG 1 | GSG 2 | GSG 3 | GSG 4 | Number of Artifacts |
| --- | --- | --- | --- | --- | --- | --- |
| SU 1 | 1 | ■■■■■■■■■ | ■■ | ■■■■■■ | ■■■■■■ | 17 |
| | 2 | ■■■■■■■■■■■■■■ | ■■ | ■■■■ | ■■■■ | 25 |
| | 3 | ■■■■■■■■■■■■■■■■ | ■■■■■■ | ■■■ | ■■■ | 27 |
| | 4 | ■■■■■■■■■■■■■■■ | ■■■■ | ■■■■■■■ | ■■■■■■■ | 31 |
| | 5 | ■■■■■ | ■■■■■■■ | ■■■■■ | ■■■■■ | 19 |
| | 6 | ■■■■■■■■■■■■■■■■■■■■■■■ | ■■■■■■■■■■ ■ | ■■■■ | ■■■■ | 43 |
| | 7 | ■■■■■■ | ■■■■■ | | | 11 |
| | 8 | ■■■ | ■■■■■■ | ■■■ | ■■■ | 15 |
| | 9 | ■■■■■■■■■■■■ | ■■ | ■■■ | ■■■ | 19 |
| | 10 | ■■■■■ | ■■■ | ■■■ | ■■■ | 13 |
| | 11 | ■■■■■■ | ■■■ | ■ | ■ | 11 |
| | 12 | ■■■■■ | ■■ | ■■■■ | ■■■■ | 12 |
| | 13 | ■■ | | | | 3 |
| | 14 | ■■ | | | | 2 |
| | 15 | ■■■■ | ■■■■ | ■ | ■ | 9 |
| SU 2 | 16 | ■ | ■ | | | 4 |
| | 17 | | | | | 0 |
| | 18 | ■■ | ■■ | ■ | ■ | 5 |
| | 19 | ■■■ | ■■ | ■■■■ | ■■■■ | 9 |
| | 20 | ■■■ | ■ | | | 8 |
| | 21 | ■ | | | | 1 |
| | 22 | ■■ | | | | 2 |
| | 23 | | | | | 0 |
| | 24 | ■ | ■ | | | 2 |
| | 25 | | | | | 0 |
| | 26 | | | ■ | ■ | 1 |
| SU 3 | 27 | | ■ | | | 2 |
| | 28 | | ■■ | ■ | ■ | 3 |
| | 29 | ■ | | ■ | ■ | 2 |
| | 30 | | | | | 0 |
| | 31 | ■ | | | | 1 |
| | 32 | | ■ | | | 1 |

*Figure 15: Seriation graph of GSGs present in XUs at Edubu 1, each black square represents one artifact.*

## ABCE

Fifteen of the 18 XUs excavated are represented in this assemblage. Appendix 4, Table 2 presents the number of artifacts from each XU that are associated with the various GSGs. Not every XU contains artifacts from each of the GSGs (Figure 16). With the exception of the XUs from which only one artifact was included, all four GSGs are present to varying degrees throughout the site. GSGs 3 and 4 are almost completely

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absent below XU 8 but are present in all XUs above this. All four GSGs are represented by the largest number of artifacts between XUs 1 and 5.

| ABCE | | | | | | |
|------|--|-----|-----|-----|-----|---|
| Strtigraphic Data | | GSG 1 | GSG 2 | GSG 3 | GSG 4 | Number of Artifacts |
| SU | XU | | | | | |
| Ocupation 1 | 1 | ■■■■■■ | ■ | ■■■■■■ | ■ | 14 |
| | 2 | ■■■■■■■ | ■■■■ | ■■■■ | ■■■ | 18 |
| | 3 | ■■■■■■■■■ | ■■■■■ | ■■■■■ | ■■■■ | 24 |
| | 4 | ■■■■■■■■■■■■■■ | ■■■■■■ | ■■■ | ■■■■ | 27 |
| | 5 | ■■■■■■ | ■■■■■■■■ | ■ | ■ | 16 |
| | 6 | ■■■■■■■■■■■ | ■■■■ | ■ | ■ | 17 |
| | 7 | ■■■■■■■ | ■■■■■ | ■■ | ■ | 15 |
| | 8 | ■■■■■ | ■■ | ■■■■ | ■■ | 13 |
| | 9 | ■■ | ■■■ | | | 5 |
| | 10 | ■ | ■ | ■ | | 3 |
| | 11 | ■■■ | ■■ | ■ | | 6 |
| | 12 | | ■ | | | 1 |
| | 13 | | ■ | | | 1 |
| | 14 | ■ | | | | 1 |
| | 18 | | ■ | | | 1 |

***Figure 16: Seriation graph of GSGs present in XUs at ABCE, each black square represents one artifact.***

ABCE contains four occupation periods that were inconsistently present in the nine squares excavated at the site. The square selected for this research was Square C which contains evidence for a single occupation period. This occupation is referred to as Occupation 1 and is dated to 2390–1910 cal BP (Richards: email 02-16-16). The dates for the Occupation 1 deposits are associated with three different ceramic traditions, the Umbo-bordered Shell Back Impressed Tradition, the Linear Shell Edge-Impressed Tradition, and the end of the Post-Lapita Transformative Tradition. Further research on the assemblage from this site is required to better define the relationship between Occupation 1 and the ceramic traditions.

The distribution of GSGs within XUs indicates two different patterns of raw material used at the site. The lithic analysis conducted by Mialanes (2016b) also identifies a change in the lithic assemblage above XU9. The largest number of flakes are

present in the upper levels of the site (XUs 1–8), and in all of these XUs, all four GSGs are present. Below in XUs 9–18, the quantity of artifacts drops significantly and so does the range of GSGs. GSG 4 is not present below XU8, and GSGs 1 and 3 are present in limited quantities. GSG 2 is the most common material in these XUs. GSG 3 is present in every XU with the exception of XU14. It is possible that the small assemblage of flakes from the lower XUs has introduced sampling bias in terms of under-representation of certain GSGs. At this site, there also appears to be a correlation between the volume of material discarded and the number of GSGs present in the sample.

## *Bogi 1*

Artifacts from 76 of the 144 XUs excavated are included in this research. The number of artifacts from each XU classified to each of the GSGs is presented in Appendix 4, Table 3. The sample of artifacts tested from Bogi 1 was the largest included in this research (Figure 17). Bogi 1 also had the deepest cultural deposits of any site included in this research. Not every XU contains artifacts from each of the GSGs, and a number of XUs are represented by only one artifact, making comparisons challenging. GSGs 3 and 4 are almost completely absent below XU30 with the exception of two artifacts from GSG 3 and three from GSG 4 between XUs 52 and 55. GSGs 1 to 3 are represented by the largest number of artifacts between XUs 3 and 5; however, the largest number of artifacts associated with GSG 4 is from XU14.

| Strtigraphic Data | | GSG 1 | GSG 2 | GSG 3 | GSG 4 | Number of Artifacts |
|---|---|---|---|---|---|---|
| SU | XU | | | | | |
| | 1 | | | | | 2 |
| | 2 | | | | | 23 |
| | 3 | | | | | 50 |
| | 4 | | | | | 67 |
| Phase 3 | 5 | | | | | 65 |
| | 6 | | | | | 45 |
| | 7 | | | | | 63 |
| | 8 | | | | | 41 |
| | 9 | | | | | 5 |
| | 10 | | | | | 21 |
| | 11 | | | | | 35 |
| | 12 | | | | | 32 |
| | 13 | | | | | 37 |
| | 14 | | | | | 54 |
| | 15 | | | | | 58 |
| | 16 | | | | | 43 |
| | 17 | | | | | 44 |
| | 18 | | | | | 22 |
| | 19 | | | | | 10 |
| | 20 | | | | | 13 |
| | 21 | | | | | 20 |
| | 22 | | | | | 8 |
| | 23 | | | | | 13 |
| | 24 | | | | | 9 |
| | 25 | | | | | 9 |
| | 26 | | | | | 11 |
| | 27 | | | | | 5 |
| | 28 | | | | | 7 |
| | 29 | | | | | 12 |
| | 30 | | | | | 6 |
| | 31 | | | | | 3 |
| | 32 | | | | | 4 |
| | 33 | | | | | 2 |
| | 34 | | | | | 5 |
| | 35 | | | | | 4 |
| | 36 | | | | | 2 |
| | 37 | | | | | 3 |
| | 39 | | | | | 1 |
| | 42 | | | | | 1 |
| | 43 | | | | | 1 |
| | 45 | | | | | 1 |
| | 47 | | | | | 1 |
| Phase 2 | 48 | | | | | 2 |
| | 52 | | | | | 2 |
| | 53 | | | | | 3 |
| | 55 | | | | | 1 |
| | 59 | | | | | 4 |
| | 61 | | | | | 2 |
| | 62 | | | | | 1 |
| | 63 | | | | | 2 |
| | 64 | | | | | 1 |
| | 65 | | | | | 2 |
| | 66 | | | | | 1 |
| | 67 | | | | | 1 |
| | 69 | | | | | 2 |
| | 70 | | | | | 3 |
| | 75 | | | | | 3 |
| | 76 | | | | | 1 |
| | 78 | | | | | 1 |
| Phase 1 | 79 | | | | | 1 |
| | 80 | | | | | 1 |
| | 81 | | | | | 1 |
| | 84 | | | | | 1 |
| | 88 | | | | | 1 |
| | 91 | | | | | 3 |
| | 93 | | | | | 1 |
| | 96 | | | | | 1 |
| | 97 | | | | | 1 |
| | 98 | | | | | 1 |
| | 100 | | | | | 1 |
| | 101 | | | | | 1 |
| | 102 | | | | | 1 |
| | 108 | | | | | 1 |
| | 122 | | | | | 1 |
| | 141 | | | | | 1 |
| | 144 | | | | | 0 |

*Figure 17: Seriation graph of GSGs present in XUs at Bogi 1, each black square represents one artifact.*

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Ten SUs were identified at Bogi 1, including three major occupational phases identified by McNiven et al. (2011). Phase 1 is a pre-Lapita phase dating to >3000-4200 cal BP and includes XUs 79-149 which together comprise SU8. This occupation has no associated ceramic material (McNiven et al. 2011:3). Phase 2 is represented by SUs 7a and 7b, dates to 2600-2900 cal BP, and contains Lapita ceramics. All four of the GSGs were being used during the Lapita period at Bogi 1 with little evidence of preference towards one GSG over another. Phase 3 is associated with SUs 5 and 6, encompasses XUs 5-35, and is dated to 2000-2150 cal BP. The dates for this occupation straddle the dates for two ceramic traditions, the Linear Shell Edge-Impressed Tradition and the Umbo-bordered Shell Back Impressed Tradition. All four GSGs are represented with the amount of material classified to a GSG consistently increasing as the total number or artifacts in the assemblage increases.

## *Ataga 1*

Twenty-three of the 40 XUs excavated are represented in this assemblage, and all four GSGs are represented. Appendix 4, Table 4 presents the number of artifacts from each XU that are associated with the GSGs. Not every XU contains artifacts from each of the GSGs, and a small number of the deeper XUs are represented by only one artifact (Figure 18). GSGs 3 and 4 are almost completely absent below XU12, with the exception of one artifact each in XU14, and one artifact of GSG 3 in XU23, and of GSG 4 in XU16. GSG 4 is also not present in the first three XUs. GSGs 1, 2, and 3 are represented by the largest number of artifacts between XUs 2 and 3; but there are also matching high numbers of artifacts from GSG 1 in XUs 9 and 10 and GSG 2 in XU6. The largest number of artifacts from GSG 4 is in XU10.

| Ataga 1 | | | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| **Strtigraphic Data** | | **GSG 1** | **GSG 2** | **GSG 3** | **GSG 4** | **Number of Artifacts** |
| **SU** | **XU** | | | | | |
| Occupation 1 | 1 | ■■ | ■■■■■■■■ | | | 10 |
| | 2 | ■■■■■■■ | ■■■■■■■■■■■ | ■ | | 19 |
| | 3 | ■■■■■ | ■■■■ | ■■■■ | | 13 |
| | 4 | ■■■■■■ | ■■■■■ | ■ | ■■ | 14 |
| | 5 | ■■ | ■■■ | ■ | ■ | 7 |
| | 6 | ■■■■ | ■■■■■■■■■■■ | ■ | | 16 |
| | 7 | ■■ | ■■■■■ | | ■ | 8 |
| | 8 | ■■ | ■■■■ | | | 6 |
| | 9 | ■■■■■■■ | ■■■■■ | ■■ | ■ | 15 |
| | 10 | ■■■■■■■ | ■■■■ | ■■■ | ■■■ | 17 |
| | 11 | ■■■■■■ | ■■■■■■■■■ | ■ | ■■ | 18 |
| | 12 | ■■■■■ | ■■■■ | ■ | | 10 |
| | 13 | ■ | ■■■ | | | 4 |
| | 14 | ■■■■ | ■ | ■ | ■ | 7 |
| | 15 | ■■ | | | | 2 |
| | 16 | ■ | ■■■■ | | ■ | 6 |
| | 17 | ■■ | ■ | | | 3 |
| | 18 | ■ | | | | 1 |
| | 19 | | ■ | | | 1 |
| | 20 | ■ | ■ | | | 2 |
| | 22 | | ■ | | | 1 |
| | 23 | | | ■ | | 1 |
| | 24 | ■ | | | | 1 |

***Figure 18: Seriation graph of GSGs present in XUs at Ataga 1, each black square represents one artifact.***

The detailed site report for Ataga 1 has not yet been published. Therefore, it is difficult to explore the data from this site in much depth. Dates for this site suggest that it was occupied primarily during the Post-Lapita Transformative Tradition (Mialanes 2016f:1). The lithic analysis carried out by Mialanes (2016f:1) suggests that there was a major occupation associated with XUs 1-18. As with other sites analysed, there appears to be a correlation between the variety of GSGs present and the number of artifacts tested.

## *AAUG*

Artifacts from 14 of the 18 XUs excavated are included in this research. With the exception of XUs 1, 2, 4, and 11, artifacts from all GSGs are present in each XU (see Appendix 4, Table 5). The stratigraphic profile for AAUG was primarily developed from Square A, and the artifacts discussed herein are from Square D, which featured a similar stratigraphy. Four culture-bearing SUs were identified, and these indicate one major occupation phase and two smaller ones. A minor recent occupation phase associated with SU1 (XUs 1–6) is noted in all five squares excavated at this site. This phase is associated, based on dates, with the Varied Incised Tradition. The majority of artifacts from this time are from GSG 1 and very few of the artifacts from this period are associated with GSGs 3 and 4. The distribution of GSGs from each XU is presented as a seriation graph in Figure 19.

| AAUG | | | | | | |
|---|---|---|---|---|---|---|
| Strtigraphic Data | | GSG 1 | GSG 2 | GSG 3 | GSG 4 | Number of Artifacts |
| SU | XU | | | | | |
| SU 1 | 1 | ▪▪ | ▪▪▪ | | | 5 |
| | 2 | ▪▪ | ▪▪▪ | | | 5 |
| | 3 | ▪▪▪▪▪▪▪▪▪ | ▪ | ▪▪ | ▪▪▪ | 15 |
| | 4 | ▪▪▪▪▪▪ | | | | 6 |
| | 5 | ▪▪▪▪▪▪▪▪▪ | ▪▪▪▪▪▪ | ▪▪ | ▪ | 20 |
| SU 2+3 | 6 | ▪▪▪▪▪▪▪▪▪▪▪▪▪ | ▪▪▪▪▪ | ▪▪▪▪▪ | ▪ | 26 |
| | 7 | ▪▪▪▪▪▪▪▪▪▪ | ▪▪▪▪▪▪▪ | ▪▪ | ▪ | 22 |
| | 8 | ▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪ | ▪▪▪▪▪▪▪▪▪▪▪▪ | ▪▪ | ▪▪ | 36 |
| | 9 | ▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪ | ▪▪▪▪▪▪ | ▪▪▪▪ | ▪▪▪▪▪▪ | 49 |
| | 10 | ▪▪▪▪▪▪▪▪▪▪▪▪▪▪ | ▪▪▪▪▪▪▪▪ | ▪▪▪▪▪▪ | ▪ | 30 |
| | 11 | ▪▪▪▪▪▪ | ▪ | ▪▪ | | 9 |
| | 12 | ▪▪▪▪▪ | ▪▪ | ▪ | ▪▪ | 10 |
| | 13 | ▪▪▪▪▪▪▪▪▪▪▪ | ▪▪▪▪▪ | ▪ | ▪ | 19 |
| | 14 | ▪▪▪▪▪▪▪▪ | ▪▪ | ▪▪ | ▪ | 13 |

***Figure 19: Seriation graph of GSGs present in XUs at AAUG, each black square represents one artifact.***

The major period of occupation at this site is represented by SU2 (XUs 6–13) and SU3 (XUs 10–18; Richards et al. 2016b:3). Only SU2 was represented by the square selected for analysis. The dates for SU2 occupation cover a range of time that is associated with three different ceramic traditions, the Umbo-bordered Shell Back Impressed tradition, the Linear Shell Edge-Impressed Tradition, and the end of the Post-

Lapita Transformative Tradition. Further research on the assemblage from this site is required in order to better define the relationship of S 2 and the ceramic sequence for the area. Throughout S 2, all four GSGs are present in all XUs with the exception of GSG 4, which is not present in XU 11. All four GSGs are present in their greatest numbers in the upper levels of SU2 which also have the largest assemblages.

## *AASI*

Analysed artifacts came from nine of the 13 XUs excavated from AASI. Overall the assemblage contains material from all four GSGs (Appendix 4, Table 6) (Figure 20). Most XUs are represented by only one artifact which makes comparisons challenging. GSGs 3 and 4 are absent from this assemblage until XUs 1 and 2. GSGs 1 and 2 are also absent from many XUs. All of the GSGs are represented in XU1, which is not only the most recent level at the site, but is also represented by the largest assemblage of tested artifacts.

| AASI | | | | | | |
|---|---|---|---|---|---|---|
| Strtigraphic Data | | GSG 1 | GSG 2 | GSG 3 | GSG 4 | Number of Artifacts |
| SU | XU | | | | | |
| SU 1+2 | 1 | ■■■■■■■ | ■ | ■■■■■■ | ■■ | 16 |
| | 2 | ■■■ | | ■ | | 4 |
| | 3 | | ■ | | | 1 |
| | 4 | ■■ | ■■ | | | 4 |
| | 5 | | ■ | | | 1 |
| | 6 | ■ | | | | 1 |
| | 8 | | ■ | | | 1 |
| | 9 | ■ | | | | 1 |
| | 13 | ■ | | | | 1 |

**Figure 20: Seriation graph of GSGs present in XUs at AASI, each black square represents one artifact.**

Three SUs were identified in the two squares excavated at AASI. Two of these SUs represent the main occupation phase and the third is believed to be non-cultural. The stratigraphy at this site is complex and SUs 1 and 2, which overlap significantly, are present throughout the upper XUs of both excavated squares. The occupation that is

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represented by SUs 1 and 2 dates to 1564-1415 cal BP and is temporally associated with the Varied Incised Tradition.

Artifacts from XU1 represent more of the assemblage than the artifacts from all the other XUs combined, a trend that is seen within the artifact data as a whole as well (Table 8, Chapter 6). With the exception of GSG 2, all the other GSGs are most common in XU1. This site appears to represent a very short, likely recent, occupation.

## *Tanamu 1*

Artifacts from 54 of the 134 XUs excavated are included in this research. All four GSGs are present in the assemblage, and although present in limited quantities (many XUs are represented by only one artifact), the four GSGs are present from the surface (XU2) down to almost the deepest level of the site (XU113). The number of artifacts from each XU classified to each of the four GSGs is presented in Appendix 4, Table 7 which shows no patterns that are immediately visible in regard to the presence or absence of a source of material over time (Figure 21). Instead, there are numerous XUs with only one or two of the materials represented followed immediately above and below by similar numbers of material from different GSGs. The greatest number of artifacts classified to all four GSGs is present between XUs 3 and 5, the three XUs with the largest assemblages.

| Tanamu 1 | | | | | | |
|---|---|---|---|---|---|---|
| Strtigraphic Data | | GSG 1 | GSG 2 | GSG 3 | GSG 4 | Number of Artifacts |
| SU | XU | | | | | |
| Upper Horizon A | 1 | ■ | ■ | | | 2 |
| | 2 | ■■ | ■ | ■ | ■■■ | 7 |
| | 3 | ■■■■■■■ | ■■■■■ | ■■■■■ | | 19 |
| | 4 | ■■■■■■■ | ■■■ | ■■ | ■ | 14 |
| | 5 | ■■■■■ | ■■■ | ■ | ■■■■ | 14 |
| | 7 | | | | ■ | 1 |
| | 12 | | | | ■ | 1 |
| | 14 | ■ | ■ | ■■■ | | 5 |
| | 15 | ■ | | | | 1 |
| | 16 | ■ | | ■ | ■ | 3 |
| | 18 | ■■ | ■ | | | 3 |
| | 19 | ■■ | ■■■ | | | 5 |
| | 20 | ■ | | ■ | | 2 |
| | 21 | ■■ | | ■■ | | 4 |
| | 23 | ■ | | | | 1 |
| Middle Horizon | 25 | ■ | | ■ | | 2 |
| | 26 | ■ | | | | 1 |
| | 27 | | | | ■ | 1 |
| | 29 | | ■ | ■ | | 2 |
| | 31 | ■ | | ■■ | ■ | 4 |
| | 32 | | ■ | | | 1 |
| | 34 | ■ | | | | 1 |
| | 36 | ■ | | | | 1 |
| | 38 | | | ■ | | 1 |
| | 39 | ■■ | | | | 2 |
| | 40 | | ■ | | | 1 |
| | 43 | ■■■ | | | ■ | 4 |
| | 44 | | | ■ | | 3 |
| | 47 | ■ | | | | 1 |
| Lower Horison | 51 | ■ | | | | 1 |
| | 53 | ■ | | | | 1 |
| | 54 | | | | ■ | 1 |
| | 55 | ■■ | | ■■ | ■■■ | 7 |
| | 56 | | ■ | | ■■ | 3 |
| | 58 | | ■ | | | 1 |
| | 60 | ■ | ■ | | ■ | 3 |
| | 63 | ■ | | | ■ | 2 |
| | 64 | ■ | ■ | ■ | | 3 |
| | 66 | | | ■ | ■ | 2 |
| | 67 | | | | ■■ | 2 |
| | 70 | ■ | | | | 1 |
| | 71 | | | | ■ | 1 |
| | 72 | ■ | | | | 1 |
| | 74 | | | ■ | | 1 |
| | 75 | | | ■ | | 1 |
| | 79 | | | ■ | | 1 |
| | 81 | ■■ | | | ■ | 3 |
| | 82 | ■■■ | | | | 3 |
| | 83 | | ■ | | | 1 |
| | 91 | | ■ | | | 1 |
| | 93 | ■ | | | | 1 |
| | 99 | ■ | | | | 1 |
| | 110 | | | | ■ | 1 |
| | 113 | ■ | | | | 1 |

*Figure 21: Seriation graph of GSGs present in XUs at Tanamu 1, each black square represents one artifact.*

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Seven SUs were identified at Tanamu 1, including three major occupational horizons referred to as the Lower, Middle, and Upper Horizons (David et al. 2016e:5). The oldest cultural material is a pre-ceramic occupation dating to c.4350-4050 cal BP that forms the Lower Horizon and is represented by XUs 42 to 70. The Middle Horizon is a dense Lapita occupation dating to c.2800-2750 cal BP and is represented by XUs 19 to 39 (David et al. 2016e:9). The Upper Horizon contains dense deposits of mainly undecorated pottery and cultural materials represented by XUs 1 to 14 (David et al. 2016e:10) and is associated with Period 5, Interaction, Specialization and Exchange. All of the cultural horizons at Tanamu 1 contain artifacts from all four GSGs. The pre-Lapita assemblage contains predominantly GSG 4 material, followed by GSG 1, GSG 3, and GSG 2. In contrast, during the Lapita period, GSG 1 is the most common with GSG 3 forming the next largest group. GSG 2 and GSG 4 are both only represented by two artifacts. The Period 5 assemblage contains the largest number of artifacts, as well as the largest number of artifacts assigned to each of the GSGs for any given XU. GSGs 1 to 3 are represented by the largest assemblage in XUs 3, and 4 (GSG 1) and GSG 4 is represented by the largest assemblage in XU 5. The Period 5 assemblage is dominated by artifacts associated with GSG 1, followed by progressively smaller amounts of material from GSGs 2, 3 and 4. The quantity of artifacts diminishes with increasing depth, but the relative proportions of each material remain similar.

## Tanamu 2

Twenty-five of the 54 XUs excavated are represented in this assemblage. The number of artifacts from each XU is generally small, with 13 XUs represented by only one artifact. Material from all four GSGs is present from near the surface down to the deepest levels of the site. Appendix 4, Table 8 presents the number of artifacts from each XU that were associated with the various GSGs. No apparent patterns exist in regard to the presence or absence of materials over time (Figure 22). Instead, there are numerous XUs with only one or two of the GSGs represented followed immediately above and below by similar numbers of artifacts from different GSGs. The greatest number of artifacts classified to all four GSGs is present between XUs 6 and 13.

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| Tanamu 2 | | | | | | |
|---|---|---|---|---|---|---|
| Strtigraphic Data | | GSG 1 | GSG 2 | GSG 3 | GSG 4 | Number of Artifacts |
| SU | XU | | | | | |
| SU 1 | 2 | | ■ | ■ | ■ | 3 |
| | 4 | | ■ | | | 1 |
| | 5 | | ■■ | ■ | ■ | 4 |
| SU 2 | 6 | ■■■■ | ■■ | ■■■■ | ■■■■ | 14 |
| | 7 | ■■■■■ | | ■■ | ■ | 8 |
| | 8 | ■ | | ■■ | ■ | 4 |
| | 9 | | ■■ | ■■ | ■■■■ | 8 |
| | 10 | ■ | ■ | ■■ | ■■ | 6 |
| | 11 | | | ■■ | ■ | 3 |
| | 12 | | | ■ | | 1 |
| | 13 | ■ | ■■■ | ■ | ■ | 6 |
| | 14 | ■ | | | | 1 |
| | 16 | ■■ | | | | 2 |
| | 17 | | | ■ | | 1 |
| | 19 | ■ | | | | 1 |
| | 22 | | | ■ | | 1 |
| | 24 | | ■ | | | 1 |
| | 29 | | | ■ | | 1 |
| | 31 | | | ■ | | 1 |
| | 32 | ■ | | | | 1 |
| | 33 | | | | ■ | 1 |
| | 35 | | ■ | | | 1 |
| | 39 | | | ■ | ■ | 2 |
| | 47 | | | | ■ | 1 |
| | 48 | ■ | | ■ | | 2 |

*Figure 22: Seriation graph of GSGs present in XUs at Tanamu 2, each black square represents one artifact.*

Excavation of this site revealed two cultural SUs. SU 1 (XUs 1–5) is a cultural layer with limited cultural materials (David et al. 2016d:3) that falls into Period 5. SU 2, which is divided into two sub SUs (SU 2a and SU 2b phase 2), is comprised of XUs 6–32 and represents the major cultural occupation at the site. The SU2 assemblage is associated with the Post-Lapita Transformative Tradition. The final SU, SU 2b phase 1 has a much older date range (6940-2715? cal BP), and it is unclear if this SU is cultural. This SU will not be discussed here. The upper levels of the Post-Lapita Transformative

Tradition assemblage (SU 2a) contain the highest number of artifacts associated with GSGs 1, 3, and 4, and also contain the majority of artifacts tested from this site. The lower levels of the Post-Lapita Transformative Tradition assemblage, SU 2b, is represented by XUs 12–31, and most of these XUs are represented by only one artifact. The greatest number of artifacts assigned to each of the four GSGs is present in SU 2a with the peak for GSG 2 at the bottom of the SU (XU 13) and the peak for the other three GSGs near the top of the SU (XUs 6–9). Other than the distinct increase in the quantity of materials from all four GSGs during SU 2a, no other observations are immediately apparent. In contrast to some of the other sites, all four GSGs were present through the entire occupation of the site. Here again is evidence that all four GSGs were available as early as Lapita and were continually available throughout the occupation of the site.

## Tanamu 3

The Tanamu 3 assemblage is one of the smaller to undergo analysis with only 30 artifacts. Artifacts from 15 of the 34 XUs excavated are included in this research, and all of the GSGs are present to varying degrees from XUs 2 and 3 at the surface down to XU16. GSGs 1, 2, and 4 are present below XU16, but in very limited quantities. The number of artifacts from each XU classified to the four GSGs is presented in Appendix 4, Table 9. No vertical patterns are immediately visible (Figure 23).

| Tanamu 3 | | | | | | |
|---|---|---|---|---|---|---|
| Strtigraphic Data | | GSG 1 | GSG 2 | GSG 3 | GSG 4 | Number of Artifacts |
| SU | XU | | | | | |
| Phase C | 2 | | ■ | ■ | | 2 |
| | 3 | ■■ | | | ■ | 3 |
| | 4 | ■ | ■ | ■ | | 3 |
| | 5 | | | ■ | | 1 |
| | 6 | | ■ | | | 1 |
| | 7 | | ■ | | | 1 |
| Phase B | 8 | | | | ■ | 1 |
| | 10 | ■ | | | | 1 |
| | 13 | ■■ | ■ | ■ | | 4 |
| | 14 | ■ | ■ | | | 2 |
| | 15 | ■■ | | | | 2 |
| | 16 | ■ | ■ | ■■ | ■ | 5 |
| | 17 | | ■ | | ■ | 2 |
| Phase A | 21 | | | | ■ | 1 |
| | 31 | ■ | | | | 1 |

*Figure 23: Seriation graph of GSGs present in XUs at Tanamu 3, each black square represents one artifact.*

Three phases of occupation were identified at this site (David et al. 2016b:65). The earliest phase, Phase A, is pre-Lapita (XUs 19-32) dating to 3046-3173 cal BP and contains low quantities of cultural materials indicating limited occupation. Pre-Lapita material that was included in this research was limited to two artifacts, one from GSG 1 and one from GSG 4.

The middle phase, Phase B, is the major period of occupation at this site. This period is associated with the Post-Lapita Transformative Tradition, dating to 2265-2545 cal BP and is represented by XUs 8–19 (David et al. 2016b:65). The densest concentration of tested artifacts is associated with this phase, and although the numbers are low, material from all four GSGs is present, with the largest assemblages of material being associated with GSGs 1 and 3. The small assemblage from this time limits the validity of any observations; however, it appears that all four GSGs were exploited to a similar very limited degree throughout this occupation.

The most recent phase is Phase C which is represented by XUs 1-7 dating to c.1800-1891 cal BP and the Umbo-bordered Shell Back Impressed Tradition(David et al. 2016b:65). The assemblage from this phase has only one artifact associated with most of the GSGs, the exception being two artifacts associated with GSG 1 in XU3. GSG 1 artifacts are the most common in both the Post -Lapita Transformative Tradition and the Umbo-bordered Shell Back Impressed Tradition assemblages. Because of the small size of this assemblage, and the generally small numbers of artifacts included for each XU, no patterns in material use are easily identified. In contrast to some of the other sites, all four GSGs are present through the entire occupation of the site.

## *ABKF*

ABKF was the shallowest site included in this research and is represented by the smallest assemblage. Ten of the 18 XUs excavated at ABKF are represented in this assemblage, and six of these XUs are represented by a single artifact. All four GSGs are present, but only GSG 4 has more than one artifact assigned to it in any XU (Appendix 4, Table 10). With such a small sample size, it is difficult to identify any patterns in the presence or absence of GSGs over time (Figure 24). The detailed site report for ABKF has not yet been published, and as a result, no temporal data or cultural information is available. The lack of information about this site necessarily limits further discussion here.

| ABFK | | | | | |
|---|---|---|---|---|---|
| Strtigraphic Data | | GSG 1 | GSG 2 | GSG 3 | GSG 4 | Number of Artifacts |
| SU | XU | | | | | |
| | 3 | ■ | | | | 1 |
| | 5 | ■ | ■ | | | 2 |
| | 9 | | ■ | | | 1 |
| | 10 | ■ | | | | 1 |
| | 11 | | | | ■■ | 2 |
| | 12 | | | ■ | ■ | 2 |
| | 13 | | ■ | | | 1 |
| | 14 | ■ | ■ | ■ | | 3 |
| | 15 | ■ | | | | 1 |
| | 18 | | | | ■ | 1 |

*Figure 24: Seriation graph of GSGs present in XUs at Tanamu 3, each black square represents one artifact.*

## Nese 1

Artifacts from seven of the 32 XUs excavated at Square C are included in this research. The number of artifacts from each XU classified to each of the GSGs is presented in Appendix 4, Table 11. Although the total number of artifacts that were tested is relatively large, the relatively small number of XUs excavated makes it difficult to identify any trends in relation to the GSGs (Figure 25). The detailed site report for Nese 1 has not yet been completed, and as a result, limited temporal data is available. The dates provided by Mialanes (2016k), c. 2730-2530 cal BP, suggest that occupation began during Lapita and continued into the Post-Lapita Transformative Tradition.

| Nese 1 | | | | | | |
|---|---|---|---|---|---|---|
| **Strtigraphic Data** | | GSG 1 | GSG 2 | GSG 3 | GSG 4 | **Number of Artifacts** |
| **SU** | **XU** | | | | | |
| **Major Occupation** | 6 | ■■■■ | ■■■■ | | ■ | 9 |
| | 7 | ■■■■■■■ | ■■■■ | ■ | ■ | 13 |
| | 8 | ■■■■■■■ | ■■■■ | ■■■■ | | 15 |
| | 9 | ■■■■■■■■ | ■ | | ■■■■ | 13 |
| | 10 | ■■■■■■■■■■ | ■■ | ■■ | ■■■ | 17 |
| | 11 | ■■■■■■■■■■■■■ | ■■■ | ■■■■ | ■■ | 22 |
| | 12 | | ■ | | | 1 |

***Figure 25: Seriation graph of GSGs present in XUs at Nese 1, each black square represents one artifact.***

## Moiapu 2

Eleven of the 23 XUs excavated are represented in this assemblage. Artifacts from all four GSGs are present and produce an interesting pattern when divided by XU (Appendix 4, Table 12) (Figure 26). GSG 1 is present in almost every XU as are GSGs 2 and 3. GSG 4, however, is not present in XUs 1–4 and XUs 8–16. Of note, the XUs with the largest assemblages of artifacts (XUs 5–7) also contained artifacts from all four GSGs. A pattern emerges that suggests that as the number of artifacts in an XU increases or decreases, so too does the variety of chert materials exploited. This is an observation made for many of the other sites included in this research, and will be investigated further in the following chapters.

Three SUs were noted at Moiapu 2; SU1, SU2 (a, b and c), and SU3. The stratigraphy at this site is complex, and as a result, there is a degree of overlap between the XUs assigned to each SU. Most of the cultural material occurs in SU2 and to a lesser extent in SU1 (David et al. 2016c:1). The most recent cultural material includes limited cultural deposits associated with SU1 (XUs 1–6) and dated to c.1700-1590 cal BP. The dates associated with this SU place it primarily within the end of the Umbo-bordered Shell Back Impressed Tradition, but it continues into the beginning for the Varied Incised Tradition. The lithic material from SU1 is limited. GSG 4 is not present in the assemblage

of artifacts from this SU, but the other three GSGs are all present, with GSG 1 being most common.

| Moiapu 2 | | | | | | |
|---|---|---|---|---|---|---|
| Strtigraphic Data | | GSG 1 | GSG 2 | GSG 3 | GSG 4 | Number of Artifacts |
| SU | XU | | | | | |
| | 1 | ■■ | | | | 2 |
| Occupation 1 | 3 | ■ | ■ | | | 2 |
| | 4 | ■■■ | ■■■ | ■ | | 7 |
| | 5 | ■■■■■■■ | ■■■ | ■■■ | ■■ | 15 |
| | 6 | ■■■■■■■■■■■■■ | ■■■■■■■■ | ■■■■■ | ■■■■■■■■■ | 35 |
| | 7 | ■■■■■■■■■■■■■■■■■■■ | ■■■■■■■■ | ■■■■■■■ | ■■■■ | 38 |
| | 8 | ■■■ | ■■■■■ | ■■■ | | 11 |
| | 9 | ■■■■■ | ■■■ | ■■■ | | 11 |
| | 10 | ■■ | ■■ | ■ | | 5 |
| | 11 | ■ | | | | 1 |
| | 16 | | | ■ | | 1 |

*Figure 26: Seriation graph of GSGs present in XUs at Moiapu 2, each black square represents one artifact.*

The major period of human activity at this site is a terminal Lapita occupation associated with SU2 (a–c; David et al. 2016d:43). This occupation is dated to c.2720-2530 cal BP and is represented by XUs 3–18. SU2 includes XUs 6 and 7, which have the two largest assemblages of artifacts as well as the greatest number of artifacts from a single XU associated with all four of the GSGs. GSG 4 material is limited to the terminal Lapita occupation assemblage at this site. Material from GSGs 2 and 3 is also much more common during this occupation. At this site, the pattern noted previously of an increase in the variety of GSGs noted in XUs with larger assemblages is once again apparent. The assemblage from this site, more than any other, clearly shows an increase in GSG variety as the number of artifacts per XU increases, and then a reduction as the number of artifacts per XU decreases.

The oldest cultural material at the site is associated with SU3 (XUs 11–23) and is associated with a small poorly defined assemblage with dates that overlap those for SU2

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and the Terminal Lapita Occupation. The assemblage from this SU contains two artifacts, one item classified to GSG 1 and another to GSG 3. There is insufficient data to make any valuable observations about this SU at this time.

## Discussion and Conclusions

The four chert GSGs identified in Chapter 9 are associated with four major sources of chert used by people inhabiting the Caution Bay area. All 12 sites analysed contained material from the four GSGs, but the use of GSGs varied from site to site, as did patterns of chronological change in the use of GSGs.

In the lithic analyses carried out by Mialanes (2016a, 2016b, 2016c) suggests that the chert used at these sites was collected from nearby areas that would have been easily accessed by people at Caution Bay. Even for sites where this is not explicitly stated, it is likely true based on the proximity of these sites to each other and the abundance of chert on the landscape. If it is assumed that all of the GSGs were available locally, then the difference in quantities of each of the GSGs at each site, and over time, must be explained in other ways beyond simple proximity and availability. First, it is possible that the difference in quantities of each GSG represented limited access to certain GSGs. A wide variety of factors could potentially limit the access of one group of people to a source material location, and these will be explored further in Chapter 13. A second possibility is the development and dissolution of trade and exchange networks. It is possible that increases in population at these sites, interaction with neighbouring communities or the arrival of new populations with different cultural systems, among other possibilities, could have resulted in the development of networks that would provide access to an increased variety of chert sources. Finally, it is possible that the difference in quantities of each GSG represent a cultural preference for one raw material over another, something that if present might be identifiable by comparing the assemblages from distinct occupations as a single site. These ideas, among others, will be perused in more detail in the following chapters.

Overall, when the assemblages are examined as a whole, GSG 1 was the most commonly used material. The exceptions to this are Ataga 1 and Tanamu 2 where GSG 2 and GSG 3 were the most common materials respectively. When the assemblages from sites are broken down into occupation phases (referred to throughout this chapter variably as SUs, occupations, phases, and horizons based on the preference of the researcher who conducted the original site research), a similar pattern emerges of GSG 1 as generally the most commonly used material. GSG 4 was, with very few exceptions, the least common material in each cultural phase. GSGs 2 and 3 were typically the second and third most common material, but there was variation between which of these was more prevalent.

In general, it was observed that GSG 4 was either not present or present in very limited quantities in the early phases of many sites. There are a number of possible explanations for this pattern. The most obvious explanation is that the source of GSG 4 had either not yet been discovered by people newly moved into the area, was geographically removed from the site, or was not visible in the landscape during this time. Visibility of the source on the landscape, in this case, would refer to potential natural or anthropogenic erosion and deposition events to cover up or expose a source of material on the landscape. Though these explanations do have merit, they are unlikely accurate. GSG 4 was present in other sites (Tanamu 1, 2, and 3) in association with some of the earliest occupations at Caution Bay and continued to be present to some degree in one or more sites during all the other cultural phases identified in Caution Bay. The absence of GSG 4 in certain assemblages cannot, therefore, be associated with its source location having not been identified. That GSG 4 was not common in many of the early occupation phases at Caution Bay is indicated by the pre-Lapita and Lapita artifact assemblage from Edubu 1 and Bogi 1. Though not a dominant source, GSG 4 was present in the Lapita assemblage from Tanamu 2 and 3, indicating the potential for different raw material selection strategies occurring at similar times at these sites.

There also appears to be a trend for GSG 4 (and in some cases GSG 3) to be less common in the assemblages associated with the more recent occupation phases at Caution Bay as indicated by the assemblage from AAUG. The absence of these GSGs

in an assemblage cannot be associated with the absence of their source in the landscape because, similar to GSG 4, they remain present in other sites dating to similar times. Other explanations for their absence will be explored in the following chapters.

Another observation that was common for most of the sites is that as the total number of artifacts in the assemblage increased, so did the number of GSGs represented. It is often assumed that an increase in the number of artifacts correlates to an increase in the intensity of the occupation (e.g. Phillipps et al. 2016; Reynard et al. 2016; Shiner 2006). For the purposes of this discussion, the intensity of an occupation can be interpreted as either an increase in population at the site, increased cultural activities occurring at the site by a stable population, or a combination of both. Four sites provide evidence of this trend, Edubu 1, Bogi 1, AASI, and Moiapu 2. At each of these sites, the SU with the largest amount of associated cultural material is also associated with the widest variety of GSGs (all four in each case) and the greatest number of artifacts associated with each of the GSGs.

The current data available is insufficient to confidently associate an increased population with these intense occupations. If, however, as a result of future research this can be demonstrated, it would allow for two readily available explanations. First, it is possible that as populations increased, all of the local or preferable GSGs were being exploited heavily, resulting in increased exploitation of more remote and less desirable materials. Alternately, but along the same lines, as the population increased, it is also possible that there would be an increase in trade and exchange that would result in the importing of an increased amount of foreign material being present at a site. Though these two explanations are not the only ones conceivable, they both provide an explanation that supports the observations, and that can be tested to some degree by examining other components at these sites. In both of these scenarios, it is likely that material from GSGs 1 and 2 was generally the preferred, or commonly available, tool material. In the first scenario, these two GSGs may have been exploited exclusively even if the other GSGs were available. This behaviour would have continued as long as these outcrops were of a size sufficient to support the needs of the local population, but as these outcrops dwindled or became harder to access due to rising populations, other

less desirable materials would begin to be utilised. If this were the case, it would be expected that GSG 3 and 4 material were of poorer quality and were being used as a necessity. In the second scenario, GSG1 and 2 would be assumed to be available locally and used as needed, but as populations, and therefore social networks, grew and developed, other materials would be introduced from locations further afield. If this was the case, it would be expected that GSG 3 and 4 material would be of better quality than the local sources to justify it being chosen as a trade item. This explanation would require evidence that other materials in the archaeological collection also demonstrated increased trade and exchange.

In cases where particular phases at a site have greater quantities of GSGs 2, 3, or 4 than of GSG 1, other potential explanations need to be investigated. During the earliest occupation at ABCE, GSG 2 is the most common material. This could relate to one of the factors discussed here, such as distance from a source, access to the source, trade and exchange, and/or cultural preferences, but it is also possible in this case, that the very small assemblage of flakes from the lower XUs introduced sampling bias in terms of under-representation of certain GSGs. As previously mentioned, due to the nature of the very small artifact collections at some of the sites, interpretation of these sites is limited. As a result, these smaller sites will be, with a few exceptions, excluded from the discussions in the following chapters.

Finally, although many observations have been made in this chapter about the distribution of GSGs at different times and at different sites, there are two overarching observations that can be made when looking at the data as a whole. First, some of the GSGs were used more regularly and for much longer periods of time than others. Not only was GSG 1 being used during the earliest occupations at Caution Bay, but it was also used during the most recent. In addition, GSG 1 is almost always the material type that is the most common during an occupation phase, and it stays the most common from the start of that occupation to the very end. This material, for whatever reason, was being used much more regularly and more frequently than the other GSGs. Possible explanations for why this material played such a significant role in the assemblages from Caution Bay will be discussed in detail in Chapter 12. The second observation about the

entire collection is that the amount of each of the GSGs varies over time and from site to site. All four GSGs can, by looking at the dates for the occupations of the 12 sites, be shown to have been available to people living in Caution Bay for the entire known span of human occupation of the area. This is a significant observation, for a number of reasons. First, if all of the sources were available for the entire length of human occupation in the area, this fact will limit the range of possible explanations that might be put forward about what was contributing to the changes seen in the use of GSGs over time. Second, if all the sources were available all the time, it is likely that cultural factors were affecting GSG selection and use more than environmental factors. This concept will be disused further in Chapter 12, but essentially, it is suggesting that if a landslide covered a source, it would be far more likely that that source would disappear from all the collections completely and not be re-introduced, or at least not for some time. In contrast to this scenario, trade or exchange networks, cultural considerations like a preference for colour and texture may represent a pattern of GSG use closer to what the data actually show.

# Chapter 11: Chronological Change in the Chert Geochemical Source Groups

This chapter examines the results of the chemical analysis of the chert artifacts from Caution Bay and explores the use of the four GSGs over time. All the sites included for which temporal information is available are examined, beginning with the oldest material and working towards the present (i.e. pre-Lapita, Lapita, and post-Lapita). Post-Lapita materials are discussed in reference to the various traditions proposed in the ceramic sequence presented by David et al. (2012b) and Irwin (1991). Site ABKF will be excluded from this discussion due to a lack of temporal information. Sites AAUG and Nese 1 each contain one major dated occupation; however, in both cases, the sites have not been analysed in sufficient detail to confidently associate them with any of the proposed ceramic traditions being discussed herein, and they will therefore also be excluded from this discussion. All the data discussed in this chapter are presented in Tables 1–12 of Appendix 4.

## Chert Use During the Pre-Lapita Period at Caution Bay

Of the 12 sites included in this research, three are known to contain pre-Lapita cultural materials: Bogi 1, Tanamu 1, and Tanamu 3. The pre-Lapita component at Bogi 1 spanned from >3000 to 4200 cal BP (McNiven et al. 2011:4). The pre-Lapita component at Tanamu 1 was much smaller and spanned c. 4350–4050 cal BP (David et al. 2016e). The pre-Lapita component at Tanamu 3 is referred to as Phase A and was only present in Square B. Pre-Lapita sites contain almost exclusively lithic artifacts and faunal remains, including marine shells and bones of marine and terrestrial animals. Shell grave goods were identified with the pre-Lapita burial at Bogi 1 (McNiven et al. 2011:4), and the occasional worked shell artifact was present in the pre-Lapita levels of Tanamu 1 (David et al. 2016e: Table 2.7). The lithic attributes analysed by Mialanes such as platform type, dorsal scarring, and flake size and weight indicate that flaked material was manufactured, used, and discarded in much the same way at each of these

sites (Mialanes 2016c, 2016d; Mialanes, Ford, et al. 2016). Lithic materials from pre-Lapita levels of these sites were almost exclusively chert, with the occasional flake of other materials such as chalcedony and unidentified igneous material. No obsidian was present in these pre-Lapita assemblages.

As the number of pre-Lapita artifacts from the three sites was small, the number of artifacts available for pXRF testing was limited. Only 19 artifacts from XUs associated with the pre-Lapita levels at Bogi 1 (XUs 79–149) were analysed. This small collection represented 13.6% of the entire lithic assemblage from these XUs (Table 5, Chapter 6). The artifacts that did not undergo testing were either too small, did not have a flat surface that could be tested or did not meet the criteria presented in Chapter 6 in some other way. Although a sample of 13.6% of the total is not ideal and may be biased, it still provides a broadly representative view of the assemblage that can be used for general interpretations. The assemblage of artifacts from the pre-Lapita Horizon at Tanamu 1 was larger than that at Bogi 1. Twenty-six artifacts from pre-Lapita levels (the Lower Horizon) at Tanamu 1 were included in the chemical testing. Several artifacts recovered from XUs below the Lower Horizon cultural level were also tested. This assemblage of 18 artifacts was from SUs 6 and 7 (XUs 70–113), and they were likely deposited during cultural activities occurring during the pre-Lapita Lower Horizon occupation. The collection of pre-Lapita artifacts from Tanamu 1 comprises 15% of the entire lithic collection from this period (Table 9, Chapter 6). Although this is a slightly more representative sample than that from Bogi 1, it is still small and limits the interpretations that can be made. The assemblage of pre-Lapita artifacts from Tanamu 3 was limited to two artifacts. This small sample, however, represents 33% of the entire lithic assemblages from this time (Table 11, Chapter 6). Although the entire collection is very small, the sample tested is statistically more representative of the whole than the previous two collections. Although the sample of pre-Lapita aged artifacts that underwent pXRF analysis was small, a few observations can be made about the use of chert by pre-Lapita peoples at Caution Bay during this relatively long span of time.

All four GSGs are present in the pre-Lapita assemblages from these sites. Their distribution from site to site, however, is variable (Figure 27).
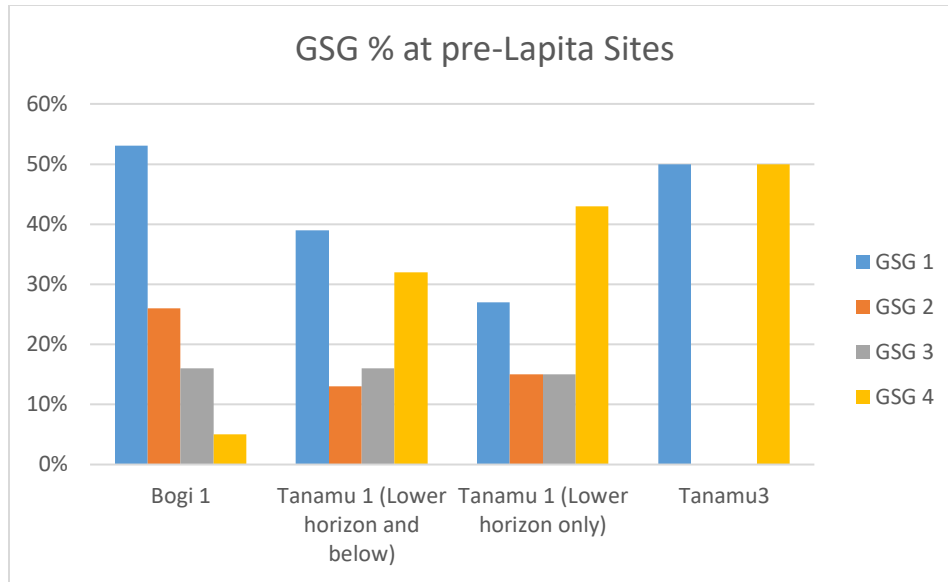
**Figure 27: Quantity of GSG (%) for pre-Lapita sites from Caution Bay.**

**Bogi 1**

The assemblage of pre-Lapita artifacts that underwent pXRF testing from Bogi 1 contained only one artifact (5%) attributed to GSG 4, which came from XU81, near the top of Phase 1 deposits. Three artifacts (16%) were attributed to GSG 3, one of which came from XU149 (lower levels of Phase 1 deposits) and two from XUs 79 and 80 in the upper section of Phase 1. GSG 1 was by far the most common lithic raw material used during Phase 1, making up 53% of the assemblage. It is represented by 11 artifacts and was present in XUs from throughout the Phase 1 deposit. Material from GSG 2 was present throughout the Phase 1 deposits as well, but was limited to only five artifacts (26%). This pattern suggests that material from GSGs 1 and 2 played a more significant role than the material from GSGs 3 and 4 during pre-Lapita times.

**Tanamu 1**

In contrast to Bogi 1, the assemblage of artifacts from the pre-Lapita deposits at Tanamu 1 contained different quantities of each of the four GSGs. The deposits associated with the Lower Horizon included XUs 48–69 and represented 19% of the lithic assemblage from this horizon. The artifacts from these XUs indicated that GSG 4 was the most common lithic raw material used during this time. Eleven (42%) of the 26

artifacts tested were associated with this group. The second largest group of artifacts (n=7) was associated with GSG 1 and made up 27%. GSGs 2 and 3 had four artifacts each that made up 15% of the assemblage. All four of the GSGs appear to be regularly represented throughout the Lower Horizon deposit at Tanamu 1, indicating the use of all four materials during this time, with a preference for GSG 4.

If the artifacts recovered from XUs below the Lower Horizon deposits (XUs 70–113) are included in the analysis (representing 12% of the total assemblage from these XUs), the results change. Of the 18 artifacts analysed from these XUs, ten (56%) were associated with GSG 1, two (11%) were associated with GSG 2, and three (17%) were associated with each of GSGs 3 and 4. These numbers indicate a very different pattern of chert resource use with an obvious preference of GSG 1 materials. No explanations for this difference are available, as the cultural material recovered from below the Lower Horizon has not been discussed in the available literature. When the two sets of artifacts are analysed together, the numbers indicate that GSGs 1 and 4 were the most significant (with a total of 17 and 14 artifacts, 39% and 32%, respectively) and that GSGs 2 and 3 were relatively uncommon with a total of six and seven artifacts (14% and 16%) respectively.

**Tanamu 3**

As the pre-Lapita assemblage from Tanamu 3 was composed of only two artifacts, it is difficult to compare this site to the other two sites. Only GSG 1 and GSG 4 materials were represented by the assemblage from this site. The other pre-Lapita sites indicated that all four GSGs were available during this time. It is possible that the very limited assemblage indicates that these two materials were the two most common at Tanamu 3. It is unclear, however, whether the other GSGs were not present in the total assemblage or were simply not represented by artifacts large enough to undergo testing.

## *Discussion*

The pre-Lapita assemblages from these three sites indicate that all the GSGs were available and used during the earliest recorded occupation of Caution Bay. The

assemblage of artifacts from Tanamu 1 (not including the lower deposit material) and Tanamu 3 suggest similar use of the raw materials available with a preference for GSGs 1 and 4. Figure 27 presents this data visually. Using the percentage values for each of the GSGs it is shown that the breakdown of GSGs between Bogi 1 and Tanamu 1 (both with and without the additional lower XUs) is quite different. Although Bogi 1 and the Tanamu sites are located geographically very close to one another, the difference in the quantities of raw materials at these sites indicates that the people inhabiting these sites were making different choices about the lithic raw materials they were using. In many of the observations made in Chapter 10, GSG 4 was the least commonly used, both at the general sites, but also in most SUs from a site. The collection from Tanamu 1 suggests that this was not the case during the pre-Lapita occupation at this site. It should, of course, be reiterated that these observations are being made based on not only a very small collection of artifacts, but also on a sample of generally less than 15% of the total lithic assemblage from sites during this time. The possibility for inaccuracies is always present.

## Chert Use During the Lapita Period at Caution Bay

Of the 12 sites included in this research, four contained a Lapita component — Bogi 1, Tanamu 1, Nese 1, and Moiapu 2. The major occupation at Nese 1 begins during Lapita and continues into the post-Lapita period, and as no other cultural data are yet available for this site, it is not possible to confidently associate this occupation with either of the ceramic traditions with which it overlaps. It has, therefore, not been included in the following discussions. The remaining three sites provide information about the choices of raw material made by Lapita peoples for the period c. 2900 cal BP at Bogi 1 to 2530 cal BP at Moiapu 2 (David et al. 2016c, 2016g; McNiven et al. 2012b). In addition to the lithic materials, these Lapita deposits include a wide variety of other cultural materials including ceramics and faunal remains.

The Bogi 1 Lapita deposit was associated with Phase 2 and SUs 7A and B (XUs 48–69). This phase dates from 2600 to 2900 cal BP (McNiven et al. 2011). At Tanamu 1,

the Lapita deposits comprised the Middle Horizon and SU3 (XUs 24–34) and covered a much shorter period of time from 2800 to 2750 cal BP (David et al. 2016e). The Lapita materials constitute the first cultural horizon identified at Moiapu 2 and are referred to as the Lapita Horizon by David et al. (2016c). This was a minor deposit associated with SU3 (XUs 11–23) and dates between 2720 and 2530 cal BP (David et al. 2016c).

Analysis of the Lapita lithic materials from these three sites indicates the almost exclusive use of chert. Other raw materials included chalcedony and obsidian (Mialanes 2016c: Table X.16; 2016e: Figure 4; Mialanes, Ford, et al. 2016a: Table 5, Mialanes et al. 2016a). The obsidian from these sites underwent pXRF analysis independently, and it has been shown to have originated on West Fergusson Island, located approximately 500 km southeast of Caution Bay (Mialanes et al. 2016a:254). In general, the other attributes analysed by Mialanes, such as platform type, dorsal scarring, flake size, and weight indicate that lithics were manufactured, used, and discarded in much the same way at each of these sites.

The number of Lapita lithic artifacts included is higher than that from pre-Lapita times for Bogi 1 but is lower for Tanamu 1. In general, the assemblage of Lapita lithic artifacts from Caution Bay is small in comparison to the post-Lapita assemblages. As the total number of artifacts is small, the number of artifacts that met the requirements for pXRF testing was limited. The Lapita artifacts analysed for this research include 24 artifacts from Bogi 1, a sample that represents 10% of the entire Lapita assemblage (Table 5, Chapter 6), 12 artifacts from Tanamu 1, 17% of the Lapita assemblage (Table 9, Chapter 6), and two artifacts from Moiapu 2, a sample of 8% of the total Lapita assemblage from this site (Table 14, Chapter 6). The quantities of each of the GSGs present in the Lapita assemblages at these three sites is presented in Figure 28.
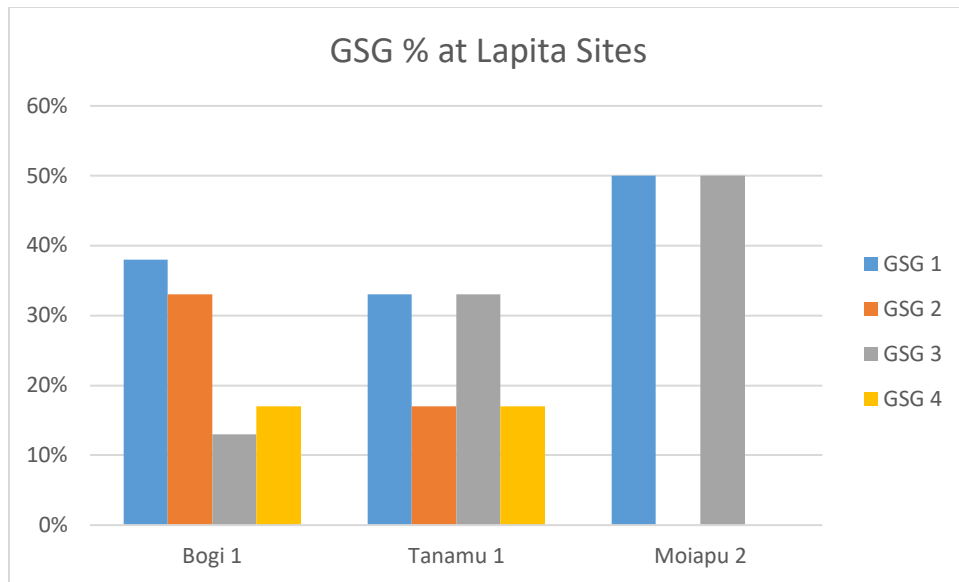
*Figure 28: Quantity of GSGs (%) for Lapita sites analysed from Caution Bay.*

**Bogi 1**

The assemblage of Lapita artifacts was the largest from Bogi 1, and all four GSGs were represented. As with the pre-Lapita levels, GSG 1 material was the most common (n=9), making up 38% of the assemblage. GSG 2 material was only slightly less common, represented by eight artifacts making up 33% of the assemblage. This is a different ratio than that noted in the pre-Lapita levels, a pattern also reflected in higher numbers of artifacts from GSGs 3 (n=3, 13%) and 4 (n=4, 17%) during the Lapita period. Though these numbers are not drastically higher than the pre-Lapita numbers, they represent a much larger proportion of the assemblage, indicating that the overall use of GSGs 3 and 4 increased dramatically during Lapita times. These observations suggest that chert resource selection during Lapita times at Bogi 1 was occurring differently than it did during pre-Lapita times.

**Tanamu 1**

The assemblage of Lapita artifacts from Tanamu 1 included all four GSGs. GSGs 1 and 3 were most common, each being represented by four artifacts which comprise 33% of the assemblage. GSGs 2 and 4 were less common, each represented by only two artifacts (each 17% of the assemblage). No distinct trends in resource use over time

are apparent during the Lapita occupation at Tanamu 1, with the data hinting at a less pronounced difference in use of the four GSGs than was observed for the pre-Lapita period. Thus, Lapita people occupying this site appear to have made regular use of all GSGs with a slightly more frequent use of GSG 1 and 3 materials.

**Moiapu 2**

The assemblage of Lapita artifacts from Moiapu 2 is too small to draw any significant conclusions. The two artifacts from Lapita levels that were tested are from XUs 11 and 16. The artifact from XU16 was associated with GSG 3, and the other artifact was associated with GSG 1. It is difficult to explore this assemblage further as it is not clear if the other GSGs were not present in the site assemblage or were simply not present in artifacts large enough to undergo pXRF testing.

## *Discussion*

The Lapita assemblages from these three sites indicate that all the GSGs were available and were being used during the Lapita period at Caution Bay. Although the data from Moiapu 2 indicate that only two of the GSGs were used, this is likely not an accurate representation due to small sample size. Both the Bogi 1 and Tanamu 1 assemblages indicate that the use of the four GSGs was much more even during the Lapita period than during the pre-Lapita period. GSG 1 material remained the most common material at Bogi 1 and was one of the two most common at Tanamu 1 (Figure 28). At Tanamu 1, the quantities of GSG 4 material changed dramatically between the Lapita and pre-Lapita assemblages shifting from most common (Lower Horizon artifacts) or second most common (Lower Horizon and all artifacts tested below it) to being one of the two smallest groups of artifacts during Lapita times.

# Chert Use During the Post-Lapita Period at Caution Bay

All 12 sites included in this research contained post-Lapita components. These sites cover a period from c. 2771 cal BP, associated with a transitionary period at the end of Lapita and the earliest occupation date for Square B at Ataga 1, (Mialanes 2016f),

to within a hundred years from present, represented by the most recent dated cultural material at Moiapu 2 (David et al. 2016c). To facilitate the analysis of lithic material use across the Caution Bay landscape after Lapita, the ceramic sequence proposed by David et al. (2012b) will be used for temporal organization. Wherever possible, the major periods of cultural activity noted at each of the sites will be discussed in association with this sequence of ceramic traditions. The sequence proposed by David et al. (2012b) includes the following cultural horizons:

- Post-Lapita Transformative Tradition (2600–2150 cal BP)
- Linear Shell Edge-Impressed Tradition (2150–2100 cal BP)
- Umbo-bordered Shell Back Impressed Tradition (2100–1650 cal BP)
- Varied Incised Tradition (1650–1000 cal BP)

The David et al. (2012b) sequence does not cover the past 1,000 years at Caution Bay. To discuss occupations from this time, the cultural periods proposed by Irwin (1991) will be used for analytical purposes. Irwin proposed two cultural periods during this time:

- Period 4 Pottery Transformation (1200–800 BP)
- Period 5 Interaction, Specialization, and Exchange (800–200 BP)

## Post-Lapita Transformative Tradition (c. 2600–2150 cal BP)

Eight sites contain components dated to the Post-Lapita Transformative Tradition: Edubu 1, ABCE, Ataga 1, AAUG, Tanamu 2, Tanamu 3, Nese 1, and Moiapu 2. The major occupations at AAUG and Nese 1 both overlap the dates proposed for this tradition and the previous or following ones, and as no data are available yet to confidently associate them specifically with any of the ceramic traditions with which they overlap they have not been included in the following discussion. The quantities of each of the GSGs present in the Post-Lapita Transformative Tradition assemblages from the remaining six sites is presented in Figure 29. Analysis of the lithic material from these sites indicates the predominant use of chert. The variety of other raw material types used during this time was wider than in previous periods, and included obsidian,

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chalcedony, quartzite, and unidentified igneous materials (Mialanes 2016a, 2016b, 2016e). Other attributes analysed by Mialanes indicate that lithics were manufactured, used, and discarded in the same way at all six sites.
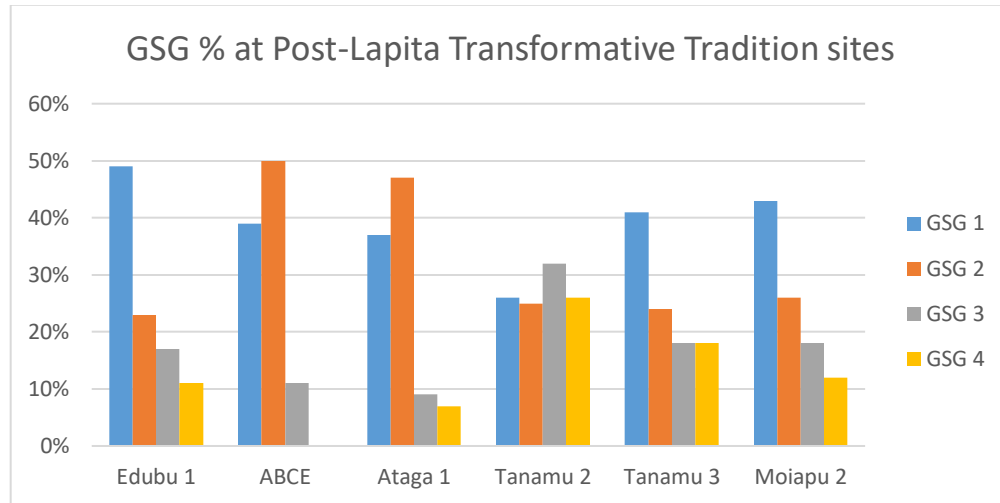


**Figure 29: Quantity of GSGs (%) for the Post-Lapita Transformative Tradition sites from Caution Bay.**

**Edubu 1**

The earliest dates for Edubu 1 overlap with the later dates for Lapita deposits at other sites in Caution Bay, with McNiven et al. (2012a) referring to the oldest deposits at Edubu 1 as Terminal Lapita. Their definition of the ceramic and other cultural materials corresponds to the description provided by David et al. (2012b) for the Post-Lapita Transformative Tradition wares. All three of the major concentrations of cultural activity have yielded dates that indicate that they were associated with the Post-Lapita Transformative Tradition and therefore the assemblage from this site will be explored as a unit. The assemblage of artifacts from Edubu 1 that underwent testing represents 11.5% of the total assemblage recovered (Table 3, Chapter 6) and includes all four GSGs. GSG 1 material was the most common, comprising 48% (n=144), and was present in almost every XU. GSGs 2, 3, and 4 each made up successively smaller portions of the assemblage, comprising 23% (n=68), 17% (n=52), and 11% (n=11). Of the three cultural concentrations, only in the lower, (oldest) was GSG 1 material not the most common. In contrast to this pattern, GSG 4 material was the least common in all,

but the middle cultural concentration and was almost completely absent from the lower cultural concentration. While it is possible that these differences represent a range of different behaviours relating to raw material use through time, the issue of small samples sizes cannot be discounted.

**ABCE**

Square C, from which samples for this research were obtained, only included cultural materials from Occupation 1, which dates from 2390 to 1910 cal BP and spans three different ceramic traditions. The lower portion of this occupation (2200–2390 cal BP) is associated with the Post-Lapita Transformative Tradition. Analysis of this site is not yet complete, but Mialanes (2016b) identified different types of lithic deposition, and it is possible that these relate to the proposed ceramic traditions. Based on Mialanes' (2016b) observations, it appears that the lower portion of this occupation, including XUs 10–18, was associated with the Post-Lapita Transformative Tradition. The assemblage that was tested from these XUs includes 18 artifacts and represents 14% of the total collection from this time (Table 4, Chapter 6). Only three of the GSGs were represented in these XUs. The GSG that made up the largest part of this assemblage was GSG 2, represented by nine artifacts (50%). Seven artifacts (39%) represented GSG 1, and two artifacts (11%) represented GSG 3. GSG 4 was not present in this analysed assemblage. The assemblage from this period was small, but the relative abundance of the three GSGs that were present indicates that it was likely an accurate representation of the actual chert use at this site during this time.

**Ataga 1**

The major occupation of Square A at Ataga 1 began between 2648 and 2540 cal BP and ended between 2558 and 2448 cal BP (Mialanes 2016f). These dates place this occupation during the time of the Post-Lapita Transformative Tradition. The majority of the XUs (XUs 1–18) from which material was included for this research were associated with this tradition. One hundred and seventy-six artifacts were included from these XUs, and they represent 18% of the artifacts excavated (Table 7, Chapter 6). A very limited number of chert artifacts (n=6) was tested from XUs below the cultural layer. Based on the descriptions of stratigraphy from the site, it is likely that these artifacts were

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deposited during the occupation of this site and have simply moved down by taphonomic processes. For the purposes of this research, all the artifacts tested from this site will be included in this discussion. With the addition of the six artifacts from XUs 19 to 25, the assemblage discussed here includes 182 artifacts and represents 18.2% of the entire assemblage.

All four GSGs were present within the assemblage, with the most common material type being GSG 2 (n=85, 47%) followed closely by GSG 1 (n=68, 37%). These two GSGs made up 84% of the total assemblage and were clearly the most heavily utilised raw materials. The least common material was GSG 4 (n=12) making up 7% of the assemblage, with GSG 3 (n=17) material only slightly more common, comprising 9%. Examining the GSG and XU data, it is apparent that the proportions of the raw materials used change from the beginning to the end of this occupation. GSGs 3 and 4 were not present during the early portion of this occupation (XUs 24–12) and only appeared in XU11. XU11 also marked a significant increase in the number of artifacts large enough to have undergone pXRF testing.

## Tanamu 2

The major occupation of Tanamu 2 corresponds to the chronology for the Post-Lapita Transformative Tradition. This occupation occurred between 2504 and 2414 cal BP, and it included all the sub-units of SU2. Almost all the material tested from this site was included in this occupation. The exceptions were the artifacts from SU1 (XUs 1-5) which were presumed to be from other contexts (David et al. 2016d). The tested assemblage of Post-Lapita Transformative Tradition artifacts from Tanamu 2 included 26% of the entire assemblage from this time (Table 10, Chapter 6). All the GSGs were present within this assemblage. GSG 3 was the most common material during this occupation, making up 32% of the assemblage (n=22) and GSG 2 was the least common (n=10, 15%). GSGs 1 and 4 had the same representation in the assemblage, each represented by 18 artifacts and each comprising 26% of the assemblage. Throughout much of the lower portion of this occupation level, only one or two artifacts were present in each XU, but all four GSGs were represented. The number of artifacts from each XU increased toward SU2a, the densest concentration of cultural material at

the site. The number of artifacts from each of the GSGs followed the same pattern, increasing towards SU2a. Generally, it appears that all four GSGs were used consistently but to slightly different degrees through the entire occupation. This is one of the few assemblages of artifacts in which GSG 1 material was never the dominant material used.

**Tanamu 3**

The major occupation of Tanamu 3 is referred to as Phase B and spans from 2265 to 2545 cal BP (David et al. 2016b:74). This occupation occurred entirely during the Post-Lapita Transformative Tradition. Phase B is represented by 17 artifacts (22% of the entire collection) from XUs 8–19 and all four GSGs were present (Table 11, Chapter 6). GSG 1 was the most common material during this time making up 41% of the assemblage (n=7). GSGs 2, 3, and 4 were all represented by fewer artifacts than GSG 1, but were all relatively close to each other, with four, three, and three artifacts (24%, 18% and 18%), respectively. These results suggest that GSG 1 was the most significant chert material for people occupying the site, but that the other GSGs were also used actively and in relatively equal quantities.

**Moiapu 2**
The major occupation of Square C at Moiapu 2 occurred between 2720 and 2530 cal BP and was represented by XUs 3–12 (David et al. 2016c:32). Although this date range overlaps with the Lapita Horizon at other sites at Caution Bay, no Lapita ceramics have been identified amongst cultural materials from this occupation. Apart from the two artifacts from below XU12 (discussed in relation to the Lapita assemblage), the cultural material from this major occupation will be examined as a unit and treated as though it is entirely associated with the Post-Lapita Transformative Tradition. The assemblage discussed here represents 25% of the total artifacts from Post-Lapita Transformative Tradition levels (

Table 14, Chapter 6). All four GSGs were present within this assemblage. GSG 1 was the most common material (n=54) making up 43% of the assemblage, followed by GSG 2 (n=33, 26%), and progressively smaller quantities of material from GSGs 3 (n=23, 18%) and 4 (n=15, 12%). These results suggest that GSG 1 was the most significant material for people occupying the site. The largest assemblage of artifacts tested, and the largest assemblage from each GSG was present in XUs 6 and 7. It is of note that GSG 4 material was not present in the assemblage until these XUs and was also absent from the assemblage in XUs 1-4. This pattern, illustrated in Figure 30, indicates that as the quantity of lithic material discarded at the site increased and decreased so did the variety of materials used.
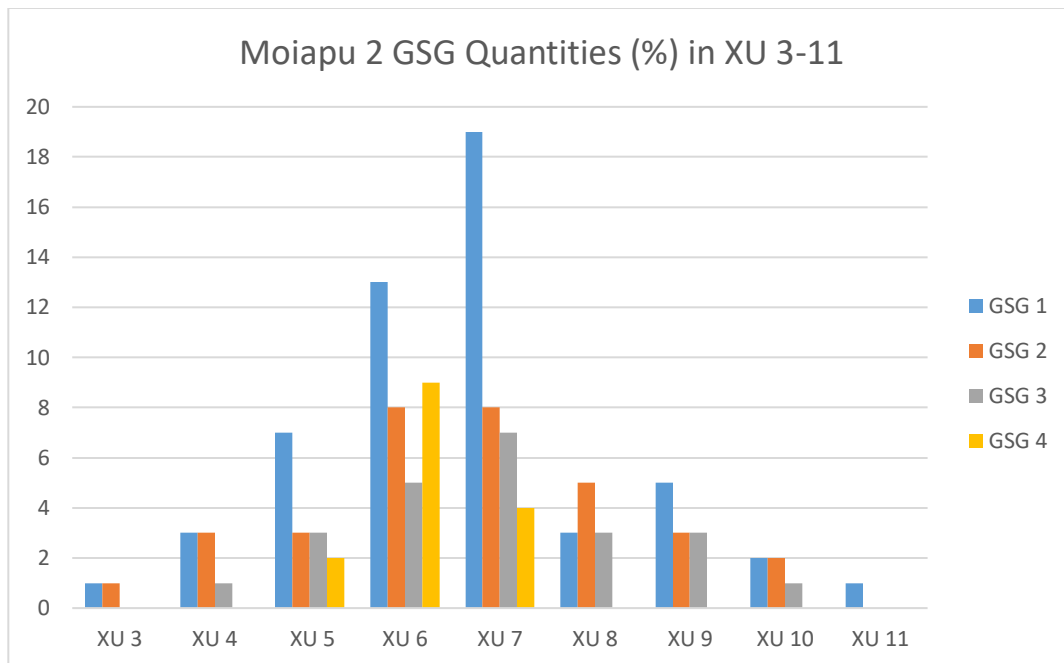


**Figure 30: Actual quantities of GSG materials tested from XUs 3–11 of Moiapu 2.**

## Discussion

In general, there appears to be one noticeable trend that is carried through all the sites associated with the Post-Lapita Transformative Tradition. In all six of these sites, GSG 4 materials made up a limited quantity of the assemblages comprising the smallest portion of the assemblage from all sites except Tanamu 2 in which it forms the second

smallest group. The dominant material being used by people during this time is generally GSG 1, as it made up the majority of the assemblages at Edubu 1, Tanamu 3, and Moiapu 2. GSG 2 was the dominant material at ABCE and Ataga 1; however, the assemblage from Ataga 1 indicates that GSG 1 material was still very important. GSG 3 material was the most common at Tanamu 2 and GSG 1 material never made up a dominant portion of the assemblage. With the exception of Tanamu 2 it appears that people during the Post-Lapita Transformative Tradition were primarily choosing to use material from GSGs 1 and 2 over material from GSGs 3 and 4 (Figure 29). In some sites, there appears to be a relationship between the amount of GSGs 3 and 4 materials and the total number of artifacts in the assemblage. That is, the quantity of material from these GSGs increased with increasing assemblage size, and vice versa.

### *Linear Shell Edge-Impressed Tradition (c. 2150–2100 cal BP)*

Three sites contain cultural materials associated chronology with the Linear Shell Edge-Impressed Tradition as defined by David et al. (2012b). Site ABCE features major occupation between 1910 and 2400 cal BP and thus potentially contains cultural materials associated with ceramic traditions prior to, and following, the Linear Shell Edge-Impressed Tradition. The second site, Bogi 1, contains a much shorter occupation that is temporally restricted to this tradition. The major occupation at the third site, AAUG, begins during the previous ceramic tradition and continues well into the Umbo-bordered Shell Back Impressed Tradition. As no data is available to confidently associate this occupation with any of the three ceramic traditions with which it overlaps it has not been included in the following discussions. The quantities of each of the GSGs present in the remaining two Post-Lapita Transformative Tradition assemblages is presented in Figure 31.
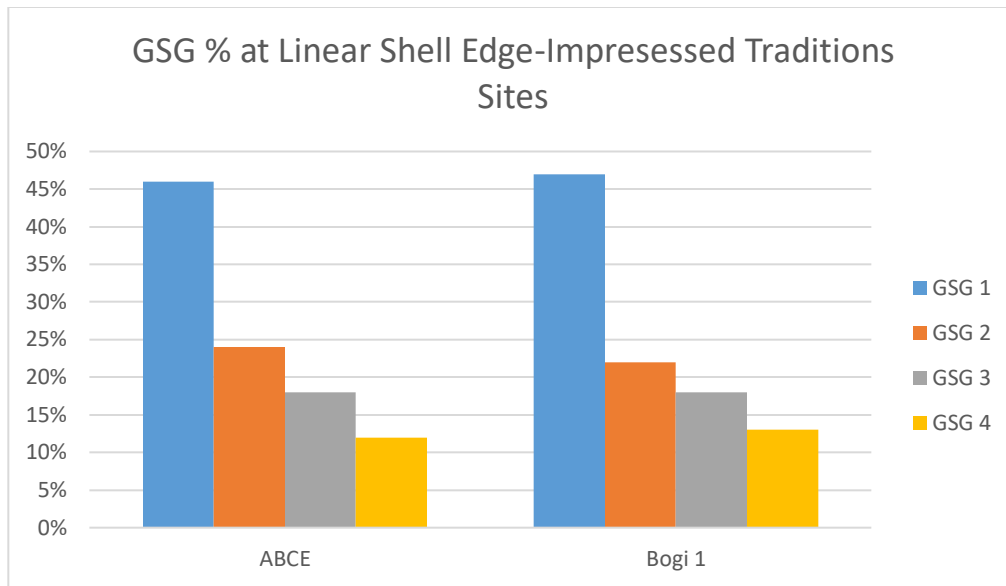
**Figure 31: GSG (%) for Linear Shell Edge-Impressed Tradition sites from Caution Bay.**

**ABCE**

Occupation 1 at ABCE dates from 2390 to 1910 cal BP (Mialanes 2016b), and thus encompasses the Linear Shell Edge-Impressed Tradition. As previously noted, based on Mialanes' observations, it is likely that the upper portion of the occupation (XUs 1–8) was associated specifically with the Linear Shell Edge-Impressed Tradition. The analysed assemblage includes 144 artifacts and represents a sample of 15% of the total lithic material from these XUs (Table 4, Chapter 6).

All four GSGs were represented, with GSG 1 the most common (n=66) comprising almost 50% of artifacts. GSGs 2 (n=35, 24%), 3 (n=26, 18%), and 4 (n=17, 12%). The assemblage is large (n=144) indicating that these results accurately reflect lithic resource use during this period (Figure 32).
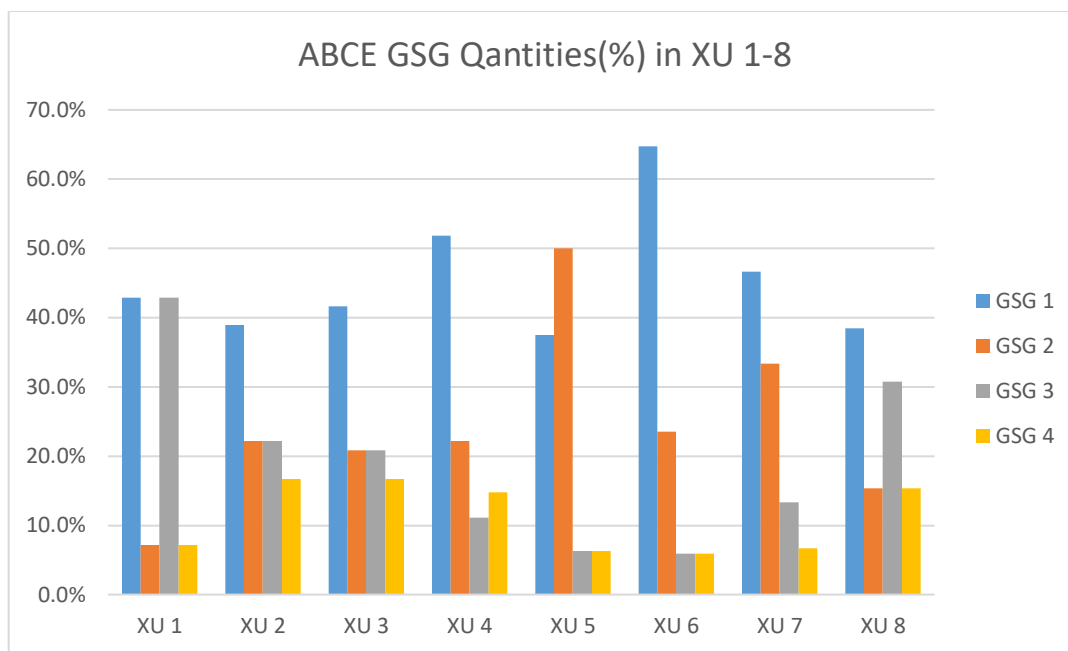
*Figure 32: Amount of each GSG materials (%) tested from XUs 1–8 of ABCE.*

**Bogi 1**

The third major occupation at Bogi 1 is referred to as Phase 3 and begins during the Linear Shell Edge-Impressed Tradition. Based on the proposed dates for this tradition, Phase 3 overlaps slightly with the following ceramic tradition. The occupation associated with Phase 3 dates to 2000–2150 cal BP, and David et al. (2012b) propose an end date for this tradition of 2100 cal BP. Due to the very short overlap of these dates, this occupation will be entirely attributed to the Linear Shell Edge-Impressed Tradition for this analysis. This assemblage of artifacts comes from XUs 5–35 and although quite large (n=706) still represents only 15.6% of the assemblage for this occupation (Table 5, Chapter 6). All four GSGs were represented in the assemblage, dominated by GSG 1 (n=335, 47%) and followed by GSGs 2 (n=155, 22%), 3 (n=127, 18%), and 4 (n=89, 13. Except for XUs 9, 24, 31, and 33, the quantities of each material were relatively constant for all XUs, and most contain artifacts from all four GSGs. Some of the deepest XUs did not contain material from GSGs 2, 3, and 4 and a few of the upper XUs did not contain material from GSG 4. Only one XU from this occupation did not contain artifacts associated with GSG 1. The consistency in the relative presence of

the various GSGs suggests that these quantities of material accurately reflect lithic resource use during this period and underline the importance of GSG 1 material at this site.

## Discussion

The assemblages of artifacts from the two sites associated with the Linear Shell Edge-Impressed Tradition show remarkable similarities. At these two sites GSG 1 material made up the largest portion comprising almost 50% of assemblages. On the opposite end of the spectrum, GSG 4 comprised the smallest number of artifacts (12–13%; Table 23). GSGs 2 and 3 made up the second and third most abundant assemblages at each of these sites and comprised similar percentages (Figure 31). Based on material proportions, these results indicate that the cultural deposits from ABCE should be associated with the much more clearly dated and defined Linear Shell Edge-Impressed Tradition deposits from Bogi 1. The assemblages of artifacts from these two sites are more similar to each other than the assemblages from any other site/time period groupings in this research.

**Table 23: Comparison of GSG percentages at ABCE and Bogi 1**

|  | ABCE | Bogi 1 |
|---|---|---|
| **GSG 1** | 46% | 47% |
| **GSG 2** | 24% | 22% |
| **GSG 3** | 18% | 18% |
| **GSG 4** | 12% | 13% |

## Umbo-Bordered Shell Back Impressed Tradition (c. 2100–1650 cal BP)

Four sites included in this research contain dated cultural material that overlaps the proposed dates for the Umbo-Bordered Shell Back Impressed Tradition – ABCE, Bogi 1, AAUG, and Tanamu 3. Moiapu 2 also contained deposits from this tradition, but these were not represented in the square chosen for this research so cannot be discussed here. Three of these sites, ABCE, Bogi 1, and AAUG all contained major occupation episodes that began in earlier ceramic traditions and contained cultural

materials potentially associated with other ceramic traditions prior to this one. There is currently insufficient data available in the published material for these sites to accurately determine if any portion of these occupations is specifically related to the Umbo-Bordered Shell Back Impressed Tradition. It is possible that the archaeological assemblages from these sites represent an occupation that began during an earlier ceramic tradition and, without a break in the occupation, transitioned to the Umbo-Bordered Shell Back Impressed Tradition. As such, the occupation deposits from these sites (although they are associated with dates that overlap the Umbo-Bordered Shell Back Impressed Tradition) have been discussed either entirely with reference to the tradition in which they commenced (ABCE and Bogi 1) and will not be discussed further here, or in the case of AAUG, due to limited publications and wide range of dates, have not been included in this discussion. Thus, Tanamu 3 is the only site that can be discussed reliably in relation to the Umbo-Bordered Shell Back Impressed Tradition. It contained a short occupation that was entirely associated with this tradition (Figure 33).
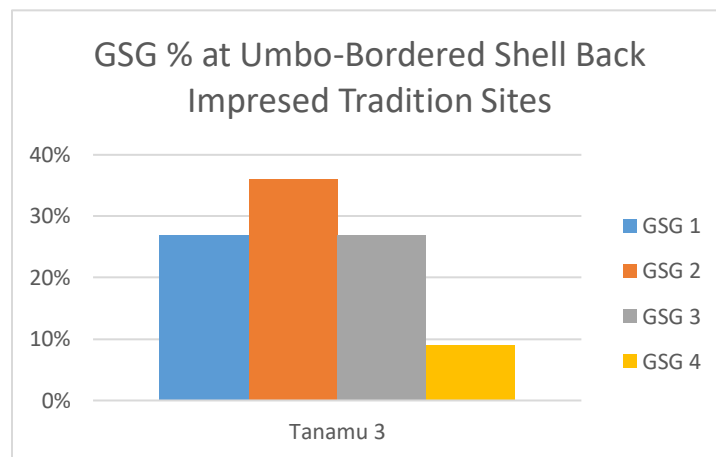


**Figure 33: GSG (%) for Umbo-Bordered Shell Back Impressed Tradition sites from Caution Bay.**

**Tanamu 3**

Phase C, the final occupation phase at Tanamu 3, is firmly located in the centre of the range of dates associated with the Umbo-Bordered Shell Back Impressed Tradition. All four GSGs were present in this small assemblage of artifacts (n=11) which

represents 17% of the total assemblage from this time (Table 11, Chapter 6). Unlike the previous sites discussed, the most common raw material during this time is GSG 2. Although GSG 2 was most common (n=4) comprising 36% of the assemblage, it was only represented by one more artifact than the assemblages for GSGs 1 and 3 (n=3 and 27% for each). As with the previously discussed sites, GSG 4 remained the least common (n=1) making up only 9% of the assemblage.

## *Discussion*

Tanamu 3 is the only site confidently associated with the Umbo-Bordered Shell Back Impressed Tradition. Based on the consistent quantities of material from XUs associated with earlier occupations at Tanamu 3 and the XUs from this occupation, it is suggested that the ratio of GSG materials at Tanamu 3 accurately represents the lithic raw material selection occurring during this time. Although difficult to confirm with such a small sample, it is possible that during the Umbo-Bordered Shell Back Impressed Tradition there is evidence that for the first time in the occupational history of the area GSG 1 was not the chert material that was most used.

## *Varied Incised Tradition (c. 1650–1000 cal BP)*

Four sites included in this research contained dated cultural material that is associated with proposed dates for the Varied Incised Tradition as defined by David et al. (2012b). Three of these sites, ABCE, AAUG, and AASI, have dates that fall within the range associated with this tradition (Mialanes 2016b; Richards et al. 2016c; Sutherland et al. 2016). The fourth site, Moiapu 2, contained a limited cultural deposit with dates that fall on either side of the lower rage of the dates proposed for this tradition (David et al. 2016c). Due to the selection process outlined in Chapter 6, the squares selected for inclusion in this research from sites ABCE, AAUG, and Moiapu 2 are all squares that do not contain cultural deposits associated with this ceramic tradition. The discussion of the chert use during the Varied Incised Tradition will, therefore, be limited to AASI.
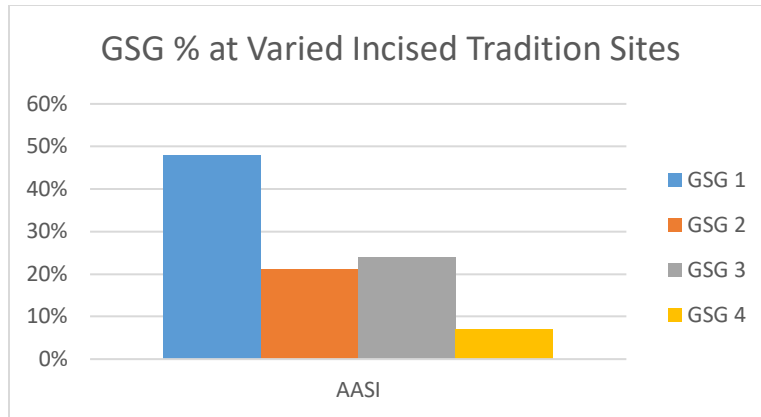
*Figure 34: GSG (%) for Varied Incised Tradition sites from Caution Bay.*

**AASI**

The cultural material from AASI was limited to SUs 1 and 2 and represents one major occupation that dates from 1564 to 1415 cal BP and is firmly associated with the Varied Incised Tradition (David et al. 2016c). The assemblage of artifacts from this time includes 29 artifacts from nine XUs; however, the majority of the artifacts were from the first two XUs, and most of the XUs below this were represented by only one artifact. This sample of artifacts represents 17% of the total collection recovered (Table 8, Chapter 6). All four of the GSGs were represented in the assemblage, with GSG 1 the most common (n=14), comprising 48% of chert artifacts. GSG 3 was the next most common material (n=7, 24%) followed by GSG 2 (n=6, 21%) (Figure 34) and GSG 4 (n=2, 7%). It is of note that GSGs 3 and 4 were only present in XUs 1 and 2. During this occupation, as the amount of cultural material discarded increased, so did the variety of lithic raw material used (Figure 35).
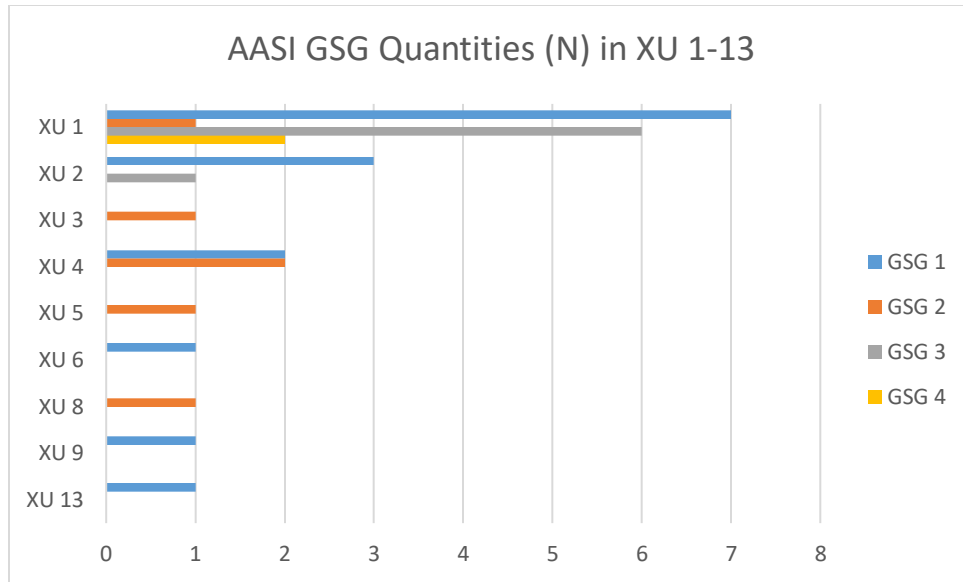
**Figure 35: Actual quantities of GSG materials tested from XUs 1–13 of AASI.**

## Discussion

The Varied Incised Tradition is represented in this research by only one site. Although the collection is small, the artifacts from AASI provide a clear picture of lithic resource use during this period. Not only is this occupation firmly dated to the Varied Incised Tradition, but also all but the deepest XUs excavated are believed to be associated with a single well-defined occupation. GSG 1 material was the most important resource for the duration of this occupation. GSGs 2, 3, and 4 were also used but with much less frequency, and in the case of GSG 4 material, were only present in the most recent levels, during the period with the greatest evidence of cultural activity. As seen elsewhere, as the quantity of material in this assemblage increased, so did the variety of raw materials being discarded at this site.

## Pottery Transformation (1200–800 BP)

None of the sites selected to be included in this research produced radiocarbon dates associated with Irwin's (1991) Period 4 — Pottery Transformation (1200–800 BP). This absence does not indicate an absence of Period 4 occupation at Caution Bay but simply that such occupation cannot be demonstrated using available data.

## Interaction, Specialization, and Exchange (800–200 BP)

Three of the sites included in this research have cultural components that are associated with Irwin's (1991) Period 5 — Interaction, Specialization and Exchange. This is final ceramic tradition present at Caution Bay, and the associated sites include ABCE, Tanamu 1, and Tanamu 2 (David et al. 2016d, 2016e; Mialanes 2016b). Two of these sites, ABCE and Tanamu 1, have dates that began during the end of the Period and persist through to almost the present day. The third site, Tanamu 2, contained a minor occupation that is undated, but is believed to be associated with the very recent past and is therefore associated with this ceramic tradition. The square from ABCE selected to be included in this research did not contain material from this occupation, so it will not be discussed here.
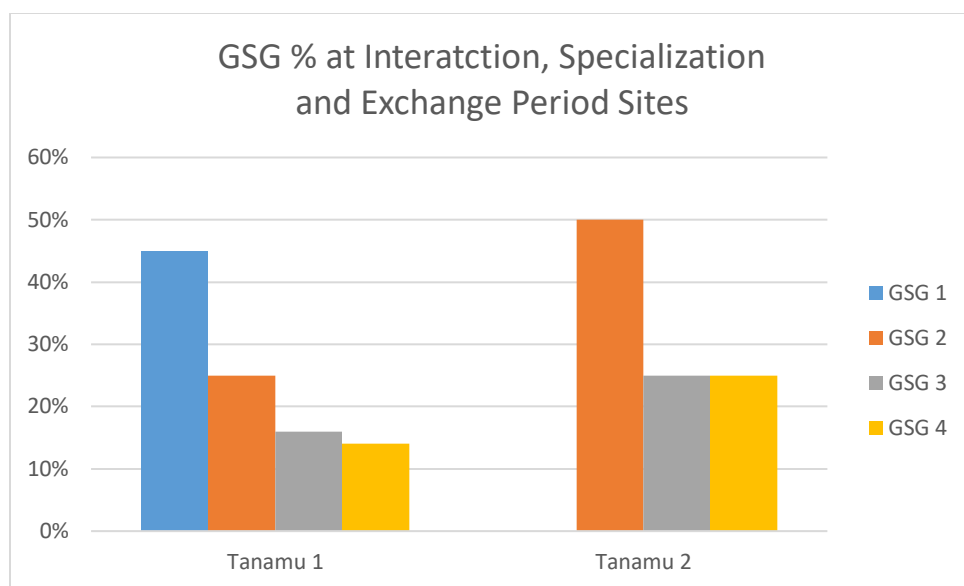
*Figure 36: GSG (%) for Interaction, Specialization and Exchange Period sites at Caution Bay.*

**Tanamu 1**

The final cultural layers at Tanamu 1 were limited to a small, poorly defined, cultural horizon referred to as the Upper Horizon B, dating from 200–100 cal BP (David et al. 2016e). The assemblage from this period included 56 artifacts from five XUs, all of which were represented by more than one artifact. More lithic material underwent pXRF testing from this horizon than any of the others at this site and represents 24% of the entire assemblage from this occupation (Table 9, Chapter 6). Although all the dates for this site fall outside of the proposed date range for Irwin's Period 5, it will be discussed in relation to this period. The decision to include it in this discussion was based on the relatively undefined end date for the period and is supported by the lack of post-contact materials present at the site in combination with the continued use of stone tools during this occupation. All four GSGs were represented in the assemblage, with GSG 1 being the most common (n=25, 45%), Followed by GSG 2 (n=14, 25%), GSG 3 (n=9, 16%), and GSG 4 (n=8, 14%) (Figure 36). Of interest with this assemblage is XU3, which contained the largest number of artifacts from GSGs 1, 2, and 3, but did not contain material from GSG 4.

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**Tanamu 2**

The second and final occupation at Tanamu 2 was a minor occupation that has no associated date and was represented by only eight artifacts (7% of the entire assemblage) from three XUs (Table 10, Chapter 6). Based on the location of this cultural material in the first SU of the site (and the first XUs) this occupation is believed to be associated with the very recent past (David et al. 2016d). As no post-contact materials were present at the site and the assemblage showed a continued use of stone tools (Mialanes 2016i), this assemblage will also be discussed in relation to Period 5. All four of the GSGs were represented in the assemblage, and GSG 2 was the most common (n=4) comprising 50% of the artifacts. GSGs 3 and 4 were the next most common materials, each comprising 25% (n=2) of the assemblage. GSG 1 was not represented in this assemblage making it the only occupation that, of all the Caution Bay sites analysed, did not contain GSG 1 materials.

## *Discussion*

The number of artifacts that made up these two assemblages is significantly different making comparisons challenging. Additionally, these two sets of artifacts represent quite different sized samples of the assemblages they represent posing further challenges to valid comparisons. If the difference in sample size is overlooked and the samples are compared directly, several observations can be made. These two sites have very different ratios of the four GSGs. Though all four materials were present at both sites, Tanamu 1 contained predominantly GSG 1 material, and Tanamu 2 contained none. Similarly, GSGs 3 and 4 represent the smallest quantity of material at Tanamu 1 but were the second most common materials at Tanamu 2. It is possible that these differences are a result of the different samples sizes, but it cannot be over looked that they may accurately represent the deposition of artifacts at these sites. It is possible that the sample size is a product of different cultural activities occurring at these sites during this period and it is further possible that whatever these different activities were, they resulted in a different selection of raw material being discarded at the site. Though these two sites generally date to the same period the assemblages, both in number and

in material, suggest that different cultural activities resulting in different chert utilisation and discard patterns were occurring.

## Discussion and Conclusions

All four GSGs were present within the assemblages from the earliest known occupation of the Caution Bay area to the most recent occupation shortly before the European contact period. The presence of all four materials in such a wide range of temporal settings provides strong evidence that the source locations of these materials were all accessible on the landscape or through trade networks for the entire length of occupation in the area. The presence of all these materials over such a long period of time makes it difficult to support the idea that the sources of some of the GSGs were not known or were not geographically exposed at certain times. Other explanations for the factors contributing to chronological changes in the ratios of GSG use at these sites are therefore required. In some cases, the assemblages from different sites from the same ceramic traditions indicate that lithic resource use was similar (e.g. Linear Shell Edge-Impressed Tradition) but in others, assemblages of lithics from different sites for the same ceramic tradition are very different (e.g. Period 5). Whether the factors affecting these similarities and differences are related to the distance a site was from the source, the access people may have had to a source, or some other factor, is unknown and will require more data to assess.

With the exception of the pre-Lapita assemblage from Tanamu 1, GSG 4 was never the most common chert type during any of the various occupation periods at Caution Bay. Even though this material was available, it may have possessed specific properties (e.g. access, knapping quality, cultural factors, etc.) that caused it to be less commonly used as a tool stone material and therefore less represented in assemblages. The GSG 1 material was, in almost all the assemblages, the most common material. Even at sites where GSG 1 was not the most common material, it generally formed the second largest group. The only exception to this pattern is the assemblage from Tanamu 2 associated with the Interaction, Specialization, and Exchange Tradition. This

assemblage was the only one that contained no GSG 1 material. The lack of GSG 1 in this assemblage is challenging to explain, as the material was clearly available during the time. It was used at the nearby contemporaneous occupation of Tanamu 1 and had been used previously at many other sites. Further discussion about this assemblage and the potential factors affecting raw material selections will be addressed in the following chapters.

Although all four GSGs were used during each ceramic tradition, the relative and absolute quantities of each change significantly over time. In some cases, the assemblage of artifacts from sites dating to the same time (e.g. the pre-Lapita period and the Interaction, Specialization and Exchange Period), appear to be quite different from one another. Alternatively, in other periods, specifically during the Linear Shell Edge-Impressed Tradition, all the contemporaneous sites appear to have similar characteristics in relation to chert use. The Linear Shell Edge-Impressed Tradition assemblages from ABCE and Bogi 1 are so similar in their composition ratio that distinctive chert usage patterns may be an additional defining feature of the tradition. In the case of the Post-Lapita Transformative Tradition assemblage, three different patterns of GSG use are represented by the six sites with occupations dating to this time. Two of these patterns of GSG use are seen at more than one site suggesting that it is possible for multiple chert selection and discard strategies to occur during the same cultural tradition. As ongoing research is made available about the faunal and ceramic materials from these sites, it will be possible to further test this association and determine its significance. Although the Linear Shell Edge-Impressed Tradition assemblage from AAUG was not included in the discussion for this Tradition due to a lack of temporal information, it is of note that when graphed this assemblage matches the pattern seen at the other two sites (Figure 37).
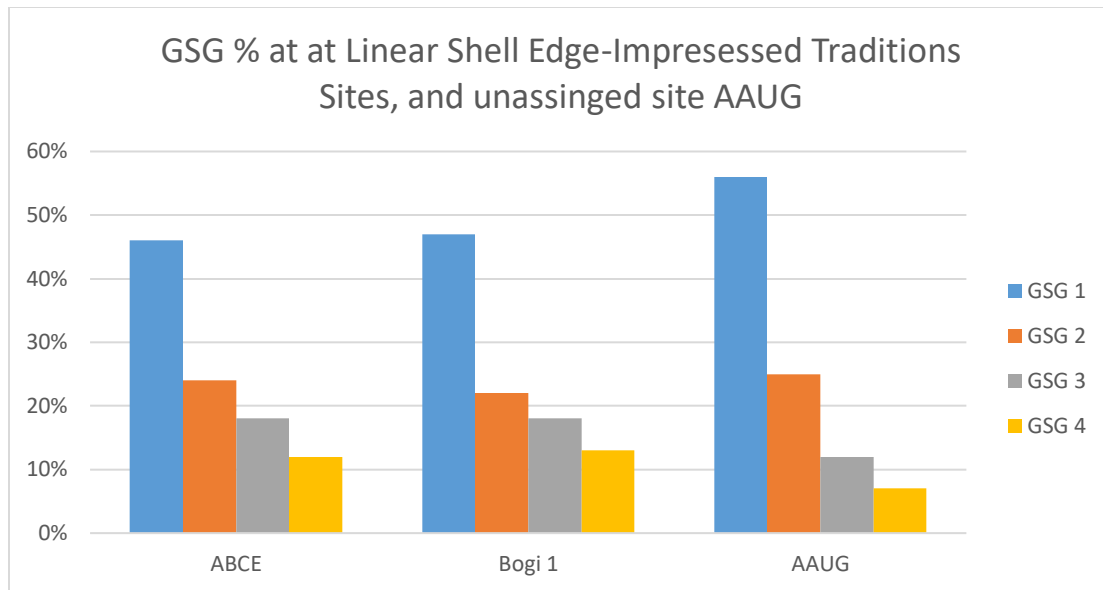
***Figure 37: GSG (%) for Linear Shell Edge-Impressed Tradition assemblages from ABCE, Bogi 1, and unassigned assemblage from AAUG.***

The Post-Lapita Transformative Tradition assemblage from Edubu 1 has similar percentages (Figure 31). Likewise, the Umbo-Bordered Shell Back Impressed Tradition assemblage from Tanamu 3 has a very different set of percentages (Figure 33). The similarity of these percentages suggests that the assemblage form AAUG is likely entirely from the Linear Shell Edge-Impressed Tradition and is not associated with the other two ceramic traditions for which its dates overlap. It will not be possible to test this suggestion until other cultural data from the site become available, however, this observation suggests that it may, with further work, be possible to identify GSG use patterns that are specific to ceramic traditions. Although it requires much more work and the inclusion of data from many more sites to develop, being able to identify temporally distinct chert use patterns would be valuable for site chronologies – especially during the aceramic pre-Lapita occupations.

In contrast to the Linear Shell Edge-Impressed Tradition assemblage, the assemblages from some of the other ceramic traditions show distinctly different percentages of the GSGs during contemporaneous occupations. Distinct differences were documented for the pre-Lapita assemblages (Bogi 1, Tanamu 1, and Tanamu 3),

the Lapita assemblages (Moiapu 2, Tanamu 1, and Bogi 1), and the Interaction, Specialization, and Exchange period occupation phase (Tanamu 1 and Tanamu 2). The pre-Lapita and Lapita assemblages are both comprised of data from three sites. In both cases, the assemblage for one site is comprised of only two artifacts, severely limiting the discussion. The remaining two sites from each of these assemblages, although represented by a larger number of artifacts, are still comprised of a significantly different quantity of artifacts. The Interaction, Specialization, and Exchange period assemblage is only represented by two sites and once again the sample from the two sites contains a significantly different quantity of artifacts.

This disparity in sample sizes provided a challenge for any confident comparison of these sites, and it should be noted that the apparent differences in GSG use at these sites may be a result of the sample size rather than a cultural construct. Although not possible to address with the information currently available, it is equally possible that the different quantity of raw materials at these sites is the result of different behaviours occurring at contemporaneous sites. That is, different activities may have produced different amounts of debitage using different types of raw material. Generally, the assemblage of artifacts that were tested from each of the cultural levels in question represented a similar quantity of the total lithic material excavated from the XUs associated with the occupation. This can be taken as evidence that the artifacts that underwent testing are a realistic sample of the whole and therefore the distribution of the GSGs is less likely to be a product of sample size and more likely a representation of the different activities. It is possible that different choices concerning the selection of raw materials would be made for different activities (e.g. a less brittle raw material would be more valuable for working harder items such as wood and bone). If different activities, potentially requiring different materials, were occurring in different areas, this could result in both a wider range of assemblage sizes and greater lithic raw material diversity at these sites. Future research focusing on the lithics used and discarded in association with specific activities (e.g. wood, shell, and bone working; butchering; food preparation etc.) would provide valuable data with which to explore this concept.

Although the data currently available limits the degree to which these hypotheses can be explored, there is one ceramic tradition with an assemblage that allows for a degree of exploration of this concept. There is a wide, although less pronounced, range of different GSGs present during the Post-Lapita Transformative Tradition occupations. This tradition is represented by the greatest number of sites and, relying on the percentages, there appear to be three different patterns of GSGs present. Figure 29 presents the percent of each GSG from the sites with Post-Lapita Transformative Tradition occupations. The first pattern of GSG use is represented by three sites, Edubu 1, Tanamu 3 and Moiapu 2. These collections are all comprised predominately of GSG 1 with progressively smaller collections of GSGs 2, 3, and 4. The second pattern is represented by two sites, ABCE and Ataga 1. These collections are comprised of predominantly GSG 2 material followed closely by GSG 1 and limited amounts of GSGs 3 and 4. Finally, the assemblage from Tanamu 2 is different again, represented by almost equal groups of all four GSGs (a distribution not seen at any other time or site). Although the size of the collections from which these percentage values have been drawn still ranges greatly, the fact that in two cases, the assemblage from more than one site demonstrates a very similar pattern of GSG use suggests that these patterns truly exist and are not a result of the sample sizes. These results suggest that smaller assemblages of artifacts and different proportions of GSGs recovered from contemporaneous occupations at sites across Caution Bay represent multiple lithic resource use and discard patterns during certain ceramic traditions. To adequately assess this statement additional data is required for a greater number of sites with dated occupations.

To further the discussion of the ratios of the four GSGs associated with the ceramic traditions the data from AAUG and Nese 1, which both had insufficient data to assign them confidently to a single ceramic tradition, were compared to the set of Post-Lapita Transformative Tradition occupations. Although experimental, due to limited data, it was hypothesised that if the assemblages from these two sites could be shown to have similar proportions of the four GSG to assemblages from dated occupations at other sites, it may be possible to attribute them to a ceramic tradition. This comparison is presented in Figure 38. The percentage of GSG materials from AAUG and Nese 1 are

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more similar to the pattern of GSG use seen at Edubu 1, Tanamu 3, and Moiapu 2 than those from ABCE and Ataga 1, or Tanamu 2. In the case of AAUG the assemblage, although similar to other Post-Lapita Transformative Tradition occupations, is not as good a fit as it was for the Linear Shell Edge-Impressed Tradition. The assemblage from Nese 1, on the other hand, is more similar to other Post-Lapita Transformative Tradition occupations than to any of the assemblages from the Lapita occupations (Figure 28).
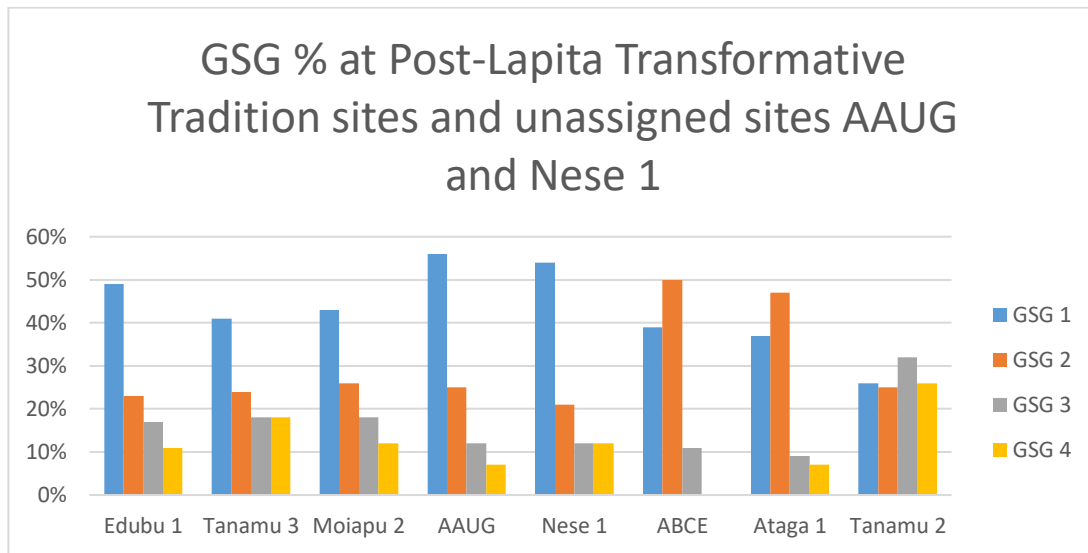


**Figure 38: GSG % at Post-Lapita Transformative Tradition Sites and unassigned sites AAUG and Nese 1**

These observations are only presented as a means of exploring the data, and to demonstrate the ways that GSG proportions can be valuable to archeologists. The suggestion that AAUG is most similar to Linear Shell Edge-Impressed Tradition assemblages and that Nese 1 is most similar to Post-Lapita Transformative Tradition occupations is valid but should not be considered a confident assignment of the occupation at these sites or to these ceramic traditions at this time. Until more data is available for chert material and the GSGs present at many more sites in the Caution Bay area, ceramics and other cultural materials still need to be included when accessing a site's temporal affiliation.

Another observation that was noted when examining the assemblages from each of the ceramic traditions is the apparent relationship between the quantity of artifacts in an SU (or XU) and the number of GSGs represented as well as the quantity of artifacts associated with each of the GSGs. Generally, the larger the quantity of lithic material recovered from a given SU or XU, the larger the sample of artifacts that were appropriate for pXRF testing. Although no GSG data is available for the artifacts that were not tested, it has been assumed here that the assemblage of artifacts analysed was generally representative of the actual assemblage of lithic artifacts from each site. Although this assumption cannot be tested, due to the limits of the pXRF instrument, it is possible to examine the proportion of artifacts from any of the assemblages to determine if the assemblage that underwent testing was statistically large enough to be generally representative of the whole. The assemblages of artifacts that underwent pXRF testing for all the SUs at each of the sites discussed here represented between 7.3% and 33% of the total artifacts recovered from these sites. Based on a 95% confidence level, this range of percentages includes confidence intervals ranging from 2.49 (very good) for the Linear Shell Impressed Tradition assemblage from Bogi 1 to 58.29 (very poor) for the pre-Lapita Assemblage from Tanamu 3. The lower the value for the confidence interval the more likely the sample accurately represents the entire assemblage. The average confidence interval for all the culturally distinct assemblages from each site discussed here is 14.33 which is good when the limitations of the pXRF sampling strategy and the high number of very small flakes recovered from wet screening are considered. Having established that the collection of artifacts that was tested does confidently represent the entire assemblage from which they were selected, the observed relationship between artifact quantity and GSGs diversity can be explored further. It was observed during this analysis that, as the quantities of material in a given SU (or XU in some cases) increased, so did the diversity of GSGs and the amount of GSG 4 material present in the assemblage. This observation is important, as it indicates that as the sample population increased, so did the range of chert material types. This pattern was noted in the general investigations of the site data presented in Chapter 10, but is even more noticeable here as it is seen at more than one site and in more than one period. It is likely that GSG 4 material was in some way less available, less desirable, or less accessible than the

other three GSG sources. Possible explanations for the limited amounts of GSG 4 material will be explored further in the following chapters.

This chapter has explored the GSG data by examining site data from contemporaneous occupations for each of the ceramic traditions identified at Caution Bay. It has been demonstrated that the use of each of the GSGs has not been consistent from one ceramic tradition to the next. Instead, data from some ceramic tradition's (Linear Shell Edge-Impressed Tradition) chert use is very similar but different from occupations dating to earlier or later ceramic traditions. This is not the rule, however, as in other ceramic traditions (Lapita, Post-Lapita Transformative Tradition, the Interaction, Specialization, and Exchange period, and in the aceramic pre-Lapita period), the use of GSGs is quite different at contemporaneous occupations. Although the differences in some of the contemporaneous assemblages may be related to sample size, a variety of data have been presented that suggests these assemblages accurately represent the entire collections from which they were selected. It is suggested therefore that the different quantities of GSG at contemporaneous sites likely represents different activities or other cultural differences that either required different raw material or resulted in different raw materials being accessed. A range of the potential explanations for the different proportions of GSG at contemporaneous sites have been suggested and will be explored in detail in the following chapter.

Significantly, the data presented in this chapter suggest that with additional research on further sites from Caution Bay GSG quantity data may be useful for identifying distinct cultural assemblages, something that has not been done previously in locations with significant ceramic artifact assemblages. Although this conclusion is tentative and will require further analysis of the Caution Bay sites and pXRF testing of many more artifacts to provide a confident analysis, the research presented here does suggest that the possibility may exist. This could eventually result in lithic material playing a much more significant role in the temporal definition of new archaeological assemblages from the Caution Bay area and potentially from the greater South Coast region of PNG.

# Chapter 12: Geochemical Source Groups and the Archaeological Assemblages: Exploring Potential Contributing Factors

This chapter explores further various explanations for similarities and differences in the relative use of the four of GSGs at selected sites at Caution Bay detailed in Chapters 10 and 11. Many factors could hypothetically be influencing the quantities of chert from each of the GSGs present in the assemblages tested. The factors and potential explanations that are presented in this chapter, therefore, do not constitute an exhaustive list of every factor that may have contributed to the creation of these assemblages. The explanations presented in this chapter are those that were considered to be testable, or that could be, at a minimum, be investigated to some degree with the data currently available. As discussed in Chapter 2, archaeological and anthropological data for Caution Bay and the surrounding area is not overly abundant and, in some cases, the available data allowed for much more in-depth investigations than in others. An additional challenge that is ever present in the discussions that follow is the complete lack of specific information about the actual geological sources of chert on the south coast of PNG. Although no data currently exists about the source locations of the GSGs identified in this research, sufficient data are nonetheless available to allow for the generation of a series of useful hypotheses on this topic.

This chapter is divided into three broad sets of factors. First, a number of physical geographic factors will be explored. These will include an investigation of the roles that geographic distance from a GSG source to an archaeological site may have played, the ease of access to the source of a GSG from an archaeological site, and the potential for natural geological processes to expose or hide the source of a GSG. The second set includes human geographic factors. This discussion will focus primarily on human impacts on the landscape and the effects of human behaviors on the deposition and erosional processes in the area. The third section will discuss social factors such as resource ownership and political boundaries, as well as the potential effects of cultural preference or avoidance of specific raw materials.

Throughout this thesis, the term GSG has been used to refer to the chemically distinct groups of chert identified in the archaeological collections. The GSGs are believed to represent actual outcrops of chert on the landscape around Caution Bay, but this association has not been confirmed in the field. There is currently no data available about the physical location of any chert deposits in the Caution Bay area. There is also no detailed data currently available concerning what chert deposits in the area would look like if they were to be located. In Chapter 3 it was explained that chert is common along the south coast of PNG and is usually present in either bedded formations or in nodules present in specific geological formations. These observations have been corroborated in discussions with other researchers, and with the authors own experiences doing archaeological fieldwork in Caution Bay. There are numerous modern road cuts between Port Moresby and Caution Bay that contain easily identifiable large bedded deposits of chert. Additionally, based on personal observations of the landscape around Caution Bay, chert nodules can be found naturally eroding out of the ground in a number of areas. Both the terms source and outcrop are used in the following discussion, and unless otherwise specified, these terms refer to a hypothetical location where either a bedded chert deposit, or a dense cluster of chert in nodule form, is visible on the surface. For the purpose of this discussion, it is also assumed that all the hypothetical sources and outcrops of chert were surface or near surface exposures and that no excavations or mining activities would have been required to access these materials.

## Physical Geographic Factors

Physical geographic factors with the potential to impact raw material selection include, but are not limited to, the distance to an outcrop, ease of access to an outcrop, visibility of an outcrop, and mass wasting events covering/exposing an outcrop. The geographical factors that are discussed here do not represent an exhaustive list of all potential geographic factors; they are a selection that was chosen based on their perceived ability to assist with investigating the data available. Chapter 3 presented an overview of the geology and geography of Caution Bay, much of which was drawn from

data about the broader southern coast of PNG. This overview included a discussion of the geographic and environmental history of the area which was somewhat limited due to a lack of published data. Some geomorphic and palaeo-environmental research has been conducted in association with the Caution Bay Project (Rowe et al. 2013), but the geological history of the Caution Bay area and the potential sources of chert raw material in the vicinity has not yet been explored. This lack of information makes it difficult to investigate the role that geography and geology have had on the selection of raw materials by people living in the area since c. 4200 cal BP. Geographic Distance from Source to Site

One of the possible explanations for the different quantities of GSGs at each site is the geographical proximity of people occupying the site to GSG outcrops. In the absence of outcrops location data, it is hypothesised that the quantity of a GSG present in an assemblage may be related to the geographical distance between the GSG outcrop and the location of GSG use at a site. The effect of source distance on stone artifact raw material use has been explored in detail in other parts of the world (e.g. Barrientos et al. 2015; Beck 2008; Blumenschine et al. 2008; Close 1999; Doelman et al. 2001; Fernandes et al. 2008; Frahm 2014; Galipaud et al. 2014; Magnin 2015; McCoy and Robles 2015; McNiven 1993; Newman 1994; Tomasso and Porraz 2016; Wilson 2007a). A number of variables should be considered in a discussion of the importance of the distance from a source to a site, including how the source is being accessed (e.g. is the source being accessed directly by people living at the site or is the material from the source finding its way to the site through a network of trade and exchange networks?) and does local geography limit or make access challenging (e.g. is there an impassible water body or mountains in the area?). Both of these factors will be explored independently in this chapter. For the investigation that follows, however, it has been assumed that the source of each of the GSGs was being accessed directly by people in Caution Bay and that there were no limiting geographical factors present on the landscape. To examine the relationship between the quantity of a GSG at a particular site and the potential for geographical distances to the source to affect this quantity, a simple experiment was devised. It was hypothesised that the GSG with the largest representation at a site would represent the source located closest to that site. If this

could be shown to be true for multiple sites located near to each other, this result would indicate that distance was playing a significant role in the choice of raw material. If it was found that sites in proximity to one another had very different amounts of each of the GSGs, than this result would suggest that other factors were playing a more significant role than simple proximity of the source to the site.

The GSG data for the Post-Lapita Transformation Tradition Sites was selected for this experiment (Edubu1, ABCE, Ataga 1, Tanamu 2, Tanamu 3, and Moiapu 2). This assemblage included the largest number of different sites providing the best geographical coverage of the entire Caution Bay Project area. In addition, all but one of the sites (ABCE) included in this assemblage contained items from all four GSGs. To conduct this experiment, the quantity of the four GSGs were ranked from most common to least common at each site and were then assigned arbitrary distances in equal intervals that increased as the amount of material decreased. Several distances were tested, and smaller distances were determined to be visually easier to interpret than larger ones. Distances beginning at 0.5 km from a site and increasing in 0.5 km intervals were used. Circles with a 0.5, 1.0, 1.5, and 2.0 km radius were plotted around each of the sites, and colour coded for the GSGs they represented (GSG 1 = green, GSG 2 = yellow, GSG 3 = red, GSG 4 = blue). These diagrams (Figure 39) were explored to see if sites in close proximity to each other had similar or different rankings of the four GSGs. The distances selected for this experiment are arbitrary, were selected primarily for their ability to be visualized on a map, and are generally much smaller than the areas from which other stone tool resources were collected (obsidian from hundreds of kilometres away was present in Caution Bay). Although small, there is no reason to believe that the distances selected for this experiment from a potential source to a discard location is not likely to have an effect on the quantities of material from different sources recovered at a site. The relatively abundant chert out crops in the vicinity of Caution Bay and the expedient flake tools made from them support the assumption that people would have had the ability to choose tool stone from a variety of sources near to their work sites and as they were not crafting formed tools, would likely simply access material from the best of the nearby sources. This assumption is supported by research done by Doelman et al. (2001) in which they note differences in the selection, use, and discard of lithic materials

in small areas were multiple, easily available, yet physically different stone sources are present, and in some cases located less than 30 m apart.

To explore visually the relationship between the quantity of a GSG at a site and the potential for geographical distances to the source to affect this, two sets of maps were created. These maps show the ranked amount (indicated by the size of the circle) of each of the GSGs (indicated by the colour of the circle) at each site, with progressively larger circles indicating progressively smaller assemblages. The first set of maps (Figure 39 A–D) shows the respective rank positions for each GSG on an individual figure. The high number of small circles on the map for GSG 1 indicates that it was the most common at most of the sites. The high number of large circles on the map of GSG 4 shows that it was the least common material.

**Figure 39 a-d: Individual GSG abundance at Post-Lapita Transformation Tradition sites in Caution Bay. Increasing circle size represents decreasing GSG quantities. GSGs are represented by different colours.**

A.  Quantity of GSG 1 at Post-Lapita Transformation Tradition Sites
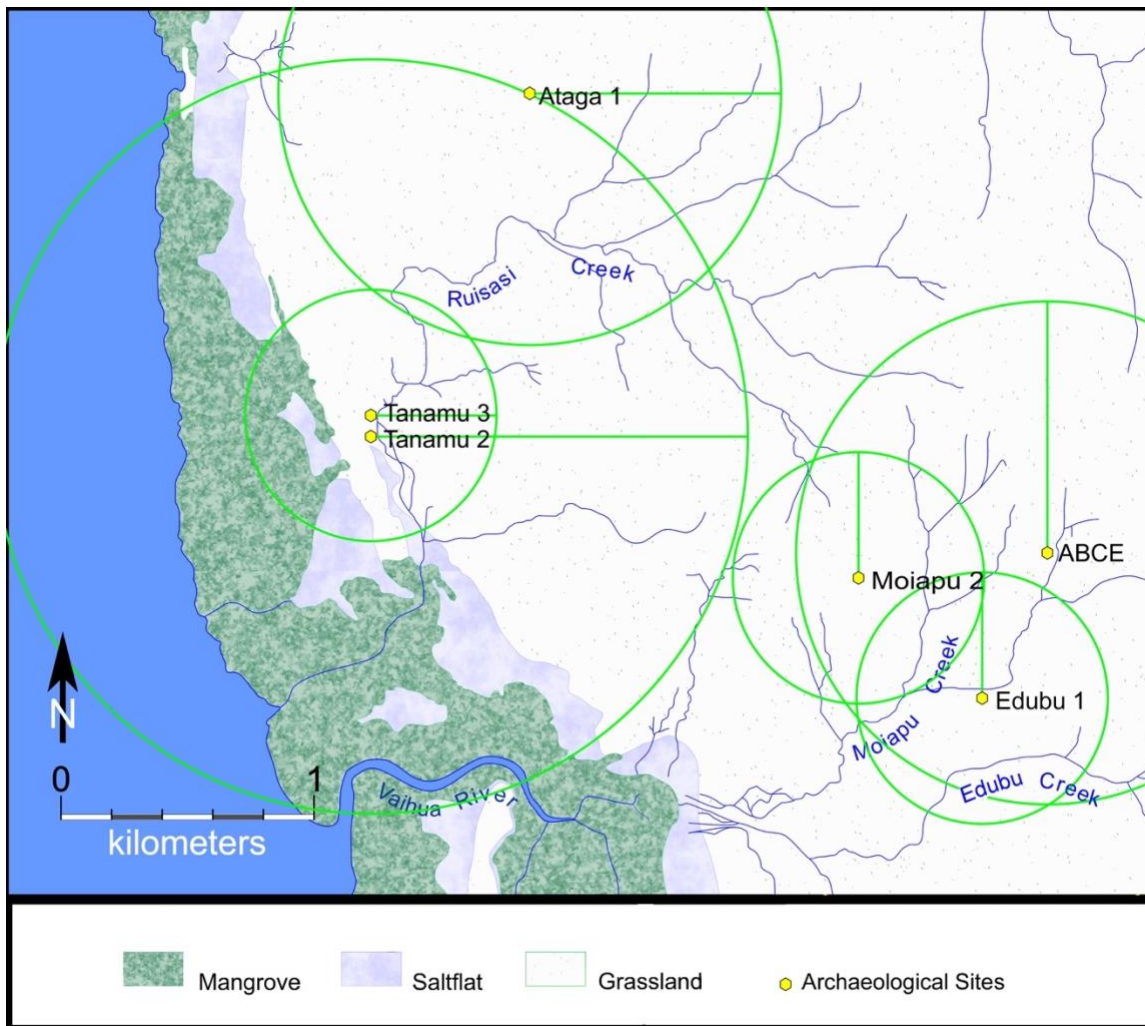
**B.   Quantity of GSG 2 at Post-Lapita Transformation Tradition Sites**
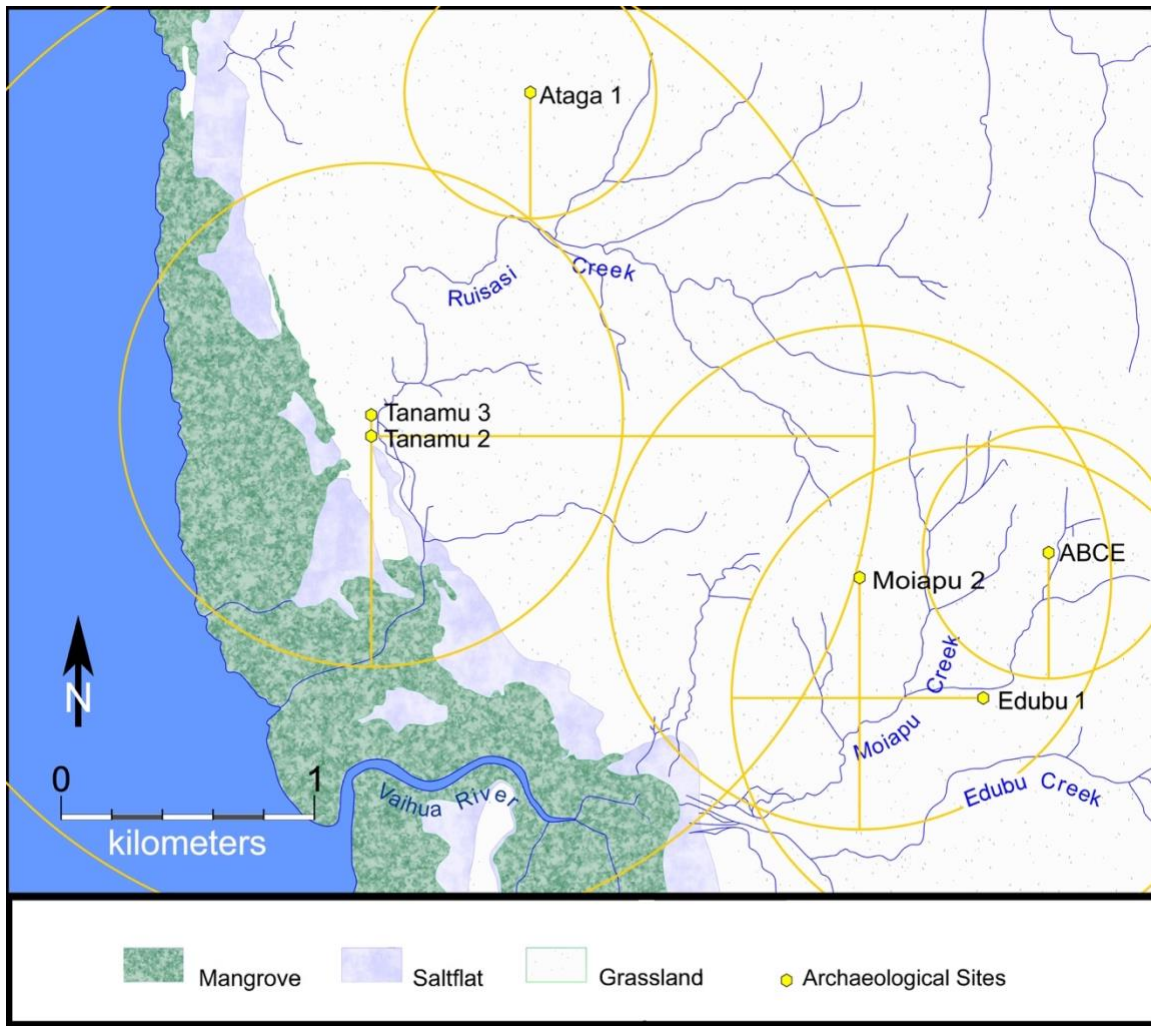
**C. Quantity of GSG 3 at Post-Lapita Transformation Tradition Sites**
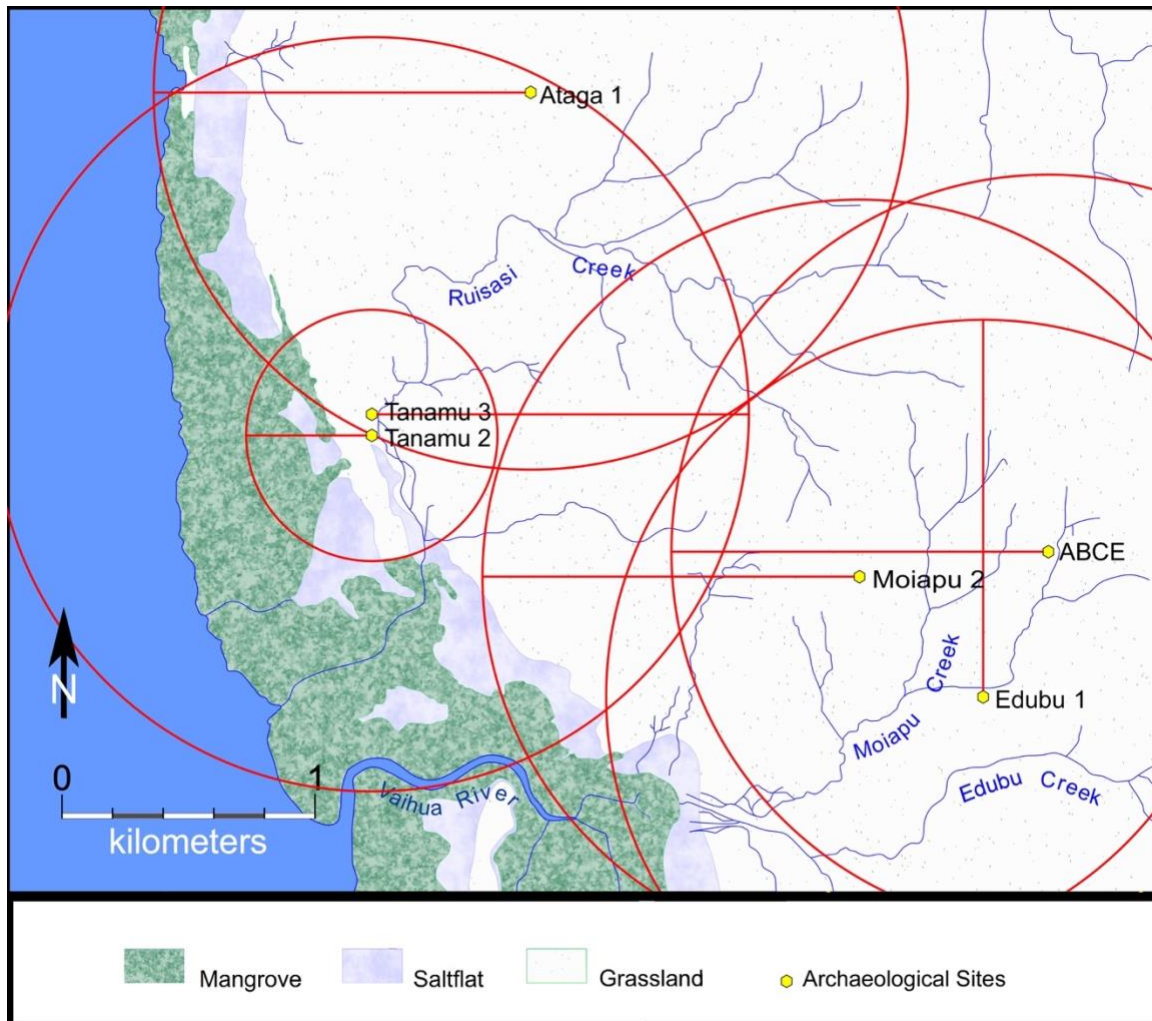
**D. Quantity of GSG 4 at Post-Lapita Transformation Tradition Sites (No GSG 4 material was recovered from this occupation at ABCE)**
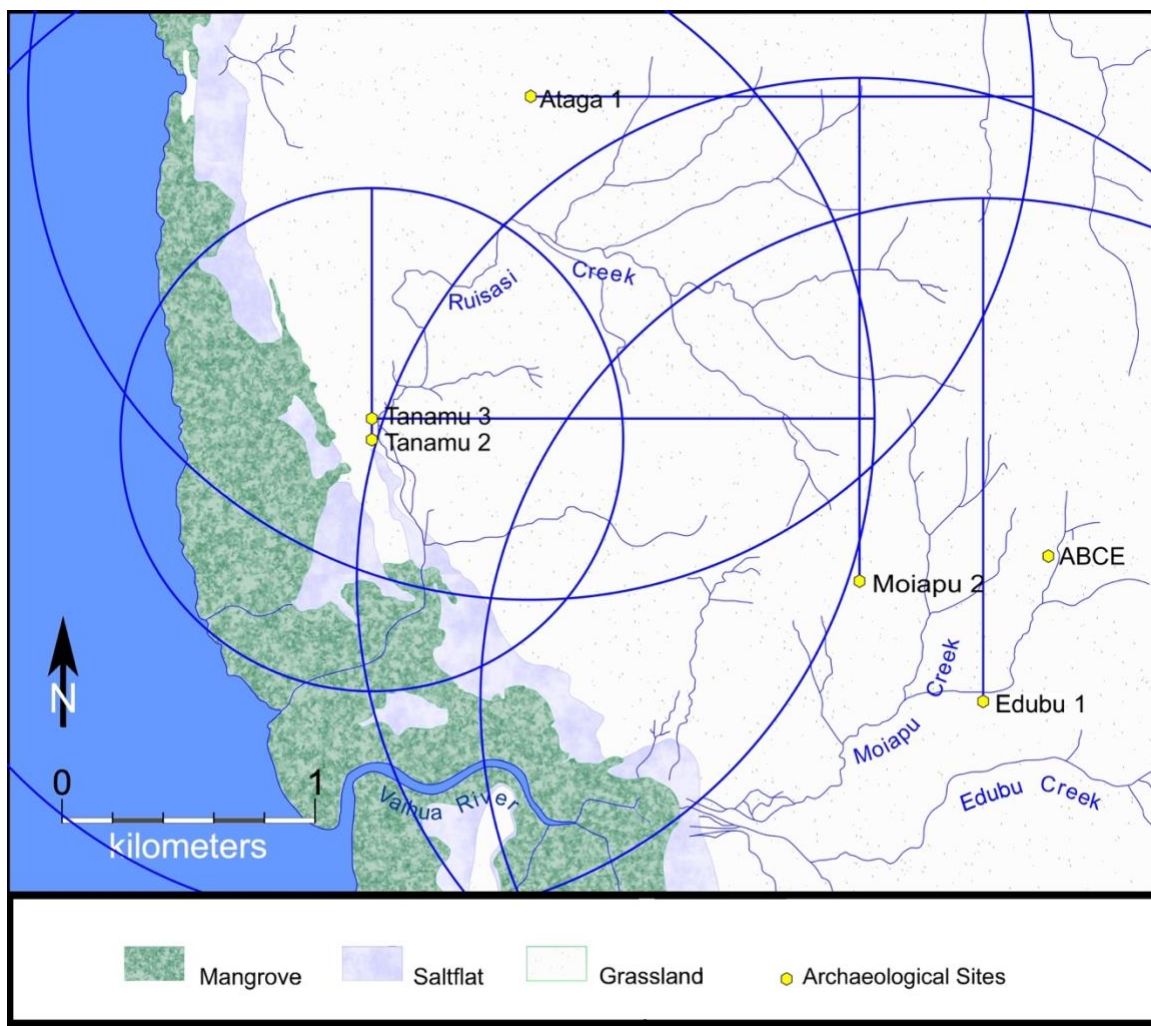
Keeping in mind that the assumptions behind the use of the arbitrary circle sizes, some interesting patterns emerge for discussion. Figure 29 A presents the data for GSG 1 from all sites, with the smallest circles indicating that GSG 1 was the most common at a site and the larger circles indicating that it was less and less common. With the exception of Tanamu 2, the two sites to the north-west of the project area (Ataga 1 and ABCE) have less GSG 1 than those to the southeast (Edubu 1, Moiapu 2, and Tanamu 3). It is possible that this demonstrates that the source of GSG 1 is located to the southeast of these sites and that the sites further way have less access to it. The data from Tanamu 2 cannot be disregarded, however, and until an explanation for the discrepancy in GSG 1 can be developed this hypothesis is difficult to support.

The data for GSG 2, presented in Figure 29 B, is slightly easier to interpret. Here there is a clear trend in the sites where GSG 2 is most common in the collection from the sties to the northeast of the project area (ABCE and Ataga 1), moderately common in sites to the southwest of these first two (Edubu 1, Moiapu 2, and Tanamu 3), and least common at Tanamu 2, the site furthest to the southwest. If it is assumed that a possible source of GSG 2 was located somewhere to the northeast of these sites, than this pattern of less and less material further and further to the southwest can be taken as support for the suggestion that distance form a source may be affecting the quantities of GSGs at the tested sites. Additional information from more sites would be required to test this idea properly, and it would be beneficial to locate the source of GSG 2 on the landscape; but the data presented here do suggest that both of these lines of research are worthwhile pursuing and that they might produce corroborative data to that presented here.

The ranked quantities of GSGs 3 and 4 are presented in Figures 39 C and D. These two figures show a similar pattern in which Tanamu 2 has a different quantity of these GSGs than all the other sites. GSG 3 is the most common at Tanamu 2 and the 3rd most common at all the other sites (Figure 39 c). GSG 4 is the second most common at Tanamu 2 and the 4th most common at all the other sites (Figure 39 d). These two figures suggest that the source of GSG 3 and 4 is closer to Tanamu 2 than to any of the other sites. It is possible that the source of these materials is somewhere to the

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southwest of this site. It is also possible (although there is no evidence to support this suggestion at this time) that these materials may have been accessed by boat from further north or south along the coast and that people living at Tanamu 2 either had access to these materials directly or controlled the movement of them into the area. Much more data will be required to explore the patterns of GSG use discussed here to determine if any of the hypotheses that have been put forward can be supported or refuted. Although it is not possible to explain all of the patterns observed in this small experiment with the data currently available, the data do suggest that here is some merit to exploring the GSGs in this way. Further analysis with additional sites that have Post-Lapita Transformation Tradition occupations would be valuable to the discussion here as would an investigation of other temporally distinct occupations.

A second set of figures displaying the same information presented in Figure 39 but displayed in a different way was also created (Figure 40 A–D). This set of maps used all the same data as those presented in Figure 39 A-D, but instead of illustrating each GSG independently, this set was constructed to show the GSGs from each of the four ranked distances on one map. Therefore, the most common GSG at each site (that represented by the smallest circle) was plotted first followed by the next three progressively smaller GSGs (and progressively larger circles). These figures were developed to look at variation in GSG use and to inspect how sites that were geographically remote or close to one another were using the GSGs.

**Figure 40 a-d: Ranked abundance of all GSGs at Post-Lapita Transformation Tradition sites. Increasing circles size represents decreasing GSG quantities. GSGs are represented by different colours.**

A. **Most abundant GSG at Post-Lapita Transformation Tradition Sites, GSG 1 - Green; GSG 2 – Yellow; GSG 3 – Red; GSG 4 – Blue.**
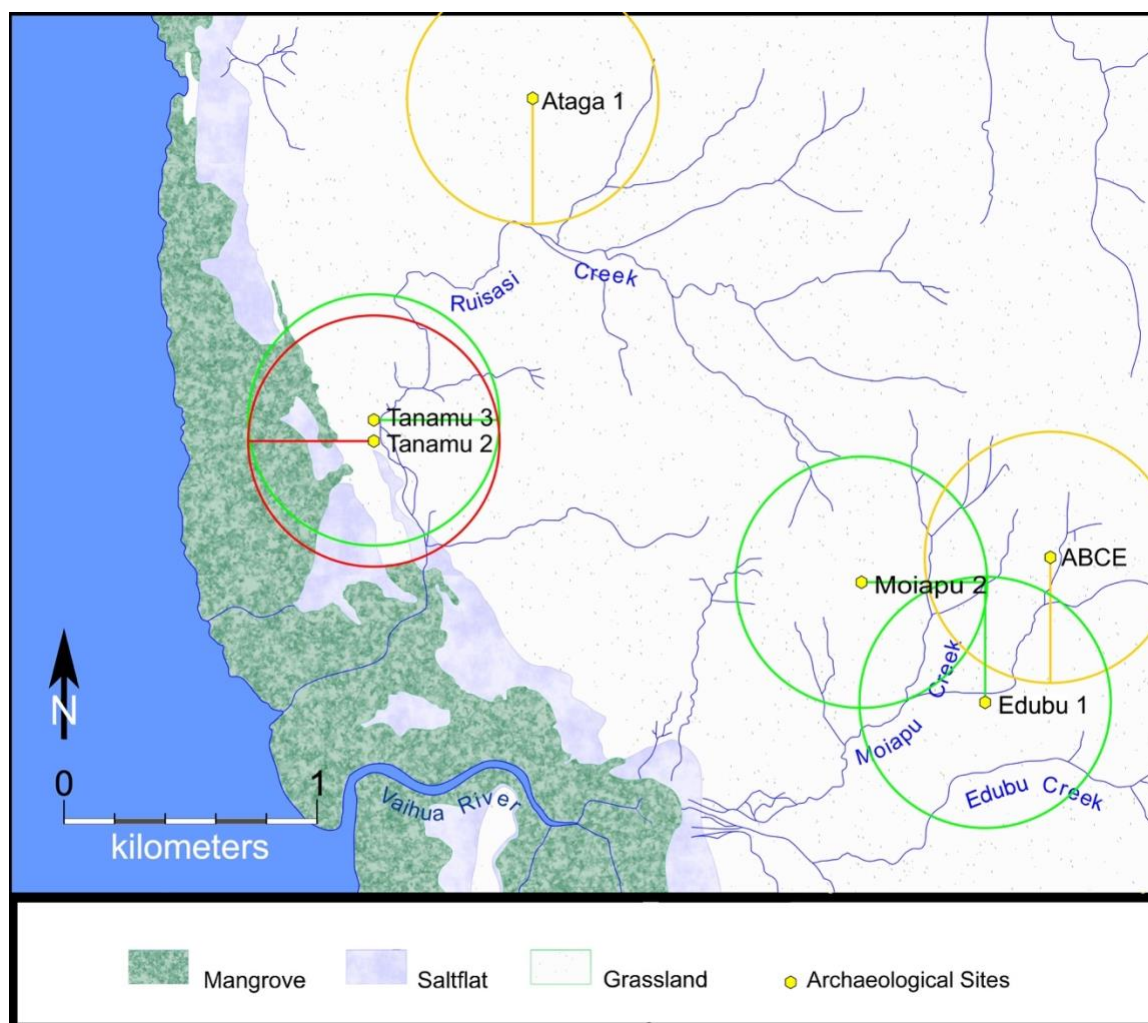
**B. Second most abundant GSG at Post-Lapita Transformation Tradition Sites, GSG 1 - Green; GSG 2 – Yellow; GSG 3 – Red; GSG 4 – Blue.**
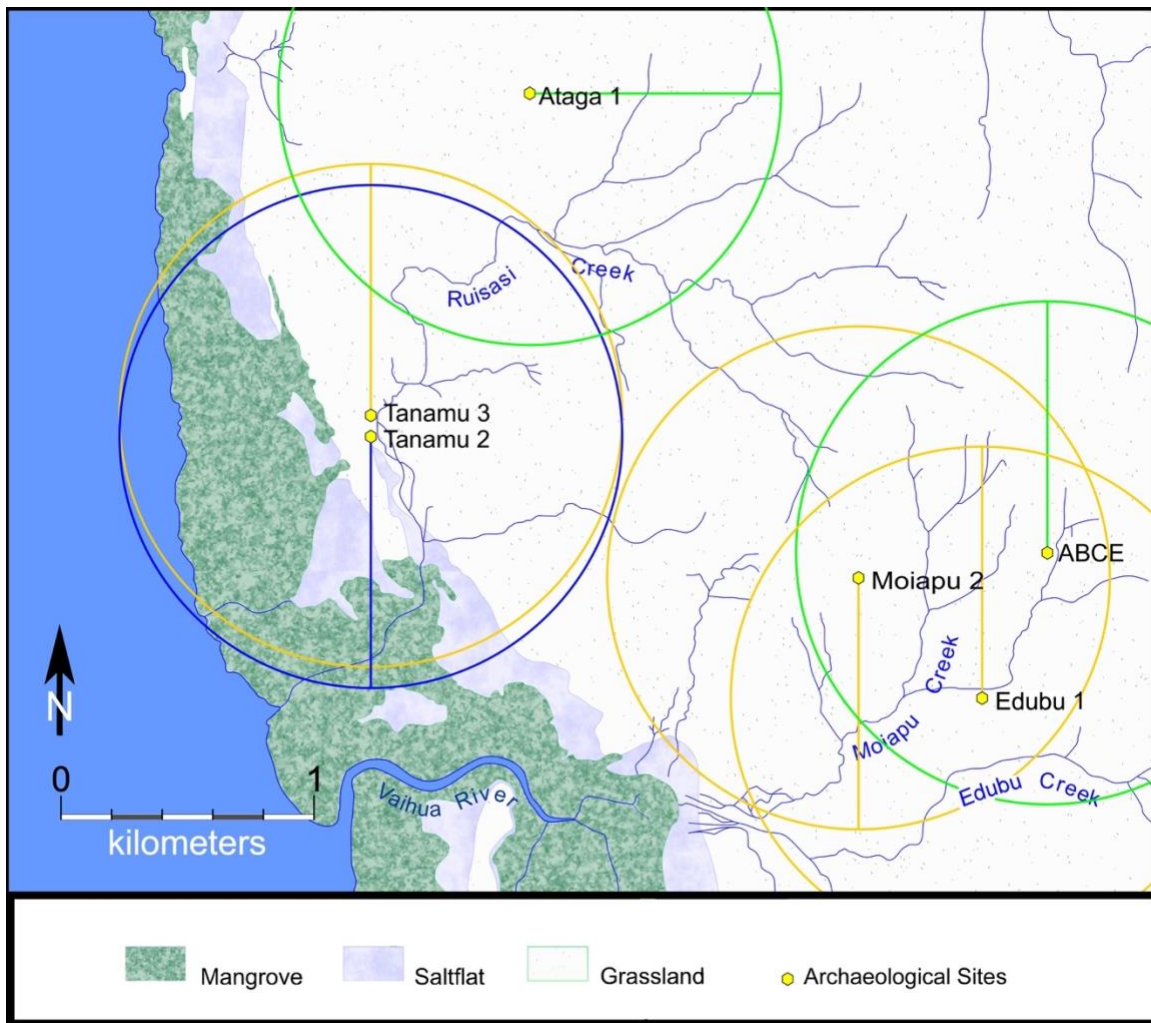
**C. Third most abundant GSG at Post-Lapita Transformation Tradition Sites, GSG 1 - Green; GSG 2 – Yellow; GSG 3 – Red; GSG 4 – Blue.**
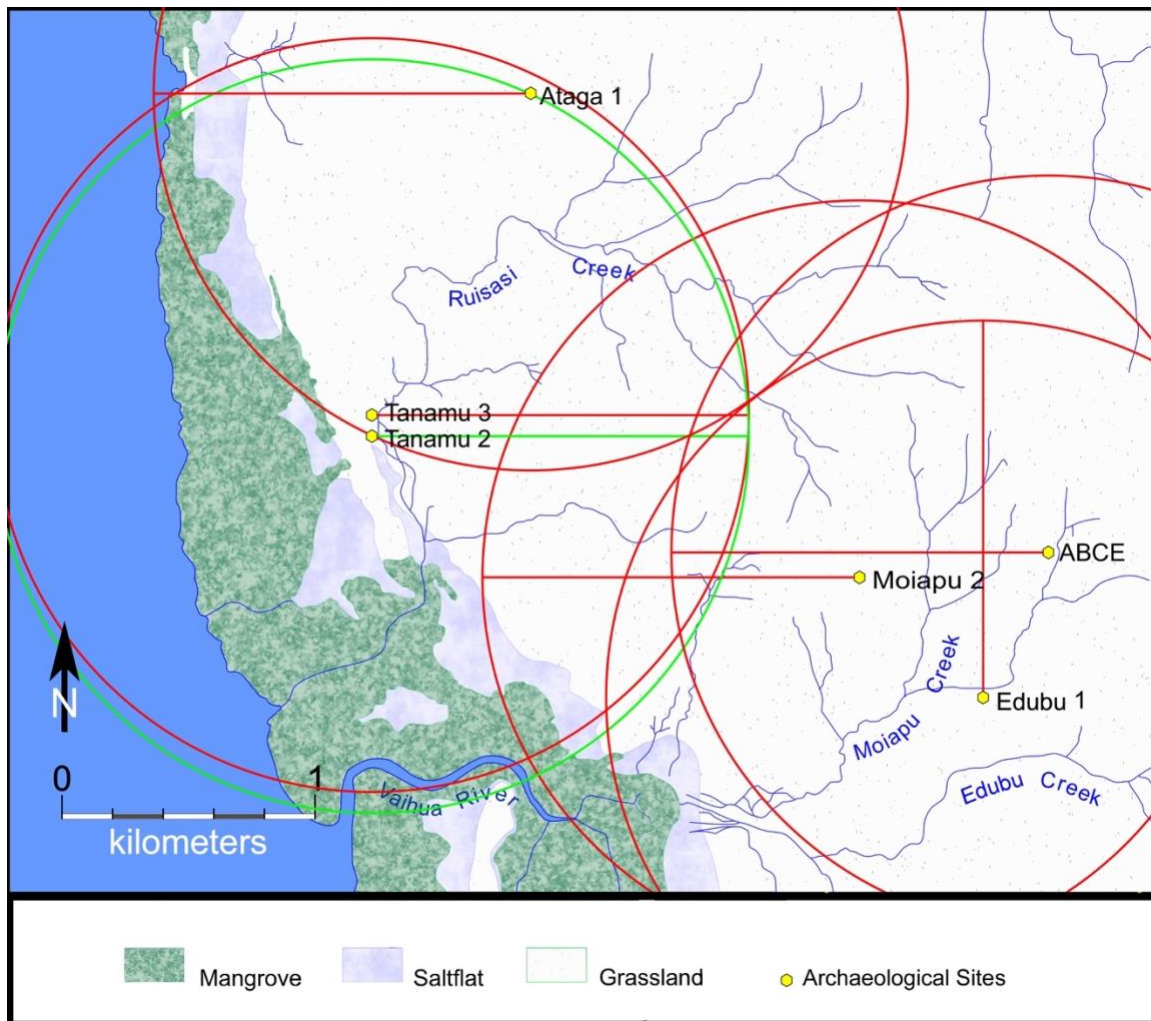
**D. Least abundant GSG at Post-Lapita Transformation Tradition Sites (only three GSGs were present during this occupation at ABCE), GSG 1 - Green; GSG 2 – Yellow; GSG 3 – Red; GSG 4 – Blue.**
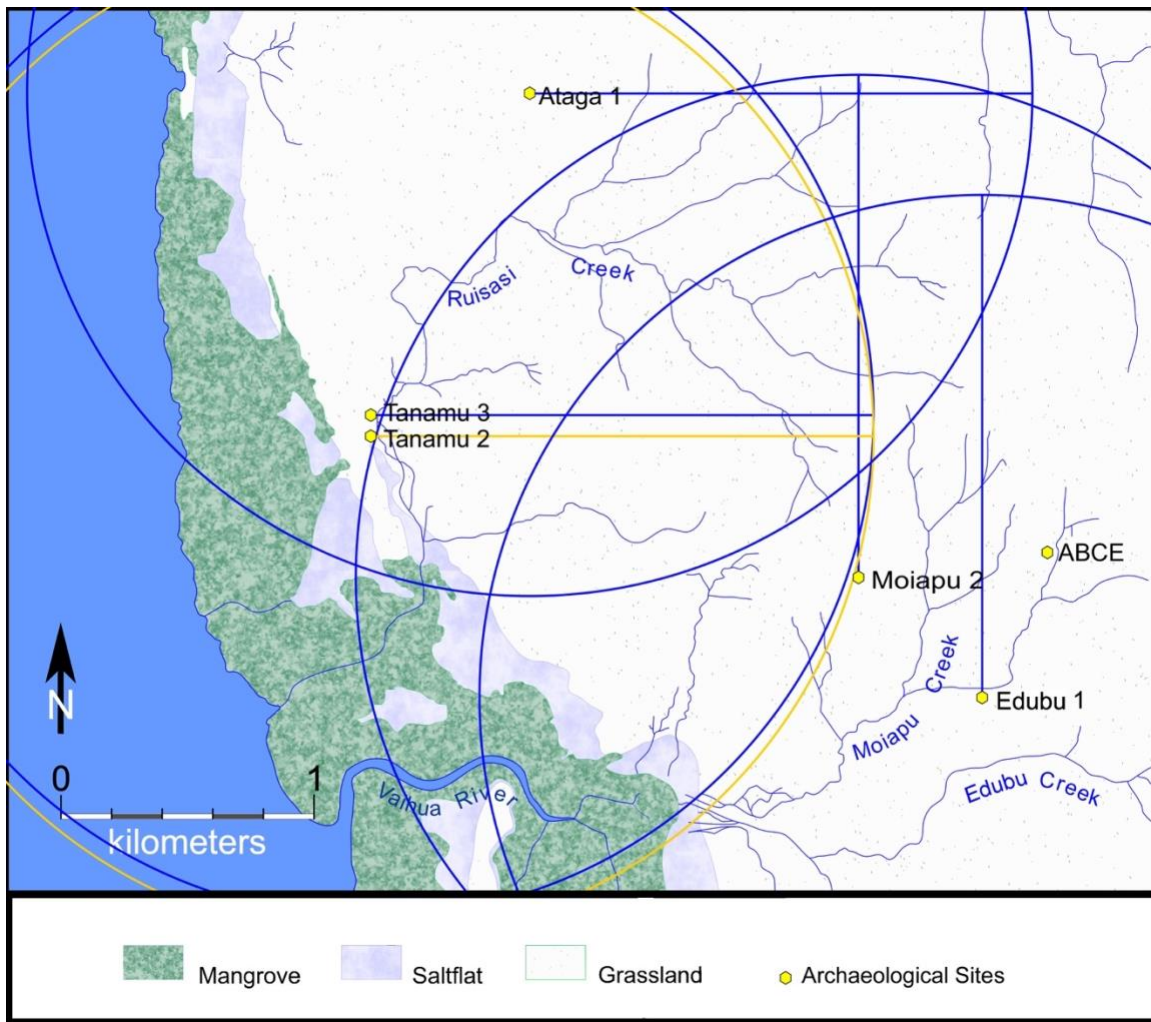


In order to test the merit of the idea that the distance from a geological source to an archaeological site had an effect on the lithic materials found at the site, the mapped results of the data are examined. The six sites included in this portion of the analysis can be divided into three geographically separate areas for the purpose of this discussion. To the north, Ataga 1 is removed from all the other nearby sites. The data from Ataga 1 will be referred to in the discussion that follows as Area 1. To the west, Tanamu 2 and Tanamu 3, which are very close to one another, form a group well removed from the other sites. These two sites will be referred to in the following discussion as Area 2.

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Finally, to the east, ABCE, Edubu 1, and Moiapu 2 form a third much looser cluster. These three sites are not as close to one another as the two Tanamu sites, but they are closer to one another than to the other sites discussed here. These three sites will be referred to as Area 3.

Area 1, with Ataga 1, is 1500 m northeast of the two Area 2 sites and 2500 m north-northeast of the Area 3 cluster centre. As this site is the furthest from all the other sites, it would be expected that if the distance from a site to a source was paying a significant role in what GSGs ended up in the tested assemblage that this site would show a different pattern of GSG use than the Area 2 and 3 sites. This is not the case. Instead, the ranking of GSGs here indicate that GSG 1 and 2 have the same ranking here as at ABCE in the Area 3 cluster (Figure 40 a-b). The ranked quantities for GSGs 3 and 4 from Area 1 are the same as that from Tanamu 3 in Area 2 and all three Area 3 sites (Figure 40 c-d). Having only looked at one of the three areas it is already apparent that the data do not support that distance to a source is likely having any significant impact on the assemblages of material at these sites.

The Area 2 sites include Tanamu 2 and Tanamu 3, and these two sites do not have a single GSG ranked at the same level of abundance. The most common GSG at Tanamu 2 is GSG 3 and at Tanamu 3 it is GSG 1 (Figure 40 a). The second, third, and fourth most common GSGs are also different at these two sites (Figure 40 c-d). The sites from this area confirm the observations made for Area 1; the data do not support that distance to a source is likely having any significant impact on the assemblages of material at these sites.

The Area 3 cluster was comprised of the largest number of sites including ABCE, Edubu 1, and Moiapu 2. Unlike Area 2 there is a lot more similarity in the ranking of the GSGs here. The collections from Edubu 1 and Moiapu 2 both have GSG 1 present in the largest quantities with GSGs 2, 3, and 4 making up progressively smaller portions of the assemblage (Figure 40 a-d). Although ABCE has a different GSG as the most common (GSG 2) and second most common (GSG 1), GSG 3 is ranked the same here as the other two sites. No GSG 4 data is available for ABCE, but in this case, the lack of data

suggests that this GSG was not used and it can, therefore, be interpreted as the least common at the site, which makes it the same as the other two sites. The Area 3 data suggest that with the exception of the ABCE assemblage, there may be some merit in the idea that these sites were all equally distant from sources of the four GSGs. Although a number of explanations may exist, it is likely that the difference noted in the ABCE assemblage is the result of differences in the size of the collections from these sites that are not taken into account when comparing percentage values as done here.

In general, this small experiment has demonstrated that there is not enough data presented in the figures to confidently support the hypothesis that the distance from a geological source to an archaeological site was affecting the types of lithic materials found at these sites. There is inadequate evidence to support the idea that a chert source's proximity played a major role in the choice of chert types found within a site and it must be concluded that the geographic proximity of the source of the GSGs was not playing a dominant role in the selection of raw material used at the sites in question. Other explanations for the different quantities of each of the four GSGs present in the assemblages from the Caution Bay sites that were tested herein must be sought.

It should be noted that along the southern coast of PNG, chert is an abundant raw material and, as noted in Chapter 3, it tends to be found in bedded formations within sedimentary units. It is, therefore, possible that there is more than one location for many of the GSGs. Due to the way in which chert is formed, it is possible that a single chemical signature could account for a wide-ranging chert source that outcrops in several discrete locations. If this were the case, it could be suggested that none of the sites were geographically far enough removed from an outcrop of a GSG to have caused an impact on the representation of that GSG in the archaeological assemblage. Future research focused on locating and providing chemical composition data of chert outcrops along the southern coast of PNG would be valuable and would allow for further refinement and testing of the results and hypotheses presented here.

### Ease of Access to a Source Outcrop

As well as geographic distance, ease of access associated with geographical features can influence the relative use of raw materials (e.g. Beck 2008; Blumenschine et al. 2008; Close 1999; Doelman et al. 2001; Newman 1994; Parish 2013). If a chert outcrop is located in steep, dangerous terrain, it is possible that it will be less regularly exploited than an outcrop that is easier to access (e.g. Brantingham 2003; Wilson 2007a, 2007b). It must also be considered that difficult-to-access materials may also serve a different cultural purpose, owing to the danger involved in procurement. Large rivers and ocean crossings also have the potential to affect the ease of access to a raw material and influence the quantities of that material at a site (e.g. Clark et al. 2014; Galipaud et al. 2014; Sparks 2013). It is very likely that Ferguson Island obsidian recovered from some Caution Bay sites may well have had a different cultural significance than the local chert due to its remote origin.

Without known outcrop locations for the GSGs, it is not possible to accurately assess how much geography and accessibility may have affected raw material use at Caution Bay. It is possible, however, to make some broad general observations. There are no topographic obstacles to human movement (e.g. large cliffs, wide rivers, and ocean crossings) that would limit access to resources within 30 km or more of any of the sites included in this research. Within 30 km of the Caution Bay sites, there are some small islands, and meandering rivers that may have required watercraft to access or cross and the terrain to the south is increasingly uneven, but not to a degree that would pose challenges to pedestrian access. It can be concluded that people gathering raw material from within a minimum of 30 km distance from Caution Bay would have had no major geographical obstacles limiting their access to chert sources

### Geological Processes

That the visibility of an outcrop of raw material in the landscape can affect its presence in an archaeological assemblage was illustrated by Parish (2013). Geological processes such as mass wasting and flooding have the potential to alter landscapes dramatically (Hudson and Middelkoop 2015) and could change the availability and

accessibility of raw materials in an area. Mahaney et al. (2010) provide an excellent example of how mass-wasting events can cover up significant archaeological remains. If such large features can be covered by mudslides or debris flows, it is not difficult to envision such events burying a chert source outcrop or making it inaccessible. Alternatively, erosion associated with such a mass wasting event, such as riverine flooding, discussed in detail by Speakman and Johnson (2006) in relation to archaeological site destruction, or increased wave action along a shoreline (Westley and McNeary 2014), has the potential to expose previously unidentified sources of chert. In this section, the varying quantities of each of the GSGs present in the major occupations of each of the included sites will be examined in relation to the possibility of geological events causing variable access to the sources of the GSGs. For the discussion that follows, it will be assumed that the presence or absence of a GSG in an assemblage is directly related to the ability to access the hypothetical source of that GSG material.

The Caution Bay area does not have the topographic relief to be affected to any great extent by mass wasting events. Small-scale erosion related to seasonal flooding may, however, have played an active role in exposing or covering chert outcrops. Current environmental conditions in Caution Bay include an annual wet season (December to April) that results in significant amounts of rainfall (80% of annual precipitation) over a short period on a landscape that has otherwise been dry (McAlpine 1983). Such seasonal weather patterns can lead to poor initial absorption of rainwater and cause extreme surface erosion and flood conditions. These conditions would result in seasonal down slope movement of sediment from elevated areas, and this sediment could potentially have been overlying previously inaccessible deposits of chert. Conversely, downslope erosion could bury previously exposed and accessible chert outcrops.

With the limited geomorphological work in the area, there is currently no evidence for a raw material outcrop being covered or exposed by natural events in Caution Bay. There is, however, evidence in the archaeological record that erosion was causing surface artifacts to move down slope. The stratigraphy at Edubu 1 illustrates this process well and indicates major periods of erosion and deposition occurring in the area

(McNiven et al. 2012b:122). The sand deposited at Bogi 1, as well as at other sites nearby, has built up a deposit of over 3 m in depth over the past 4,000 years (McNiven et al. 2011), providing another clear example of the active erosion and deposition occurring in this area. Wet-dry cycles in the mud and clay soils at some sites caused downward movement of artifacts as well (e.g. Tanamu 1: David et al. 2016e). Some sites, including Edubu 1 and Moiapu 2, which are located in the areas with more topographic relief are described as having down slope movement of artifacts on the sloping edges of the landforms on which they are located (David et al. 2016c; McNiven et al. 2012a:122). These observations, made from detailed archaeological excavations, provide a valuable indication of how dynamic the landscape at Caution Bay has been in the past.

During archeological fieldwork carried out for the Caution Bay Project a number of outcrops of nodular chert were noted. These were all low to the ground and would not have needed much sediment build up to cover and bury them. The degree of erosion indicated by the excavations at sites such as Edubu 1 and Moiapu 2 (David et al. 2016c; McNiven et al. 2012a:122) and the significant deposition at sites such as Bogi 1 (McNiven et al. 2011) help to illustrate how feasible it would be for a chert source that was only identifiable as a surface exposure to be covered and disappear from the landscape.

This erosion and deposition process works in the other direction as well. With local chert outcrops in Caution Bay being generally low to the ground, it would also not require a significant degree of erosion to uncover them. Chert is a very hard compound, and regardless of its nature (bedded formations or nodular outcrops), it could withstand weathering far more than the surrounding sediment matrix. It is possible that heavy precipitation events during the wet season could easily remove sufficient quantities of sediment and expose new chert outcrops. It is also possible that sites like Tanamu 2, Moiapu 2, and ABCE, where a particular GSG does not appear in the assemblage until a specific time period, are examples of an outcrop of a GSG being exposed in the vicinity of the site and subsequently being exploited for tool manufacture. Although unlikely, it is also possible that the chert being used was not coming from bedrock deposits but rather

from nodules in riverine deposits and that erosional and depositional events would expose or cover up the materials available. Further geomorphological work focusing on land formation processes in the area is required before these ideas can be explored in appropriate detail.

# Human Geographic Factors

## *Landscape Modification*

Human occupations, especially densely inhabited, long-lived ones, are known to have a wide range of effects on both the ecology and the geography of an area (Ellis 2017). A discussion of the various factors that may have contributed to the assemblage of chert recovered from the Caution Bay sites would not be complete without addressing this topic. Human landscape modification, as discussed here, is focused on the ways that general human behaviours relating to facets of life not related to lithic procurement may inadvertently affect the visibility or access to a source of lithic material. Among other things, human activities, such as gardening and associated burning of the landscape which will be the focus discussed here, can lead to soil erosion and coastal progradation (McNiven et al. 2012a:121). Gardening and increased anthropogenic burning are behaviours that can be identified or inferred using other archeological materials such as charcoal, pollen, and specialised tool assemblages. Increased erosion resulting from human activities has the potential to expose previously unidentified outcrops of raw material in the same fashion as natural erosion. Human activities, however, can cause these natural processes to be exaggerated, potentially resulting in more pronounced erosional and depositional episodes.

The ethnographic record should not always be relied on as an indicator of human behaviour in the distant past. This issue will be discussed in further detail in the section on social factors that follows, but it is mentioned here as ethnography is often the first place a researcher will look for information about the past behaviours of a culture. It is not possible to infer from ethnographic records alone if activities like gardening, which were occurring around Caution Bay during the contact period (Lawes 1879:375), were

occurring, or if they were occurring with the same intensity during the earlier occupation phases at Caution Bay. Research conducted by Rowe et al. (2013:1139), focusing on the pollen and charcoal records, indicates increased burning episodes and vegetation shifts in the Caution Bay area after c. 2000 cal BP. This evidence, combined with research from other parts of PNG (e.g. Denham and Haberle 2008; Lentfer et al. 2010), has been interpreted as an indication of change towards reduced settlement mobility and increased management of vegetation associated with increased dependence on plant food production. Although Rowe et al. (2013) do not state that these changes are directly associated with gardening activities, the combination of the widespread human burning of the landscape and changes in the diversity of plant species can be interpreted as strong evidence of gardening activities. With evidence from Edubu 1, (McNiven et al. 2012a:145) suggest that anthropogenic firing regimes similar to those recorded historically were occurring during Lapita times in the Caution Bay area as early as 2900 cal BP. In addition to the environmental and faunal data from Edubu 1, the presence of other inland Lapita sites such as Moiapu 2 (David et al. 2016c) may also indicate a Lapita focus on gardening over other food sources. Even without using the local evidence for gardening, evidence from other locations suggests that gardening activities were occurring as part of Lapita culture. Cultivated plants including taro (*Colocasia esculenta*), elephant ear taro (*Alocasia macrorrhizos*), yam (*Dioscorea* spp.), banana (*Musa* spp.), and sugarcane (*Saccharum officinarum*) have been identified and tied to Lapita cultivation practices in other parts of the South Pacific (e.g. Kinaston et al. 2015:33; Valentin et al. 2010:1827).

Having established that gardening activities were likely occurring as early as the Lapita period at Caution Bay (McNiven et al. 2012a; Rowe et al. 2013), it is possible to conclude that these activities may have resulted in the exposure and burial of chert outcrops. Three sites included in this research have assemblages that may provide support for this hypothesis. At Edubu 1, GSG 4 is almost completely absent for the first half of the Post-Lapita Transformative Tradition occupation but becomes common in the more recent XUs (Figure 41).
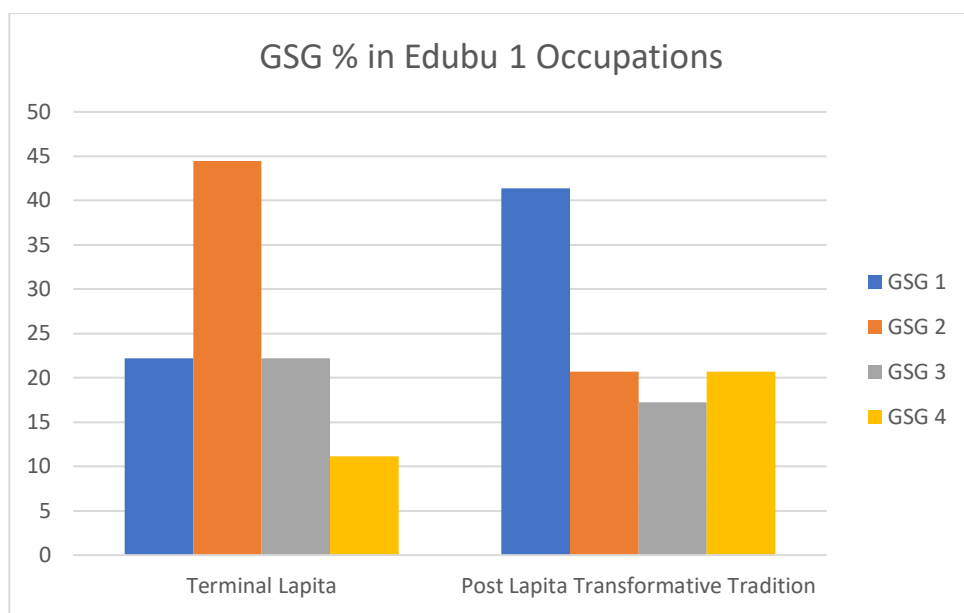
**Figure 41: GSG % at distinct occupation phases from Edubu 1**

Another example of this phenomenon is found in the assemblage from Bogi 1 (Table 24; Figure 42). Here GSGs 3 and 4 are present in very limited quantities during the pre-Lapita occupation (GSG 3 n=3, GSG 4 n=1) and the Lapita occupation (GSG 3 n=3, GSG 4 n=4). However, during the Linear Shell Edge-Impressed Tradition occupation, these numbers jump significantly, with 127 artifacts associated with GSG 3 and 89 with GSG 4. It is of note that the percentage values for these two GSGs do not change significantly during the three occupation phases. Although other explanations, including an increase in local population, may be used to explain these figures, they do support the idea that gardening activities may have instigated processes of erosion that had the potential to expose new outcrops of chert.

**Table 24: Frequency and percentage of artifacts classified to each GSG from three occupation phases at Bogi 1**

| Bogi 1 Occupations | GSG 1 | | GSG 2 | | GSG 3 | | GSG 4 | |
|---|---|---|---|---|---|---|---|---|
| | # | % | # | % | # | % | # | % |
| pre-Lapita | 11 | 53 | 5 | 26 | 3 | 16 | 1 | 5 |
| Lapita | 9 | 38 | 8 | 33 | 3 | 12 | 4 | 17 |
| Post-Lapita | 335 | 47 | 155 | 22 | 127 | 18 | 89 | 13 |

**GSG % in Bogi 1 Occupations**
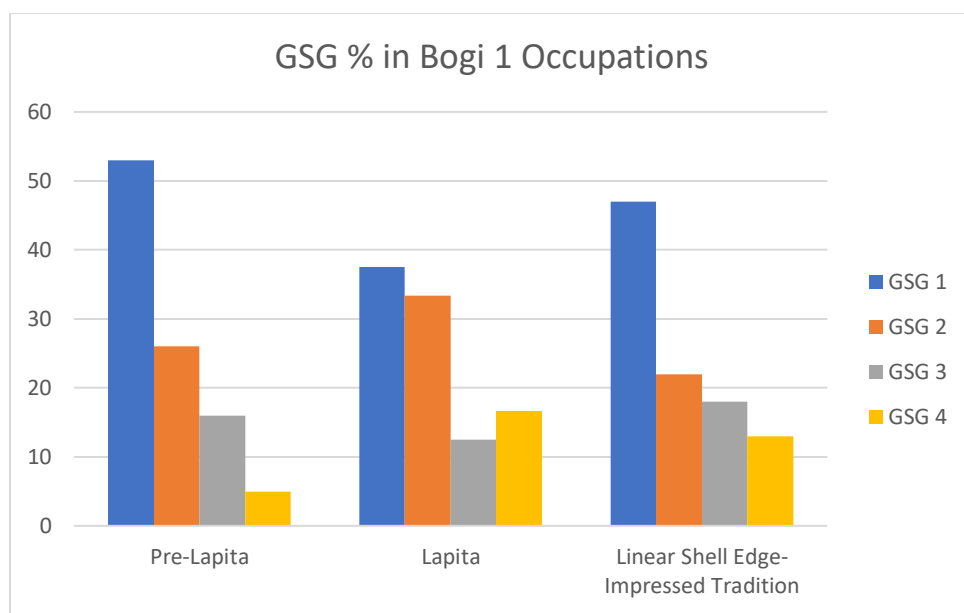
***Figure 42: Percentage of artifacts classified to each GSG from three occupation phases at Bogi 1***

Although there is evidence to suggest that natural geomorphological processes were functioning to expose or cover up sources of chert on the Caution Bay landscape, this evidence is limited. The evidence for changes in the visibility of chert outcrops as a result of human activities, however, is more substantial. As well as data about plant cultivation and increased burning in the Caution Bay area, we also have data from other sites outside of PNG that provide details about Lapita and Post-Lapita cultures and the manner in which the landscape was manipulated by people. Available data suggest that farming and associated burning began during the Lapita occupation at Caution Bay and likely continued and intensified through to the contact period. The sites with assemblages that could be used to examine this development show that there is indeed a pattern of increased lithic resource use in occupations that follow an occupation that was associated with either initial development of, or rapidly intensifying gardening. It cannot be overlooked that these increases in diversity of GSGs also correspond to the total number of artifacts being discarded at a site, something assumed to represent occupation intensity. Although there exists strong circumstantial evidence that human modification as a result of gardening and associated activities resulted in the exposure of new chert sources, the data is not sufficient at this time to provide any strong

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conclusions. In particular, dating of the origins of gardening and associated soil management practices would be most valuable. As data from the remainder of the sites excavated for the Caution Bay Project becomes available and is published the answers to these questions will likely become clearer and allow for the discussions presented here to be re-evaluated.

## *Resource Exhaustion*

A second human activity that may have had a significant impact on the visibility of a given GSG is its overuse and exhaustion over time. The continued use of one outcrop of chert over time has the potential to exhaust that source or reduce it to a point where it is no longer viable as a resource (Sutton et al. 2015). Examples of humans exhausting a natural resource are not uncommon, with the Moa of New Zealand (Holdaway 2014; Rawlence 2013) and the trees of Rapa Nui (Easter Island: Gossen 2011; Mieth and Bork 2010) being two notable examples. Although not commonly observed in the assemblages from the sites included in this research, the assemblage from two sites, Ataga 1 and Moiapu 2, may indicate this type of occurrence. At both Ataga 1 (Appendix 4, Table 4) and Moiapu 2 (Appendix 4, Table 12), material from GSG 4 disappears shortly after the XU in which it is most common. A similar pattern is noted in the AAUG assemblage where GSGs 3 and 4 are almost absent above XU 5 after being present in prior XUs. The disappearance of a GSG from the assemblage at a site may indicate, among other factors, that the outcrop source was used to the point of depletion (Sutton et al. 2015) and/or it became buried through sedimentation processes – see above. Although the bedded nature of the chert deposits on the south coast of PNG may have allowed for the presence of more than one outcrop of a GSG, it is possible that the quality of different outcrops of the same GSG would have varied. This variation may have resulted in people only selecting material from one outcrop of a particular chert formation. The consistent use of a single outcrop has the potential to result in its depletion and disappearance from the archaeological assemblage. Further research examining the entire assemblage of artifacts from the sites referenced here, in combination with fieldwork to locate outcrops of the GSGs in the Caution Bay area, is required to explore this hypothesis further.

It is likely that new outcrops of the various GSGs may have been exposed in the vicinity of Caution Bay as a result of human activities such as gardening and associated soil erosion. Sites such as Edubu 1 and ABCE, where a particular GSG does not appear in the assemblage until a certain time period, may be examples of that source being exposed near to the site and being subsequently included in the variety of local materials exploited. It is equally possible that human activity in the landscape will have caused the disappearance of an outcrop of a particular GSG. The disappearance of GSG 4 at Ataga 1 and Moiapu 2 are potential examples of this process. Unfortunately, with the information currently available, it is not possible to further access the significance that any of these processes may have had on the variety of visible raw materials in the landscape throughout the duration of occupation in Caution Bay.

## *Settlement Patterns and Population Mobility*

Although both population mobility and settlement patterns are social constructs (Brockwell et al. 2011; Brück 1999; Fisher et al. 2016; Kellett et al. 2017; Ramsden et al. 1995; Silverman 2002), they are discussed in this section because they relate to the ethnographical use of places. By investigating artifact assemblages (in terms of raw material diversity and quantities) from contemporaneous sites that are geographically separate, it is possible to identify differences in the intensity (Brück 1999; Fisher et al. 2016; Wilson and Rasic 2008; Yerkes 1989), mobility (Cowan 1994; Edmonds 2009; McSwain 1989) and inter-connectivity (Al-Nahara and Olszewskib 2016; Peterson 1999; Silver 1991; Yerkes 1989) of occupations. These patterns can be compared to those identified in other temporally distinct occupations to investigate changes in the intensity, mobility, and inter-connectivity of sites over time.

The pre-Lapita period is represented at Caution Bay by Bogi 1, Tanamu 1, and Tanamu 3 (McNiven et al. 2011:4; Richards et al. 2016b). The Kukuba Cave site, located to the north of Caution Bay, also has a pre-Lapita component (Skelly 2014:51; Vanderwal 1973). Other than the Kukuba Cave site, no other pre-Lapita sites have yet been identified along the south coast of PNG outside of Caution Bay, but that does not mean that they do not exist, simply that they have not yet been located. In other regions

of coastal PNG and in the islands to the east, pre-Lapita sites are rare and include data from Island Melanesia (Torrence 2004), the Arawe Islands, West New Britain, PNG (Gosden et al. 1994; Specht et al. 2017), and some wooden artifacts from Apalo, West New Britain, PNG (Specht et al. 2015). This very limited collection of data suggests that pre-Lapita cultures were primarily relying on marine resources for sustenance and were living in smaller groups that were likely highly mobile resulting in limited discard of cultural material at sites. Although the ground stone adze collected from pre-Lapita levels at Bogi 1 is evidence for complex wood working (McNiven et al. 2011), there is currently no data to suggest that people at this time were building gardens or actively burning the landscape. The nature of the limited archaeological assemblages from this time suggest a population that was relatively small and mobile.

Hypothetical lithic resource use for people living in this fashion would appear in the archeological record as having a diverse range of materials and be limited in the number of artifacts discarded at any one site. It is assumed that a more varied range of lithic materials would be present for two reasons; first, people who are more mobile are more likely to encounter a wider range of raw materials on the landscape, and secondly, more mobile cultures are less likely to transport raw materials in significant quantities; they are more likely to take what they need for the task at hand with the intention of getting more material at the next source or when it is next needed. These observations are both supported by the collections of lithic artifacts from Bogi 1 (Table 5, Chapter 6; Figure 27) and Tanamu 1 (Table 9, Chapter 6; Figure 27). Each site has a wide variety of GSG material present and is represented by a relatively small collection of artifacts. Although the Tamanu 3 assemblage did not include all four GSGs, it was represented by a very small collection of pre-Lapita artifacts. The limited data from the small number of sites from this time period suggest that there is a connection between settlement patterns and population mobility, but the data is so limited it is hard to have much confidence in this hypothesis. Many other factors could still be influencing GSG selection, but, as stated earlier, to test these ideas, it was necessary to focus the discussion on only one factor at a time.

As well as the three sites with Lapita assemblages that were included in this research (Bogi 1, Tanamu 1, and Moiapu 2) an additional six that were also excavated as part of the Caution Bay Project have also been shown to contain Lapita occupations (McNiven et al. 2011:2). Outside of Caution Bay, on the south coast of PNG, there were no known Lapita sites prior to the Caution Bay Project (McNiven et al. 2011). It is, therefore, necessary to look further afield for an understanding of general Lapita settlement patterns. Lapita sites from the north coast of PNG and in the Islands to the northeast and east are relatively common and much has been published on the nature of Lapita and Lapita settlement patterns (e.g. Bedford et al. 2007; Green and Kirch 1997; Green 1974; Sheppard 1993; Specht and Torrence 2007 Summerhayes 2000; Torrence and Swadling 2008; Valentin et al. 2010). The nature of Lapita settlements is still debated, and there appears to be some degree of difference both between the earliest Lapita occupations and the later ones, as well as from region to region (Valentin et al. 2010:1821). It has been suggested that there is a general change in Lapita subsistence over time, from an initial foraging strategy to an increasing level of food production (Hather 1992; Burley 1999; Burley et al. 2001; Davidson and Leach 2001). Valentin et al. (2010:1821) identify three broad hypotheses about the nature of Lapita occupations that are currently being debated in the literature. One suggestion is that food production was important and that Lapita peoples were ''farmer-foragers'' who combined horticultural production, domesticated animal husbandry, and exploitation of natural faunal (terrestrial and marine) resources (Kirch 2000; Kirch and Green 2001). A second suggestion is that Lapita peoples were ''forager-hunters'' with a focus on exploitation of both terrestrial and marine environments often to the extent of over-exploitation and extinction (Burley 1999; Burley et al. 2001; Anderson 2002; Kennett et al. 2006). A third suggestion is that Lapita peoples employed a combination of ''farmer-foragers'' and ''forager-hunters'' and survived on a mixed economy of foraged marine and terrestrial resources and supplemented this diet with a limited selection of domesticates (Kennett et al. 2006; Anderson 2009).

Because of the wide range of different potential strategies employed by Lapita people in the broader region the discussion of Lapita settlement patterns presented here will focus only on the data from the Caution Bay Lapita sites. The Lapita assemblages

from Caution Bay demonstrate an intense focus on the exploitation of marine resources with over 130 species of shellfish, crabs, fish (both marine and estuarine), and marine turtles present (McNiven et al. 2011:4). This marine assemblage was accompanied by terrestrial fauna with a focus on macropods potentially in grasslands maintained by firing (McNiven et al. 2012a:121). McNiven et al. (2011) do not mention any of the typical domesticate species present in the Lapita assemblages, but there is discussion of pig, dog, and rat bones in the Terminal Lapita assemblages from Edubu 1 (McNiven et al. 2012a). Stone tools and other artifacts from Lapita assemblages in Caution Bay are typical of Lapita assemblages elsewhere and include ground stone adzes and unretouched flakes. Generally, raw materials for these items are believed to have been sourced locally, but some obsidian is also present in very limited quantities in the later Lapita assemblages, and it has been imported to these sites from a great distance away. The archaeological data suggests that the Lapita peoples in Caution Bay were living in small semi-permanent villages. They were predominantly harvesting marine resources from reef environments but were equipped with vessels that could go beyond the reef and whether through trade or direct access were, near the end of the occupation, incorporating foreign obsidian into their tool kits. Lapita peoples were also harvesting terrestrial resources, including hunting macropods and harvesting various plants.

Based on the data presented here about Lapita settlements and mobility, a series of hypotheses can be generated concerning GSG use at Caution Bay sites. Llimited use of a GSG in the early portion of the occupation (a result of new migrants to an area not knowing the locations of all sources), an increased amount of foreign or exotic materials in the earliest XUs of the occupation that disappears shortly after settlement (a result of new migrants to an area bringing raw material with them from when they came, but not revisiting those locations once settled in Caution Bay), and finally an increased use of local GSGs (both in quantity and in diversity) over time as a result of increased mobility, increased awareness of an area, and the development of trade and exchange networks with nearby communities can all be tested. It would, therefore, be expected that a change of the quantities of different GSG materials over the length of the Lapita occupations would be noted in the assemblages that were tested. Additionally, on an occupation level scale, as it is generally assumed that Lapita represents a migration of

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new people into an area, it would, therefore, be expected that Lapita assemblages would have a wider variety of lithic materials and possibly include higher quantities of foreign materials than previous occupations.

When the GSG data from the Caution Bay Lapita sites are examined, it is difficult to identify any of these hypothetical patterns in the collection. The Lapita assemblages from two sites are discussed here: Bogi 1 (McNiven et al. 2012b:21; Mialanes 2016c:13) and Tanamu 1 (David et al. 2016e:16; Mialanes, Ford, et al. 2016:2). The Lapita occupation from Moiapu 2 (David et al. 2016c:1; Mialanes 2016e) is not included in this discussion as it only contained two tested artifacts. Figure 43 illustrates the quantities of each of the GSGs present in the XUs associated with Lapita occupations at Bogi 1 and Tanamu 1. The collection of GSG materials for Bogi 1 is so limited that it is difficult to confidently identify any significant trends in GSG use. Two observations are of note. First, the only GSG 4 artifact is from the most recent portion of the Lapita assemblage, an observation that could support the idea that with continued occupation over time, new local resources would be identified and come into use. Secondly, GSG 3 is represented by one artifact in the first XU associated with the Lapita occupation and is not present in the collection again until the last two Lapita XUs. If the assumption made herein, that GSG 3 is a locally available material is wrong, this observation supports the idea that Lapita peoples brought this GSG 3 material with them when they came to Caution Bay and that access to it (through direct access or trade and exchange) was not re-established until the end of the Lapita occupation. The presence of GSG 3 in pre-Lapita occupations and in greater numbers in the Tanamu 1 Lapita occupation, however, suggests that other factors (possibly including sampling bias) are impacting the presence of GSG 3 during Lapita at Bogi 1. The other GSGs present in the Bogi 1 Lapita assemblage do not show any obvious changes over the length of this occupation.

The Tanamu Lapita assemblage contains more artifacts than that from Bogi 1, but is equally challenging to interpret. Instead of seeing the hypothesised pattern of more variety in the early and late XUs of the occupation, the variety of GSGs at Tanamu 1 is most diverse in the central XUs of the assemblage with the widest variety of GSGs present between XUs 64 and 55. Although the pattern of GSG use at Tanamu 1 does

suggest that with continued occupation, material from more and more GSGs was being accessed and incorporated into the assemblage, this pattern does not continue for the entirety of the occupation as would be expected. Instead, the final XUs of this occupation contains material from only GSG 1 and 4.
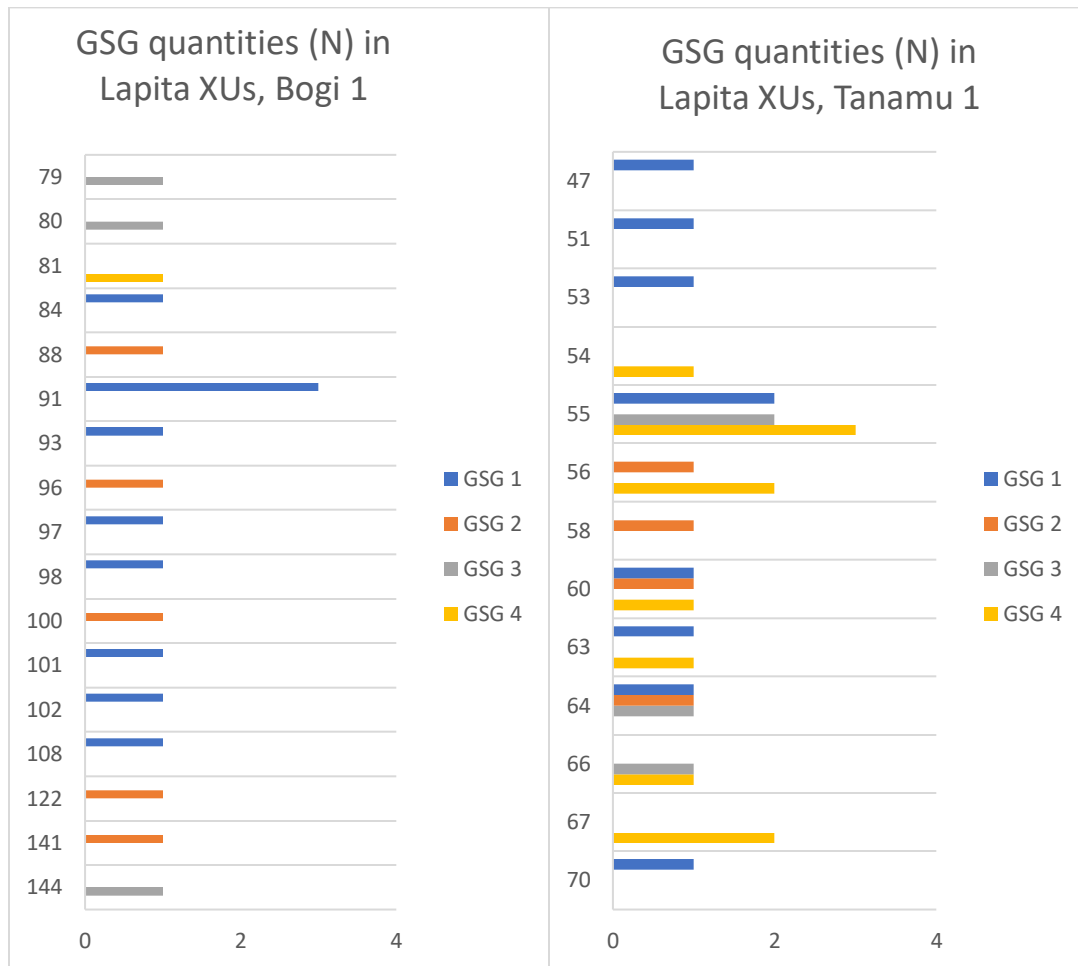


*Figure 43: GSG (n) by XU from Lapita assemblages at Bogi 1 and Tanamu 1*

Generally, the data from these two sites do not show GSG proportions that support the hypothesized quantities of each GSG expected based on what is known about the nature of Lapita settlement and mobility at Caution Bay. The limited number of artifacts from the Bogi 1 assemblages makes interpretations from this site challenging. The Tanamu 1 assemblage, although larger than that from Bogi 1, does not display any

of the hypothesised patterns of GSG use suggested by the presumed nature of Lapita settlement and mobility in Caution Bay. It is possible that with a larger collection of Lapita sites, or with more material (artifacts from the other squares excavated at these two sites) some of the hypothesized patterns of GSG use may become apparent and future research to investigate this would be very valuable for understanding the lithic selection process of Caution Bay Lapita peoples. Additionally, this investigation, as with many others presented in this thesis, would benefit greatly from research carried out to locate the geographical sources of chert in Caution Bay and the surrounding areas. Knowing the location of the source of GSG 3 material would be very useful for continuing the discussion about GSG 3 in the Bogi 1 Lapita assemblage.

Based on the nature of Lapita settlement and mobility in Caution Bay it was also hypothesised that the quantities of each GSG would be different in Lapita occupations compared to pre-Lapita occupations. Both Bogi 1 and Tanamu 1 have a pre-Lapita occupation and a Lapita occupation allowing for exploration of this hypothesis. Figures 44 and 45 display the percentage of the four GSGs present in the various occupations from these two sites.

At both sites, the amount of each GSG present in the pre-Lapita assemblages is different from that in the Lapita assemblages. Notable, however, in both assemblages is the fact that all four GSGs are present suggesting that there was no abrupt change in the availability of the four GSGs to people before and during Lapita. The percentage of GSG 4 (which for both sites is derived from a very small number of artifacts) is the only one that shows a significant difference between the pre-Lapita and Lapita assemblages. At Bogi 1 the amount of GSG 4 increases dramatically during the Lapita occupation, but at Tanamu 1 it decreases dramatically. Although this difference may be a result of comparing the percentage values for this material it cannot be overlooked. The distinctly different amount of this material at the different occupations of these two sites does not support the suggested hypotheses and indicates that something other than the nature of settlement patterns is having an effect on the GSG quantities during Lapita times.
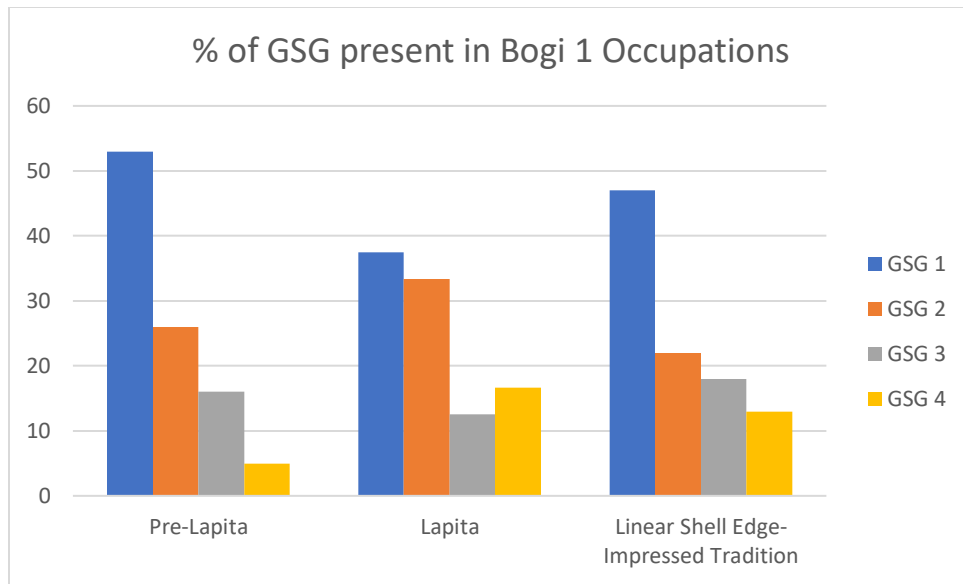
**Figure 44: Percentage of each GSG present in the three occupations at Bogi 1**
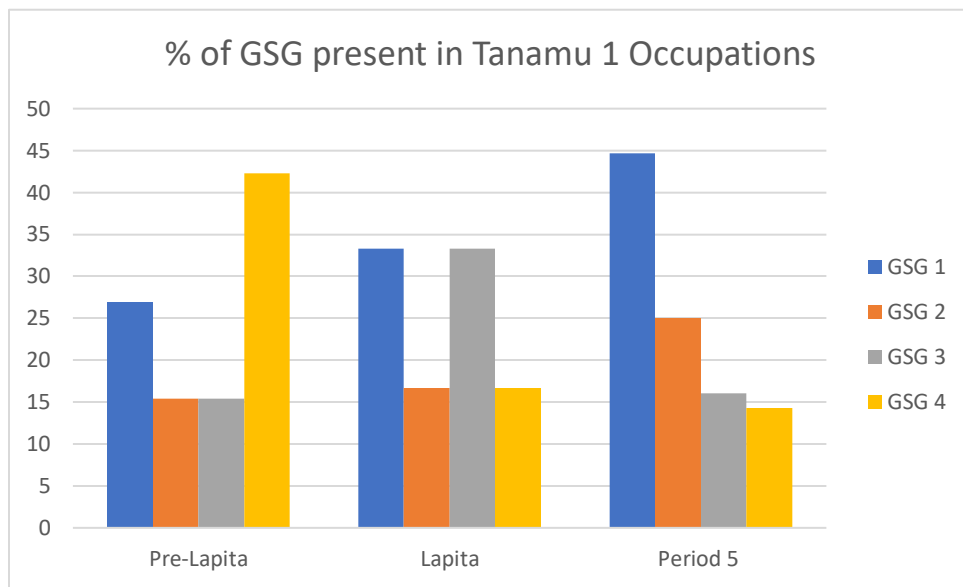


**Figure 45: Percentage of each GSG present in the three occupations at Tanamu 1**

Although this research is focused on chert and an investigation of the GSGs identified through chemical analysis, the quantity of imported or exotic materials (items made from materials other than chert) was also suggested as a testable hypothesis about lithic resource use during the Lapita period. The quantity of imported or exotic

materials recorded by Mialanes (2016c, 2016e) and Mialanes et al. (2016b:2) in the analysis of these Lapita lithic assemblages was investigated. The amount of lithic material that was not chert (and is in this case considered to be imported or exotic) is presented in Chapter 6, Table 5 (Bogi 1), Table 9 (Tanamu 1), and Table 14 (Moiapu 2). The amount of material that was not chert is very limited from the XUs associated with Lapita occupations, being limited to one or two items throughout the entire set of XUs from all three sites. These small amounts of non-chert material are not present in any visible patterns or in quantities large enough to allow for a discussion of change over time. It is concluded that with the data currently available for these sites, there is insufficient information to support or refute any hypotheses about the settlement mobility of Lapita peoples.

The Post-Lapita occupation at Caution Bay discussed here have been presented in reference to the ceramic traditions presented by David et al. (2012b). The assemblage includes six sites with Post-Lapita Transformative Tradition occupations (Edubu 1, ABCE, Ataga 1, Tanamu 2, Tanamu3, and Moiapu 2), two sites with Linear Shell Edged-Impressed Tradition occupations (ABCE and Bogi 1), one site with an Umbo-Bordered Shell Back Impressed Tradition occupation (Tanamu 3), one site with a Varied Incised Tradition occupation (AASI), and two sites with occupations associated with Irwin's (1991) Period 5 (Tanamu 1 and 2). As these ceramic traditions have only been recently proposed, they have not been used by other researchers to discuss the cultural assemblages from southern PNG sites outside of Caution Bay. This, of course, makes a one to one comparison very difficult. Other sites from the southern coast of PNG have typically been discussed with reference to either the Early Papuan Wares period (Irwin 1991:503) or to the Early Papuan Pottery (EPP) phase (Summerhayes and Allen 2007), both of which incorporated a number of ceramic styles that have been referred to by a variety of other names (Red Slip pottery – Bulmer 1971; Laloki Style – Bulmer 1999; Initial Ceramic Phase – Vanderwal 1973, 1978; Early Period – Allen 1977, Bickler 1997; and Early Ware – Allen et al. 2011, Irwin 1991, Summerhayes and Allen 2007:100).

In addition to this, two other factors severely limit the ability to discuss the nature of the Post-Lapita occupation at Caution Bay. First, with the exception of the Post-Lapita

Transformative Tradition, all the other ceramic traditions discussed here are either represented by only one site (making comparisons difficult) or are represented by collections of artifacts that are drastically different in number (providing issues for direct comparisons). Secondly, although the ceramic material from many sites excavated as part of the Caution Bay Project has been analysed in detail, analysis of the many other cultural materials recovered is still on going. In most cases, the data for other artifact types associated with the ceramic traditions proposed by David et al. (2012b) have either not yet been analyzed or, if they have been analyzed, have not been published.

Generally, the quantities of GSGs present in the various assemblages from the Caution Bay sites analyzed here do not appear to have distributions that support the assumptions made about how lithic resource use would be presented. These assumptions were based on the various inferred settlement patterns and levels of population mobility identified in the pre-Lapita and Lapita assemblages from Caution Bay. It is possible that with more research on the collections of data from Caution Bay that the assumptions made here about settlement and mobility may prove to be incorrect and need refinement, but unless they change drastically, which is not expected, the data still suggest that the quantities of GSGs present at these sites is a result of some other factor or combination of factors. It will be valuable to revisit the discussion here once work has been done to locate chert outcrops in the greater Caution Bay area.


## Social Factors

As well as the geological and geographical factors that have already been discussed, socio-political factors can also have an effect on the selection of, and access to, a source of raw material (e.g. Aagesen 2010; Aoyama 1994; Aubry et al. 2012; Clark et al. 2014; Fernandes et al. 2008; Fortin 2015; Frahm 2014; Humphrys 2012; Jiao et al. 2011; Mackay et al. 2013; McCoy and Robles 2015). Social factors that have the potential to affect the selection and use of raw materials include, but are not limited to, resource ownership, political boundaries, and cultural preferences for specific colours and textures of material. Research examining social factors in relation to lithic resource

use is common, with recent examples provided by Fortin (2015), Humphrys (2012), and Mackay et al. (2013). A common means of exploring past socio-cultural behaviours is to compare the ethnographic and archaeological records. It is, however, problematic to rely heavily on ethnographic records for areas that don't directly relate to that ethnography. Much of the material recovered from the 12 sites included in this research is associated with cultural assemblages that are temporally, and in some cases technologically, distinct from the cultures documented by early ethnographers along the southern coast of PNG. Further, due to the limited nature of ethnographic information focused on flaked stone tool manufacture on the southern coast of PNG, it is not possible to explore social factors related to this in any detail. That being said, a few general observations can be made about social factors and their potential effects on the Caution Bay archaeological assemblages. As with the geological factors, the social factors that are discussed here were selected because they could be addressed using the data currently available for the Caution Bay area. They are resource ownership, political boundaries, and cultural preference for specific materials. These factors are not intended to represent an exhaustive list of the all the social factors that may have influenced the selection of chert raw material over the course of human occupation in Caution Bay.

**Resource Ownership and Political Boundaries**

The first set of social factors that will be investigated are resource ownership and political boundaries. For the purpose of this discussion the term 'resource ownership' is associated with use of a particular resource limited to a single group of people. The resource may be visible and accessible on the landscape but as a result of cultural practices, is only used by a select group of people. The term 'political boundary' will be defined here as a geographic division of the landscape determined by the cultural practices of two or more groups of people. Both resource ownership and political boundaries are very challenging to access and identify in the archaeological record. These two factors, although different, will be discussed together in this research, as the methods for identifying both in the archaeological material are similar. In both cases, the use of ethnographic information is critical.

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There are a variety of sources for ethnographic information available about the people living on the southern coast of PNG and the Port Moresby area. These sources include personal journals, sections written in books about the area, and actual ethnographic documentation, and have been written by a variety of people with different cultural and educational backgrounds (e.g. Barton 1910; Bevan 1890; Chalmers 1887; Haddon 1900; Holmes 1903; Lawes 1879; Moresby 1875; Oram 1968; Seligmann 1910; Stone 1880; Williams 1969). Unfortunately, the subject of this research, the use of chert, is very poorly documented. No sources of ethnographic information were identified that discussed flaked stone tools (apart from ground axes/adzes), the sources of these items, or how these sources were selected. Additionally, and detrimental to the accuracy of the ethnographic record, is that the use of stone tools was likely one of the first of many cultural practices to be discontinued following the establishment of contact and trade with Europeans (Goddard 2011:282). The result is that even if early ethnographers wished to talk about how the material for expediently-made flaked stone tools was selected and where the material came from, they might not have been able to do so due to the relatively quick adoption of metal tools. The ethnographic sources simply do not provide sufficient data to pursue any significant inquiry into the location of chert sources and of their use in Caution Bay.

What the ethnographies can provide data about is the manner in which societies were organized, how people were distributed on the landscape, and how this distribution affected the access to particular resources. The discussion that follows focuses on a single example of an ethnographically recorded socio-political division that can be used to explore the possibility that resource ownership and political boundaries may have influenced the access and use of the four GSGs. There are likely many more social systems recorded ethnographically that could also be explored, but, as a result of the exploratory nature of this discussion, only one well-documented example was needed.

A particular theme that comes up in many of the ethnographic sources is the relationship between the Motu and Koita peoples. The Motu people are geographically restricted, living in coastal villages along a 144 km strip of coastline stretching from Manumanu in the north to Gabagaba in the south (Oram 1968:432). Directly inland from

these villages is the territory of the Koita (Seligmann 1910:41) who live on the grasslands and low hills between Redscar Bay in the north and Port Moresby to the south (Seligmann 1910:41). The Motu and Koita speak different languages, and have separate origin stories, but they are intricately linked to one another, with members of each group often speaking both languages (Seligmann 1910:45) and in some cases occupying separate sections of the same villages (Haddon 1900:278). The missionary James Chalmers (1887:13) provided a description of the Koita view of this relationship: "yours (Motu) is the sea, the canoes, and the nets; ours (Koita) the land and wallaby. Give us fish for our flesh, and pottery for our yams and bananas". Seligmann (1910:44) points out that Motu-Koita relations are much more than simply a subsistence alliance; the social organisation of both groups is similar, and intermarriage is common.

There is no clear-cut geographical division between the two groups given inter-marriage, close social connections, and overlapping settlement locations. This in association with the lack of evidence relating to the location of the four GSGs makes it difficult to pursue any discussion linking these two cultural groups. The statement made by Chalmers (1887) about the division of the landscape and the associated natural resources between the Motu and Koita, however, provides a context with which to briefly discus the lithics and associated GSG groups from the Caution Bay sites. This statement highlights the potential for factors relating to political boundaries and resource ownership to be involved in the access and selection of chert materials. This social organisation, with two groups of people living in proximity, has the potential to result in people living at certain sites and having restricted access to particular resources. At Caution Bay, there is a difference between the underlying geology of coastal and inland sites. The inland sites have the potential to be located on sediments that may contain outcrops of chert. The coastal sites, many of which are situated on sand dunes, do not. There are lessthen3 km between the most coastal site (Bogi 1) and the furthest inland site (ABCE) included in this thesis research, but that distance might have been enough to produce a difference in resource access in the most recent assemblages if the ethnographic tradition mentioned by Chalmers (1887) was also applied to lithic materials. Unfortunately, the only sites included in this research with evidence of being occupied into the ethnographic period are Tanamu 1 and Tanamu 2, both of which are located

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along the coast. Without a temporally similar artifact assemblage from an inland site to compare with these assemblages, it is not possible to pursue this explanation further. The possibility of complex social systems having an effect on the lithic assemblages of the Caution Bay sites should not be overlooked, and further research focusing on the differences in the assemblages of inland and coastal sites at Caution Bay may provide valuable information to pursue the effects of social organisation of lithic resource use further.

**Cultural Preference for Specific Material**

Another factor that may be contributing to the different compositions of the various assemblages is the culturally driven preference for a particular type of chert over others. A variety of attributes could make one type of chert more preferred, and these include but are not limited to colour, texture, material purity and flake predictability (Sutton et al. 2015:9). Currently, the only information available for the chert artifacts tested for this research is colour. Examining the archaeological assemblages and comparing this to the limited geological outcrop material collected may provide some insight into the primary colours of materials being selected for tools at Caution Bay.

The natural range of chert colours and the abundance of each colour in the vicinity of Caution Bay are not known. It is possible that the range of colours discussed below are the product of the natural range and abundance of chert at Caution Bay. Until further research is carried out in the study region, it is not possible to access the degree to which the natural range of chert colours has affected the assemblage. The discussion that follows is presented with the assumption that chert of all colours represented in the assemblage would have been available in the landscape in similar quantities. It is possible that this is not the case; however, as the exploration and documentation of all the colours present in the region surrounding Caution Bay is beyond the scope of this research, the following analysis was conducted in full understanding of this assumption.

Twenty-two different colours were identified from the entire Caution Bay Project chert assemblage (Table 25). Of these, 18 colours were identified in the assemblage of artifacts included in this research (Mialanes 2016a, 2016b, 2016c, 2016d, 2016e, 2016f,

2016g, 2016h, 2016i, 2016j, 2016k; Mialanes, Ford, et al. 2016). Each of these colours was assigned an arbitrary working number during the recording process and was later associated with a Munsell Colour Code and description. For this discussion, the working number will be used. The colour codes, names, and descriptions used by Mialanes are presented in Table 25.

Colour 6 was the most common in the assemblage that underwent pXRF testing (38%, n=866), followed by Colour 21, a colour that Mialanes believes to be a weathered version of colours 5 and 6, which was the second most common (13%, n=299), and Colour 5, also thought by Mialanes to be associated with Colour 6 comprising 11% of the assemblage (n=242).

Though Mialanes identified 18 different colours of chert, he noted that many of these colours appear to be associated with each other and include weathered or burned varieties and alterations of the more common colours. Based on Mialanes' colour data observations, this research further grouped the Mialanes' colours into two major colour groups labelled Group A and Group A1. Group A included colours 5, 6, 7, and 21 and is primarily comprised of a range of yellow to brownish orange colours. Colour group A1 includes colours 3, 15, 17, 18, and 19 and is primarily comprised of a range of reddish brown colours. The remaining colours make up such a small portion of the assemblage that they were lumped together for analysis. This group was labelled 'Other' and consists of colours 1, 2, 4, 9, 10, 11, 12, 13, 16, and 22.

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***Table 25: Chert colours identified by Mialanes and frequency of each within the overall assemblage of artifacts included in this research.***

| Colour Number | Colour | Munsell colour code | Munsell colour name | Frequency (N) | Percent (%) |
|---|---|---|---|---|---|
| 1 | | 5YR 3/4 | moderate brown | 27 | 1.5 |
| 2 | | 5YR 5/2 | pale brown | 10 | 0.5 |
| 3 | | 10YR 4/6 | moderate reddish brown | 52 | 2.8 |
| 4 | | 10R 6/6 | moderate reddish orange | 2 | 0.1 |
| 5 | | 10YR 8/2 | very pale orange | 242 | 13.1 |
| 6 | | 10YR 6/6 | dark yellowish orange | 621 | 33.7 |
| 7 | | 10YR 6/2 | pale yellowish brown | 41 | 2.2 |
| 9 | | 5R 6/6 | light red | 4 | 0.2 |
| 10 | | 5YR 4/1 | brownish gray | 32 | 1.7 |
| 11 | | 5YR 2/2 | dusky brown | 2 | 0.1 |
| 12 | | 5R 2/2 | blackish red | 1 | 0.1 |
| 13 | | 10YR 4/2 | dark yellowish brown | 15 | 0.8 |
| 14 | | 5R 8/2 | greyish pink | 11 | 0.6 |
| 15 | | 10R 2/2 | very dusky red | 61 | 3.3 |
| 16 | | N3 | dark grey | 54 | 2.9 |
| 17 | | 5R 4/2 | grayish red | 98 | 5.3 |
| 18 | | 5R 5/4 | moderate red | 53 | 2.9 |
| 19 | | 10R 5/4 | pale reddish brown | 214 | 11.6 |
| 21 | | 5Y 8/1 | yellowish gray | 299 | 16.2 |
| 22 | | N1 | black | 2 | 0.1 |
| | | | **Totals** | **1841** | **100** |

***Note: No colour #20 was provided, Data for Edubu 1 and ABCE are not included***

Artifacts from colour Groups A and A1 are present in all four GSG groups. Artifacts from most of the colours in the other category are also present to some degree in each of the GSG groups. All three colour groups are present in all GSGs and make up similar portions of the assemblages of artifacts from each GSG (Figure 46).
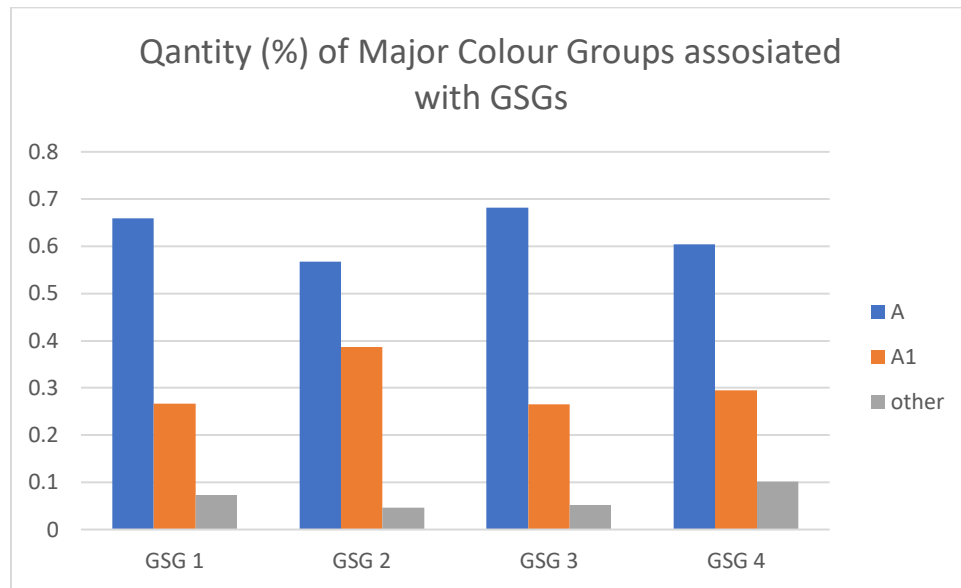


*Figure 46: Quantity (%) of the three colour groups associated with each GSG.*

As has been noted, all of the GSGs were present for the entire length of occupation at Caution Bay. It is possible that the colour of chert was an important criterion for material selection. Colour Group A, associated with the largest number of artifacts from each of the GSGs, is the colour with the largest number of associated artifacts. Though none of the GSGs are distinguishable on the basis of colour, only chemical composition, it is of note that each of the GSGs has almost equal quantities of each of the major colour groups. The variety of colours represented in the 'Other' group were the least commonly used, even though they were likely available in the vicinity of Caution Bay. The paucity of the 'Other' coloured materials in the archaeological assemblage may indicate that these colours were less desirable than the Group A and A1 colours. There does appear to be a correlation between the colour of a raw material and its presence in the archaeological assemblage, and it can be concluded that

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throughout the length of occupation at Caution Bay people were selecting raw material that was predominantly from colour Groups A and A1 over all other colours.

Future research to locate outcrops of chert in the Caution Bay area and record the range of colours present would provide valuable information with which to investigate this colour patterning further. Understanding the natural range and abundance of chert colours in the Caution Bay area would also help to test whether or not the degree of relative colour use was related to colour preference and/or relative availability at sources.

## Conclusions

This chapter has explored a carefully selected sample of factors that may have contributed to the diversity of the archaeological lithic assemblages from the 12 Caution Bay sites. The factors discussed here do not represent an exhaustive list of all the factors that may have been affecting the use of chert in the area. It is possible that other factors that were not discussed here such as existence and development of complex trade and exchange networks, or the technological process of raw material reduction, amongst others, may have contributed significantly to the creation of the chert assemblage. The decision not to explore these and other factors was based on the limited amount of published information currently available about the various Caution Bay sites. In research such as this, where no source data is yet available, it is to be expected that some of the factors presented will not be possible to investigate in sufficient detail. Due to the nature of the Caution Bay Project, it was also expected that exploring some factors would be difficult due to the different sizes of the sampled collections from the different sites. This would also be challenging due to the significantly different amounts of published data and draft reports available for not only the lithic materials, but also other materials and aspects from these sites. As more and more information is published, it will be possible to revisit the GSG data produced here and explore other factors that might be impacting the use and discard of particular GSGs during particular occupations. Although each of the factors that were selected for

discussion were chosen because it was expected that the data currently available would be sufficient to at least minimally assess them, this turned out not to be the case. For a number of factors, the available information is still limited and severely restricted the degree to which some factors could be pursued.

## *Summary*

The data in this chapter was presented with reference to three broad headings. First, physical geographical factors were explored. These included geographic distance from source to site, ease of access to a source outcrop, and geological processes. This was followed by a discussion of some human geography related factors, such as the effects of human activities on landscape modification, resource exhaustion due to overuse, and settlement patterns and population mobility. The final group of factors that was discussed included social factors, such as cultural resource ownership and political boundaries, and cultural preference for specific materials. The results from each of these analyses will be revisited here and will be followed by a discussion of the implications of these results for current archaeological understanding of Caution Bay and generally for a discussion of how pXRF analysis of chert materials can be of value to archaeological questions.

The exploration of geographic distance from a source to a site was done by using a mapping experiment. It was hypothesized that if the distance from a site to a source was directly affecting the quantities of chert recovered from a site, this would be visible by using arbitrary circles of different sizes to represent the ranked amounts of each GSG and comparing these. This experiment was only conducted on the collection of sites from the Post-Lapita Transformative Tradition occupation due to insufficient data for other occupations. The results indicated that not enough data was available to confidently support the hypothesis. Although the data was inconclusive, it was suggested that there is still value in the experiment and with additional GSG data from a larger number of sites from Caution Bay, it may prove to be a valuable tool even without information about the geographical locations of chert sources.

With only the GSG data, it was not possible to accurately assess how much the geography of the Caution Bay area may have affected artifact assemblages. It was determined, however, that no topographic obstacles to human movement that might limit access to resources exist within 30 km of any of the Caution Bay sites. It is unlikely, therefore, that this factor had any significant impact on the creation of the GSG assemblages at Caution Bay.

Although limited, there was a variety of data available with which to explore the effects that geomorphological processes may have had on the collection of GSGs at each of these sites. A number of the sites included in this research had collections from consecutive occupations that support the idea that a particular GSG may have been covered up or exposed by erosional processes. Additional data about the type and timing of geomorphological processes and their effects on the Caution Bay landscape would be beneficial to explore this factor, as would knowing the geographical locations of chert sources. The GSG data, however, does provide sufficient detail to explore this factor and suggests that it may have had an impact on what GSGs were utilized during specific times at specific sites.

In much the same manner as the natural geomorphological processes were investigated, the effects of human behaviours such as burning and gardening activities on the process of erosion and deposition were investigated. By including information about the approximate timing of gardening and burning from other regions with the data from Caution Bay it was possible to discuss this factor in moderate detail. The data suggest that human modification to the landscape as a result of gardening and associated activities may have resulted in the exposure of previously unavailable chert sources, but it is not possible to provide any strong conclusions at this point. Here again, the lack of data for a number of variables poses a challenge to investigation and interpretation.

Using another example of humans overusing natural resources, the idea of resource exhaustion as a result of overuse of a chert source was examined. Although two sites contained assemblages in which this factor may explain the pattern presented,

the data are not sufficient to properly access this factor. Without knowing at least limited information about the location of geological chert sources and how they relate to the GSGs, factors other than this one should be considered.

The final human geographic factor that was investigated was the role that settlement patterns and population mobility may have played in shaping the lithic assemblages. As a result of the limited number of discreet occupations and the different regional sequences for ceramic materials, this factor was only discussed in relation to the pre-Lapita and Lapita assemblages. Based on the published data about pre-Lapita and Lapita cultures, a number of assumptions were developed about what would be expected in the pattern of GSG use during these times. These assumptions were compared to the GSG data, and it was demonstrated that the assemblages from the Caution Bay sites do not have GSG distributions that support the assumptions. Generally, this investigation suggests that either the assumptions made are incorrect or that the data indicate that settlement and mobility did not have a significant impact on GSG use.

Two possible social factors were examined – resource ownership and political boundaries. In both cases, historical sources were consulted to see if any ethnographically noted patterns of either resource use or political boundaries could be identified. Although ethnographic sources for the area are available, the data is limited, and no mention of flaked chert use was identified. One political boundary that may have resulted in a resource ownership scenario was the division between the Motu and Koita in which one group was ethnographically focused on land-based resource gathering and another on sea-based resource gathering. It is likely that this relationship extended to the sources of chert in these areas. However, the small sample of sites from Caution Bay and the relatively close proximity of these sites to one another made it impossible to explore this division in any depth.

The final social factor that was investigated involved examining the potential impact of cultural preferences for certain materials. This investigation was focused on the colour of chert materials in an effort to ascertain if there was a way to use colour to

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identify resource selection. Due to the chemical nature of chert, it has been demonstrated that the colour of chert does not always accurately reflect its chemistry and colour may have been a more important factor to people than the origin of the chert when selecting a raw material. Without information about the natural colour range included in the geological source of these GSGs, it is not possible to eliminate other possible explanations. The data available, however, do support this idea and suggest that throughout the length of occupation at Caution Bay people were selecting material predominantly from colour Groups A and A1 over all other colours.

## *Implications*

The goal of this chapter has been to explore some of the suggested explanations for similarities and differences of the quantities of GSG materials noted in Chapters 10 and 11 and to provide data with which to discuss the main goal of this thesis – Can pXRF data be used to explore how chert was selected and used by past peoples living at Caution Bay. The answer to that main research question is yes, and although no strong conclusions were made this was not a failing of the pXRF testing or the GSG groups that were identified. In general, all of the investigations into the factors presented here provided inconclusive results, generally due to a lack of other available information. Even with the lack of conclusive results, this chapter has successfully demonstrated a number of ways that pXRF data, and the GSGs identified using it, can be incorporated into discussions about chert selection by people over the past 5,000 years at Caution Bay. Chemical characterisation studies that do not involve sourcing the material in questions are rare, but they are still valuable and produce data that can be used to explore a wide range of factors such as those discussed here or to focus on a specific research question as demonstrated by Sutton et al. (2015). There is no doubt that locating geological sources of chert at Caution Bay and conducting pXRF testing of those source materials would allow for a deeper exploration of many of the factors discussed here, but this research has shown that it is not 100% necessary. Regardless of the reason for not identifying geological source locations, be it time, money, or dangerous wildlife, this chapter has demonstrated that although limited, the research can go on without source data.

Throughout this chapter a number of avenues for further research were identified, most notably that future research should focus on locating all outcrops of chert in the Caution Bay area and associating these with the four GSGs identified herein. Future research developing a more detailed geomorphological record for Caution Bay with an emphasis on landscape-scale erosion and deposition events, as well as further investigations into the potential differences in chert use and access between coastal and inland sites in Caution Bay were also suggested. Although somewhat disappointing, this work is valuable to other archaeologists and will likely help guide future studies. Highlighting what did and did not work and identifying topics for future studies are important parts of any research project.

# Chapter 13: Conclusion and Future Research

This thesis has explored the application of pXRF analysis to a large assemblage of chert artifacts from the Caution Bay area of PNG. The main research question of this thesis was: Can the use of pXRF data from chert artifacts collected using factory settings on a pXRF instrument provide data with which to explore how chert was selected and used by people in Caution Bay area over the past 5,000 years? A secondary research question was required in order to investigate the first: Is it possible to use an 'out-of-the-box' pXRF to successfully identify geochemically similar archaeological chert artifacts.

This research was driven by two key factors. First, expediently-made flaked chert artifacts are common in sites at Caution Bay and along the south coast of PNG, but they are rarely discussed in the literature beyond metric observations and technological analyses. The limited number of discussions of this artifact type in archeological publications for the area is in contrast to the abundance of these artifacts. As the first step to bridging this gap, this research was conducted with the aspiration of producing data that would allow for chert artifacts to be included in discussions about cultural change over time. Another goal was to identify if these artifacts could be used to supplement and strengthen the ceramic focused, cultural sequences developed for Caution Bay and southern PNG. The second major factor that was driving this work was the general lack of conclusive data relating to the application of pXRF to chert materials. Although the use of pXRF is common when discussing lithic materials like obsidian, its use with chert has been far less common and far less successful. While this thesis was being prepared, Sutton et al. (2015) conducted research and published a paper that presented one of the few successful applications of pXRF to chert materials. The fact that Sutton et al. (2015) were carrying out similar research to that detailed here in a nearby region of PNG is further indication of the need for better incorporation of lithic materials into the cultural chronologies. It also highlights the ongoing quest by archaeologists to find ways to use pXRF with chert material in a meaningful way. This research was intended not only to build on the existing published literature showing that pXRF can be used successfully when applied to chert materials, but also to illustrate the

variety of questions and inferences that can be explored and generated in relation to chert using geochemical data produced by pXRF.

This concluding chapter is divided into three sections: 1) a brief summary of the three-major sections of the thesis; 2) a discussion of the outcomes and future research considerations for each of the project's major research goals, and; 3) a discussion of the value of this research to the archaeological community and the implications of the findings for archaeological interpretations for the broader Caution Bay region.

# Thesis Summary

## *Section 1: Background and Context*

Section 1 presented the background information necessary to understand the relevance of this research. It highlighted ways in which this thesis could contribute to the current understating of lithic resource use in Caution Bay area. This section began by providing a summary of the current understanding of the archaeology of Caution Bay and the surrounding region of PNG (Chapter 2). A review of previous archaeological research across southern coastal PNG was presented accompanied by currently accepted archaeological timelines and cultural phases. Areas in which geochemical data from chert artifacts could be used to support or challenge current archaeological understandings of the area were identified. Following the introduction of the archaeology, the geographic location, regional geology and environment (both past and present) were presented (Chapter 3). The underlying geology is relevant to this thesis as it provided important information about the potential availability of lithic resources in the region. This discussion focused on the Caution Bay area where possible, but included information about the surrounding region as needed, to supplement the limited local data.

The discussion of Caution Bay archaeology and environmental data was followed by a discussion of the history and applicability of geochemical artifact analysis in archaeological contexts generally and specifically in the Pacific region (Chapter 4). The

reasons for selecting pXRF as an analytical tool for this research were discussed. The affordability, non-invasive nature, and the speed at which testing can be conducted were all factors which favoured pXRF analysis over other available methods. Additionally, a brief history of the chemistry and the process of the pXRF system, as well as an explanation of how it works were provided. The final chapter of this section introduced chert and provided a brief history of its analysis in terms of geochemical sourcing, specifically using pXRF. A number of potential problems with using pXRF on chert artifacts were noted (e.g. lack of chemical homogeneity and predominance of one major mineral) and possible solutions to these problems were presented.

## Section 2: The Data Set, pXRF Methods, and Statistical Analysis

Section 2 introduced the data set used for this research. The excavation methodology used for the Caution Bay Project was presented, as was the process by which individual sites, squares, and artifacts were selected for inclusion in this research (Chapter 6). It is acknowledged that as a result of artifacts being selected based on their physical potential for pXRF analysis, a bias was inadvertently introduced to the data set. It was not possible to assess this potential bias, and the research has been undertaken with the assumption that a possibility of bias is present in the artifact sample. In total, 2,454 artifacts from 12 archaeological sites from Caution Bay were included in this research. The cultural sequence at each of these sites was described with emphasis wherever possible on the lithic material present in the various cultural horizons.

The methodology used to prepare the archaeological samples for pXRF testing was also presented (Chapter 7). All the methods used in this research were developed following best practices and were based on previously published research working with pXRF analysis on a variety of substances, including chert. Details of the pXRF data analyses and a summary of the statistical analyses that were conducted for this research were presented. Details of the methods used to test the accuracy and consistency of the pXRF instrument were provided (Chapter 8) and demonstrated that the pXRF instrument was functioning consistently for the duration of the testing. Using a variety of statistical methods, the geochemical composition data collected from the chert artifacts were

investigated (Chapter 9) and four geochemically distinct groups of chert, referred to as Geochemical Source Groups (GSGs), were identified in the assemblage.

## Section 3: Applying the Results of the Geochemical Analysis to Archaeological Questions

Section 3 focused on the results from the geochemical characterisation in the context of the use of chert resources by the inhabitants of the Caution Bay area over the past 5,000 years (David et al. 2016e). The four GSGs identified in Section 2 were examined in relation to the archaeological assemblage to explore patterns and trends relating to the occurrence of each GSG within the assemblages from each site (Chapter 10). Key findings include:

- All GSGs were used (to some degree) for the entire length of occupation in the region;
- Some GSGs were used more regularly and for much longer periods than others;
- Artifacts assigned to all four GSGs were present in all 12 archaeological sites;
- The quantity of artifacts assigned to each GSG varied at each site;
- The chronology of the variations of the quantity of each GSG varied at each site.

Focusing on the quantities of GSGs recovered from distinct occupation phases at each site, the data were analysed to identify trends or changes over time in the quantities of each GSG being discarded (Chapter 11). The following general observations were made:

- With rare exceptions, GSG 1 was the most common material in each occupation phase, and GSG 4 was the least common.
- GSG 4 was either not present or present in very limited quantities in the early and late phases of many sites.
- In some cases, a GSG, although not present at a particular occupation at one site, was often present in a contemporary occupation at an adjacent site.

- As the total number of artifacts in an assemblage increased, so too did the variety of GSGs exploited.

As these observations were presented, they were generally followed with suggestions about the factors that may have been directly influencing the ways in which the four GSGs were represented at each site. Section 3 concluded with a discussion of a number of these factors (Chapter 12). The potential factors that could provide explanations for the observed similarities, differences, and patterns noted in the chert artifact assemblages were explored using a combination of the GSG data and other readily available sources. A selection of possible physical and human geographical factors as well as social factors that may have affected the assemblage were explored. Although generally inconclusive, these analyses demonstrate the value of exploring chert geochemical characterization, even in the absence of data about known sources of chert. Additionally, a variety of areas for future research are identified and some suggestions about the manner in which these ideas could be investigated were presented.

## Answering the Research Questions

The research presented here has been successful in addressing the questions it set out to explore – ***Can an 'out-of-the-box' pXRF Instrument produce geochemical data that can be used to successfully identify geochemically distinct groups of archaeological chert artifacts?*** and – ***Can geochemical data from chert artifacts collected using an 'out-of-the-box' pXRF Instrument in factory settings be used to explore how people in Caution Bay selected and used chert over the past 5,000 years?*** The following section will discuss these research questions. Each question will be addressed in relation to the successes and shortcomings identified in this research followed by a discussion of suggested considerations and directions for future research.

### *Can pXRF Identify Geochemically Distinct Groups of Chert?*

It has been successfully demonstrated that it is possible to use geochemical composition data collected by a pXRF instrument, using factory settings, to successfully identify groups of geochemically distinct chert in an archaeological assemblage. Geochemical composition data was collected for 42 different elements and through the application of statistical methods it has been demonstrated that only six elements were needed in order to identify four geochemically discrete groups of artifacts. Although only six elements were required to identify the four GSGs, the large elemental data set created for this research contributed to the success of this analysis. The large number of elements for which data were collected could be explored in detail and that allowed for the reduction of the number of elements required to produce valid geochemical characterization results. Importantly, these results reflect and support the results presented by Sutton et al. (2015) who successfully identified geochemically distinct groups of chert in a smaller (n=81) assemblage of artifacts from the nearby Port Moresby area using similar methods. There is insufficient data currently available to compare the data presented in Sutton et al. (2015) to the data presented here, but this would be a valuable next step and would likely provide additional support for the application of pXRF to chert.

The methodology that has been used for geochemical characterization of chert was based on a combination of best practices and on the pXRF manufacturer's recommendations. The methodology used has been provided in detail and as such, provides valuable guidelines for future researchers wishing to undertake this type of research. As well as detailing the success of this methodology, this research has identified and highlighted a number of areas in which this analysis could be improved including sample size, recorded element ranges, the development of chert-specific pXRF settings, and the selection of more appropriate standard materials. This research has also demonstrated the advantages of using pXRF over other chemical analytical techniques by highlighting the potential for an efficient mass sampling of artifacts. No other chemical analytical techniques currently available would have been able to

produce comparable amounts of chemical data in the same time frame as that presented here.

## pXRF and Chert: Considerations and Directions for Future Work

Despite the success of this research in demonstrating that geochemically distinct chert materials can be identified within the archaeological assemblage from Caution Bay using pXRF, the process has not been a direct one. As well as the valuable contributions for future research that have been presented in this research, a number of issues were identified that should be considered by anyone considering future research involving the application of pXRF to chert.

The first consideration of working with the pXRF instrument is instrument accuracy and consistency (Chapter 8). Although the instrument was shown to be functioning consistently, it was not providing accurate measurements for some elements. In all cases where the results for an element were not what was expected, investigation showed that the results were consistently inaccurate to the same degree for each element in question. Slightly inaccurate, but consistent, results such as this are common with pXRF instruments and have led to what Speakman and Shackley (2013) refer to as "silo science". Although it is true that the data provided here may be different from data provided by an alternative pXRF instrument, the use of certified scientific standard material allows future researchers to transpose the results of this research to match their instruments' results on the same certified scientific standard material. Regular and consistent use of CSRMs in the testing procedure can eliminate the issue of inter-instrument comparability. Future research focused on the geochemical characterization of chert should always include CSRMs, and the results of these tests should be made available for data set comparisons.

A second consideration relates to the CSRM that were used. The CSRM used in this research were provided by the manufacturer of the pXRF Instrument and were not chosen specifically for use with chert. Future studies should seek out chert-oriented CSRM for two reasons. Using CSRMs that are more likely to have the same elements as the material being tested will allow for a better assessment of the instrument's function.

Secondly, increased focused elemental analysis could potentially eliminate a large number of the elemental readings that were below the level of detection of the pXRF instrument as a result of not being present either in the artifacts or in the CSRMs. Results with limited very low or non-existent data readings would make statistical analysis easier and more accurate as it would eliminate the need for data transformations. These considerations would likely result in standard testing being more accurate, allowing for a better focus on chert-specific elements.

A third consideration involves the statistical analysis connected to this research. Generally, researchers using pXRF for geochemical characterization studies have used only Principal Components Analysis. This is a statistical method that can be valuable when working with a material such as obsidian, for which there is a considerable amount of research, and for which it has already been determined that data for a select few elements is all that is needed to distinguish between different geological sources. This background information does not yet exist for chert. As a result, a wider range of elements must be accessed, and alternative methods of statistical exploration must be developed. The statistical methods presented here were developed with in collaboration with a professional statistician and they build on the conventional methods to provide a more robust, and consequently, more likely to be accurate, interpretation of the data. As with the other steps of this research, the details of the statistical analysis have been provided in full to help facilitate comparisons of the data set and to help direct future research. Although the statistical analysis carried out for this work was successful, the methods were neither straight forward nor easy to apply. Future researchers wishing to pursue analyses of the sort presented here should discuss their research in advance of the geochemical testing with a statistician to assure that they are a) collecting the most appropriate data, and b) collecting data in the most appropriate manner for the questions that are being asked.

This research has provided valuable new data concerning the application of pXRF to chert and has provided a detailed methodology and a step by step process that can be used by other researchers interested in the application of pXRF to chert. It has been shown that having a large quantity of elemental data opens possibilities for the

identification of patterns and trends that would most likely not have been visible in smaller data sets. This research has also highlighted a variety of directions for future research by pointing out the data gaps that exist in chert analyses globally and the archaeological implications of these data gaps locally in southern PNG. Researchers pursuing chert-based studies should first be aware of the ability and limitations of pXRF instruments and how these can be detrimental to, or supportive of, chert elemental analysis.

One of the most important areas for future research in the application of pXRF to chert is to focus on developing a baseline of geochemical characteristics of chert. A detailed study of what elements other than Silica (Si) are present in cherts from different regions would allow for the development of a list of key elements that could allow a more focused analysis with a pXRF instrument. Knowing what elements to look for in a chert sample would mean that the pXRF instrument could be tuned to focus more on those elements. This focus would also allow pXRF analysis to provide increasingly detailed results for the elements in question and contribute to a more robust data set. In addition, having a better understanding of what elements are likely to be present in most chert formations would allow for the selection of Certified Standard Reference Materials more appropriate to chert sourcing projects. Although these materials do not contribute to the chert analysis proper, they are valuable indicators of the function of the pXRF instrument and its settings. The more appropriate these settings are for the subject matter being tested, the less time a researcher would need to spend on the function of the instrument and facilitate comparison with different data sets collected by different instruments.

### *Can pXRF be Used to Explore Ancient Chert Use at Caution Bay?*

Having been successful in the identification of geochemically distinct groups of chert using data provided by a pXRF instrument, it was possible to explore the primary goal of this research. The primary goal of this research is perhaps an overly broad question that avoids focus on any single aspect of the Caution Bay archaeology. This goal was, however, deliberate, and is the result of two issues with this project. First, when developing this research project, the limited data about the successful application

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of pXRF to chert suggested a possibility that the pXRF portion of the project would not successfully identify geochemical distinct groups. This result would limit the cultural aspects with which geochemical data could be discussed. Secondly, when this research was being conceptualized the vast majority of the archeological materials recovered as a result of the Caution Bay Project had not been analyzed, and certainly not published. Focusing this research on how general geochemical data could be used to interpret observed differences and similarities in the use of chert materials at Caution Bay ensured that regardless of what other types of data were available by the time this research was finalized, there would be something to discuss. Fortunately, four GSG groups were identified within the pXRF data and therefore the variety of factors that could be discussed in relation to the primary research goal was quite significant and varied. The question of how the GSG data could be used for exploring how chert was selected and used by past people in Caution Bay area was explored in a number of ways in this thesis. As well as examining and comparing the quantities of each GSG through the various XUs and SUs at each of the sites investigated, a variety of factors that had the potential to be affecting these collections were explored. Each of these factors was assessed using the available data from Caution Bay or nearby areas and, where applicable, though small experiments with clear hypotheses based on a limited number of variables. Although the exploration of these various factors was not entirely successful a number of valuable observations were made and a wide variety of avenues for further analysis and research were identified.

This research has demonstrated that all four GSGs were available in the landscape for the entire length of occupation currently represented by the Caution Bay sites included in this thesis. With rare exceptions, GSG 1 was the most common material at each site, and during each occupation phase. At the other end of the spectrum, GSG 4 was most often the least common material at the various locations and during the different occupation phases. The quantities of each GSG vary in different occupation phases and it is suggested that the differences in the quantity of GSGs in the various occupation phases at each site was associated with a range of factors, including the distance of a source from the site, limited access to certain GSGs, and cultural preference for one raw material over another. The presence or absence of particular

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GSGs in contemporary occupation phases at nearby sites was also noted, and this pattern may indicate that a variety of raw material selection strategies was occurring at similar times. This research proposes that the variable quantity of raw materials at contemporary sites may be a product of different site-specific activities, as these activities have the potential to produce variable amounts of debitage and may rely on specific types/qualities of raw materials. A correlation was also observed between the quantities of artifacts in a particular occupation phase and the variety of GSGs. In all cases, as the number of artifacts in a contemporary stratigraphic unit (both at the XU level and at the occupation phase level) increased, so too did the variety of GSGs present in the corresponding assemblage. The increase in artifacts at these sites is assumed to be associated with more intense artifact discard associated with an overall population increase. Although other explanations may be available for this phenomenon, if the assumption made here proves to be true, this observation suggests that as populations increased, preferred lithic resources would become more heavily used. As a result, the more desirable sources would have diminished or been in higher demand, and it is possible that people may have begun using less desirable materials, introducing a greater variety of chert sources to the assemblage. It is also possible that increasing use of GSGs is an artefact of sampling such that increasing sample size captures increasing variability of the sampled population.

While all four GSGs were used at one or more sites during each ceramic tradition, the relative and absolute quantities of each GSG changed over time. In some cases, the assemblage of chert artifacts from sites dating to the same time period (e.g. pre-Lapita sites) appears to be quite different from one another, whereas in other cases (e.g. Linear Shell Edge-Impressed Tradition sites), contemporary sites appear to have similar chert assemblages. These similar chert assemblages are, in some instances, so similar that they may represent an additional defining feature of the associated ceramic tradition. Additional data from other sites with contemporary occupations will be required in order to investigate this apparent pattern further, but this observation is one of the more significant outcomes of this research. This pattern suggests that with additional data it may be possible to identify culturally discrete occupations by analysing the quantities of different geochemically distinct groups of chert present in the

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archaeological collection. The ability to use lithics to identify discreet cultural assemblages in aceramic occupations, and in combination with ceramic materials in occupations with ceramics, would result in a better defined and more accurate identification of different cultural phases in the archeological assemblage.

With the exception of the pre-Lapita assemblage from Tanamu 1, GSG 4 was not the most common chert type during any occupation phase at Caution Bay. Even though this material was available, it appears to have possessed either undesirable physical properties, originate in a location to which access was restricted in some way, or be associated with a social construct that resulted in relatively less of it used as a tool-making stone and therefore being less represented in the various site assemblages. GSG 1 material was, in almost all of the assemblages, the most common material. Even at sites where GSG 1 was not the most common material, it was the second largest group with the only exception being the 'Interaction, Specialization, and Exchange Tradition' assemblage from Tanamu 2.

After a discussion of the observations about the chert GSGs over time, an exploration of factors that may have contributed to the changes observed in the artifact assemblages was presented. The factors selected for discussion were grouped under three broad headings; physical geographic factors, human geographic factors, and social factors. These factors were selected based on testability in terms of data currently available for Caution Bay, and do not represent all of the possible factors that may have affected the selection and use of GSG materials.

Three physical geographic factors were explored: geographical distance from source to site, ease of access to a source, and the impacts of geological processes on the availability of a source. The geographical location of these sites was explored in relation to hypothetical geological source locations. The location of the archaeological sites and the relationship between the quantity of each GSG that a site contained was examined in reference to the hypothetical proximity of GSG sources. This relationship was tested by comparing the number of artifacts assigned to each of the four GSGs at sites located near to each other. The analysis was conducted based on the assumption

that sites located near to each other would be equidistant from the hypothetical sources of the four GSGs. It was shown that this assumption was not the case and results suggested that factors other than distance to a source were likely involved in processes of chert selection by Caution Bay residents.

The ease of access to a source was investigated, but the topography of the Caution Bay region suggests that there are not, and likely have not been, any significant challenges to human movement over at least a 30 km area surrounding Caution Bay. Though unlikely, due to the variety of chert present along the south coast of PNG, it is possible that the source of some of the GSGs may be further away than the arbitrary 30km area investigated in this thesis. There is evidence for imported obsidian in the collections from Caution Bay during the terminal Lapita and the Post Lapita Transformative Tradition occupations. This pattern suggests that regardless of local availability of lithic materials, there was still a drive to import and use exotic materials. It is unclear whether obsidian was imported due to cultural factors or due to its physical properties, but regardless it indicates that material from outside of Caution Bay was (during specific occupation periods) being brought to the area, and suggests that further research on this topic is required.

The final physical geographic factor that was explored was the impact of geological processes on the availability of a source. This investigation demonstrated that although large mass wasting events are unlikely to have impacted the access to chert outcrops, there is plenty of evidence to indicate that small scale erosion and rapid deposition were occurring throughout the period of human occupation of the area. Although some of the sites included here demonstrated patterns of GSG use that could be used to support the natural exposure or removal of a source, it was not possible to properly investigate this hypothesis without additional data. It was determined that as well as research to locate the geographical sources of the four GSGs identified, additional research into the paleogeography of Caution Bay would be required in order to investigate this factor further.

The human geographic factors that were discussed included the effects of human landscape modification on the availability and selection of sources, the potential for resource exhaustion as a result of over use, and the potential effects of different settlement patterns and population mobility on the assemblage of discarded chert at a site. In terms of human landscape modification, discussion focused on the effects of gardening and firing as activities that would result in increased erosion. The archaeological record for the area suggests that there may be some correlations between the onset of increased gardening and landscape firing activities and the disappearance of particular GSGs from the archaeological record, but, as with the investigation of geological processes, the GSG data alone are insufficient for exploring this hypothesis in detail. Geographical locations of the source(s) of the chert associated with the GSGs are needed in order to pursue this line of enquiry further.

Although there are a number of good examples of humans over-using a resource in other regions of the South Pacific, it does not appear to have happened with chert use at Caution Bay. Although some GSGs were absent from the archaeological record during occupations at specific sites that follow earlier occupations where the GSG was included, there was invariably another site occupied at the same time in which the same GSG is present. The evidence currently available suggests that resource exhaustion was unlikely to have been a contributing factor to the absence of GSG material in the assemblages from Caution Bay.

The investigation of settlement patterns and population mobility that was presented herein was focused primarily on the pre-Lapita and Lapita assemblages. There were insufficient sites and limited cultural data with which to conduct comparative analyses for the more recent occupations. Although it was anticipated that the specific hypotheses about chert usage developed for the different settlement and mobility patterns identified would be supported by the GSG data, this was not the case. For each of the sites and occupations investigated the hypotheses put forward were not supported by these data. This result may be the by-product of either incorrect assumptions about the settlement and mobility of these cultural groups or an indication that chert usage at the sites from Caution Bay that were included in this research was not defined or

depended on the way people lived on, and moved across, the landscape. There is still a large amount of material recovered from the excavations for the Caution Bay Project that has not been processed, analyzed, or published. It is possible that as more research is conducted the assumptions made here may prove to be incorrect. This would, however, require a very different interpretation of these cultures and is seems unlikely. Although the results of this analysis were not anticipated, it will be valuable to revisit this discussion with more data about the Caution Bay sites once work has been done to locate chert outcrops.

The final set of factors that was explored were social factors. Social factors are challenging to investigate in archaeological contexts in general, but are exceedingly challenging in situations like that presented here, where the published information about many sites excavated remains limited. Three social factors were investigated: resource ownership, the presence of political boundaries, and the potential for culturally driven material selection. The first two factors were discussed together in relation to the available ethnographic data as they overlap to a significant degree.

The ethnographic record was used to explore both resource ownership and the potential for the presence of political boundaries. Generally, the use of chert is not something discussed in the available ethnographic literature. There was, however, information about the use of the landscape and about the ownership and access to certain resources by members of a particular group. Although the ethnographic data suggested the possibility of an entirely cultural division of what lithic resources could be used by which groups of people, the data are currently insufficient to test this hypothesis for three reasons. First, to explore the ethnographic division between Motu and Koita land use, additional sites further inland would be required for comparisons about what GSG were being accessed and brought to a site. The current data, although coming from a wide region, does not show any differences in the use of GSGs between contemporary occupations at inland and coastal sites. Among other possible options, this result suggests that the ethnographically noted divisions did not apply to chert, the ethnographic traditions were only relevant in the very recent past and do not reflect the archeological assemblage back in time, or the sites included here are all from the

coastal side of this ethnographic division. For all three of these possibilities, a significant amount of additional work will be required to access their merit.

The idea of a cultural preference for raw material was also examined, and it was suggested that colour might have played a significant role in raw material choice by the people inhabiting these sites. Colour appears to be a more significant factor than texture for the selection of raw material. This conclusion is supported by the observation that within the assemblage of good-quality and poor-quality materials from each GSG, one colour (dark yellowish orange) is dominant. Although it is possible that this colour of material is simply the dominant colour for a variety of distinct chert outcrops, this conclusion is unlikely. There are based on the archaeological collection, other colours of chert present in the Caution Bay area, and had texture been a more important selection factor than colour, there likely would have been more range in colour between the groups of different quality materials and this was not the case.

Generally speaking, the avenues of investigation available for exploring geographical and social factors that may have affected chert use in Caution Bay provided inconclusive results due to a lack of available data. The attempts to explore these ideas did highlight, however, numerous gaps in the current understanding of the archaeology of Caution Bay and have identified many opportunities for future research. Most importantly, the ability to explore these factors relying primarily on GSG data developed from pXRF analyses of chert artifacts demonstrated clearly the potential for this technique and provided a plethora of examples of how these types of data can be incorporated into discussions about the nature of the settlements and cultures that have existed in Caution Bay area over that past 5,000 years.

## Considerations and Directions for Future Chert Research at Caution Bay

Exploring the GSGs and their distribution across the 12 archaeological sites has provided valuable new information about the use of chert at Caution Bay. It has, however, highlighted several problems with the data set that can be considered limiting

factors for this research. The first challenge was reconciling the different range of dates available for each site. Naturally, each site has its own stratigraphy and number of occupation phases. All of the occupation phases from each site had at least one associated radiocarbon date. At some sites, however, the dates did not provide enough detail to conduct accurate comparisons. In some cases, comparisons proved challenging due to different quantities of dates from two sites, and in other cases, the range of precision available for the dates provided was too large for accurate comparisons. As such, future research targeting chronological changes in chert use should focus on sites with as much chronological data as possible to create more detailed and accurate comparisons between sites.

In addition to the range and quantity of temporal data available for each archaeological site, the assemblages were vastly different in size. The assemblage of artifacts that underwent testing from Bogi 1 included 935 artifacts and contrasts greatly with the 20 artifacts tested from ABKF. This discrepancy limited all comparisons between the assemblages to proportion (%) to allow for any degree of comparability. Although the percentage values do represent the ratio of items at a site, the vast differences in the assemblage of artifacts from which these percentages were derived means that there is potential for patterns and trends to be identified that may not be representative of the entire site's assemblage. If it had been possible to test every artifact recovered from each level of each site, the results presented here may have been different. However, it must also be noted that even if all artifacts from a site had been included, the smaller sites would still have had fewer artifacts than the large ones. This discussion highlighted the potential issues that the vastly different sized assemblages may have introduced to this research and suggested that future research focuses on sites of similar size with more comparably sized assemblages. Additionally, due to the limits of the pXRF instrument only artifacts over a particular size, and with a generally flat un-blemished surface could be included in the research. Although the sample that underwent testing is believed to represent the whole, it is not a random sample and may therefore not be appropriate. Future research should try to identify a way to address this issue by either selecting a random sample of all items that meet the testing requirements or finding a way to conduct testing on a larger portion of the artifact

assemblage. This consideration is important as it is quite possible that preferred or rare materials would be reduced and reused more than other items, resulting in their representation in the archeological collection by only very small artifacts. If these items were too small to be tested with the pXRF instrument it is possible that a material that was far more important than others may be completely missed in the analysis and discussion of a site. With the rate at which pXRF technology is progressing it is likely that the size of an artifact will be less and less of an issue for future analyses.

A final issue for consideration that posed a challenge for this research was the complexity of the colour ranges identified within the assemblage of chert artifacts, and whether or not this reflected the actual range of colour present in the geological outcrops from which these materials were collected. As the actual sources of the materials from which the archaeological artifacts were procured were not identified, the natural range of colours present in those geological outcrops was not available. Although it has been suggested that the absence or abundance of particular colours may reflect the choices made by people living in the Caution Bay area, it is possible that this is not entirely the case. Without knowing the natural range of colours present in the local outcrops of chert, it is not possible to be absolutely certain whether the colour(s) of material present in this assemblage reflect a natural overabundance of one geological colour rather than a cultural preference for that colour. Future chert studies must take into consideration the natural colour range of chert outcrops.

This research has provided valuable new data about the use of chert at Caution Bay, but it has also highlighted the need for more detailed information about the chert resources available in the area. There is a clear need for a survey of the chert outcrops available in the Caution Bay area and for the description of the physical properties of these outcrops as well as a complete analysis of their geochemical composition. Having this data would allow for further refinement and testing of the analyses and hypotheses presented in this thesis. This data would not only allow for a more accurate interpretation of the use of the geological landscape in the Caution Bay area but also would provide valuable data to investigate the natural colour range of chert further. Many of the possible factors that were presented as potentially having an impact on the creation of

the archeological assemblages were limited by having only the GSG data. Knowing the actual source of these GSGs on the landscape and knowing if other possible chert sources existed that were not present in the archaeological collections would allow not only for a far more in-depth discussion of each of the factors, but also would allow for the development of additional hypotheses about chert use over time at Caution Bay. Understanding the natural range and abundance of colours at Caution Bay and how these related to the geochemical sources identified, would allow future researchers to assess the degree to which colour, among many other things, was affecting the selection of raw materials by people in the area.

In addition to the need to identify and conduct pXRF testing of all locally visible chert outcrops in the Caution Bay area, this research has shown that it would be valuable to have a better understanding of the geomorphologic record for Caution Bay. Detailed investigations of landscape-scale erosion and deposition events could provide valuable data about the visibility and accessibility of chert resources in the landscape during the human occupation of the area. This data would provide further insights into why specific GSGs are present at certain sites and not others over time. This type of investigation could provide further data about the geochemical composition of chert outcrops, as the depositional environments in which they first formed would have been highly affected by ancient erosion events and local geology. The use of pXRF in the field to test the sediments around chert outcrops could potentially provide important details about the depositional environments in which they formed. Although the methods used to develop a detailed geomorphological timeline for the area would necessarily require a diverse range of data and could be done without a particular focus on chert, including data about the current (and past) chert sources in the area would be beneficial to this investigation as well. If a GSG was noted in the archaeological collection but the source of it could not be identified on the landscape, or alternatively, if a source was identified that was not represented in the archaeological collections, these data could represent the outcome of geological processes acting on the landscape and affecting access to, and visibility of, chert sources.

A final area in which the need for further work was highlighted during this research was the investigation of how lithic materials were used in the Caution Bay area. Although a technological analysis of all the lithic artifacts has been conducted by Mialanes, his analysis was focused on how the materials were reduced and the taphonomic process that they underwent. This has great value for accessing the degree to which individual nodules of material were used and the physical techniques being used to make these artifacts. It does not, however, provide details about why these techniques were being used. With additional research focused on chert sources it may be possible to identify cores of particular materials that are being reduced to a greater degree than others. Being able to explore questions like this would be valuable to the continued discussion of chert use and selection. Future research focusing on the lithics used and discarded in association with specific activities (e.g. wood, shell, and bone working, butchering, food preparation, etc.) would complement analyses undertaken as part of this thesis. The use for which a chert flake is intended to be put may have an effect on raw material selected. It is not unrealistic to suggest that different activities may have required the use of raw materials with different properties (e.g. colour, texture, etc.). Data concerning this relationship would be valuable for the comparison of assemblages from different contemporary occupation phases in which the GSG distributions were different and may provide a further explanation for these differences.

## Concluding Remarks

This research was designed to test the application of pXRF to chert and to explore the way that pXRF data can be used to investigate the archaeological record. Both of these goals have been successfully accomplished. This research has demonstrated that pXRF application to chert artifacts can be successfully undertaken and its successful application can provide a wide range of data with which to investigate variability in archaeological assemblages from 12 Caution Bay sites. While this research has produced valuable new information about the use of pXRF and its application to chert, a significant contribution has been the range of new questions that have emerged and the suggestions for future research directions.

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# Appendices

# Appendix 1: pXRF Testing of Archaeological Artifacts Results

The data collection referred to in this appendix is an excel database and is currently stored as part of the Caution Bay Project archive at Monash University

# Appendix 2: pXRF Testing of Certified Standards Reference Materials Results

The data collection referred to in this appendix is an excel database and is currently stored as part of the Caution Bay Project archive at Monash University.

**Appendix 3: Analysis of the Geochemical Composition Data of Chert Artifacts from Caution Bay, Papua New Guinea**

# Analysis of the Geochemical Composition Data of Chert Artifacts from Caution Bay, Papua New Guinea

**REVISION**

**May 7, 2018**

**by**

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# GLOSSARY

Artifact  Individual piece of chert that has been modified by human behavior.

Elements and Symbols

| | | | |
|---|---|---|---|
| Aluminium (Al) | Antimony (Sb) | Arsenic (As) | Barium (Ba) |
| Bismuth (Bi) | Cadmium (Cd) | Caesium (Cs) | Calcium (Ca) |
| Chlorine (Cl) | Chromium (Cr) | Cobalt (Co) | Copper (Cu) |
| Gold (Au) | Hafnium (Hf) | Iron (Fe) | Lead (Pb) |
| Magnesium (Mg) | Manganese (Mn) | Mercury (Hg) | Molybdenum (Mo) |
| Nickel (Ni) | Niobium (Nb) | Palladium (Pa) | Phosphorus (P) |
| Potassium (K) | Rhenium (Re) | Rubidium (Rb) | Scandium (Sc) |
| Selenium (Se) | Silicon (Si) | Silver (Ag) | Strontium (Sr) |
| Sulphur (S) | Tantalum (Ta) | Tellurium (Te) | Thorium (Th) |
| Tin (Sn) | Titanium (Ti) | Tungsten (W) | Uranium (U) |
| Vanadium (V) | Zinc (Zn) | Zirconium (Zr) | |

CV  Coefficient of variation. Indicates the accuracy of the readings. The CV is equal to the Standard deviation divided by the Mean (CV = SD / Mean).

Factor score  A composite measure created for each reading on each factor extracted in the factor analysis. The factor weights (loadings) are used in combination with the log of the element values to calculate each reading's score (Hair, Jr., Black, Babin, and Anderson, 2010; 92-3).

<LOD  Less than level of detection.

95% CI  95% Confidence Interval: mean ± (t0.05, x df x SEM).

Null value  A numeric variable that has a blank field.

ppm  Parts per million.

Reading  Refers to the collective element data from the pXRF testing on an artifact. Additionally, 'reading' is also used to refer to individual element values from a single pXRF test.

<u>Sample of convenience</u> A non-probability sampling technique where the sample is drawn from a part of the population that is close at hand.

<u>SD</u>   Standard deviation.

<u>SEM</u>   Standard Error of the Mean: SD / $\sqrt{n}$.

<u>Site</u>   Geographical location from which archaeological artifacts have been recovered. There are 12 sites in this research project.

<u>Standardize, standardization</u> Transforming a variable where the mean becomes 0 and the standard deviation becomes 1 by first subtracting the variable mean from each observation's value and then dividing by the standard deviation.

<u>Standard</u> Material provided by a certified laboratory that contains a known quantity of specific elements.

<u>Valid reading(s)</u> Readings from a pXRF or XRF in ppm.

# 1 INTRODUCTION

This analysis was prepared under contract from Greg Morrissey for his PhD thesis, Chemical Characterization of Chert Artifacts from Caution Bay, Papua New Guinea: Exploring Archaeological Resource use via Portable X-ray fluorescence, Monash University, Melbourne, Australia. The collection of the chert artifacts is described in Morrissey (2018: 2-3).

Morrissey tested the artifacts using a Niton Model XL3p portable X-ray Fluorescence Analyzer (pXRF) manufactured by Thermo Fisher Scientific Inc. It is a chemical, analytical device that produces elemental composition, in parts per million (ppm), of the item being tested. The pXRF unit was configured to detect the presence of the 43 elements listed in *Appendix 1, Table 1*. Mr. Morrissey's instructions were:

(1) Analyze the chemical reference standards to determine the accuracy and consistency of the pXRF (Section 3),
(2) Determine if the chert artifacts could be grouped into chemically, distinct clusters (Section 4), and
(3) Use as much of the data as possible.

The Analysis of Caution Bay Chert Artifacts includes three methods of preparing the data for cluster analysis. The first two methods are principal components analysis (PCA) and factor analysis (FA), where the components and factors are used to create the clusters. The third is an extension of FA where surrogate elements (variables) are selected to represent all elements tested. In addition to creating the clusters, the cluster analysis compares the results of the three preparation methods.

All analyses were performed using the IBM Corporation Statistical Package for the Social Sciences (SPSS), Version 24.

# 2 LITERATURE REVIEW

Of the research reviewed, the materials analyzed for element concentrations were obsidian (Burley, et al., 2011), (Phillips and Speakman, 2009), (Sheppard, et al., 2010),

and (Sheppard, et al. 2011); pottery (Bickler, 1997) and (Frankel and Webb, 2012); strata (Davis, et al., 2012); and chert (Gauthier, et al., 2012); (Rafferty, et al., 2007); and (Reifenstuhl, et al., 2009).

In addition to artifact analysis, the publications included analysis of chemical reference standards. The artifact analyses were examined to determine the methods generally used to analyze chert artifacts. The chemical reference standards, analyses were reviewed to determine an appropriate methodology for the analysis of the chert and reference standards.

The chemical analysis of obsidian, pottery, stratigraphic profiles, and chert have been done using X-ray diffraction, X-ray fluorescence, spectrometry (XRF) and other radiographic methods, which have been in use since the 1950s (Phillips and Speakman, 2009). Since 2005 the pXRF has become the most common device used to measure element composition in archaeological artifacts (Sheppard, et al., 2011; 48). Readings are in ppm are the most common and permitted the consistent use of specific analytical methods and easy comparison of results.

These papers are summarized in *Table 2-1, Summary of Statistical Analysis Methods in Literature Review*. The elements tested for each study and compared with Morrissey (2018) are listed in *Table 2-2*. For this study the elements tested were determined by the settings on the pXRF. The presence of other elements was not tested, such as Yttrium (Y), which was tested in some of the studies.

The analytical methods in the reviewed studies suggested methods that could have been considered for the Caution Bay Area data (*Table 2-1);* however*,* since this is not a replication study, none of the methods will be exactly duplicated. Unlike the reviewed studies, the chert artifacts in Morrissey (2018) do not have any known geological source.

Generally, principal components analysis and factor analysis were used for data reduction and creating principal components and factors for graphing. Some studies used bivariate scatterplots with *95% CI* ellipses to identify clusters of artifacts or elements (Burley, et al., 2011; Eker, et al., 2012; Evans, et al., 2010; Gauthier, et al., 2012; and Rafferty, et al., 2007). The investigators used various methods or a mixture of methods to analyze their data. *Table 2-*1 indicates the analysis and graphing methods for the clusters analyses.

The analyses were generally of two types; scatterplots (some with 95% density ellipses) and statistical analyses. The later analyses were mainly principal component analysis (Bickler, 1997; Gauthier, et al., 2012; Rafferty, et al., 2007; and Reifenstuhl, et al., 2009), factor analysis (Bickler, 1997 and Frankel and Webb, 2012), cluster analysis (Bickler, 1997; Rafferty, et al., 2007; and Reifenstuhl, et al., 2009), and discriminant analysis (Reifenstuhl, et al., 2009; Sheppard, et al., 2010; and (Sheppard, et al., 2011).

Cluster analysis was done using both hierarchical and non-hierarchical methods. Bickler (1997) used hierarchical methods to cluster the output of PCA, FA, and correspondence analysis (CA) and the k-means non-hierarchical method. Rafferty, et al. (2007) used the dendrogram hierarchical method, and Sheppard, et al. (2011) used a classification tree method.

Although there has been much discussion in the literature about whether principal components analysis (PCA) or factor analysis (FA) is the preferred method both were used in the papers cited. Some analysts find PCA easier to understand compared to FA, with its variety of extraction and rotation methods to choose from.

Cluster analysis and multiple discriminant analysis are also used for specific purposes. Cluster analysis will always create clusters. The difficulty is knowing how many clusters to look for. It is generally used as an exploratory method. Discriminant analysis is used to determine if a combination of elements can correctly predict cluster membership.

Visual displays are often used to gain further understanding of cluster formation. Scatterplots were used to show the relationships between elements that statistical results may obscure. A combination of statistical and graphical methods may be used to answer various questions, depending on the goal(s) of the researchers and nature of the data.

The standards analysis was adapted from Sheppard, et al. (2011: 48-49) for the current analysis. It discussed, in detail, the analysis of standards and data quality controls and discussed the importance of routine running of reference standards as a significant part of any geochemical analysis. Running standards allows the researchers to monitor the operating conditions of the pXRF by assessing the accuracy and precision of the equipment using 95% CIs and CVs, respectively. Referring to other studies, they argued that high precision can produce useful results despite varying accuracy, a point omitted in the other papers.

# 3 ANALYSIS OF CHEMICAL REFERENCE STANDARDS

## 3.1 Data

A set of four chemical reference standards were provided by the manufacturer to measure the accuracy and consistency of the pXRF. They are the *SiO2, Till 4, RCRA* and *NISP 2780* chemical reference standards. pXRF tests were carried out on them once daily during the testing of the chert artifacts and the geological source samples.  The chemical reference standards were tested using the pXRF instruments built in *Soil* and *TestAll Geo Modes*.

## 3.2 Methods

The analytical method follows those reported in Sheppard, et al., (2010), Sheppard, et al. (2011), and Burley, et al. (2011). To report the precision of the pXRF element readings and the *95% CIs* for the accuracy of the readings, Sheppard, et al. (2011) used the Coefficient of variation (*CV)*. The smaller the *CV* value, the less variation there is in the element readings. A *CV* of 1.0 is the maximum acceptable value (Sheppard, et al., 2011: 48-9) where the standard deviation is equal to the mean.

Readings less than the Level of Detection (*<LOD)* were treated as missing and not included in the analysis. The summary statistics of the chemical standards readings are presented in *Tables 3-1 to 3-4*. Each table shows the *ThermoFisher Calibration Results* and the readings from one of the four standard reference materials for the *Soil* and *TestAll Geo* test modes.

The analysis of the chemical standards material compared the *ThermoFisher Calibration Results* with the reference material testing modes for each element based on the *CVs* and the *95% CIs*. Sheppard, et al. (2011: 48) measured the accuracy of their instrument using the Standard Error of the Mean (*SEM*) to calculate the CI. The *95% CI* is affected by the sample size; the smaller the sample, the greater the error. To increase the accuracy of the *CIs,* the *SEM* was multiplied not by 2, as in Sheppard, et al. (2011: 48), but with the appropriate t-value for the sample size.

## 3.3  Analysis

For the *SiO2* reference standard (*Table 3-1*) all elements had *Expected* values of zero ppm (ThermoFischer SCIENTIFIC, 2010). Of the 32 elements tested, 25 of those detected using the *Soil* mode and 26 detected using the *TestAll Geo* mode produced <LOD readings. They are assumed to be within the Low and High acceptable reading ranges and are interpreted as zero. Means, standard deviations, CVs and *95% CIs* are shown if there were 2 or more valid readings (greater than the limit of detection). Only two of the *95% CIs* (yellow high-lighted in *Table 3-1*) had ranges that included zero.

With a range of CV values from 0.132 to 1.618 (*Soil*) and 0.135 to 0.935 (*TestAll Geo*), they indicate a moderate to high degree of variability. *Appendix 2, Figure 1-1* compares the *Soil* and *TestAll Geo CVs*. The nine *CVs* indicate a moderate to high degree of reading variability, depending on the *Instrument Mode*. Only two of the available *95% CIs* (yellow high-lighted on *Figure 1-1*) included zero.

*Table 3-2* shows the results for the *Till 4* reference materials. Six of the eight elements produced 63 of 63 valid readings. Only three readings were *<LOD*. The instrument mode *TestAll Geo* had lower *CVs* than the *Soil* mode for five of the eight elements (*Figure 1-2*). The remaining three *CVs* were similar for both modes. The 95% *CIs* did not include the expected values for any of the *Soil* or *TestAll Geo* readings. Several of the *CIs* were within 10 to 20 ppm of the certified value, suggesting some readings were close to or within the measurement error of the pXRF unit.

Five of seven *Soil CV* values, for the RCRA reference standard had readings, were higher than the *TestAll Geo* values (*Figure 1-3*). The remaining two *CVs* for *Soil* and *TestAll Geo* were similar to each other. The reference standard readings (Table 3-3) had expected values of 500 ppm. Two elements, Lead (Pb) and Selenium (Se), tested in *Soil* mode had *95% CIs* that included 500 ppm. The expected readings for the remaining elements and all those tested in *TestAll Geo* mode were outside their *CIs*.

Table 3-4 shows the results of the *NISP 2780* readings. The *95% CIs* that include the Certified value are high-lighted. Both test modes had low *CVs*. As with the other standards, *Soil* mode had higher *CVs* for eight of the 11 elements. While the values were low, the *Soil* mode readings were about twice the size of the *TestAll Geo* ones, as seen in *Figure 1-4*.

The Magnesium (Mg) *95% CIs* included the *Certified* value for both test modes. For Barium (Ba), the *certified* value was within the 95% *CI* bounds for *TestAll Geo*.

## 3.4  Results

The pXRF is suitable for testing concentrations at zero, as demonstrated with the *SiO2* reference standard when the Level of Detection (LOD) is greater than the expected value. In summary, the tests conducted using *Soil* mode gave accurate results for 25 of the 32 elements and the TestAll Geo mode tests gave accurate results for 28 of the results.

For the *Till 4*, *RCRA* and *NISP 2780* reference materials (Tables 3-2 to 3-4) the pXRF unit produced generally low CVs. There was some variability related to the reference standard being tested and the instrument testing mode. Generally, the *CVs* varied across instrument mode, reference standards and elements. Specifically, *TestAll Geo* had the lowest *CVs* and the NISP 2780 reference standard the lowest *CVs.*

While the *95% CIs* were often close to the *Certified/Expected* value only one for *Soil Mode* and four for *TestAll Geo* were within these values. These results suggest that the pXRF unit is unable to accurately measure element concentrations. The precision of the *CVs* is very good, especially for the *TestAll Geo* test mode. Only one of the *TestAll Geo CVs* were greater than 0.10, while six of the *Soil CVs* were greater. Although accuracy is low, precision is high. The results of the chemical reference standards analysis agree with Sheppard, et al. (2011: 48), who argued that "… as long as precision is high, useful sourcing results can be obtained despite variable accuracy."

# 4  ANALYSIS OF CAUTION BAY AREA CHERT ARTIFACTS

## 4.1  Introduction

The data is composed of pXRF readings from an apparently random collection of 2,460 archaeological, chert artifacts. Each artifact was scanned for the concentration of 43 pre-set elements (*Table 1*).

Before it could be analyzed the data was put through several steps to prepare it for analysis. First, there was cleaning of the data. There were minor changes to variable names, variable labels and value labels to clarify the meaning of some variable and value labels. These edits did not change the data and were made to improve the understandability and interpretation of the output. More importantly, was the identification of missing values, incorrect data and extreme outliers. Decisions were made how to best prepare the data for analysis and, if necessary, which data transformations perform.

Secondly, to create the inputs for the cluster analyses the data were pre-processed using principal component analysis (PCA), factor analysis (FA), and exploratory factor analysis to select the surrogate elements (EFA). Both FA and EFA are treated with the Varimax method. Since there are varying opinions about the best pre-processing method to use, each input was tested, and the results compared.

## 4.2  Data Description

The artifacts for this study were chosen, in an apparently random manner, based on their physical characteristics. A total of 2,460 archaeological, chert artifacts were analyzed. They were scanned by the pXRF for concentrations of 43 pre-set elements. A description of the selection process is given in Morrissey (2018: 2-3). While the sample was not randomly selected, the description indicates that it is probably representative of the artifacts available. For this analysis, the data is treated as a sample of convenience. The selection process does not invalidate the analysis, but it does indicate that the results should be accepted with some degree of caution.

## 4.3  Data Cleaning

Before the data could be analyzed, identifiable errors were either corrected or removed. Minor errors occurred in some variable names, and variable and value labels and were corrected to clarify their meaning. For individual readings, errors were found in the values of one or more elements in several readings. These errors were identified as missing values or extreme outliers and resolved accordingly.

### 4.3.1  Variable Names, Variable Labels and Value Labels

Two minor changes were made to variable and value labels. The variable Site_No was changed to Site_Name since the sites were identified by name and not number. For Site_Name, the sites were entered as text names instead of the more commonly used values corresponding to site names. For one site the name was incorrectly spelled as 'bogi 1' rather than the correctly spelled 'Bogi 1'. As SPSS is case sensitive, 'bogi 1' was changed to 'Bogi 1' to avoid any problems with the site name.

### 4.3.2  Missing Values

Ideally, data sets have valid values for all elements, as missing values usually present problems with the analysis.  While it was possible to include only elements with valid values this method is not without its problems. If missing values are included, SPSS will remove the associated artifact reading so the analysis can run. Only four element readings have valid values for all artifacts. Missing values for one element usually overlaps with missing values for other elements. If all missing values are removed no artifact readings would remained.

While elements could be removed to include only a subset which had only valid values, the elements and the number of elements would be reduced. The sample size would be reduced to less than, approximately, 1,200 artifacts, depending on which elements were retained. The trade-off between the sample size (number of artifacts), the element names, and the numbers of each element could result in too little data for a satisfactory and reliable analysis.

The pXRF could not determine concentrations for all elements. There are of two categories of missing values. First, the pXRF could not determine if any concentration of an element existed in the artifact, in which case it is a Null Value. Second, there is a concentration but the pXRF could not determine if was below the level of detection (<LOD) and greater than zero (>0), if so, it was indicated with a '0' and called an Indeterminant Value.

### 4.3.2.1   Null Values

Null values indicate that the presence an element could not be detected. How to handle null values depends on the whether artifacts or elements are most affected. Eight artifact readings have some elements with null values, which are: Aluminium (Al), Barium (Ba), Caesium (Cs), Calcium (Ca), Chlorine (Cl), Magnesium (Mg), Phosphorus (P), Potassium (K), Scandium (Sc), Silicon (Si), Sulphur (S), and Tellurium (Te). They are present in 0.7% to 100.0% of the artifacts. Depending on which elements are included in an analysis will affect the number of artifacts analyzed. To keep the number of artifacts the same throughout the analysis the artifacts listed in *Table 4-1* were deleted.

Elements that are absent in 100.0% of the artifacts were also deleted. They are: Bismuth (Bi), Cobalt (Co), Gold (Au), and Thorium (Th) (see Table 4-3); Hafnium (Hf), Rhenium (Re), and Tantalum (Ta) (see Table 4-1).

### 4.3.2.2   Indeterminant Values

The Indeterminant Values are those that could not be determined because they were less than the level of detection, in which case the pXRF gives the element reading a value of 0. For these elements it is assumed that the minimum value recorded for each element was at or near the level of detection. These values create a gap between two values, 0 and <LOD. In this situation it is acceptable to impute the mid-point in the gap, which would be one-half, or the average, of zero and the minimum value.

Imputing unknown values with a constant, especially where large proportions of the artifact readings are composed of them, distorts the distribution and possibly results in erroneous conclusions. It was assumed that PCA and FA would automatically correct this problem and retain only those elements that made important contributions to the components or factors.

### 4.3.3  Artifact Anomalies

Single element outliers were identified by inspecting plots of the standardized[*] element readings (*Figures 2-1-1 to 2-1-40*). Mr. Morrissey inspected these distributions and based on his original testing notes identified 161 anomalies in 52 artifact readings. The errors were deemed to be poor readings due to the surface morphology of the

artifacts. They were removed on the basis that they could bias the results. Each artifact had one or more of the following characteristics:

- Cortex/inclusions present on the tested surface of artifact
- Crystalline inclusions present in the material
- Mixed, mottled or multi-coloured testing surface
- Indeterminate raw material type (item is possibly not chert)

### 4.3.4  Factor Score Outliers

*Figures 2-1 to 2-40* show histograms of the standardized data. The proportion of readings less than the level of detection (<LOD) are shown as a bar below 0. The Factor Score outliers are shown in *Figures 4-1 to 4-29*. Were they occur they are the small numbers of readings separated from the distribution.

The outlier element readings were identified from a listing that included readings of Factor Scores greater than the absolute value of 5.0 and two or more element readings with Z-scores also greater than the absolute value of 5.0. As examples, two readings are shown in *Table 4-2*. Sixty-two readings were identified and removed from the data set. The valid readings and those <LOD are included in the distributions (*Figures 4-1 to 4-29*).

### 4.3.5  Summary

The original data file had readings for 2,460 artifacts and each reading had 43 elements. Removing Hf, Re, and Te reduced the number of elements to 40.

Removing the single element outliers reduced the number of artifact readings from 2,460 to 2,400. Removing factor score outliers further reduced the number of readings to 2,338, which caused four elements with only a few occurrences (Bi, Co, Au and Th) to drop to zero. Consequently, three artifacts were removed resulting in a final sample size of 2,335.

The eight elements that had more than 99% valid values were removed from the analysis, further reducing the total number of elements in the analysis to 26 (blue high-lighted elements in *Table 4-3*.).

## 4.4 Methods

The descriptives of the cleaned, valid values are presented in *Table 4-3*. The table summarizes the readings with the number of imputed values, value <LOD, mean, minimum, 25th percentile, 50th percentile, 75th percentile and maximum for each element. For data with skewed distributions, the median is a better measure of central tendency than the mean and the difference between the two is an indication of the degree of skewness present.

### 4.4.1 Sample Size

Hair et al. (2010: 104) provide criteria to calculate the minimum sample size required for an exploratory factor analysis. They present a method of estimating the sample size needed. With the expectation that 43 elements would be tested, their recommendations for this study would range from five artifacts per element to 20 artifacts per element. Five artifacts per element would be a minimum, ten as acceptable and 20 or more have been recommended by some researchers. They recommend that a researcher should always try to obtain the highest cases-per-variable ratio to avoid the risk of overfitting the data, which would produce results specific only to the sample at hand and not generalizable to other chert artifact studies (Hair, et al., 2010: 102).

With an original sample of 2,460 artifacts and 43 elements this study has an artifact to element ratio of 57, 2.8 times greater than 20 artifacts per element recommended by some researchers. This sample provides a substantial margin that could easily accommodate a variety of exploratory analyses. This could provide comparisons between readings with many imputed element values and those with none and possibly demonstrate the importance of complete data sets for chert analysis.

### 4.4.2 Normality and Data Transformations

Factor analysis does not require the data to be multivariate normal (Johnson and Wichern 1982). Although multivariate normal data has useful interpretations for this analysis multivariate normal data was not required. The distributions of the standardized element scores are shown in *Figures 2-1 to 2-40*. They reveal that most of the element distributions, to varying degrees, are positively skewed. Distributions with a high proportion

of <LOD values cannot be transformed into normal ones, however log 10 transformations did improve the distributions for analysis and plotting.

### 4.4.3 Summary

Missing values were imputed with one-half the minimum value recorded. To reduce the skewed distributions, the values were transformed using log 10 transformations. Sample size recommendations were investigated for this type of research and it was determined that this sample size was more than adequate to identify surrogate elements using exploratory factor analysis.

## 4.5 Analysis

Identifying the principal components, factors and surrogate elements that account for most of the variance in the elements is the method to produce the input for the cluster analysis. Other methods, particularly principal components analysis, is often preferred. To compare the major results of these methods, cluster analyses, using principal components, factor, and exploratory factor analysis (surrogate elements) will be performed.

The inputs for the cluster analyses are: (1) principal components, (2) factors, and (3) surrogate variables. All methods are forms of data reduction, where fewer than the original numbers of components, factors, or variables (elements) are selected. The principal components are a few linear combinations of the original elements (Johnson and Wichern, 1992; 356) and the factors are unobservable random quantities (ibid; 396). The surrogate variables are a sub-set of the original variables using a decision process meant to represent as much of the variance as possible in the original variables.

### 4.5.1 Inputs

This section describes the three sets of inputs produced for the cluster analysis. The results will be compared to determine if one set of inputs is preferable to the others.

### 4.5.1.1   Principal Components

Principal components analysis is concerned with explaining the variance-covariance structure through a few linear combinations of the original variables. PCA creates one component for each variable. Often a small number of components can account for as much variability as all variables. From these components, those that have eigenvalues greater than or equal to one, were selected as input for the cluster analysis. (An eigenvalue represents the amount of the total variance accounted for by the component.) In this analysis ten components met the minimum eigenvalue criteria for inclusion into the cluster analysis. They account for 67.707% of the total variance of the 33 original variables, a moderate amount considering the number of variables included in the analysis. See *Table 4-4*.

Bickler (1999) and Gauthier, et al. (2012) used XRF techniques to test pottery and chert artifacts, respectively. Bickler (1999) used a combination of techniques, including PCA, FA/Varimax, hierarchical cluster analysis, correspondence analysis (CA), and k-means non-hierarchical analysis. It is conceptually similar to principal component analysis but applies to categorical rather than continuous data (Hair Jr., Black, Babin, and Anderson, 2010: 587).

Gauthier, et al. (2012) analyzed their data using hierarchical and non-hierarchical clustering methods. Principal component score diagrams were used to portray the geochemical signatures of the quarries being studied (Gauthier, et al., 2012: 2442). Graphical and 90% confidence interval methods were used to estimate cluster sizes and distances (ibid: 2443-2446). Regardless of the analytical techniques, the sample sizes (29 and 9) are too small (especially 9) to produce reliable results.

### 4.5.1.2   Factors

Factor analysis, using varimax rotation, can be considered an extension of PCA. Both can be viewed as attempts to approximate the covariance matrix $\Sigma$. The difference being that factor analysis rotates the factors so that the maximum amount of variance is explained by each factor. Three factors, accounting for 82.384% of the total variance, were extracted from the data (*Table 4-7*) and used in the cluster analysis.

Using a pXRF to collect element concentrations from pottery artifacts, Frankel and Webb (2012) used factor analysis (PCA with Varimax rotation) results to identify non-local pottery from Bronze Age Cyprus. Plotting Factors 1 and 2 for three sites quite successfully separates one site from the other two, however, without colour coding it might be difficult to separate the two sites from each other. The factor plots distinctly showed local and non-local clusters.

### 4.5.1.3   Surrogate Elements

Exploratory factor analysis was used to identifying representative elements as inputs for cluster analysis. It starts with factor analysis, varimax rotation, with the results from Section 4.5.1.2. Rather than selecting factors, a sub-set of elements was selected to represent all elements, using the guidelines recommended in Hair, et al. (2010: 103-4).

The first step was to remove one element of a pair of elements with a Pearson product-moment correlation coefficient (correlation) greater than 0.90. This condition, multicollinearity, can distort the relationships between the elements. Examination of the correlation matrix (*Table 4-5*) shows that three pairs of elements have correlations greater than 0.90. They are Cs/Sb (Caesium/Antimony) (0.929), Te/Sb (Tellurium/ Antimony) (0.947), and Te/Cs (Tellurium/Caesium) (0.964). To identify which two elements to remove the factor analysis was run in turn with each of the three elements removed.

Based on the results the Kaiser-Meyer-Olkin Measure of Sampling Adequacy, Bartlett's Test, communalities, and rotated component matrix, Sb was found to have the smallest effect on the results. Therefore, Cs and Te were removed.

To create a parsimonious set of variables a substantial number of elements should be sufficiently correlated (i.e. greater than 0.30) to justify the application of factor analysis (Hair et al, 2010: 103-4). The correlations (Table 4-5) were inspected and a sufficient number of correlations greater than 0.30 were identified. Negative partial correlations (Table 4-6) were used to indicate the existence of factors in the data. Small values indicate that "true" factors exist, while high partial correlations indicate no underlying factors. Many partial correlations with high, absolute values (greater than 0.7) are indicative of a data matrix not suited for factor analysis. For this analysis, variables indicating high partial correlations were removed. An exception to this occurred when high correlations have substantially higher loadings than other variables on that factor. In this case, their partial

correlations may be high because the elements are not explained to any great extent by other elements, but they do explain each other.

Other statistical results such as Bartlett's test of sphericity and the measure of sampling adequacy (MSA) were also examined to insure they fell within specified ranges. In *Table 4-6* the diagonal values are the MSA values. A Bartlett p-value of less than 0.05 (not shown) indicates a sufficient number of correlations between the elements. The MSA must exceed 0.50 for the overall test (not shown) and for individual variables. Variables with MSA values less than 0.50 were removed one at a time, the analysis re-run, the MSA value re-inspected, and, if necessary, an element removed. This procedure was repeated until all MSA values exceeded 0.50.

Communalities (not shown) measure the amount of variance an element shares with all other variables. To produce a good factor structure, an element should be greater than 0.50. If a communality was less than 0.50 the element was removed, the procedure re-run and the communalities re-inspected. If communality for any element was less than 0.50 the process was repeated until all communalities were greater than 0.50.

Factor scores measure the relationship between the elements and the factors. Low element loadings on two or more factors (i.e. < 0.50) indicate that the relationships are not clear. To resolve this issue one of the elements was removed, the analysis re-run and the component matrix re-inspected, and the process repeated if necessary. The exploratory factor analysis, done according to these methods, identified eight elements suitable as surrogates for all elements. The results of the analysis are summarized in *Table 4-8*, sorted by the largest to smallest factor loading within each factor. While an element has loadings on all factors, only loadings greater than 0.5 are shown. The set of eight surrogate elements, Sb, Ba, Mo, Ni, Nb, Sn, W, and V, was used as input for the cluster analysis.

## 4.5.2  Cluster Analysis

The SPSS TwoStep Cluster Component is a two-step clustering method that promised to solve at least some of the problems associated with k-means clustering and agglomerative hierarchical techniques (Bacher, et al., 2004). In addition, the number of clusters is automatically determined (SPSS Inc., 2001). Bacher, et al. (2004) evaluated the SPSS TwoStep clustering in a simulation study. They concluded that the SPSS TwoStep

Cluster Component performs well if all variables are continuous and do not overlap extensively. In particular, it is designed to analyze large amounts of data. Continuous variables and a large data set are characteristics of this study.

This auto-cluster procedure is different from any other existing method. Simulation studies have shown that either the Bayesian information criterion (BIC) {(or other criteria like approximate weight of evidence (AWE) or Akaike information criterion (AIC)} or distance changes alone do not automatically find the number of clusters in many situations. Combining both BIC and distance change, as in this procedure, works much better than using either one alone (SPSS Inc., 2001).

The cluster analyses were executed using the three sets of inputs described in *Section 4.5.1*. To evaluate the inputs cluster analysis was performed on each set of inputs. Each evaluation usually needs several runs to determine the best sub-set of inputs to describe the final clusters. To evaluate each run the results were examined to judge the importance of the inputs and determine which input, if any, to remove and the procedure repeated. On the other hand, if all inputs were retained the cluster analysis was concluded and the results examined. This procedure was assembled from SPSS Inc. (2001), Bacher, et al. (2004), and Schiopu (2010).

### 4.5.2.1   Principal Component Inputs

The first cluster analysis evaluated the ten principal components from the PCA. One component was removed after each of six runs as their importance was too low to produce an acceptable cluster quality. After the seventh run all components attained maximum importance (values of 1.0) and the number of clusters remained stable for ten runs, ending the principal components, cluster analysis.

### 4.5.2.2   Factor Inputs

The second cluster analysis used the three factors from the varimax factor analysis as inputs. After one run four clusters were created and the three factors had the highest levels of importance, which was maintained in the subsequent test runs.

### 4.5.2.3 Surrogate Elements Inputs

The third cluster analysis was run on the eight surrogate elements identified in the Exploratory Factor Analysis. The Auto-Clustering output for the last run is given in *Table 4-9*. The Two-Step procedure calculates the ratios of the current number of clusters against the previous number (*Ratio of Distance Measures* column). The greatest "Ratio of Distance Measures" value, 3.360, indicates that four clusters (high-lighted row) is the best solution for the current inputs (Bacher, et al., 2004).

## 4.6  Results

The comparisons of the three input data methods are given in *Tables 4-10* and *4-11*. The cluster distributions (*Table 4-10*) show that the inputs can produce different distributions, which should not be surprising as the inputs were created using different methods. It will require source data to determine which input method, if any, predicts membership more accurately than the others. *Table 4-11* compares the results of the input methods. Each input method resulted in four clusters. The main difference is in the values of the silhouette measures of cohesion and separation. Again, without source data it is not possible to judge if the equal number of clusters is a coincidence and how significant are the silhouette measures of cohesion and separation.

Since the surrogate elements produced the largest silhouette value these results will be discussed in some detail. Stable clusters were obtained from six input elements, Antimony (Sb), Barium (Ba), Molybdenum (Mo), Nickel (Ni), Niobium (Nb), and Tin (Sn), of the original eight elements.

The Model Summary (*Figure 5-1)* shows the numbers of inputs (6) and clusters (4) for the final run of the cluster analysis. Cluster Quality, horizontal bar graph, on a scale of -1.0 to 1.0, indicates the quality of the silhouette measure of cohesion and separation is Good and an actual value 0.68 (IBM Corporation, 2017).

The cluster profiles illustrate the differences in element distributions between the clusters. *Figure 5-3* gives the cluster centres, sorted by size and the elements arranged by overall importance. *Figure 5-4* is like *Figure 5-3* except the elements are ordered by within-cluster importance. Cluster 1, the largest, is displayed first. The most important element in

defining this cluster (*Table 5-4*) is Barium, whose centre is 1.27. Barium is also the most important element in Clusters 2 and 4, with centres at 1.26 and 2.38, respectively.

*Figure 5-5* shows the absolute distribution of each element by overall importance. The distributions are dark red overlaying the total distribution in light read. The differences between clusters are shown by the element distributions and the importance of the elements in each cluster. Barium is the most important element in Cluster 2 shown by its almost complete absence. Each element has different distributions in each cluster. Molybdenum is almost absent in Clusters 3 and 4, a small amount in Cluster 1, and most of the Molybdenum in Cluster 2. Similar distributions are shown for Niobium. Nickel and Antimony have little or none in Clusters 1 and 2, and a fairly even split between Clusters 3 and 4. The last element, Tin, mostly occurs in Cluster 4.

The elements' level of importance and distribution provide information about the cluster profiles and assist the reader in separating one cluster from another based on individual elements. The boxplots (*Figure 5-7)* show the element distributions for each cluster. The white box includes 50% of the element values, ranging from 25% to 75%. The element distributions for each cluster are indicated by a single, coloured square and whiskers extending from each end. For example, the first boxplot shows the distribution for Ba. Its distribution for Cluster 4 is shown with ——■—— . The presence of only one whisker indicates a skewed distribution and the absence of whiskers shows the element had only imputed values for that cluster.

The Ba boxplot indicates there is likely a statistically significantly difference between Clusters group 1 and 3 and Clusters group 2 and 4. Non-overlapping whiskers in the Sb boxplot indicate a statistically significant difference between Clusters 2 and 4. Comparing the cluster distributions in the boxplots shows which elements are separated into two or more clusters and which elements make up the clusters.

Data plots (*Figures 6-1 to 6-15*) are included to visually assess the SPSS clusters. Scatterplots of each element are plotted against each other and the artifacts indicated by cluster number.

Several characteristics of the scatterplots are worth noting. As previously discussed, each element appears to be a combination of categorical and continuous data. The imputed data is indicated by a single value for each element. The categorical values are

indicated by a horizontal or vertical line of artifacts, mostly from more than one cluster and occasionally from one cluster.

For example, *Figure 6-1* plots Barium and Molybdenum. The green vertical line represents Barium readings less than the level of detection (<LOD) and Molybdium readings greater than the level of detection (>LOD). Almost all these artifacts belong to Cluster 2. The blue and red, horizontal line indicates Molybdium readings <LOD, composed of artifacts belonging to Clusters 1, 3, and 4. Similarly, the other plots may be examined for element characteristics of cluster categorization.

## 4.7  Conclusions

The chert artifact data is a sample of convenience that is likely representative of the artifacts available. The chemical composition was measured in parts per million. Data cleaning included imputing missing values, removing extreme outliers for single elements and removing readings where extreme factor scores were associated with several outlier elements. The cleaning reduced the sample size from 2,460 artifact readings to 2,335 readings. Originally, each reading included 43 elements. The removal of extreme outliers reduced the number of elements to 36. From this sample, 26 elements were selected for analysis. The sample exceeded the minimum standards for sample size and number of elements per factor (Hair, et al., 2010).

Principal components analysis, factor analysis (with Varimax rotation), and exploratory factor analysis were used to create principal components, factors, and surrogate elements, respectively, as inputs for the cluster analysis.

Using the SPSS TwoStep Cluster Component, four clusters were found to be the best solution for each set of inputs. The number of principal components were reduced from ten to four. None of the three factors from FA were removed to create its clusters. From the eight surrogate elements (EFA) six were retained to create clusters.

The silhouette measure of cohesion and separation varied between the inputs The quality of the analyses are principal components (0.52), factor analysis (Varimax) (0.60) and, exploratory factor analysis (surrogate elements) (0.68).

PCA and FA suggest they are efficient methods to create clusters. The components were analyzed without any intervention or manipulation. Even the selection of the best

factors was unnecessary since the first cluster analysis produced four clusters with three factors of maximum importance. The surrogate elements had a solution with the highest silhouette measure which was examined in detail.

This cluster analysis demonstrates that a large assemblage of chert artifacts (greater than 2,300), collected from diverse sites, tested using a pXRF provided data that may be satisfactorily clustered based on their geochemical composition. Using the statistical methods described, it has been shown that the chert artifacts from Caution Bay possibly represent chert from four separate locations.

# 5  DISCUSSION

## 5.1  Chemical Reference Standards

The pXRF measured the chemical reference standards with good precision (*CV*) and varying degrees of accuracy (95% CI). The *TestAll Geo* instrument mode consistently had lower *CV* values (higher precision) than the *Soil* mode. The accuracy of the measurements was very good for the *SiO2* standard where the expected concentrations were zero. For the other three standards, *Till 4*, *RCRA* and *NISP 2780,* the *CV*s produced more accurate results than the *95% CIs*, indicating that accuracy is high for concentrations at or near zero and precision (*CV*) is high for a range of *certified* concentrations (Till 4 and NISP 2780) and a standard of the same *expected* values (RCRA). While the *95% CI* results (accuracy) are disappointing, Sheppard, et al. (2011: 48), argued that "… as long as precision is high, useful sourcing results can be obtained despite variable accuracy."

## 5.2  Caution Bay Area Chert Artifacts

The large number of artifacts provided an opportunity to remove outliers without risking a substantial reduction in the chert sample size. The high proportion of element values below the level of detection required additional attention to include in the cluster analysis. Removing missing data would have reduced the amount of data available for the analysis and waste the resources required to collect it. This is a method other studies

appeared to use. Imputing missing values with an acceptable value maintained the sample size and extended the range of element concentrations below the pXRF's level of detection.

It was determined that the pXRF unit is sufficiently reliable to produce element readings which can be analyzed to identify distinct clusters of chemically similar artifacts.

Using results from principal components analysis and factor analysis it is possible to produce cluster results of similar levels of satisfaction. Using exploratory factor analysis, with Varimax rotation, eight surrogate elements extracted. Six were required to create four clusters.

Evaluating the three data input methods using the silhouette measure of cohesion and separation, it is likely that the exploratory factor analysis, with Varimax rotation, to identify surrogate elements is superior to the principal components and factors methods.

The SPSS TwoStep Cluster procedure was successful in identifying distinct clusters. That four clusters were derived from data inputs using different, but related, methods may be partly due to the procedure applying the critical, analytical process to each set of inputs.

While the cluster procedure appears to have been successful, it was necessary to refer to SPSS and IBM documents and evaluation papers to produce a workable cluster analysis method.

# 6  SUMMARY AND CONCLUSIONS

## 6.1  Chemical Reference Standards

This analysis tested the performance of the pXRF unit while the artifacts where being tested with four chemical reference standards: *SiO2, Till 4*, *RCRA* and *NISP 2780*. The results of this analysis showed that the portable X-ray Fluorescence Analyzer (pXRF) used in this study (Niton Model XL3p Analyzer) performed well. It is concluded that useful sourcing results can be obtained using a pXRF unit, despite variable accuracy as long as the precision of the instrument is high.

## 6.2  Chert Artifacts

The purpose of this analysis was to identify a few chemically distinct clusters. Using exploratory factor analysis to derive surrogate elements and the SPSS TwoStep Cluster procedure this goal appears to have been met.

While not the stated purposes of this analysis there are two results worth mentioning, the usefulness of the SPSS TwoStep Cluster Component and the methods of producing inputs for it.

Inputs for the cluster analysis were produced using principal components analysis, factor analysis (using Varimax rotation), and exploratory factor analysis to create principal components, factors, and surrogate elements. Judging from the research literature principal components analysis is generally preferred, Although each method produced four clusters, the surrogate elements produced clusters with the highest silhouette measure of cohesion and separation. This outcome suggests that when principal components analysis is indicated using exploratory factor analysis to identify surrogate variables (elements) may be the preferable method to achieve the highest silhouette measure.

We have demonstrated that the SPSS TwoStep Cluster Component is a useful clustering method having several advantages compared to the standard clustering techniques. While there is adequate basic documentation in the SPSS resources some important information is lacking. To fill these gaps, it was necessary to search other documents to produce a reliable and workable method. This difficulty alone may be the main reason this procedure appears to have been so little used.

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# APPENDICES

# APPENDIX 1 — TABLES

**Table 1-1 The Forty-Three Elements and Symbols Measured by the Portable X-ray Fluorescence Analyzer (pXRF)**

| | | | | | |
|---|---|---|---|---|---|
| Aluminium (Al) | Chlorine (Cl) | Magnesium (Mg) | Potassium (K) | Sulphur (S) | Vanadium (V) |
| Antimony (Sb) | Chromium (Cr) | Manganese (Mn) | Rhenium (Re) | Tantalum (Ta) | Zinc (Zn) |
| Arsenic (As) | Cobalt (Co) | Mercury (Hg) | Rubidium (Rb) | Tellurium (Te) | Zirconium (Zr) |
| Barium (Ba) | Copper (Cu) | Molybdenum (Mo) | Scandium (Sc) | Thorium (Th) | |
| Bismuth (Bi) | Gold (Au) | Nickel (Ni) | Selenium (Se) | Tin (Sn) | |
| Cadmium (Cd) | Hafnium (Hf) | Niobium (Nb) | Silicon (Si) | Titanium (Ti) | |
| Caesium (Cs) | Iron (Fe) | Palladium (Pa) | Silver (Ag) | Tungsten (W) | |
| Calcium (Ca) | Lead (Pb) | Phosphorus (P) | Strontium (Sr) | Uranium (U) | |

# Table 2-1 Summary of Analysis Methods in Literature Review

| Author | Year | Material | Geological Analysis Device | Units | Data Transformation | Analysis Methods | | | | | Graphing Methods | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | PCA | FA | Cluster | Discriminant | Other | ppm | log-log | Discrim Func. | Factor Scores | Other |
| Bickler, S. | 1999 | pottery | XRF | ppm | log 10 | ✓ | ✓ | ✓ | | Correspondence | | Vanadium x Niobium. | | | histograms (chromium) |
| Burley, D.V., et al. | 2011 | obsidian | pXRF | ppm | none | | | | | | Rb x Sr, 95% CI density ellipses. | | | | |
| Davis, L.G., et al. | 2011 | strata | pXRF | ppm | none | | | | | | Fe x Zn scatterplot | discrim fn-discrim fn, Fe x Zn | | | |
| Frankel and Webb | 2011 | pottery | pXRF | ppm | none | | ✓ | | | | | | | Site and element plots. | box plots. |
| Gauthier, G., A.L. Burke and M. Leclerc | 2012 | chert | P-ED-XRF | ppm, wt% | none? | ✓ | | | | | Ti vs Si | | | | |
| Phillips, S. Colby and Robert J. Speakman | 2009 | obsidian | pXRF | ppm | none | | | | | | Sr x Rb and Sr x Zr, 95% CI density ellipses | | | | |
| Rafferty, S.M., C. Wood and C.B. Rieth | 2007 | chert | XRF (Energy dispersion spectroscopy) | qualitative | | ✓ | | ✓ | | Ratio combinations | | | | | PCA scatterplots and cluster trees. |
| Reifenstuhl, R.R, et al. | 2009 | chert | XRF | ppm, wt% | | | | ✓ | ✓ | ANOVA | ppm-wt%, Vanadium x MgO. | | by groups. | | |
| Sheppard, Peter, B Trichereau, C Milicich | 2010 | obsidian | p-XRF | ppm | none | | | | ✓ | | | | by sources. | | |
| Sheppard, Irwin, Lin and McCaffrey | 2011 | obsidian | p-XRF | ppm | log 10 | | | | ✓ | Classification tree | Zr x Rb, 95% CI density ellipses. | | by sources. | | Box plot, classification tree |

**Table 2-2 Comparison of Elements Tested by Other Researchers**

| Symbol | Bickler, S. (1999) | Davis, L.G., et al. (2011) | Frankel and Webb (2011) | Luedtke (1978) | Sheppard (1997) | Elker, et al. (2012) | Malyk-Selivanova, et al. (1998) | Ward and Smith (1974) | Reifenstuhl, et al. (2009) | Gauthier, et al. (2012) | **Morrissey (2016)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Al |  |  | ✓ |  | ✓ |  | ✓ | ✓ |  |  | ✓ |
| Sb |  |  | ✓ | ✓ |  |  | ✓ | ✓ |  |  | ✓ |
| As | ✓ |  | ✓ |  | ✓ |  |  | ✓ |  | ✓ | ✓ |
| Ba | ✓ |  |  | ✓ | ✓ | ✓ | ✓ |  | ✓ | ✓ | ✓ |
| Bi |  |  | ✓ |  |  |  |  | ✓ |  |  | ✓ |
| Cd |  |  | ✓ |  |  |  |  | ✓ |  |  | ✓ |
| Cs |  |  |  | ✓ |  | ✓ | ✓ |  |  | ✓ | ✓ |
| Ca |  | ✓ |  |  |  |  | ✓ | ✓ |  |  | ✓ |
| Cl |  |  |  |  |  |  |  | ✓ |  | ✓ | ✓ |
| Cr | ✓ |  |  | ✓ | ✓ |  |  | ✓ | ✓ | ✓ | ✓ |
| Co |  |  |  | ✓ | ✓ | ✓ | ✓ | ✓ |  | ✓ | ✓ |
| Cu | ✓ |  |  |  |  | ✓ |  | ✓ |  | ✓ | ✓ |
| Au |  |  |  |  |  |  |  |  |  |  | ✓ |
| Hf |  |  |  |  | ✓ | ✓ | ✓ | ✓ |  |  | ✓ |
| Fe |  | ✓ |  | ✓ | ✓ |  | ✓ | ✓ |  | ✓ | ✓ |
| Pb | ✓ |  |  |  |  | ✓ |  | ✓ |  | ✓ | ✓ |
| Mg |  |  |  |  |  |  |  | ✓ |  |  | ✓ |
| Mn |  | ✓ |  |  | ✓ |  | ✓ | ✓ |  |  | ✓ |
| Hg |  |  |  |  |  |  |  |  |  |  | ✓ |
| Mo |  |  | ✓ |  |  | ✓ |  | ✓ |  |  | ✓ |
| Ni | ✓ |  |  |  |  | ✓ |  | ✓ |  | ✓ | ✓ |
| Nb | ✓ |  | ✓ |  |  | ✓ | ✓ | ✓ |  | ✓ | ✓ |
| Pd |  |  | ✓ |  |  |  |  | ✓ |  |  | ✓ |
| P |  |  |  | ✓ |  |  |  | ✓ |  |  | ✓ |
| K |  | ✓ |  |  |  |  | ✓ | ✓ |  |  | ✓ |
| Re |  |  | ✓ |  |  |  |  | ✓ |  |  | ✓ |

**Table 2-2 Comparison of Elements Tested by Other Researchers**

| Symbol | Bickler, S. (1999) | Davis, L.G., et al. (2011) | Frankel and Webb (2011) | Luedtke (1978) | Sheppard (1997) | Elker, et al. (2012) | Malyk-Selivanova, et al. (1998) | Ward and Smith (1974) | Reifenstuhl, et al. (2009) | Gauthier, et al. (2012) | **Morrissey (2016)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rb | ✓ | ✓ | ✓ | ✓ |  | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Sc | ✓ |  |  | ✓ | ✓ |  | ✓ |  |  |  | ✓ |
| Se |  |  | ✓ |  |  |  |  | ✓ |  |  | ✓ |
| Si |  |  | ✓ |  | ✓ |  |  | ✓ |  | ✓ | ✓ |
| Ag |  |  | ✓ |  |  |  |  | ✓ |  |  | ✓ |
| Sr | ✓ | ✓ | ✓ | ✓ |  | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| S |  |  |  |  |  |  |  | ✓ |  | ✓ | ✓ |
| Ta |  |  |  |  |  |  |  | ✓ |  |  | ✓ |
| Te |  |  |  |  |  |  |  |  |  |  | ✓ |
| Th | ✓ |  |  | ✓ | ✓ | ✓ | ✓ |  |  | ✓ | ✓ |
| Sn |  |  | ✓ |  |  | ✓ |  |  |  |  | ✓ |
| Ti |  | ✓ |  |  | ✓ |  |  | ✓ |  | ✓ | ✓ |
| W |  |  | ✓ |  |  | ✓ |  | ✓ |  |  | ✓ |
| U | ✓ |  |  | ✓ |  | ✓ |  |  |  | ✓ | ✓ |
| V | ✓ |  |  |  | ✓ | ✓ |  | ✓ | ✓ | ✓ | ✓ |
| Y | ✓ |  |  | ✓ | ✓ | ✓ | ✓ |  |  |  |  |
| Zn | ✓ | ✓ |  | ✓ |  | ✓ |  | ✓ |  | ✓ | ✓ |
| Zr | ✓ | ✓ | ✓ |  |  | ✓ |  | ✓ | ✓ | ✓ | ✓ |

**Table 3-1 Chemical Standards Analysis: SiO2 Reference Standard (ppm) by Instrument Mode.**

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Instrument Mode | | | | | | | | | | | | | |
| | | | | | | Soil | | | | | | | | TestAll Geo | | | | |
| | ThermoFisher Calibration Results | | | | N | | | | | 95% CI Bounds | | N | | | | | 95% CI Bounds | |
| Element (Symbol) | Expected** | Low | High | Measured | Err | Valid | <LOD | Mean | SD | CV* | Lower | Upper | Valid | <LOD | Mean | SD | CV* | Lower | Upper |
| Antimony (Sb) | 0 | -120 | 120 | 3.5 | 5.5 | 0 | 64 | — | — | — | — | — | 0 | 10 | — | — | — | — | — |
| Arsenic (As) | 0 | -10 | 10 | -0.3 | 1.6 | 0 | 64 | — | — | — | — | — | 0 | 10 | — | — | — | — | — |
| Barium (Ba) | 0 | -200 | 200 | -17.8 | 19.2 | 0 | 64 | — | — | — | — | — | 0 | 10 | — | — | — | — | — |
| Cadmium (Cd) | 0 | -50 | 50 | -0.3 | 4.4 | 0 | 64 | — | — | — | — | — | 0 | 10 | — | — | — | — | — |
| Caesium (Cs) | 0 | -200 | 200 | -11.9 | 7.3 | 0 | 64 | — | — | — | — | — | 0 | 10 | — | — | — | — | — |
| Calcium (Ca) | 0 | -2000 | 2000 | -12.2 | 22.0 | 49 | 15 | 52.1 | 84.3 | 1.618 | 27.9 | 76.3 | 4 | 6 | 59.2 | 14.4 | 0.243 | 36.3 | 82.1 |
| Chromium (Cr) | 0 | -120 | 120 | -2.3 | 4.6 | 27 | 37 | 10.3 | 2.4 | 0.233 | 9.4 | 11.2 | 2 | 8 | 46.2 | 43.2 | 0.935 | -341.9 | 434.3 |
| Cobalt (Co) | 0 | -50 | 50 | -4.0 | 9.7 | 0 | 64 | — | — | — | — | — | 0 | 10 | — | — | — | — | — |
| Copper (Cu) | 0 | -20 | 20 | -0.7 | 5.5 | 0 | 64 | — | — | — | — | — | 0 | 10 | — | — | — | — | — |
| Gold (Au) | 0 | -10 | 10 | -0.4 | 2.3 | 0 | 64 | — | — | — | — | — | 0 | 10 | — | — | — | — | — |
| Iron (Fe) | 0 | -50 | 50 | 36.3 | 13.4 | 1 | 63 | 19.1 | N/A | N/A | N/A | N/A | 0 | 10 | — | — | — | — | — |
| Lead (Pb) | 0 | -10 | 10 | -2.7 | 2.1 | 0 | 64 | — | — | — | — | — | 0 | 10 | — | — | — | — | — |
| Manganese (Mn) | 0 | -100 | 300 | -11.6 | 20.0 | 0 | 64 | — | — | — | — | — | 0 | 10 | — | — | — | — | — |
| Mercury (Hg) | 0 | -10 | 10 | 7.5 | 2.8 | 11 | 53 | 5.0 | 1.1 | 0.220 | 4.3 | 5.7 | 1 | 9 | 5.6 | N/A | N/A | N/A | N/A |
| Molybdenum (Mo) | 0 | -10 | 10 | 0.6 | 1.3 | 0 | 64 | — | — | — | — | — | 0 | 10 | — | — | — | — | — |
| Nickel (Ni) | 0 | -70 | 70 | 10.5 | 9.8 | 0 | 64 | — | — | — | — | — | 0 | 10 | — | — | — | — | — |
| Potassium (K) | 0 | -3000 | 3000 | -36.3 | 22.3 | 64 | 0 | 121.5 | 60.7 | 0.500 | 106.3 | 136.7 | 10 | 0 | 176.4 | 83.1 | 0.471 | 117.0 | 235.8 |
| Rubidium (Rb) | 0 | -10 | 10 | 0.1 | 0.7 | 0 | 64 | — | — | — | — | — | 0 | 10 | — | — | — | — | — |
| Scandium (Sc) | 0 | -100 | 100 | -0.6 | 2.2 | 0 | 64 | — | — | — | — | — | 0 | 10 | — | — | — | — | — |
| Selenium (Se) | 0 | -20 | 20 | 0.2 | 1.2 | 0 | 64 | — | — | — | — | — | 0 | 10 | — | — | — | — | — |
| Silver (Ag) | 0 | -30 | 30 | -1.5 | 2.8 | 0 | 64 | — | — | — | — | — | 1 | 9 | 3.9 | N/A | N/A | N/A | N/A |

**Table 3-1 Chemical Standards Analysis: SiO2 Reference Standard (ppm) by Instrument Mode.**

| | | | | | | Soil | | | | | | | TestAll Geo | | | | | |
| | ThermoFisher Calibration Results | | | | N | | | | | 95% CI Bounds | | N | | | | | 95% CI Bounds | |
| Element (Symbol) | Expected** | Low | High | Measured | Err | Valid | <LOD | Mean | SD | CV* | Lower | Upper | Valid | <LOD | Mean | SD | CV* | Lower | Upper |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Strontium (Sr) | 0 | -10 | 10 | 0.5 | 0.6 | 0 | 64 | — | — | — | — | — | 0 | 10 | — | — | — | — | — |
| Sulphur (S) | 0 | -14000 | 14000 | -39.6 | 44.2 | 1 | 63 | 333.1 | N/A | N/A | N/A | N/A | 0 | 10 | — | — | — | — | — |
| Tellurium (Te) | 0 | -220 | 220 | 0.9 | 14.9 | 0 | 64 | — | — | — | — | — | 0 | 10 | — | — | — | — | — |
| Thorium (Th) | 0 | -10 | 10 | -0.4 | 1.1 | 0 | 64 | — | — | — | — | — | 0 | 10 | — | — | — | — | — |
| Tin (Sn) | 0 | -120 | 120 | -5.2 | 4.3 | 0 | 64 | — | — | — | — | — | 0 | 10 | — | — | — | — | — |
| Titanium (Ti) | 0 | -700 | 700 | 2.9 | 8.5 | 0 | 64 | — | — | — | — | — | 0 | 10 | — | — | — | — | — |
| Tungsten (W) | 0 | -60 | 60 | -21.6 | 11.3 | 0 | 64 | — | — | — | — | — | 0 | 10 | — | — | — | — | — |
| Uranium (U) | 0 | -10 | 10 | -1.0 | 1.5 | 0 | 64 | — | — | — | — | — | 0 | 10 | — | — | — | — | — |
| Vanadium (V) | 0 | -160 | 160 | -2.8 | 3.4 | 21 | 43 | 7.6 | 1.0 | 0.132 | 7.1 | 8.1 | 2 | 8 | 8.9 | 1.2 | 0.135 | -1.9 | 19.7 |
| Zinc (Zn) | 0 | -10 | 10 | 0.2 | 2.7 | 0 | 64 | — | — | — | — | — | 0 | 10 | — | — | — | — | — |
| Zirconium (Zr) | 0 | -10 | 10 | -5.3 | 1.0 | 0 | 64 | — | — | — | — | — | 0 | 10 | — | — | — | — | — |

NOTES:   ** Not Certified

* CV (Coefficient of Variation) = SD / Mean

highlight 95% CI includes Expected value

**Table 3-2 Chemical Standards Analysis: Till 4 Reference Standard (ppm) by Instrument Mode.**

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | **Instrument Mode** | | | | | | | |
| | | | | | | | | | *Soil* | | | | | | | | *TestAll Geo* | | | |
| | | *ThermoFisher Calibration Results* | | | | N | | | | | 95% CI Bounds | | | N | | | | | 95% CI Bounds | |
| Element (Symbol) | Certified | Low | High | Measured | Err | Valid | <LOD | Mean | SD | CV* | Lower | Upper | Valid | <LOD | Mean | SD | CV* | Lower | Upper |
| Barium (Ba) | 395 | 195 | 595 | 452.4 | 25.2 | 63 | 0 | 420.8 | 50.0 | 0.119 | 408.2 | 433.4 | 11 | 0 | 406.9 | 13.8 | 0.034 | 397.6 | 416.2 |
| Copper (Cu) | 237 | 200 | 280 | 222.2 | 11.6 | 63 | 0 | 225.6 | 22.9 | 0.102 | 219.8 | 231.4 | 11 | 0 | 224.8 | 7.8 | 0.035 | 219.6 | 230.0 |
| Iron (Fe) | 39700 | 29700 | 49700 | 31492.0 | 169.5 | 63 | 0 | 33655.4 | 1709.2 | 0.051 | 33224.9 | 34085.9 | 11 | 0 | 41593.6 | 272.6 | 0.007 | 41410.5 | 41776.7 |
| Rubidium (Rb) | 161 | 100 | 210 | 150.0 | 3.2 | 63 | 0 | 149.3 | 9.0 | 0.060 | 147.0 | 151.6 | 11 | 0 | 72.4 | 1.0 | 0.014 | 71.7 | 73.1 |
| Strontium (Sr) | 109 | 50 | 150 | 115.1 | 2.4 | 63 | 0 | 116.5 | 9.1 | 0.078 | 114.2 | 118.8 | 11 | 0 | 115.1 | 1.4 | 0.012 | 114.2 | 116.0 |
| Titanium (Ti) | 4840 | 3870 | 5808 | 4758.4 | 67.8 | 63 | 0 | 5087.7 | 131.0 | 0.026 | 5054.7 | 5120.7 | 11 | 0 | 5052.3 | 94.1 | 0.019 | 4989.1 | 5115.5 |
| Tungsten (W) | 204 | 130 | 275 | 155.3 | 19.1 | 62 | 1 | 177.0 | 10.0 | 0.056 | 174.5 | 179.5 | 11 | 0 | 175.9 | 10.3 | 0.059 | 169.0 | 182.8 |
| Uranium (U) | 5 | -20 | 20 | 5.0 | 3.7 | 61 | 2 | 9.3 | 2.0 | 0.215 | 8.8 | 9.8 | 9 | 2 | 9.6 | 1.8 | 0.188 | 8.2 | 11.0 |

NOTES: * CV (Coefficient of Variation) = SD / Mean

**Table 3-3 Chemical Standards Analysis: RCRA Reference Standard (ppm) by Instrument Mode**

| Element (Symbol) | Expected** | Low | High | Measured | Err | Valid | <LOD | Mean | SD | CV* | Lower | Upper | Valid | <LOD | Mean | SD | CV* | Lower | Upper |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ThermoFisher Calibration Results | | | | | N (Soil) | | | | | 95% CI Bounds | | N (TestAll Geo) | | | | | 95% CI Bounds | |
| Arsenic (As) | 500 | 400 | 600 | 455.4 | 11.8 | 64 | 0 | 457.7 | 44.9 | 0.098 | 446.5 | 468.9 | 10 | 0 | 464.4 | 8.3 | 0.018 | 458.5 | 470.3 |
| Barium (Ba) | 500 | 400 | 900 | 661.3 | 26.9 | 64 | 0 | 809.5 | 54.9 | 0.068 | 795.8 | 823.2 | 10 | 0 | 808.5 | 34.4 | 0.043 | 783.9 | 833.1 |
| Cadmium (Cd) | 500 | 400 | 600 | 516.9 | 10.3 | 63 | 1 | 535.2 | 7.7 | 0.014 | 533.3 | 537.2 | 10 | 0 | 534.9 | 9.1 | 0.017 | 528.4 | 541.4 |
| Chromium (Cr) | 500 | 400 | 900 | 442.0 | 11.5 | 64 | 0 | 323.6 | 38.4 | 0.119 | 314.0 | 333.2 | 10 | 0 | 329.5 | 8.7 | 0.026 | 323.2 | 335.7 |
| Lead (Pb) | 500 | 400 | 600 | 467.4 | 12.1 | 64 | 0 | 499.3 | 58.7 | 0.118 | 484.7 | 514.0 | 10 | 0 | 530.4 | 29.7 | 0.056 | 509.2 | 551.6 |
| Selenium (Se) | 500 | 400 | 600 | 472.8 | 8.1 | 64 | 0 | 500.9 | 63.2 | 0.126 | 485.1 | 516.7 | 10 | 0 | 508.6 | 6.8 | 0.013 | 503.8 | 513.5 |
| Silver (Ag) | 500 | 400 | 600 | 515.5 | 9.1 | 63 | 1 | 521.1 | 8.4 | 0.016 | 519.0 | 523.2 | 10 | 0 | 518.3 | 9.7 | 0.019 | 511.3 | 525.2 |

NOTES: ** Not Certified

* CV (Coefficient of Variation) = SD / Mean

**Table 3-4 Chemical Standards Analysis: NISP 2780 Reference Standard (ppm) by Instrument Mode**

| Element/Symbol | Certified | Low | High | Measured | Err | Valid | <LOD | Mean | SD | CV* | Lower | Upper | Valid | <LOD | Mean | SD | CV* | Lower | Upper |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *ThermoFisher Calibration Results* | | | | | N | | | | | 95% CI Bounds | | N | | | | | 95% CI Bounds | |
| Barium (Ba) | 993 | 844 | 1142 | 943.7 | 28.5 | 39 | 0 | 975.4 | 20.0 | 0.021 | 968.9 | 981.9 | 3 | 0 | 980.8 | 8.8 | 0.009 | 959.1 | 1002.6 |
| Copper (Cu) | 216 | 151 | 280 | 171.4 | 12.1 | 39 | 0 | 187.2 | 7.9 | 0.042 | 184.7 | 189.8 | 3 | 0 | 191.9 | 9.0 | 0.047 | 169.5 | 214.4 |
| Iron (Fe) | 27840 | 22272 | 33408 | 23056.8 | 157.2 | 39 | 0 | 23838.9 | 291.4 | 0.012 | 23744.4 | 23933.3 | 3 | 0 | 28846.8 | 153.6 | 0.005 | 28465.2 | 29228.3 |
| Lead (Pb) | 5770 | 4904 | 6835 | 5029.4 | 36.4 | 39 | 0 | 5197.3 | 76.0 | 0.015 | 5172.7 | 5221.9 | 3 | 0 | 5214.3 | 26.3 | 0.005 | 5148.9 | 5279.7 |
| Manganese (Mn) | 462 | 415 | 508 | 435.9 | 40.9 | 39 | 0 | 463.6 | 24.2 | 0.052 | 455.7 | 471.4 | 3 | 0 | 469.0 | 37.1 | 0.079 | 376.9 | 561.2 |
| Potassium (K) | 33800 | 30420 | 37180 | 35161.1 | 268.3 | 39 | 0 | 38455.0 | 601.2 | 0.016 | 38260.1 | 38649.9 | 3 | 0 | 37674.3 | 216.2 | 0.006 | 37137.3 | 38211.4 |
| Strontium (Sr) | 217 | 195 | 239 | 230.7 | 3.7 | 39 | 0 | 232.7 | 3.4 | 0.015 | 231.6 | 233.8 | 3 | 0 | 231.5 | 1.7 | 0.007 | 227.4 | 235.7 |
| Sulphur (S) | 12630 | 5000 | 15000 | 7213.8 | 283.1 | 39 | 0 | 8520.1 | 167.2 | 0.020 | 8465.9 | 8574.3 | 3 | 0 | 20638.5 | 224.4 | 0.011 | 20081.2 | 21195.9 |
| Titanium (Ti) | 6990 | 6291 | 7689 | 6804.1 | 75.7 | 39 | 0 | 7510.5 | 133.0 | 0.018 | 7467.4 | 7553.6 | 3 | 0 | 7439.7 | 42.5 | 0.006 | 7334.2 | 7545.2 |
| Zinc (Zn) | 2570 | 1800 | 3340 | 2024.6 | 25.9 | 39 | 0 | 2299.9 | 116.1 | 0.050 | 2262.3 | 2337.5 | 3 | 0 | 2241.6 | 43.0 | 0.005 | 2134.9 | 2348.3 |

NOTES: * CV (Coefficient of Variation) = SD / Mean
highlight 95% CI includes Certified value

**Table 4-1 Readings and Elements Removed**

| Reading | | | | | Elements | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 468 | Al | Ba | Cs | Ca | Cl | Mg | P | K | Sc | Si | S | Te |
| 745 | Al | Ba | Cs | Ca | Cl | Mg | P | K | Sc | Si | S | Te |
| 778 | Al | Ba | Cs | Ca | Cl | Mg | P | K | Sc | Si | S | Te |
| 951 | Al | Ba | Cs | Ca | Cl | Mg | P | K | Sc | Si | S | Te |
| 1703 | | | Cs | | | | | | | | | Te |
| 1719 | Al | Ba | Cs | Ca | Cl | Mg | P | K | Sc | Si | S | Te |
| 1805 | Al | Ba | Cs | Ca | Cl | Mg | | K | Sc | Si | S | Te |
| 3004 | Al | Ba | Cs | Ca | Cl | Mg | P | K | Sc | Si | S | Te |
| All readings | Hf | Re | Ta | | | | | | | | | |

# Table 4-2 High Factor Scores and Standardized Element Concentrations

The Factor Number (e.g. FAC1) and factor score are high-lighted in yellow.

The Element Symbol (e.g. Co) and log10 of element value are high-lighted in blue.

## Example 1

| | Reading | FAC1 | Al | Sb | As | Ba | Bi | Cd | Cs | Ca | Cl | Cr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Co | Cu | Au | Fe | Pb | Mg | Mn | Hg | Mo | Ni | Nb | Pd |
| | K | P | Rb | Sc | Se | Si | Ag | Sr | S | Te | Th | Sn |
| | Ti | W | U | V | Zn | Zr | | | | | | |
| Reading_No: | 3382 | 48.36 | -.97 | 9.40 | -.12 | -.51 | 41.17 | 48.96 | -.49 | -.15 | -.42 | 15.16 |
| ZCobalt: | 13.46 | -.30 | 39.85 | 1.33 | 25.78 | -.07 | .56 | -.83 | -.52 | -.42 | 1.87 | 48.97 |
| ZPotassium: | -2.72 | 1.48 | 1.96 | 2.58 | -.06 | -7.34 | 48.97 | -.20 | 3.24 | 8.70 | -.05 | 32.46 |
| ZTitanium: | -.75 | -.35 | -.57 | 2.29 | -.37 | .25 | | | | | | |

## Example 2

| | Reading | FAC1 | Al | Sb | As | Ba | Bi | Cd | Cs | Ca | Cl | Cr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Co | Cu | Au | Fe | Pb | Mg | Mn | Hg | Mo | Ni | Nb | Pd |
| | K | P | Rb | Sc | Se | Si | Ag | Sr | S | Te | Th | Sn |
| | Ti | W | U | V | Zn | Zr | | | | | | |
| Reading_No: | 3793 | 5.91 | 3.71 | -.46 | 2.94 | .09 | -.04 | -.03 | .39 | 8.28 | .37 | 10.58 |
| ZCobalt: | -.04 | -.30 | 16.95 | 9.05 | -.06 | -.07 | 1.16 | 2.86 | -.52 | 5.41 | 1.33 | -.01 |
| ZPotassium: | -2.72 | 1.43 | -.16 | -.07 | -.06 | -6.73 | -.02 | 5.87 | 1.50 | -.48 | -.05 | -.28 |
| ZTitanium: | 5.78 | 1.12 | -.57 | 3.25 | 5.26 | .46 | | | | | | |

## Table 4-3 Descriptive Statistics for the Chert Artifacts

Legend:
- ▇ (green) Missing Reading
- ▇ (cyan) Factor score outlier
- ▇ (yellow) Element removed, correlation > 0.9

N=2335

| Element (Symbol) | Valid N | % Valid | <LOD | Mean | Minimum | 25th | 50th | 75th | Maximum | Range |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Percentiles | | | | |
| Aluminium (Al) | 2329 | 99.7% | 6 | 3981.8 | 509.2 | 2480.5 | 3268 | 4442.8 | 33959.3 | 33450.1 |
| Antimony (Sb) | 440 | 18.8% | 1895 | 19.3 | 10.3 | 14.5 | 18.8 | 22.7 | 43.5 | 33.2 |
| Arsenic (As) | 113 | 4.8% | 2222 | 4.9 | 3.1 | 3.6 | 4.1 | 5.6 | 15.4 | 12.3 |
| Barium (Ba) | 706 | 30.2% | 1629 | 203.9 | 36 | 116.1 | 180.2 | 261.3 | 894.4 | 858.4 |
| Bismuth (Bi) | 0 | 0.0% | 2335 | | | | | | | |
| Cadmium (Cd) | 238 | 10.2% | 2097 | 10.4 | 5.8 | 8.9 | 10 | 11.9 | 20.3 | 14.5 |
| Caesium (Cs) | 521 | 22.3% | 1814 | 53 | 13.8 | 33.1 | 49.4 | 71.7 | 117.3 | 103.5 |
| Calcium (Ca) | 2335 | 100.0% | 0 | 2740.4 | 84.1 | 710.5 | 1035.1 | 1674.6 | 136311.2 | 136227 |
| Chlorine (Cl) | 923 | 39.5% | 1412 | 283.4 | 24.8 | 92.9 | 201.6 | 370.2 | 2082 | 2057.3 |
| Chromium (Cr) | 4 | 0.2% | 2331 | 53.4 | 15.8 | 17.6 | 28.4 | 114.1 | 141.1 | 125.3 |
| Cobalt (Co) | 0 | 0.0% | 2335 | | | | | | | |
| Copper (Cu) | 242 | 10.4% | 2093 | 17.7 | 10.2 | 12.7 | 14.9 | 19.9 | 55.4 | 45.2 |
| Gold (Au) | 0 | 0.0% | 2335 | | | | | | | |
| Iron (Fe) | 2335 | 1.0% | 0 | 2028.3 | 56.1 | 1159 | 1618 | 2187.7 | 75085.6 | 75029.5 |
| Lead (Pb) | 2 | 0.1% | 2333 | 11 | 8.5 | 8.5 | 11 | N/A | 13.5 | 5 |
| Magnesium (Mg) | 17 | 0.7% | 2318 | 5081.2 | 3905.2 | 4155 | 4638.1 | 5674.4 | 8359.4 | 4454.3 |
| Manganese (Mn) | 465 | 19.9% | 1870 | 117.1 | 39 | 52.5 | 68.3 | 98.2 | 2338.6 | 2299.7 |
| Mercury (Hg) | 1003 | 43.0% | 1332 | 6.9 | 4.6 | 5.8 | 6.6 | 7.7 | 15.2 | 10.6 |
| Molybdenum (Mo) | 585 | 25.1% | 1750 | 3.9 | 1.7 | 2.5 | 3.6 | 4.8 | 10.2 | 8.5 |
| Nickel (Ni) | 409 | 17.5% | 1926 | 29.4 | 17.6 | 22.8 | 27.6 | 34.5 | 64.6 | 47 |
| Niobium (Nb) | 738 | 31.6% | 1597 | 3.7 | 1.5 | 2.2 | 3.2 | 4.7 | 24 | 22.5 |
| Palladium (Pd) | 213 | 9.1% | 2122 | 5.2 | 3.1 | 3.8 | 4.6 | 6.1 | 14.3 | 11.2 |
| Phosphorus (P) | 2334 | 1.0% | 1 | 2523.9 | 303.2 | 2051.5 | 2363.2 | 2794.8 | 12019.5 | 11716.3 |

## Table 4-3 Descriptive Statistics for the Chert Artifacts

Legend: 🟩 Missing Reading
🟦 Factor score outlier
🟨 Element removed, correlation > 0.9

N=2335

| Element (Symbol) | Valid N | % Valid | <LOD | Mean | Minimum | Percentiles 25th | 50th | 75th | Maximum | Range |
|---|---|---|---|---|---|---|---|---|---|---|
| Potassium (K) | 2335 | 1.0% | 0 | 1445.8 | 166.8 | 1107.4 | 1370.9 | 1666.4 | 6210.7 | 6043.9 |
| Rubidium (Rb) | 2092 | 89.6% | 243 | 3 | 1.2 | 2.1 | 2.8 | 3.6 | 14.8 | 13.6 |
| Scandium (Sc) | 42 | 1.8% | 2293 | 23.6 | 4.9 | 7.6 | 13.6 | 25.8 | 148.6 | 143.7 |
| Selenium (Se) | 1 | 0.1% | 2334 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 0 |
| Silicon (Si) | 2335 | 1.0% | 0 | 524144.7 | 254400.8 | 499815.5 | 521177.6 | 546506 | 705434.1 | 451033.4 |
| Silver (Ag) | 162 | 6.9% | 2173 | 5.9 | 3.1 | 4.4 | 5.9 | 7 | 12.4 | 9.3 |
| Strontium (Sr) | 2323 | 99.5% | 12 | 23 | 1.1 | 10.7 | 17.5 | 27.4 | 225.9 | 224.8 |
| Sulfur (S) | 464 | 19.9% | 1871 | 255.5 | 65.6 | 111.9 | 145.5 | 311.6 | 1395.2 | 1329.6 |
| Tellurium (Te) | 481 | 20.6% | 1854 | 63.9 | 26.9 | 45.2 | 62.4 | 81 | 131.7 | 104.8 |
| Thorium (Th) | 0 | 0.0% | 2335 | | | | | | | |
| Tin (Sn) | 279 | 11.9% | 2056 | 11.7 | 13.7 | 7.8 | 21.6 | 9.5 | 11.1 | 13.4 |
| Titanium (Ti) | 2318 | 99.3% | 17 | 230.9 | 1590.4 | 18.9 | 1609.3 | 147.5 | 203.5 | 277.8 |
| Tungsten (W) | 382 | 16.4% | 1953 | 59.9 | 21 | 33.2 | 47.5 | 71.9 | 265.2 | 244.2 |
| Uranium (U) | 694 | 29.7% | 1641 | 5 | 2.8 | 3.5 | 4.5 | 5.9 | 16 | 13.2 |
| Vanadium (V) | 2005 | 85.9% | 330 | 18.8 | 7.1 | 13.3 | 16.7 | 21 | 372.6 | 365.6 |
| Zinc (Zn) | 426 | 18.2% | 1909 | 7.5 | 5 | 6 | 6.7 | 8.3 | 28.4 | 23.4 |
| Zirconium (Zr) | 1331 | 57.0% | 1004 | 6.1 | 2.7 | 4.7 | 5.7 | 7.1 | 23.5 | 20.8 |

N/A: Not Applicable

**Table 4-4 Principal Component Analysis, Total Variance Explained**

| Component | Initial Eigenvalues | | | Extraction Sums of Squared Loadings | | |
|---|---|---|---|---|---|---|
| | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % |
| 1 | 6.943 | 21.040 | 21.040 | 6.943 | 21.040 | 21.040 |
| 2 | 3.976 | 12.047 | 33.087 | 3.976 | 12.047 | 33.087 |
| 3 | 2.713 | 8.221 | 41.308 | 2.713 | 8.221 | 41.308 |
| 4 | 1.717 | 5.202 | 46.509 | 1.717 | 5.202 | 46.509 |
| 5 | 1.407 | 4.264 | 50.773 | 1.407 | 4.264 | 50.773 |
| 6 | 1.221 | 3.701 | 54.475 | 1.221 | 3.701 | 54.475 |
| 7 | 1.188 | 3.599 | 58.074 | 1.188 | 3.599 | 58.074 |
| 8 | 1.088 | 3.297 | 61.371 | 1.088 | 3.297 | 61.371 |
| 9 | 1.083 | 3.282 | 64.653 | 1.083 | 3.282 | 64.653 |
| 10 | 1.008 | 3.054 | 67.707 | 1.008 | 3.054 | 67.707 |
| 11 | .967 | 2.930 | 70.638 | | | |
| 12 | .867 | 2.627 | 73.265 | | | |
| 13 | .809 | 2.450 | 75.715 | | | |
| 14 | .796 | 2.411 | 78.126 | | | |
| 15 | .771 | 2.337 | 80.463 | | | |
| 16 | .695 | 2.106 | 82.568 | | | |
| 17 | .639 | 1.935 | 84.504 | | | |
| 18 | .604 | 1.830 | 86.333 | | | |
| 19 | .584 | 1.770 | 88.104 | | | |
| 20 | .563 | 1.707 | 89.811 | | | |
| 21 | .524 | 1.588 | 91.399 | | | |
| 22 | .456 | 1.381 | 92.780 | | | |
| 23 | .428 | 1.298 | 94.078 | | | |
| 24 | .383 | 1.162 | 95.240 | | | |
| 25 | .331 | 1.003 | 96.243 | | | |
| 26 | .302 | .915 | 97.158 | | | |
| 27 | .281 | .852 | 98.010 | | | |
| 28 | .180 | .544 | 98.554 | | | |
| 29 | .152 | .459 | 99.013 | | | |
| 30 | .142 | .430 | 99.443 | | | |
| 31 | .101 | .305 | 99.749 | | | |
| 32 | .058 | .175 | 99.924 | | | |
| 33 | .025 | .076 | 100.000 | | | |

Extraction Method: Principal Component Analysis.

**Table 4-5 Factor Analysis, Correlation Matrix.**

Elements in alphabetical order by name.

| Element | Al | Sb | As | Ba | Bi | Cd | Cs | Ca | Cl | Cr | Co | Cu | Au | Fe | Pb | Mg | Mn | Hg | Mo | Ni | Nb | Pd | P | K | Rb | Sc | Se | Si | Ag | Sr | S | Te | Th | Sn | Ti | W | U | V | Zn | Zr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Al | 1.000 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Sb | -.130 | 1.000 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| As | .082 | .022 | 1.000 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Ba | -.047 | .781 | .074 | 1.000 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Bi | .055 | .061 | .043 | .053 | 1.000 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Cd | -.125 | .539 | .028 | .406 | .286 | 1.000 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Cs | -.112 | .929 | .029 | .855 | -.022 | .473 | 1.000 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Ca | .407 | .017 | .086 | .036 | .017 | -.032 | .042 | 1.000 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Cl | .079 | .018 | .017 | .003 | .012 | .016 | .015 | .131 | 1.000 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Cr | .166 | .088 | .247 | .068 | .340 | .180 | .055 | .151 | .049 | 1.000 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Co | -.073 | .056 | .018 | .045 | .306 | .175 | .061 | -.049 | .004 | .146 | 1.000 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Cu | .133 | .105 | .209 | .144 | -.009 | .024 | .140 | .127 | .048 | .114 | .061 | 1.000 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Au | -.037 | .084 | .036 | .005 | .594 | .302 | .013 | .097 | -.002 | .400 | .321 | .010 | 1.000 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Fe | .390 | -.032 | .299 | .003 | .109 | -.024 | -.015 | .208 | -.036 | .232 | .097 | .193 | .093 | 1.000 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Pb | .146 | .022 | .318 | .076 | .668 | .149 | -.016 | .057 | -.001 | .275 | .171 | .233 | .335 | .206 | 1.000 | | | | | | | | | | | | | | | | | | | | | | | | | |
| Mg | .282 | .021 | .205 | .063 | .033 | .009 | .043 | .264 | .062 | .469 | -.004 | .101 | .090 | .189 | .057 | 1.000 | | | | | | | | | | | | | | | | | | | | | | | | |
| Mn | .148 | .445 | .244 | .479 | .128 | .220 | .495 | .318 | .044 | .232 | .054 | .281 | .137 | .294 | .268 | .197 | 1.000 | | | | | | | | | | | | | | | | | | | | | | | |
| Hg | .097 | -.081 | .047 | -.078 | .023 | -.057 | -.070 | .023 | .008 | .035 | .005 | -.020 | .013 | .111 | .023 | .009 | .014 | 1.000 | | | | | | | | | | | | | | | | | | | | | | |
| Mo | .169 | -.247 | .005 | -.322 | -.002 | -.174 | -.268 | .071 | .053 | -.018 | -.002 | -.016 | .002 | .168 | .051 | .014 | -.098 | .248 | 1.000 | | | | | | | | | | | | | | | | | | | | | |
| Ni | -.011 | .672 | .084 | .677 | .006 | .275 | .745 | .147 | .018 | .093 | .038 | .163 | .074 | .074 | .029 | .153 | .538 | -.006 | -.202 | 1.000 | | | | | | | | | | | | | | | | | | | | |
| Nb | .248 | -.272 | .001 | -.336 | .106 | -.169 | -.300 | .114 | .048 | .093 | -.010 | -.026 | .058 | .191 | .112 | .094 | .255 | -.091 | .255 | .878 | -.218 | 1.000 | | | | | | | | | | | | | | | | | | |
| Pd | -.028 | .015 | .027 | -.022 | .342 | .227 | -.046 | .026 | .045 | .172 | .178 | -.024 | .382 | .003 | .182 | .029 | .029 | .001 | -.144 | -.008 | -.116 | 1.000 | | | | | | | | | | | | | | | | | | |
| P | .159 | -.247 | -.034 | -.253 | -.146 | -.154 | -.266 | -.319 | -.034 | -.179 | -.055 | -.014 | -.260 | .018 | -.027 | -.190 | -.297 | .100 | .256 | -.292 | .223 | -.113 | 1.000 | | | | | | | | | | | | | | | | | |
| K | .711 | -.049 | .014 | .007 | .239 | -.017 | -.051 | .186 | .188 | .193 | -.016 | .124 | .041 | .453 | .232 | .202 | .097 | .006 | .024 | -.036 | .106 | .012 | .157 | 1.000 | | | | | | | | | | | | | | | | |
| Rb | .429 | -.065 | -.041 | -.012 | .168 | -.043 | -.058 | .080 | -.069 | .132 | -.035 | .086 | .019 | .433 | .140 | .081 | .044 | .088 | .143 | -.044 | .220 | -.017 | .151 | .626 | 1.000 | | | | | | | | | | | | | | | |
| Sc | .162 | .060 | .105 | .060 | .116 | .104 | .059 | .237 | .014 | .383 | .060 | .201 | .122 | .147 | .060 | .386 | .295 | .010 | -.033 | .160 | .021 | .063 | -.075 | .158 | .124 | 1.000 | | | | | | | | | | | | | | |
| Se | .021 | .068 | .009 | .077 | -.003 | -.020 | .099 | .323 | .056 | .058 | -.003 | .052 | .089 | .051 | -.004 | .067 | .224 | .027 | .034 | .201 | .044 | .021 | -.409 | -.091 | -.084 | -.008 | 1.000 | | | | | | | | | | | | | |
| Si | -.003 | -.183 | -.057 | -.186 | -.184 | -.108 | -.201 | -.553 | -.054 | -.186 | -.087 | -.039 | -.330 | -.067 | -.116 | -.224 | -.374 | .025 | .070 | -.297 | .030 | -.170 | .731 | .155 | .114 | -.088 | -.542 | 1.000 | | | | | | | | | | | | |
| Ag | -.107 | .367 | .035 | .226 | .332 | .456 | .283 | .013 | .009 | .224 | .204 | .036 | .376 | .002 | .187 | .035 | .142 | -.070 | -.124 | .130 | -.109 | .236 | -.220 | .004 | -.018 | .075 | .052 | -.183 | 1.000 | | | | | | | | | | | |
| Sr | .332 | -.037 | .046 | .114 | .043 | -.044 | -.012 | .377 | -.018 | .134 | -.082 | .115 | .081 | .171 | .113 | .193 | .223 | .045 | .116 | .066 | .198 | .036 | -.171 | .143 | .237 | .175 | .232 | -.349 | -.005 | 1.000 | | | | | | | | | | |
| S | .388 | .043 | .111 | .060 | .077 | .044 | .045 | .427 | .333 | .150 | .056 | .110 | .088 | .203 | .097 | .236 | .181 | .013 | .041 | .068 | .086 | .038 | -.121 | .256 | .066 | .116 | .149 | -.307 | .058 | .205 | 1.000 | | | | | | | | | |

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**Table 4-5 Factor Analysis, Correlation Matrix.**

Elements in alphabetical order by name.

| Element | Al | Sb | As | Ba | Bi | Cd | Cs | Ca | Cl | Cr | Co | Cu | Au | Fe | Pb | Mg | Mn | Hg | Mo | Ni | Nb | Pd | P | K | Rb | Sc | Se | Si | Ag | Sr | S | Te | Th | Sn | Ti | W | U | V | Zn | Zr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Te | -.126 | .947 | .020 | .822 | .051 | .535 | .964 | .018 | .006 | .080 | .077 | .122 | .077 | -.025 | .028 | .019 | .469 | -.069 | -.258 | .700 | -.288 | -.001 | -.249 | -.049 | -.055 | .063 | .071 | -.183 | .342 | -.031 | .038 | 1.000 | | | | | | | | |
| Th | .204 | -.006 | .079 | .103 | .618 | -.015 | -.006 | .108 | .040 | .080 | -.002 | .006 | .052 | .129 | .507 | .164 | .155 | .052 | .013 | .050 | .127 | .008 | -.128 | .312 | .206 | .051 | -.003 | -.111 | -.012 | .106 | .069 | -.006 | 1.000 | | | | | | | |
| Sn | -.102 | .806 | .017 | .618 | .142 | .574 | .747 | .050 | .018 | .140 | .088 | .093 | .181 | -.006 | .072 | .053 | .385 | -.047 | -.182 | .556 | -.197 | .097 | -.244 | -.040 | -.055 | .097 | .071 | -.205 | .424 | -.003 | .063 | .792 | -.004 | 1.000 | | | | | | |
| Ti | .708 | -.054 | -.016 | .050 | .013 | -.108 | -.014 | .491 | .014 | .175 | -.123 | .102 | -.003 | .355 | .041 | .292 | .226 | .052 | .015 | .096 | .114 | .003 | -.137 | .608 | .536 | .169 | .193 | -.312 | -.071 | .498 | .294 | -.044 | .165 | -.047 | 1.000 | | | | | |
| W | .138 | -.177 | .004 | -.223 | -.003 | -.127 | -.186 | .118 | .058 | .015 | -.021 | -.010 | .030 | .123 | .034 | .043 | -.058 | .393 | .616 | -.129 | .628 | -.078 | .121 | -.009 | .121 | .030 | .100 | -.050 | -.088 | .149 | .068 | -.186 | .025 | -.126 | .077 | 1.000 | | | | |
| U | .007 | -.045 | .005 | -.076 | .042 | -.035 | -.061 | -.029 | .044 | -.017 | -.021 | -.070 | -.023 | -.012 | .040 | -.004 | -.052 | -.007 | .311 | -.080 | .311 | -.049 | .116 | -.012 | -.114 | -.065 | -.017 | .075 | -.048 | -.015 | .017 | -.057 | .076 | -.044 | -.154 | .137 | 1.000 | | | |
| V | .287 | -.155 | .150 | -.075 | .039 | -.086 | -.141 | -.036 | -.009 | .162 | .019 | .082 | .024 | .312 | .103 | .099 | .065 | .170 | .070 | .045 | .109 | .086 | .298 | .212 | .189 | .124 | -.094 | .197 | -.146 | .087 | -.008 | -.141 | .007 | -.139 | .220 | .093 | -.005 | 1.000 | | |
| Zn | .266 | .207 | .162 | .268 | .131 | .089 | .269 | .245 | .037 | .237 | .031 | .315 | .038 | .358 | .229 | .239 | .419 | .039 | -.065 | .322 | -.030 | -.027 | -.137 | .323 | .301 | .229 | .154 | -.186 | .028 | .150 | .178 | .235 | .226 | .161 | .326 | -.026 | -.065 | .127 | 1.000 | |
| Zr | .455 | -.222 | .006 | -.165 | .170 | -.155 | -.221 | .160 | -.013 | .154 | -.024 | .087 | .041 | .381 | .167 | .159 | .038 | .193 | .466 | -.152 | .563 | -.079 | .155 | .417 | .598 | .139 | .010 | .031 | -.080 | .378 | .117 | -.221 | .236 | -.169 | .495 | .365 | -.004 | .193 | .206 | 1.000 |

**Table 4-6 Factor Analysis, Negative Partial Correlations, and Measures of Sampling Adequacy**

Negative Partial Correlations - off-diagonals. Measures of Sampling Adequacy - diagonals. Elements in alphabetical order by name.

| Element | Al | Sb | As | Ba | Bi | Cd | Cs | Ca | Cl | Cr | Co | Cu | Au | Fe | Pb | Mg | Mn | Hg | Mo | Ni | Nb | Pd | P | K | Rb | Sc | Se | Si | Ag | Sr | S | Te | Th | Sn | Ti | W | U | V | Zn | Zr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Al | 0.831 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Sb | .004 | 0.939 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| As | -.050 | -.025 | 0.686 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Ba | -.016 | .045 | -.054 | 0.94 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Bi | .055 | -.053 | .146 | -.055 | 0.631 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Cd | .012 | -.041 | -.023 | -.033 | -.131 | 0.944 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Cs | .034 | -.253 | .006 | -.354 | .139 | .019 | 0.865 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Ca | -.196 | .012 | -.016 | .065 | .065 | -.001 | -.006 | 0.885 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Cl | .166 | -.009 | -.023 | .008 | .053 | -.012 | -.016 | -.053 | 0.365 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Cr | -.002 | -.024 | -.144 | .008 | -.194 | -.001 | .038 | .015 | -.054 | 0.795 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Co | -.029 | .102 | .037 | -.001 | -.204 | -.011 | -.112 | .044 | .001 | .017 | 0.765 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Cu | -.011 | .014 | -.050 | .001 | .110 | .044 | -.028 | -.026 | -.035 | .027 | -.059 | 0.806 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Au | .006 | .025 | .011 | .057 | -.479 | -.033 | .025 | -.022 | .039 | -.103 | -.049 | -.019 | 0.745 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Fe | .037 | -.004 | -.244 | .037 | .076 | .000 | .011 | -.034 | .184 | -.037 | -.114 | -.018 | -.012 | 0.816 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Pb | -.033 | .032 | -.291 | -.025 | -.380 | .005 | .055 | .022 | .065 | -.058 | .025 | -.237 | .052 | .046 | 0.782 | | | | | | | | | | | | | | | | | | | | | | | | | |
| Mg | -.056 | .018 | -.084 | -.016 | .236 | -.011 | -.026 | .046 | .035 | -.023 | .019 | -.067 | .023 | .044 | 0.748 | | | | | | | | | | | | | | | | | | | | | | | | | |
| Mn | -.038 | .002 | -.059 | -.048 | .057 | .007 | -.070 | -.064 | -.049 | .009 | .025 | -.056 | -.039 | -.188 | -.189 | .058 | 0.929 | | | | | | | | | | | | | | | | | | | | | | | |
| Hg | -.041 | .045 | -.032 | .007 | -.002 | .003 | -.001 | .010 | -.008 | -.027 | -.008 | .038 | -.010 | -.020 | .045 | .035 | -.025 | 0.775 | | | | | | | | | | | | | | | | | | | | | | |
| Mo | -.038 | .007 | -.016 | .022 | .027 | .013 | .022 | -.029 | -.056 | .129 | -.036 | -.008 | -.001 | -.078 | -.038 | -.001 | -.028 | -.011 | 0.773 | | | | | | | | | | | | | | | | | | | | | |
| Ni | -.041 | -.006 | .032 | -.096 | .037 | .108 | -.241 | .010 | -.015 | -.120 | .020 | -.010 | -.078 | -.002 | .025 | -.004 | -.125 | -.026 | -.048 | 0.938 | | | | | | | | | | | | | | | | | | | | |
| Nb | -.052 | -.013 | .032 | .104 | -.044 | -.014 | -.026 | -.007 | .004 | -.139 | .026 | .018 | -.016 | .030 | .024 | -.041 | .023 | .007 | -.728 | .018 | 0.78 | | | | | | | | | | | | | | | | | | | |
| Pd | -.026 | -.021 | -.021 | .014 | -.179 | -.087 | .047 | .012 | -.076 | .041 | -.018 | .004 | -.076 | .006 | .014 | -.047 | .004 | -.040 | .036 | -.011 | .050 | 0.841 | | | | | | | | | | | | | | | | | | |
| P | -.118 | -.018 | .023 | .022 | -.046 | .009 | .014 | -.038 | .020 | .099 | -.023 | .014 | .074 | .034 | -.114 | .039 | .014 | -.013 | -.063 | -.004 | -.045 | -.031 | 0.839 | | | | | | | | | | | | | | | | | |
| K | -.422 | -.017 | .094 | .000 | -.114 | .007 | -.027 | .029 | -.356 | .009 | .012 | -.008 | -.080 | -.278 | -.077 | -.047 | .053 | .063 | .025 | .065 | .038 | .024 | .059 | 0.733 | | | | | | | | | | | | | | | | |
| Rb | .208 | .010 | .047 | -.008 | -.036 | .003 | -.006 | .046 | .153 | -.013 | .036 | .010 | .025 | -.151 | .019 | .083 | .071 | -.011 | .000 | -.009 | -.021 | -.031 | -.040 | -.335 | 0.831 | | | | | | | | | | | | | | | |
| Sc | .043 | .008 | .011 | .056 | -.119 | -.049 | .039 | -.171 | .048 | -.165 | -.025 | -.125 | .072 | .073 | .155 | -.240 | -.221 | .025 | .030 | -.065 | .023 | .005 | .004 | -.052 | -.021 | 0.749 | | | | | | | | | | | | | | |
| Se | .001 | .015 | .020 | .026 | -.020 | .027 | -.008 | -.006 | -.015 | -.009 | .019 | -.024 | .073 | .003 | .033 | .065 | -.035 | -.015 | -.008 | -.085 | -.022 | .023 | .070 | -.043 | .064 | .073 | 0.871 | | | | | | | | | | | | | |
| Si | -.110 | .007 | -.019 | -.034 | .106 | -.041 | .024 | .290 | .043 | -.071 | .055 | -.053 | .141 | .091 | .076 | .088 | .078 | -.032 | .021 | .066 | .019 | .078 | -.498 | -.320 | -.038 | -.075 | .269 | 0.736 | | | | | | | | | | | | |
| Ag | .016 | -.084 | -.029 | .019 | -.133 | -.137 | .020 | -.006 | .009 | -.039 | -.037 | -.022 | -.054 | -.009 | -.015 | -.036 | .018 | .015 | .005 | .107 | .014 | -.040 | .058 | -.033 | -.006 | .009 | -.030 | .000 | 0.926 | | | | | | | | | | | |
| Sr | -.056 | .010 | .018 | -.252 | .070 | -.010 | .055 | -.051 | -.006 | .012 | .056 | -.041 | -.056 | .015 | -.086 | .016 | -.030 | .027 | .046 | .054 | -.073 | -.037 | -.012 | .163 | -.049 | -.101 | -.058 | .080 | -.018 | 0.847 | | | | | | | | | | |
| S | -.245 | -.015 | -.033 | -.037 | -.055 | -.023 | .014 | -.139 | -.302 | .021 | -.039 | -.020 | .039 | -.083 | .013 | -.083 | .031 | -.002 | .056 | .041 | -.026 | .041 | -.092 | -.001 | .012 | .014 | .032 | .188 | -.002 | -.011 | 0.801 | | | | | | | | | |
| Te | -.009 | -.362 | .031 | -.024 | -.069 | -.087 | -.641 | .000 | .030 | -.003 | .022 | .011 | -.027 | .015 | -.044 | .034 | -.011 | -.025 | -.020 | .050 | .013 | .011 | -.003 | .014 | -.019 | -.015 | .017 | -.023 | -.018 | .027 | -.005 | 0.887 | | | | | | | | |

**Table 4-6 Factor Analysis, Negative Partial Correlations, and Measures of Sampling Adequacy**

Negative Partial Correlations - off-diagonals. Measures of Sampling Adequacy - diagonals. Elements in alphabetical order by name.

| Element | Al | Sb | As | Ba | Bi | Cd | Cs | Ca | Cl | Cr | Co | Cu | Au | Fe | Pb | Mg | Mn | Hg | Mo | Ni | Nb | Pd | P | K | Rb | Sc | Se | Si | Ag | Sr | S | Te | Th | Sn | Ti | W | U | V | Zn | Zr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Th | -.035 | .018 | -.045 | -.062 | -.651 | .112 | -.055 | -.063 | -.034 | .242 | .152 | .053 | .394 | .000 | -.088 | -.258 | -.034 | -.056 | .103 | -.071 | -.090 | .136 | .149 | -.064 | .020 | .071 | .068 | -.023 | .136 | -.007 | .085 | .062 | 0.56 | | | | | | | |
| Sn | -.023 | -.255 | .029 | .046 | -.018 | -.185 | .071 | -.021 | -.003 | .003 | .026 | -.017 | -.006 | -.028 | .001 | -.036 | -.005 | -.025 | -.016 | -.074 | .002 | -.036 | .010 | .008 | .008 | -.015 | .007 | .008 | -.119 | -.027 | .001 | -.164 | .015 | 0.956 | | | | | | |
| Ti | -.344 | .010 | .069 | .012 | .091 | -.001 | -.007 | -.109 | .128 | -.037 | .071 | .029 | .081 | .128 | .091 | -.024 | -.030 | -.001 | .082 | -.015 | .027 | -.015 | .006 | -.345 | -.194 | .071 | .012 | .377 | .020 | -.218 | .079 | .000 | .023 | .022 | 0.802 | | | | | |
| W | -.011 | -.014 | .015 | .004 | .058 | -.001 | -.022 | -.008 | -.049 | .028 | .017 | -.001 | -.036 | -.005 | -.042 | .013 | .057 | -.297 | -.149 | .038 | -.193 | .006 | -.021 | .048 | -.028 | -.070 | -.044 | .065 | -.003 | .004 | .000 | .017 | -.016 | -.001 | .008 | 0.887 | | | | |
| U | -.006 | -.012 | .008 | -.018 | -.010 | .007 | -.018 | -.002 | .036 | -.023 | .033 | .046 | .027 | .002 | .027 | -.004 | -.015 | .067 | -.087 | .040 | -.147 | -.014 | -.024 | -.110 | .107 | .036 | -.006 | .014 | .021 | -.067 | -.016 | .010 | -.045 | .010 | .117 | .046 | 0.756 | | | |
| V | -.085 | .028 | -.052 | -.032 | -.068 | -.004 | .059 | .090 | -.085 | -.036 | -.009 | .001 | -.034 | -.227 | -.012 | -.025 | -.025 | -.086 | .063 | -.179 | -.025 | -.088 | -.169 | .143 | .035 | -.037 | -.007 | -.129 | .075 | -.006 | .074 | -.019 | .063 | .034 | -.197 | -.037 | -.029 | 0.743 | | |
| Zn | .022 | .046 | .006 | .024 | .012 | -.034 | -.092 | -.042 | .005 | -.062 | .002 | -.174 | .035 | -.101 | -.057 | -.051 | -.109 | -.030 | .005 | -.056 | .048 | .029 | -.014 | -.057 | -.113 | -.041 | -.084 | .036 | .039 | .062 | -.018 | .019 | -.065 | .034 | -.005 | .014 | -.018 | -.029 | 0.932 | |
| Zr | -.026 | .008 | .021 | -.030 | -.074 | .041 | .008 | .068 | -.042 | -.009 | -.019 | -.037 | -.012 | -.112 | .017 | -.019 | -.024 | -.025 | -.066 | .072 | -.223 | .055 | .010 | .119 | -.299 | -.043 | -.007 | -.124 | -.016 | -.152 | .006 | .005 | -.047 | -.005 | -.240 | -.022 | .113 | .053 | -.056 | 0.89 |

**Table 4-7 Factor Analysis, Varimax Rotation, Total Variance Explained**

| Component | Initial Eigenvalues | | | Extraction Sums of Squared Loadings | | | Rotation Sums of Squared Loadings | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % |
| 1 | 3.706 | 46.328 | 46.328 | 3.706 | 46.328 | 46.328 | 3.089 | 38.618 | 38.618 |
| 2 | 1.857 | 23.212 | 69.540 | 1.857 | 23.212 | 69.540 | 2.453 | 30.657 | 69.275 |
| 3 | 1.028 | 12.844 | 82.384 | 1.028 | 12.844 | 82.384 | 1.049 | 13.109 | 82.384 |
| 4 | .467 | 5.833 | 88.217 | | | | | | |
| 5 | .397 | 4.967 | 93.183 | | | | | | |
| 6 | .299 | 3.736 | 96.920 | | | | | | |
| 7 | .141 | 1.760 | 98.680 | | | | | | |
| 8 | .106 | 1.320 | 100.000 | | | | | | |

Extraction Method: Principal Component Analysis.

**Table 4-8 Exploratory Factor Analysis, Rotated Factor-Loading Matrix[a]**

| Elements | Component | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| Antimony (Sb) | .929 | | |
| Tin (Sn) | .857 | | |
| Barium (Ba) | .857 | | |
| Nickel (Ni) | .830 | | |
| Molybdenum (Mo) | | .927 | |
| Niobium (Nb) | | .919 | |
| Tungsten (W) | | .807 | |
| Vanadium (V) | | | .981 |

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.[a]
a. Rotation converged in 4 iterations.

**Table 4-9 Two-Step Auto-Clustering**

| Number of Clusters | Schwarz's Bayesian Criterion (BIC) | BIC Change[a] | Ratio of BIC Changes[b] | Ratio of Distance Measures[c] |
|---|---|---|---|---|
| 1 | 9801.061 | | | |
| 2 | 5454.995 | -4346.066 | 1.000 | 2.358 |
| 3 | 3665.612 | -1789.383 | .412 | 1.593 |
| 4 | 2576.659 | -1088.953 | .251 | 3.360 |
| 5 | 2317.910 | -258.749 | .060 | 1.419 |
| 6 | 2163.108 | -154.802 | .036 | 1.131 |
| 7 | 2036.960 | -126.148 | .029 | 1.078 |
| 8 | 1926.763 | -110.197 | .025 | 1.003 |
| 9 | 1817.193 | -109.569 | .025 | 1.491 |
| 10 | 1774.356 | -42.838 | .010 | 2.073 |

a. The changes are from the previous number of clusters in the table.

b. The ratios of changes are relative to the change for the two-cluster solution.

c. The ratios of distance measures are based on the current number of clusters against the previous number of clusters.

**Table 4-10 Two-Step Cluster Distributions**

| PCA Clusters | Frequency | Percent | Cumulative Percent |
|---|---|---|---|
| 1 | 840 | 36.0 | 36.0 |
| 2 | 627 | 26.9 | 62.9 |
| 3 | 434 | 18.6 | 81.5 |
| 4 | 434 | 18.6 | 100.0 |
| Total | 2335 | 100.0 | |

| FA Clusters | | | |
|---|---|---|---|
| 1 | 1173 | 50.2 | 50.2 |
| 2 | 488 | 20.9 | 71.1 |
| 3 | 419 | 17.9 | 89.0 |
| 4 | 255 | 10.9 | 100.0 |
| Total | 2335 | 100.0 | |

| Surrogate Element Clusters | | | |
|---|---|---|---|
| 1 | 1032 | 44.2 | 44.2 |
| 2 | 623 | 26.7 | 70.9 |
| 3 | 406 | 17.4 | 88.3 |
| 4 | 274 | 11.7 | 100.0 |
| Total | 2335 | 100.0 | |

**Table 4-11 Comparison of Two-Step Cluster Analysis Methods**

| Method | Number and Type of Inputs | Number of Clusters | Silhouette measure of cohesion and separation |
|---|---|---|---|
| 1 Principal Components Analysis | 10 principal components | 4 | 0.52 |
| 2 Factor Analysis (varimax rotation) | 3 factors | 4 | 0.60 |
| 3 Exploratory Factor Analysis (varimax rotation) | 8 surrogate elements | 4 | 0.68 |

# APPENDIX 2 — FIGURES

**Figure 1-1 Coefficients of Variation for SiO2 Reference Standard.**
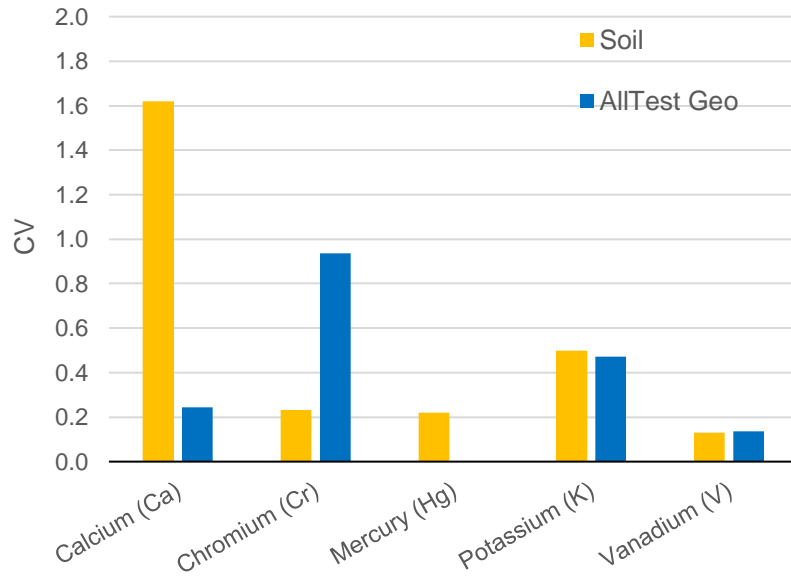


**Figure 1-2 Coefficients of Variation for Till 4 Reference Standard.**
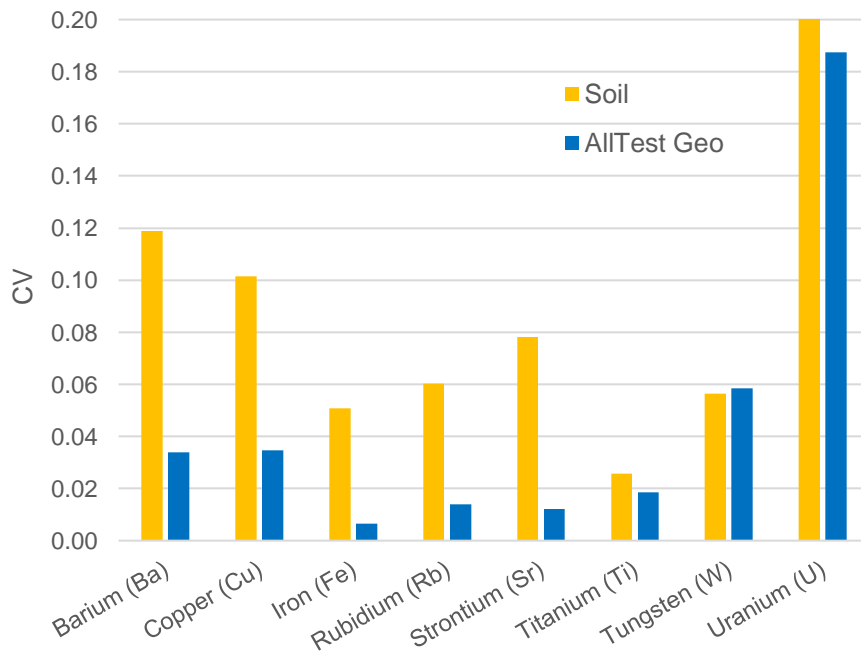
**Figure 1-3 Coefficients of Variation for RCRA Reference Standard.**
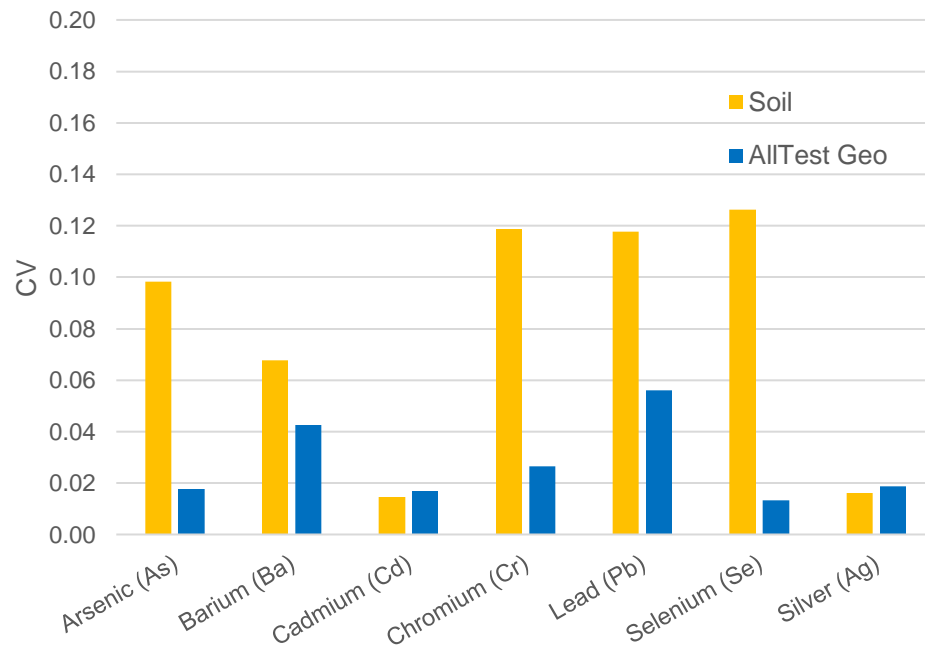


**Figure 1-4 Coefficients of Variation for NISP 2780 Reference Standard.**
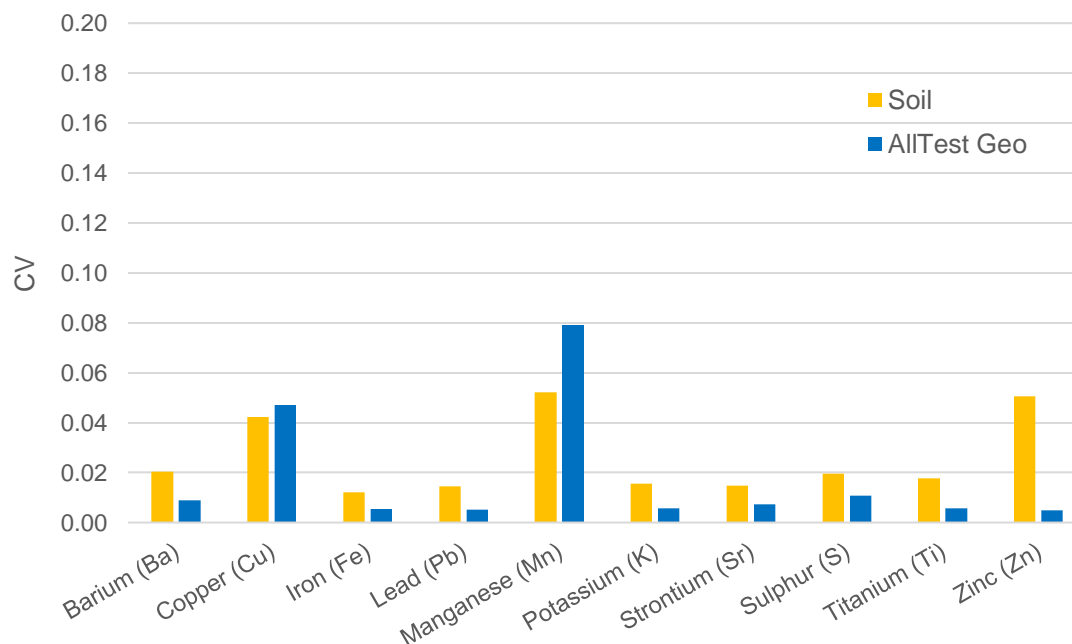
**Figures 2-1 to 2-40 Standardized Element Readings**

Includes Valid and <LOD readings.

Figure 2-1 Aluminium
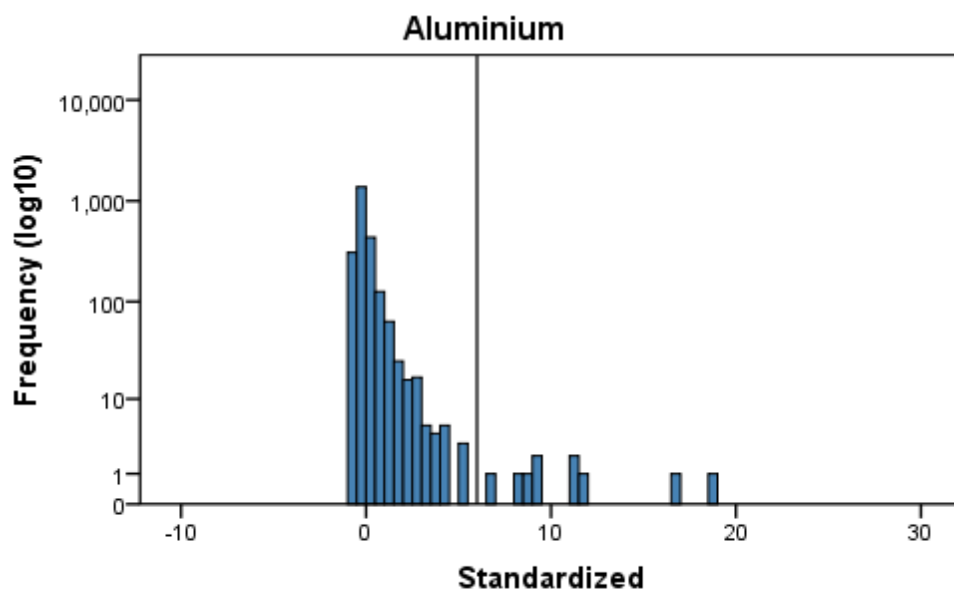


Values greater than reference line are outliers.

Figure 2-2 Antimony
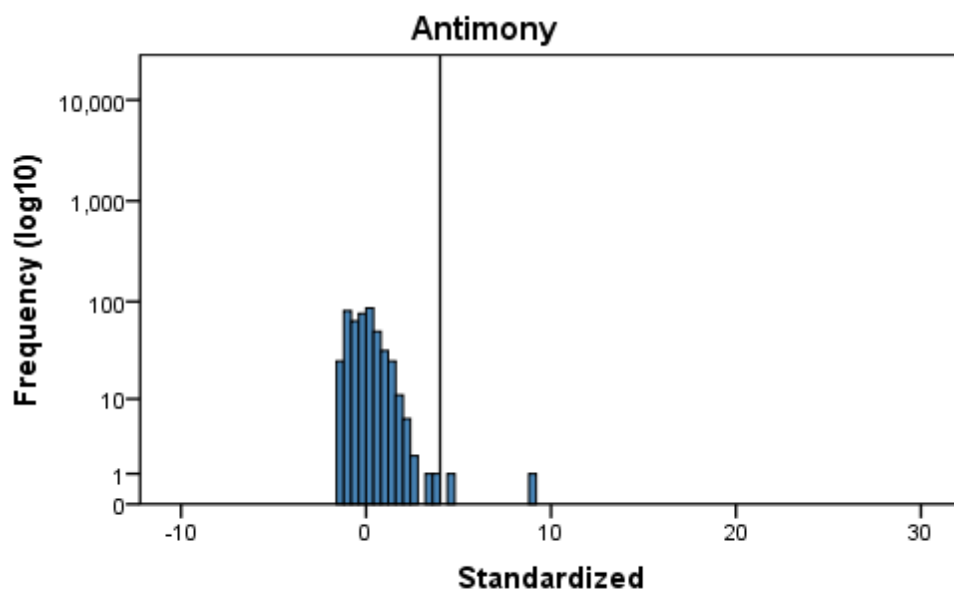


Values greater than reference line are outliers.

Figure 2-3 Arsenic



Arsenic
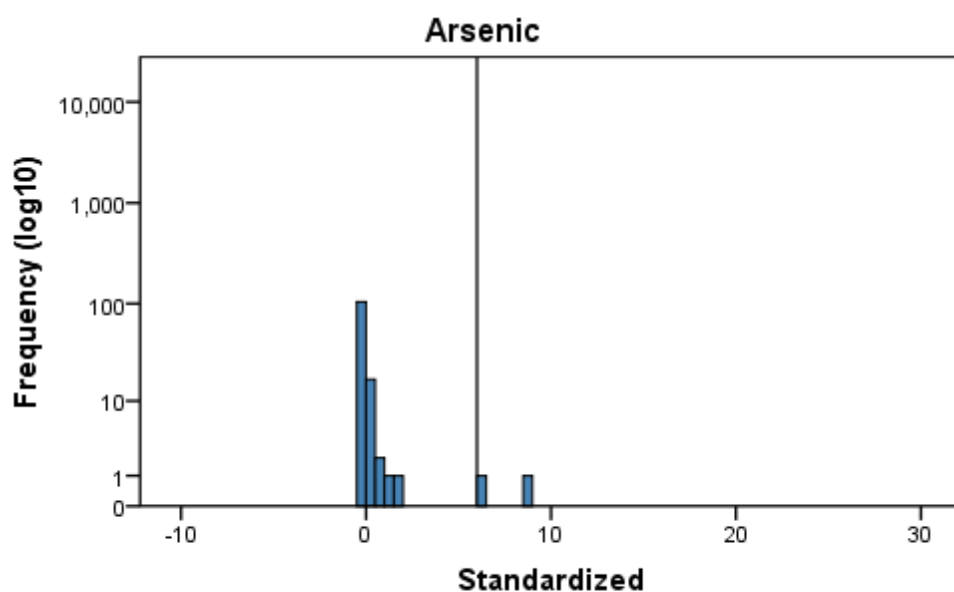
Values greater than reference line are outliers.

Figure 2-4 Barium



Barium
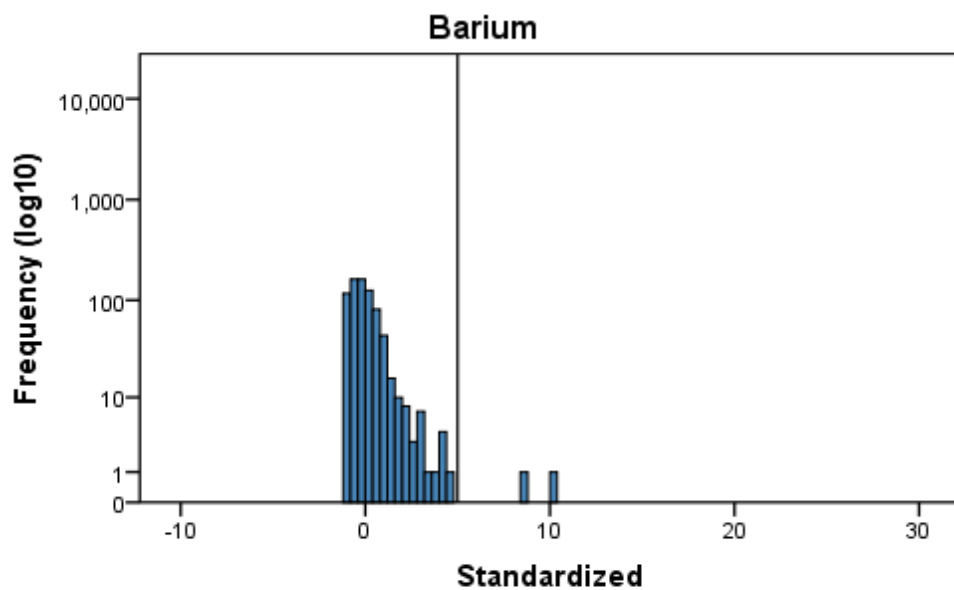
Values greater than reference line are outliers.

Figure 2-5 Bismuth



**Bismuth**
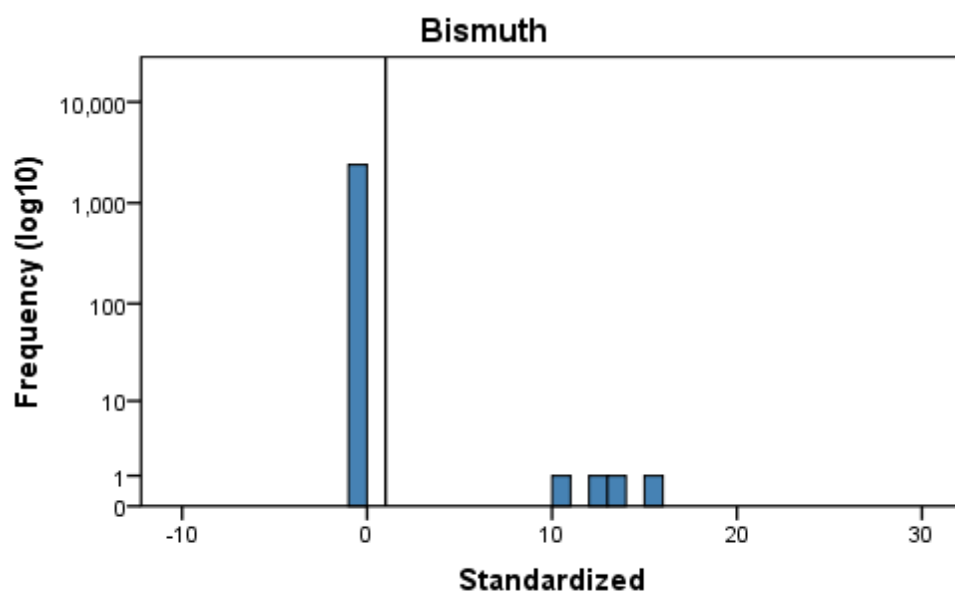
Values greater than reference line are outliers.

Figure 2-6 Cadmium



**Cadmium**
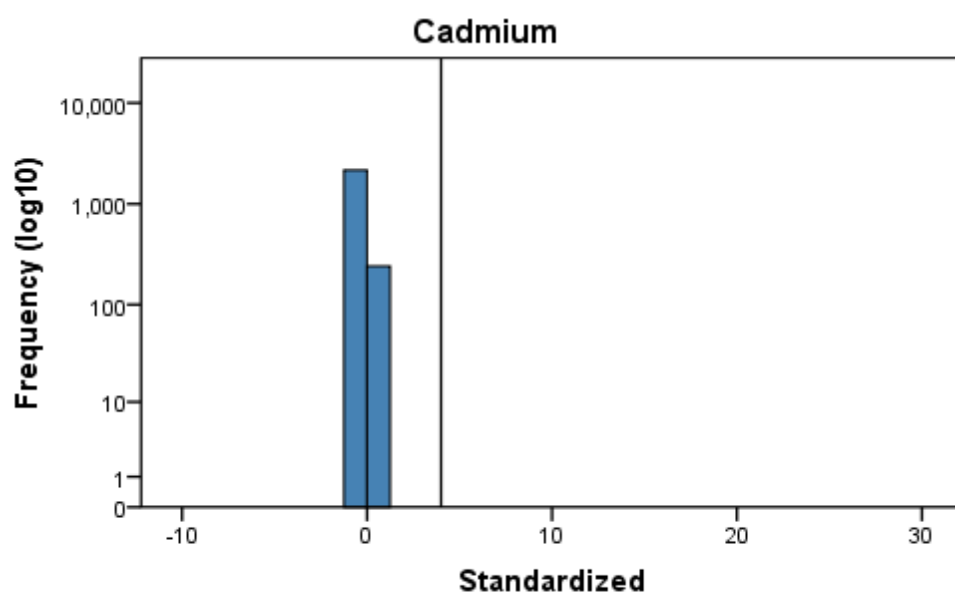
Values greater than reference line are outliers.

Figure 2-7 Caesium



**Caesium**
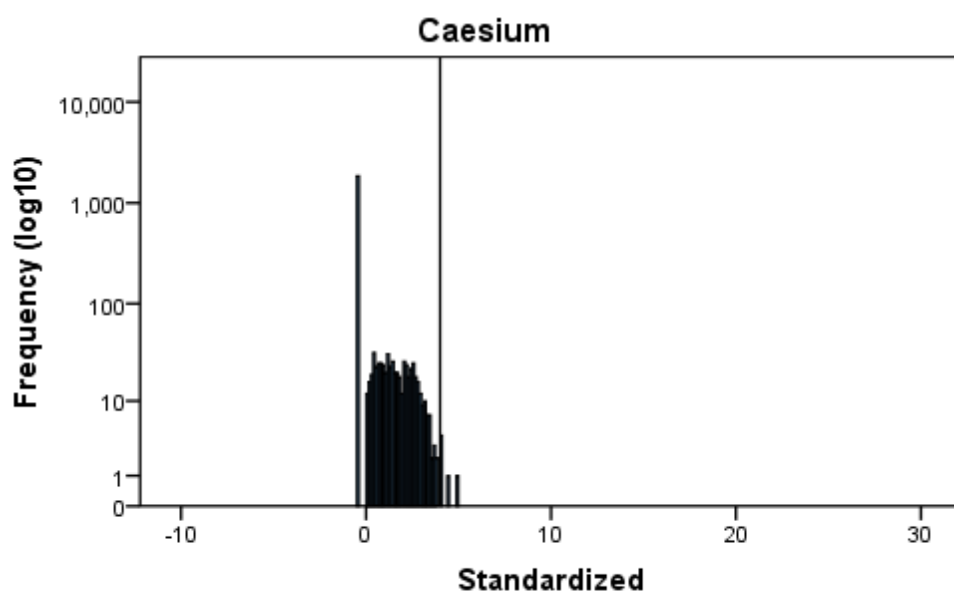
Values greater than reference line are outliers.

Figure 2-8 Calcium



**Calcium**
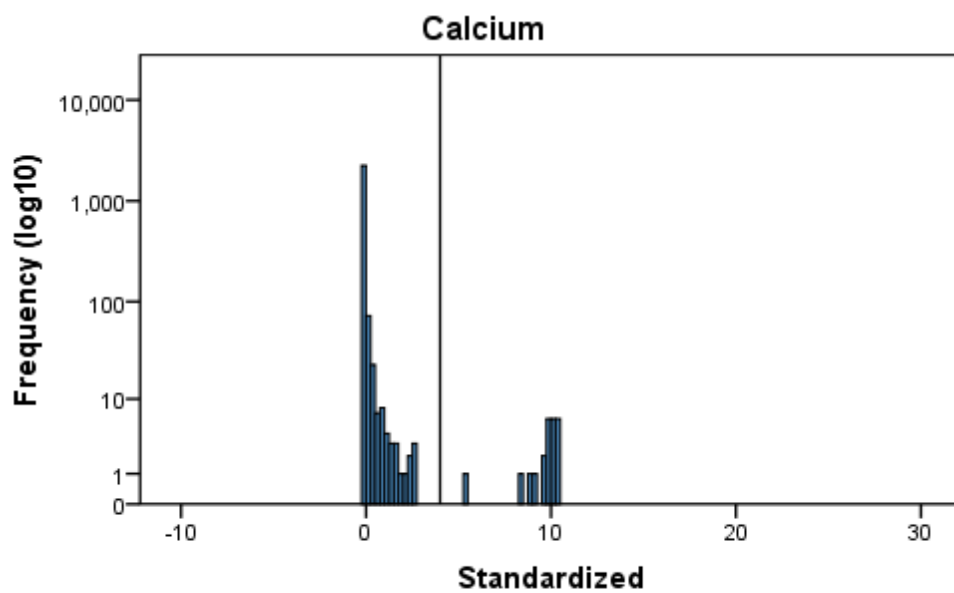
Values greater than reference line are outliers.

Figure 2-9 Chlorine
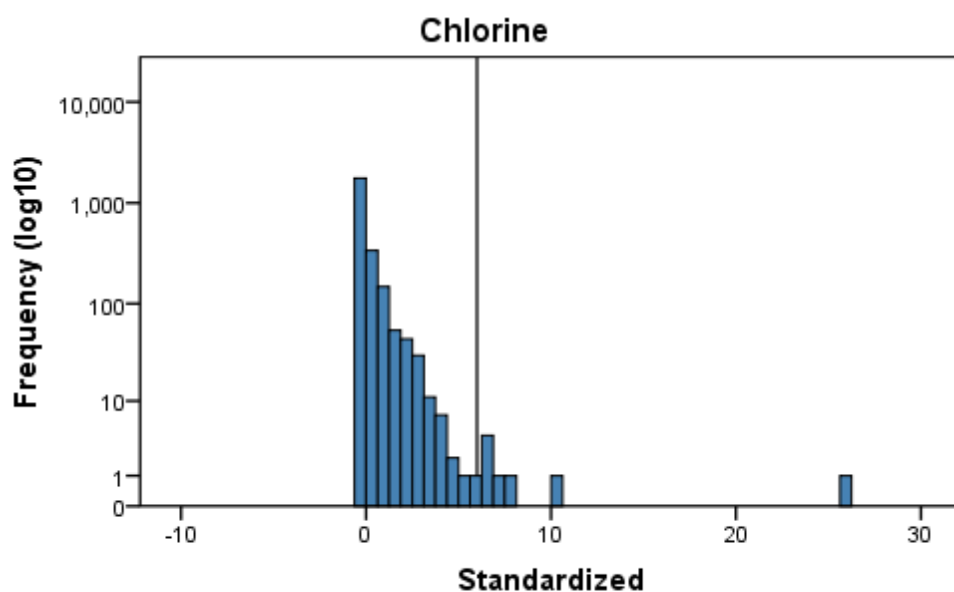


Values greater than reference line are outliers.

Figure 2-10 Chromium
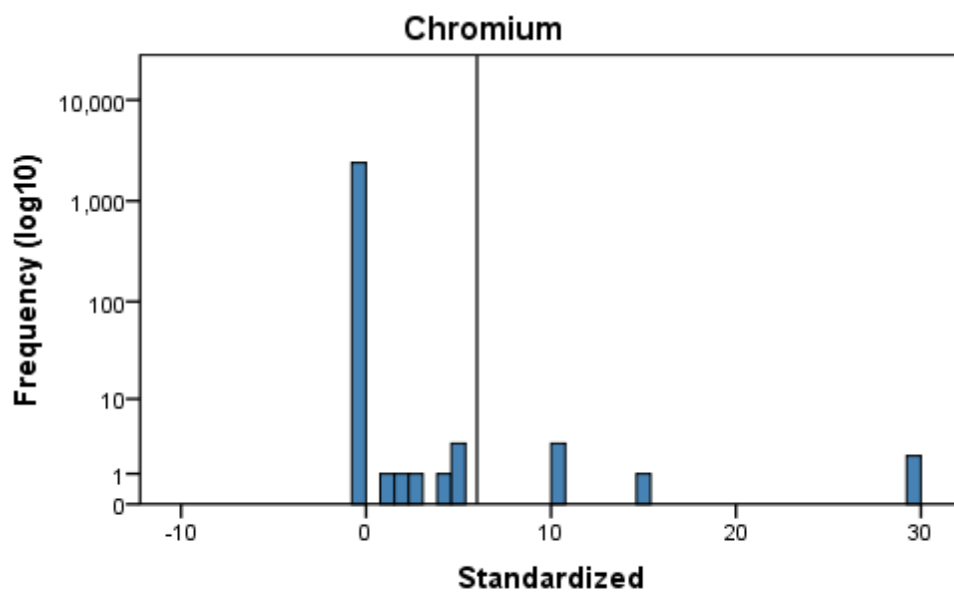


Values greater than reference line are outliers.

Figure 2-11 Cobalt



Values greater than reference line are outliers.

Figure 2-12 Copper



Values greater than reference line are outliers.

401
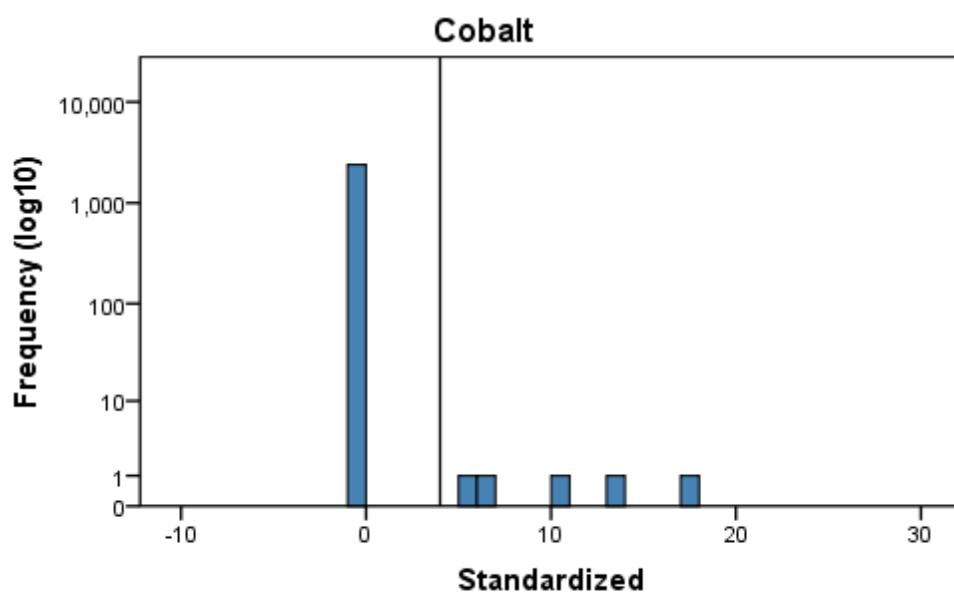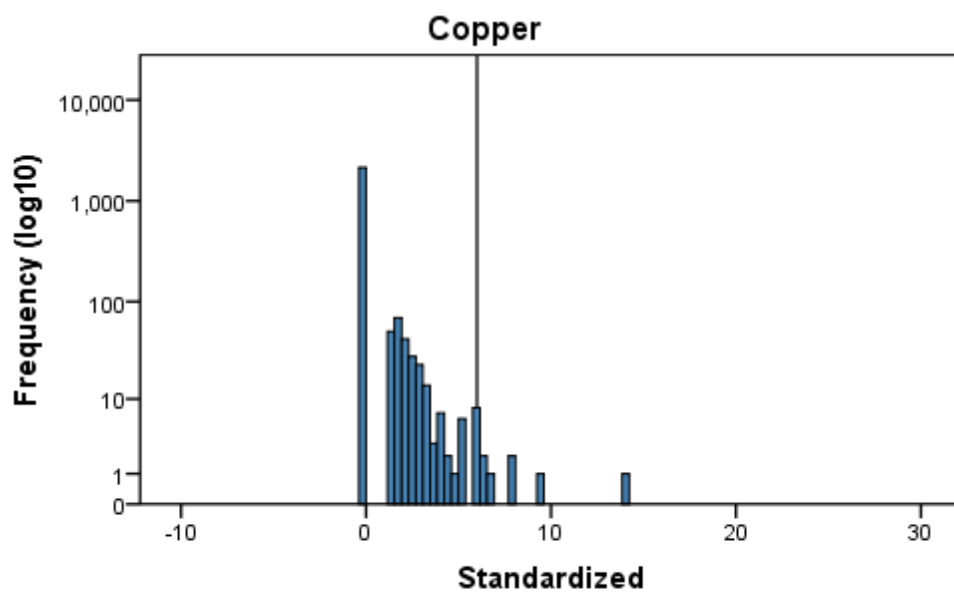
Figure 2-13 Gold
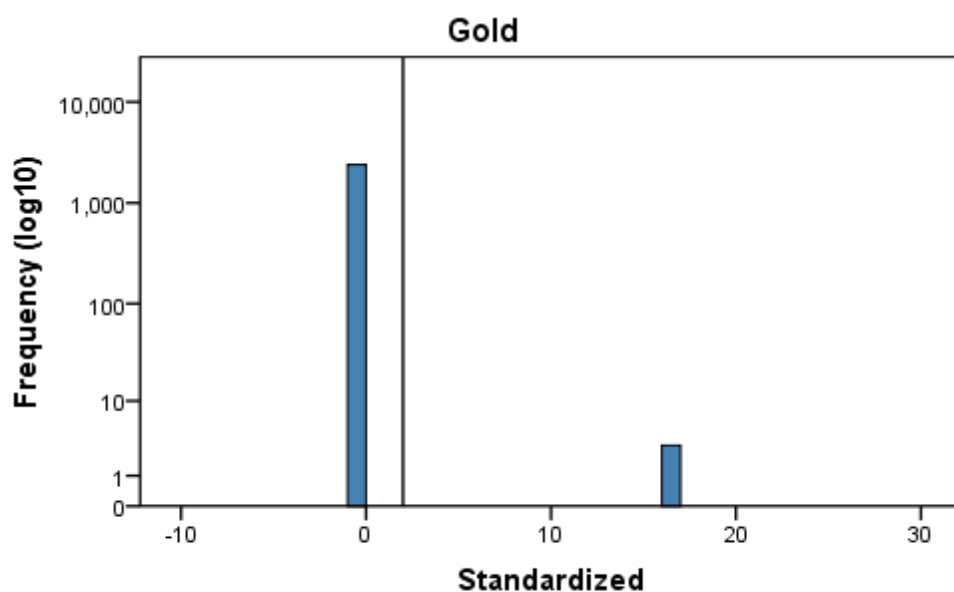


Values greater than reference line are outliers.

Figure 2-14 Iron
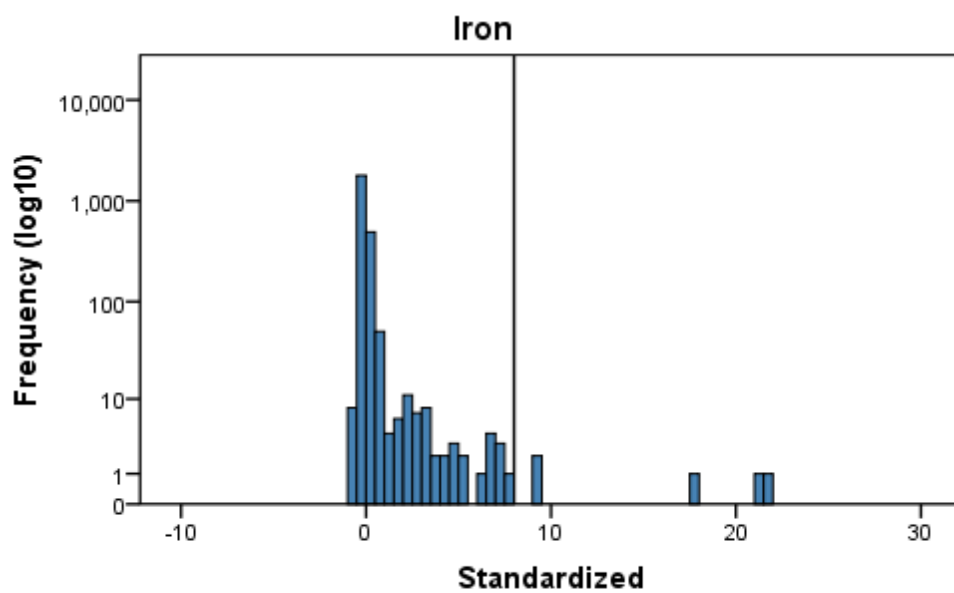


Values greater than reference line are outliers.

Figure 2-15 Lead



Lead
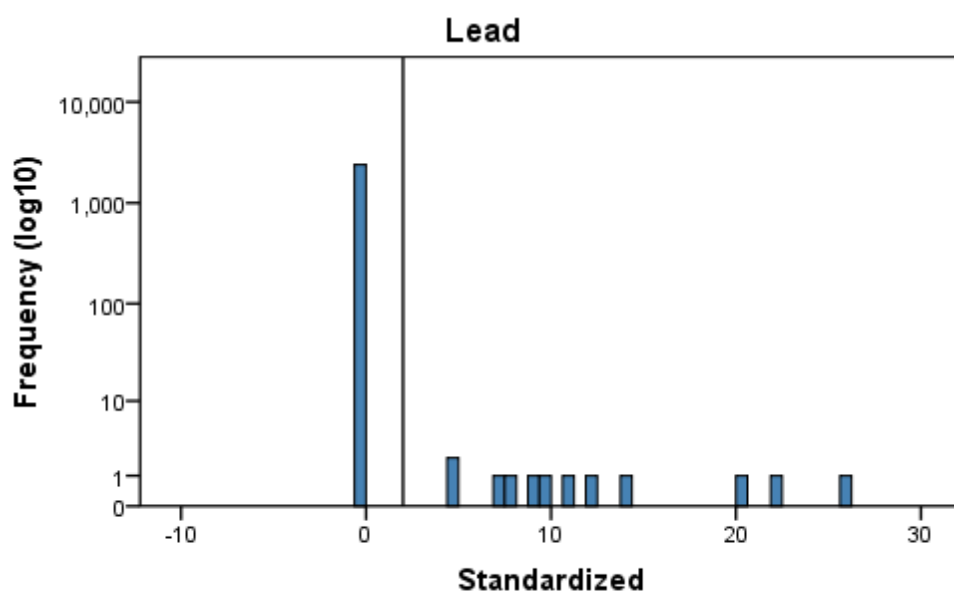
Values greater than reference line are outliers.

Figure 2-16 Magnesium



Magnesium
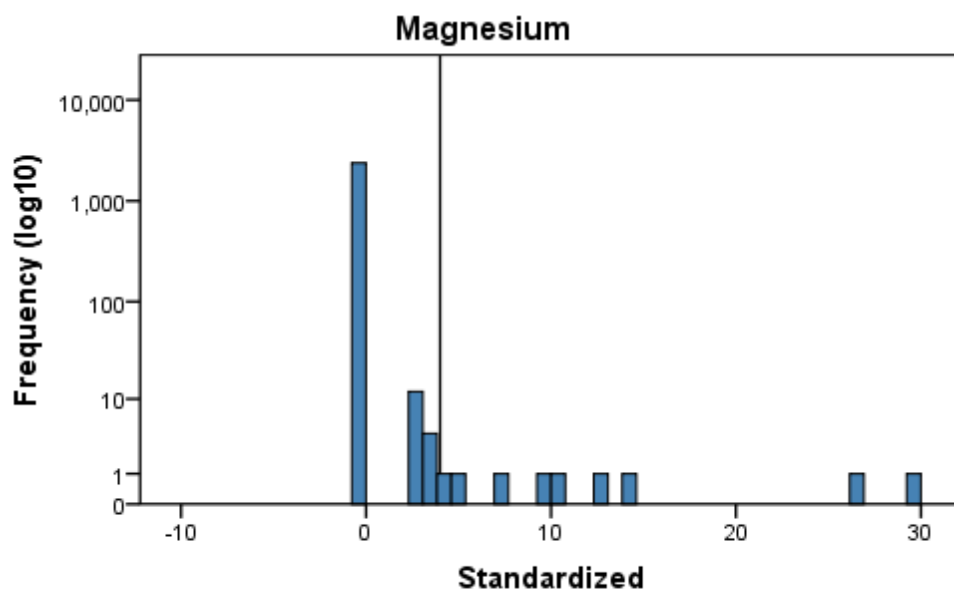
Values greater than reference line are outliers.

Figure 2-17 Manganese



**Manganese**
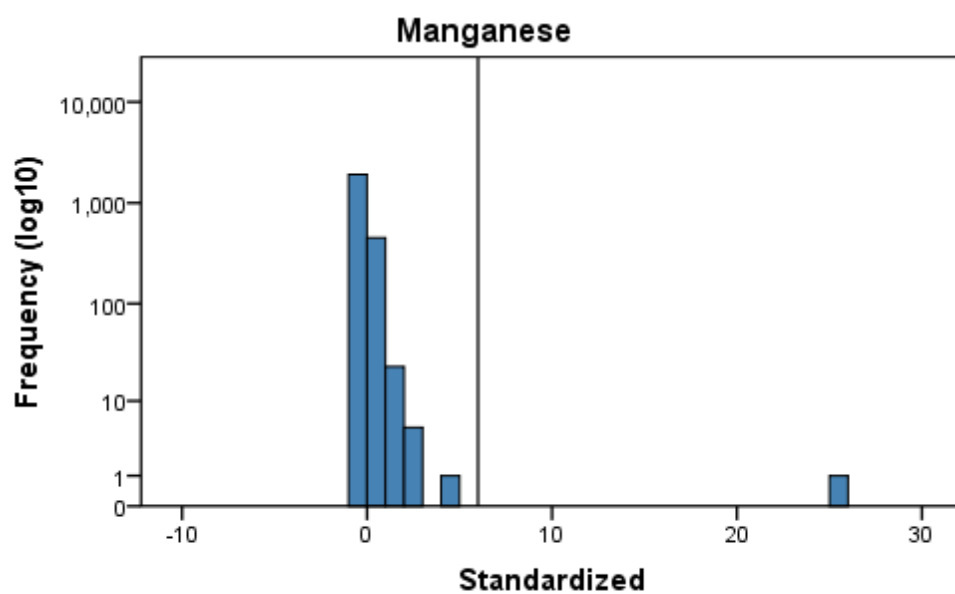
Values greater than reference line are outliers.

Figure 2-18 Mercury



**Mercury**
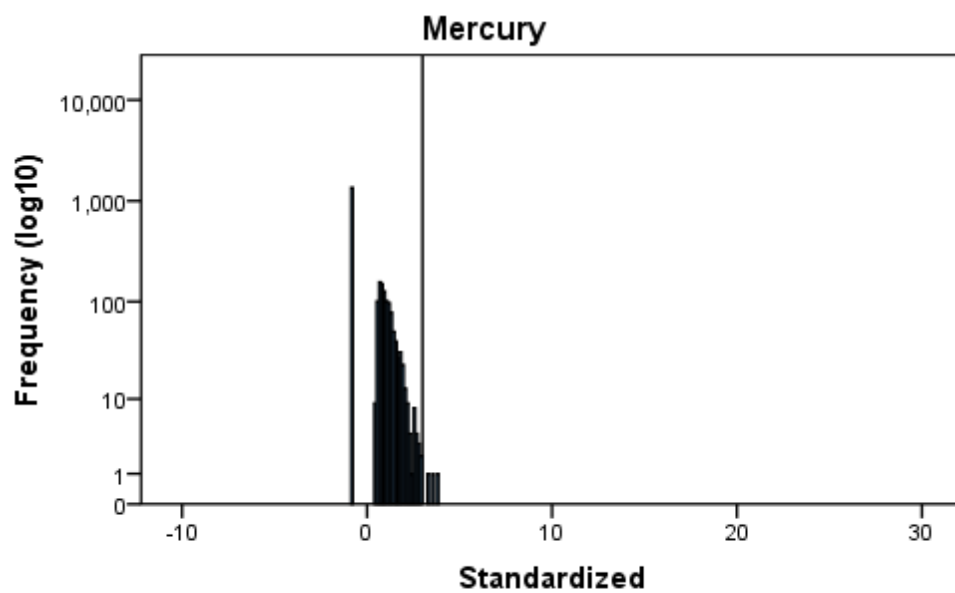
Values greater than reference line are outliers.

Figure 2-19 Molybdenum



Molybdenum
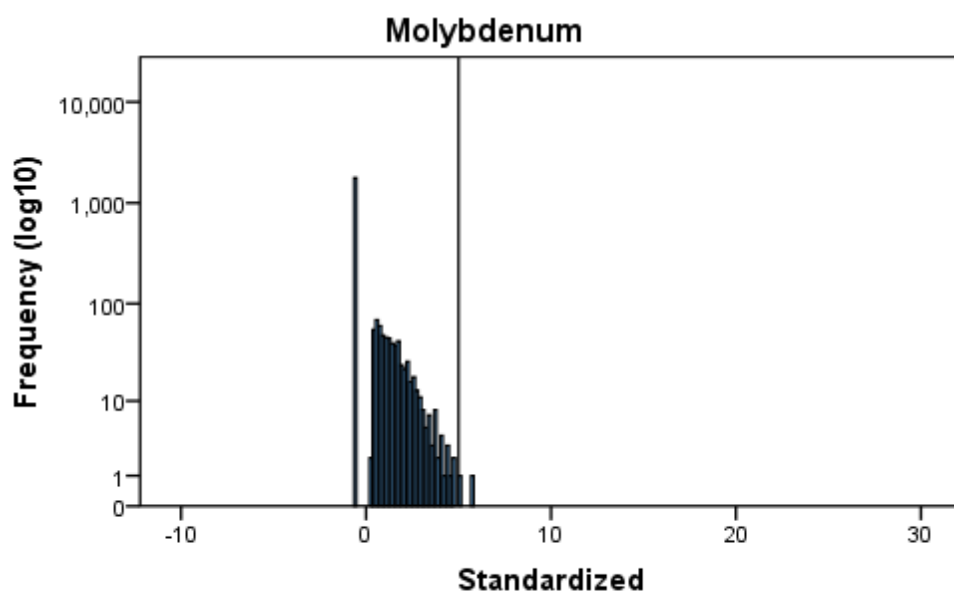
Values greater than reference line are outliers.

Figure 2-20 Nickel



Nickel
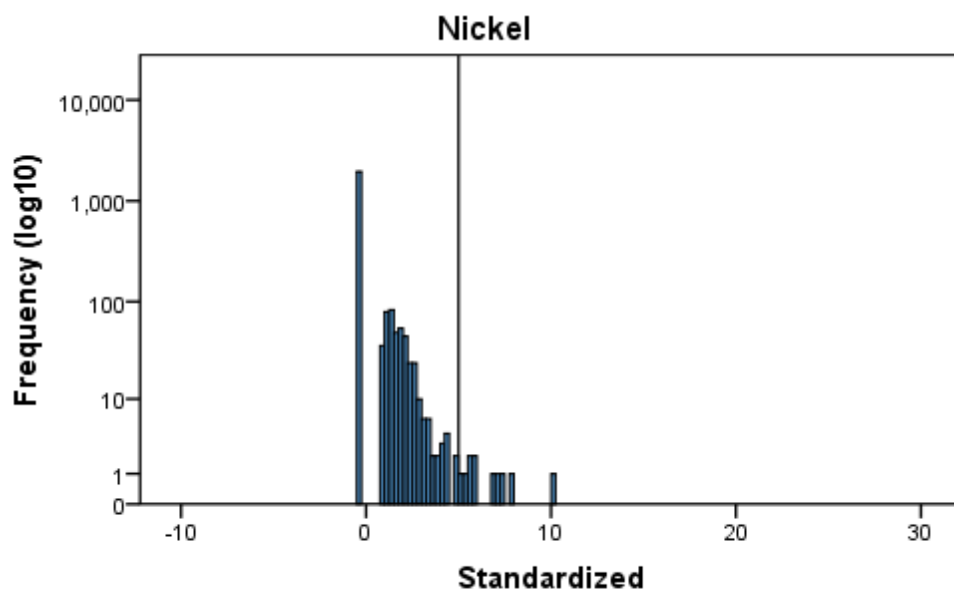
Values greater than reference line are outliers.

Figure 2-21 Niobium



**Niobium**
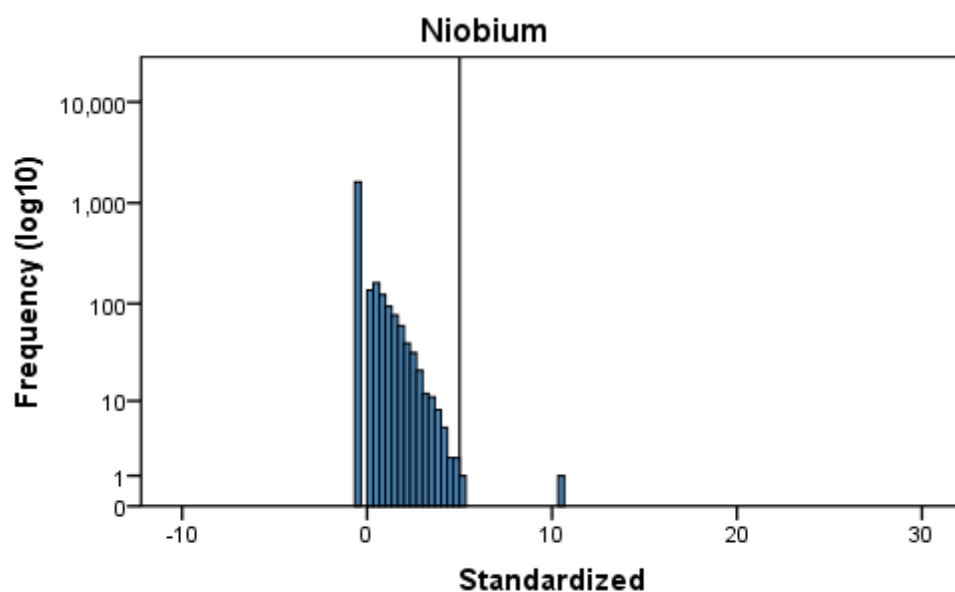
Values greater than reference line are outliers.

Figure 2-22 Palladium



**Palladium**
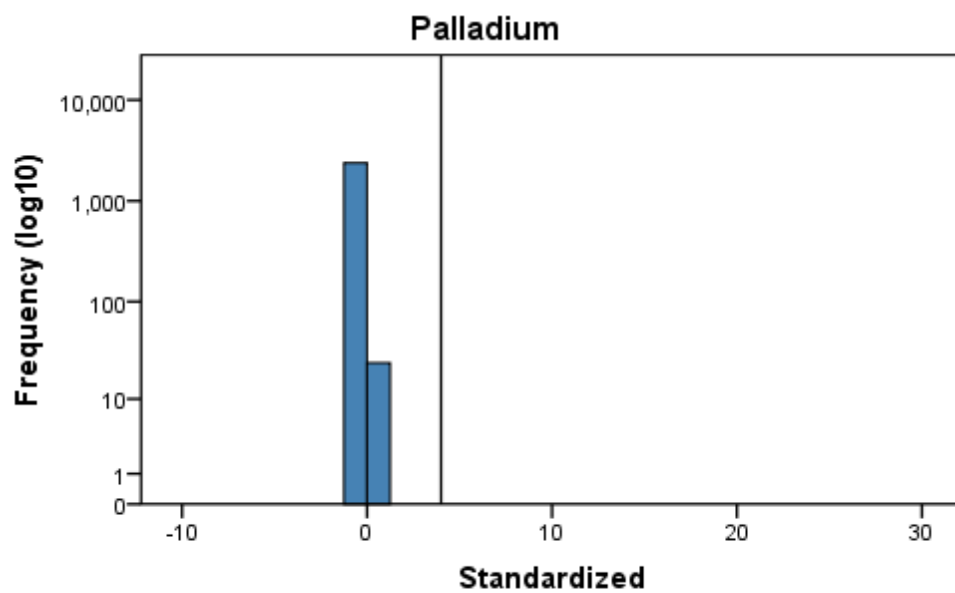
Values greater than reference line are outliers.

Figure 2-23 Phosphorus



Phosphorus
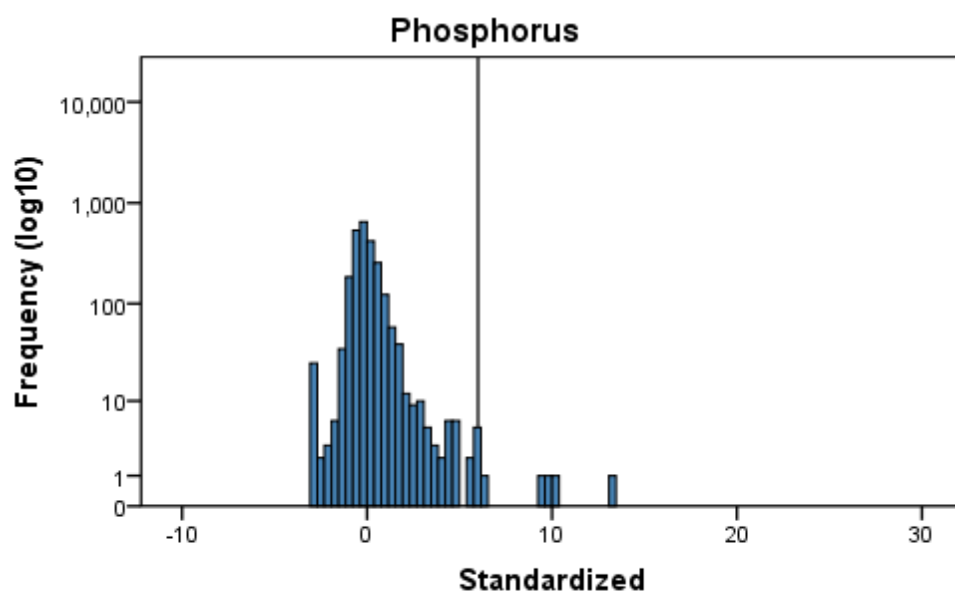
Values greater than reference line are outliers.

Figure 2-24 Potassium



Potassium
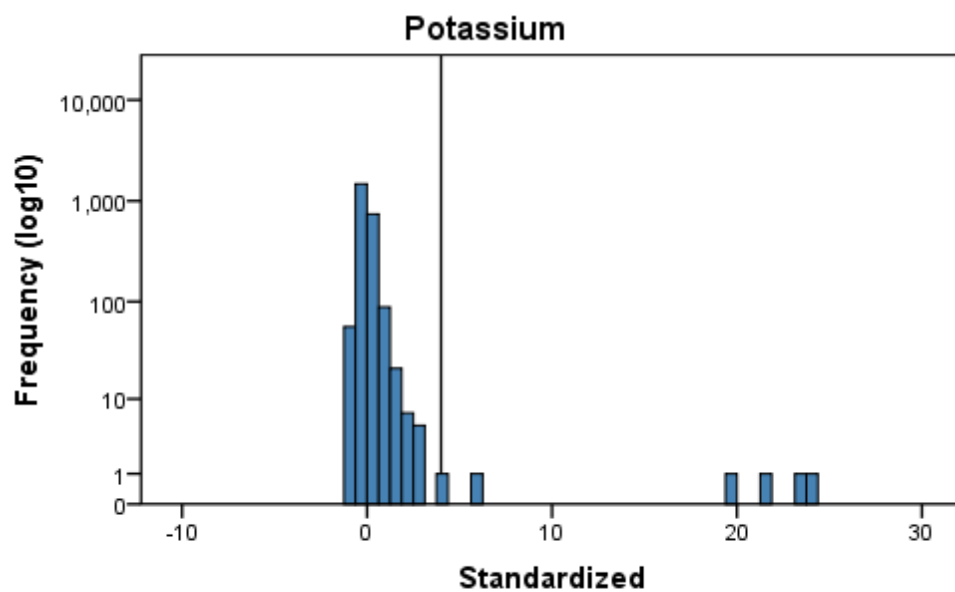
Values greater than reference line are outliers.

Figure 2-25 Rubidium



**Rubidium**
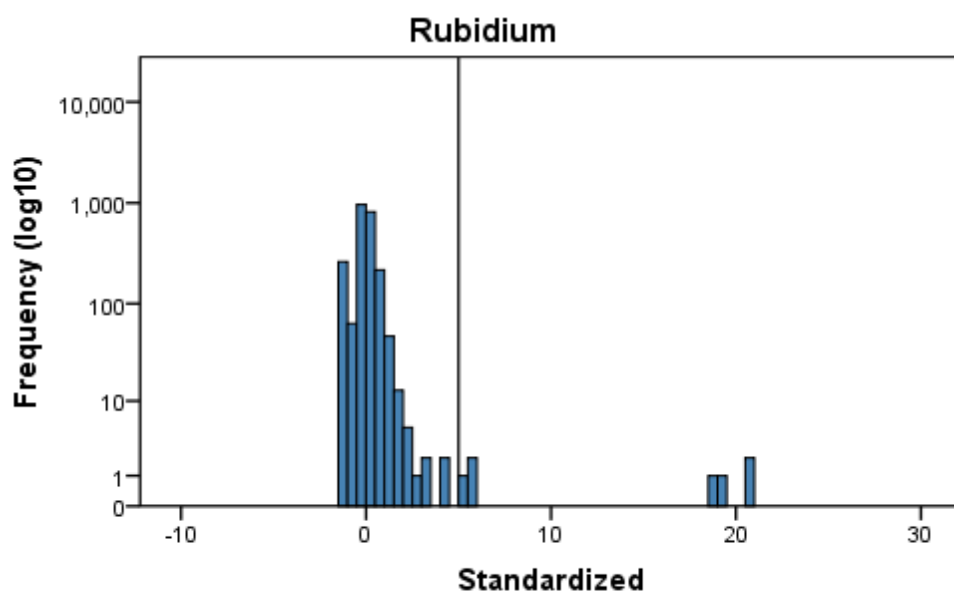
Values greater than reference line are outliers.

Figure 2-26 Scandium



**Scandium**
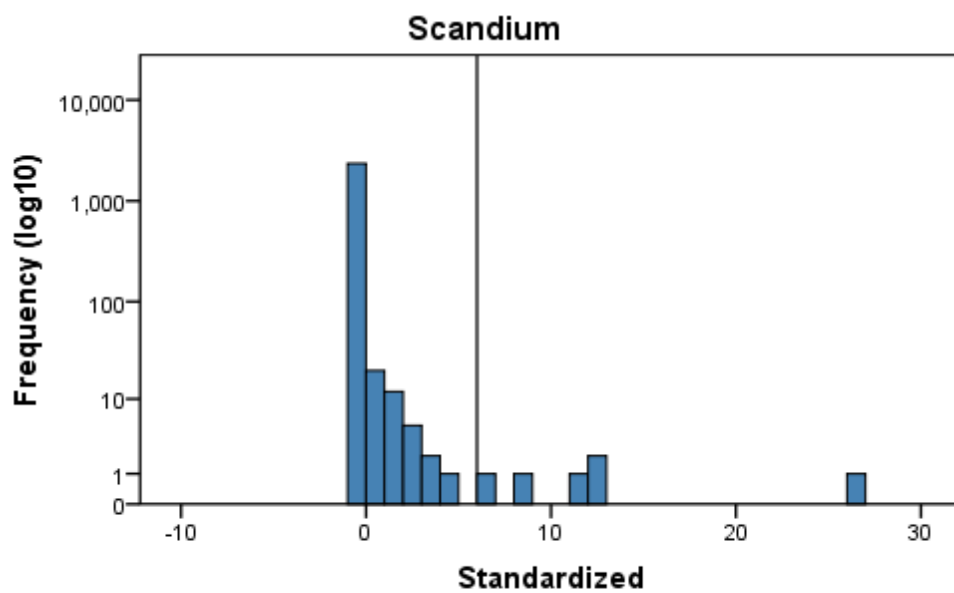
Values greater than reference line are outliers.

Figure 2-27 Selenium
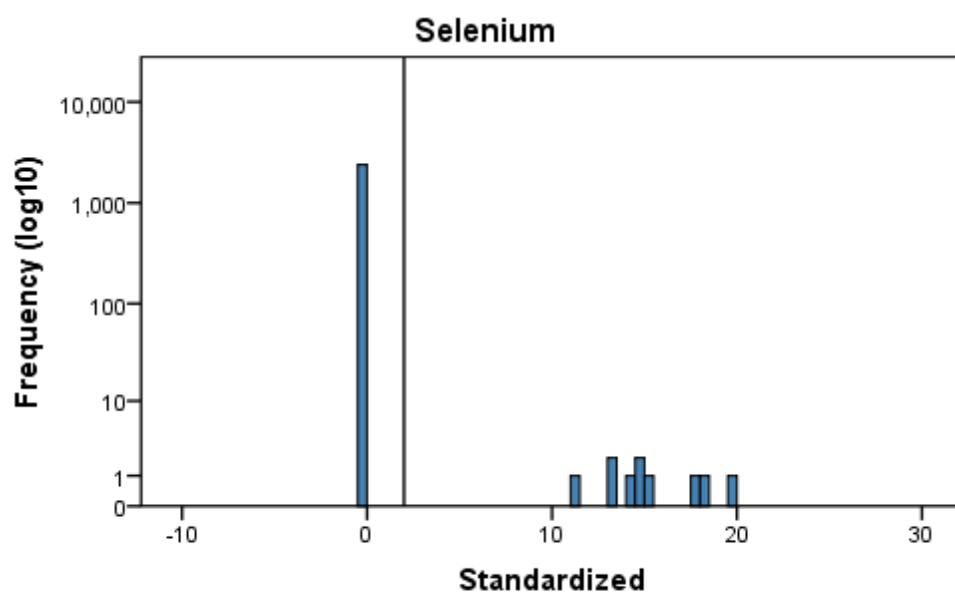


Values greater than reference line are outliers.

Figure 2-28 Silicon
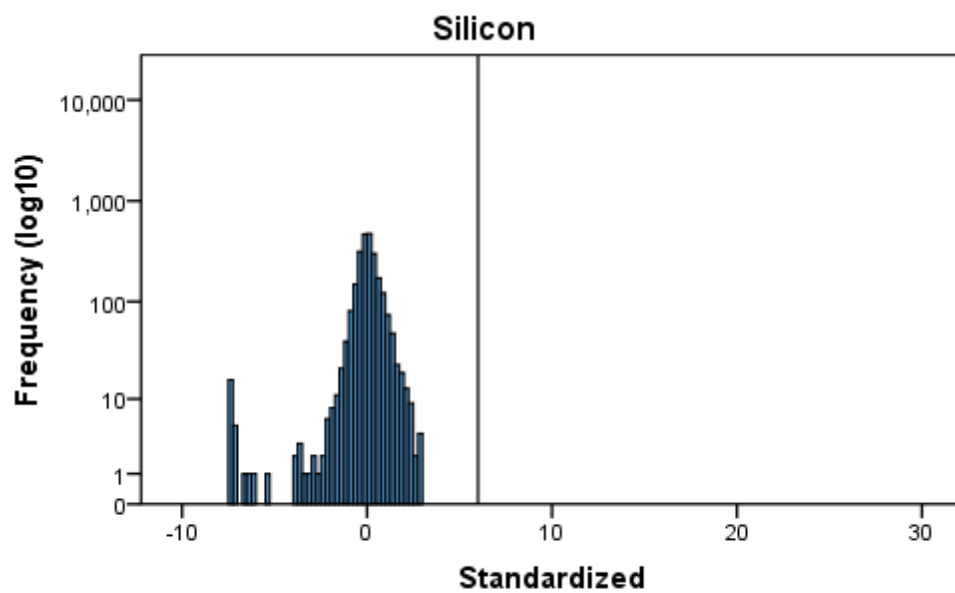


Values greater than reference line are outliers.

Figure 2-29 Silver



Silver
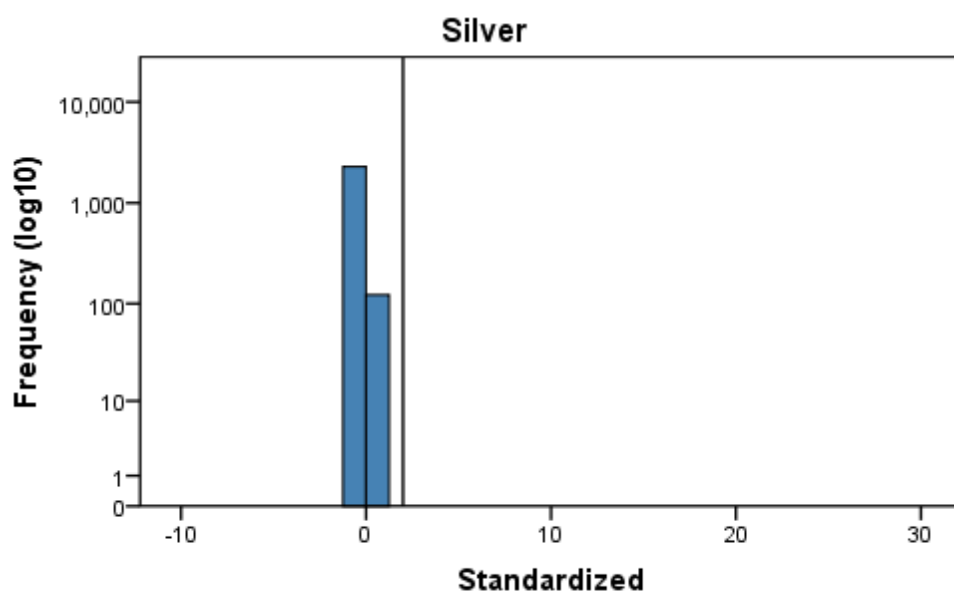
Values greater than reference line are outliers.

Figure 2-30 Strontium



Strontium
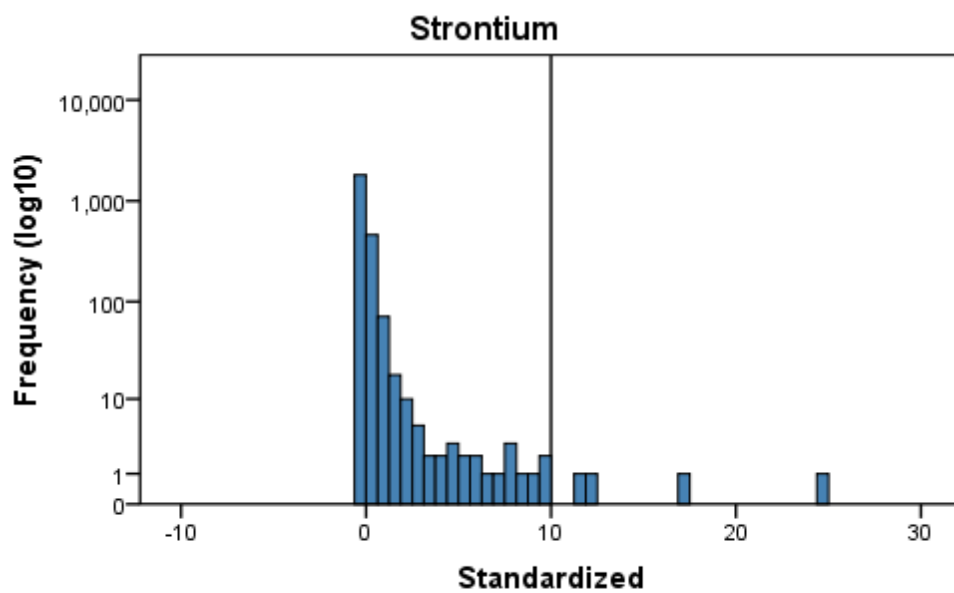
Values greater than reference line are outliers.

Figure 2-31 Sulphur
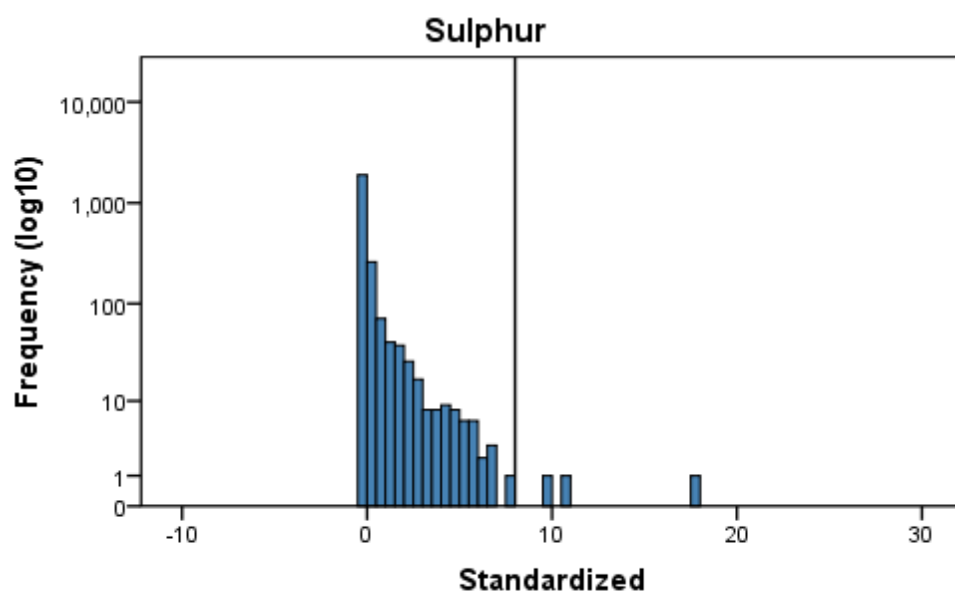


Values greater than reference line are outliers.

Figure 2-32 Tellurium
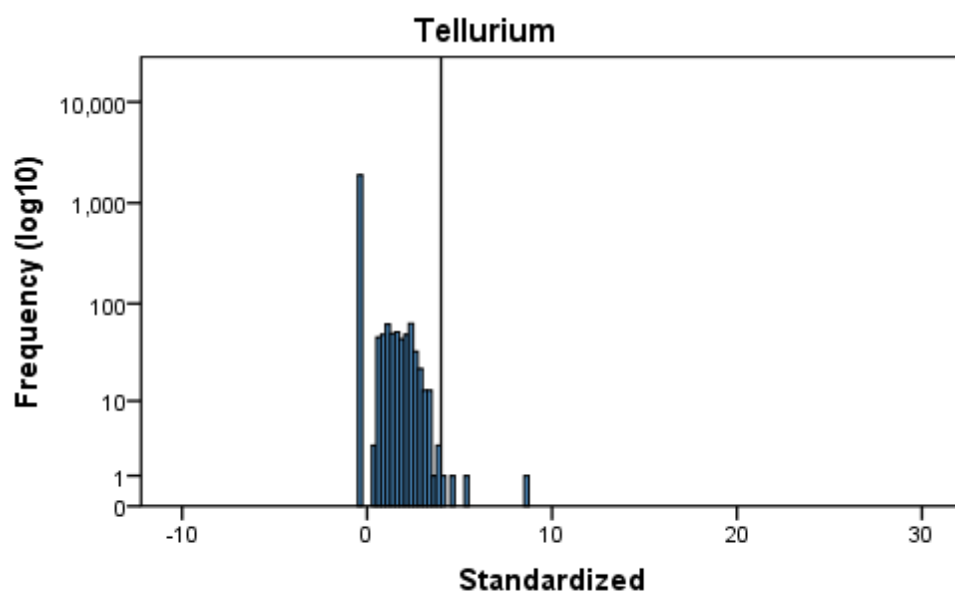


Values greater than reference line are outliers.

Figure 2-33 Thorium
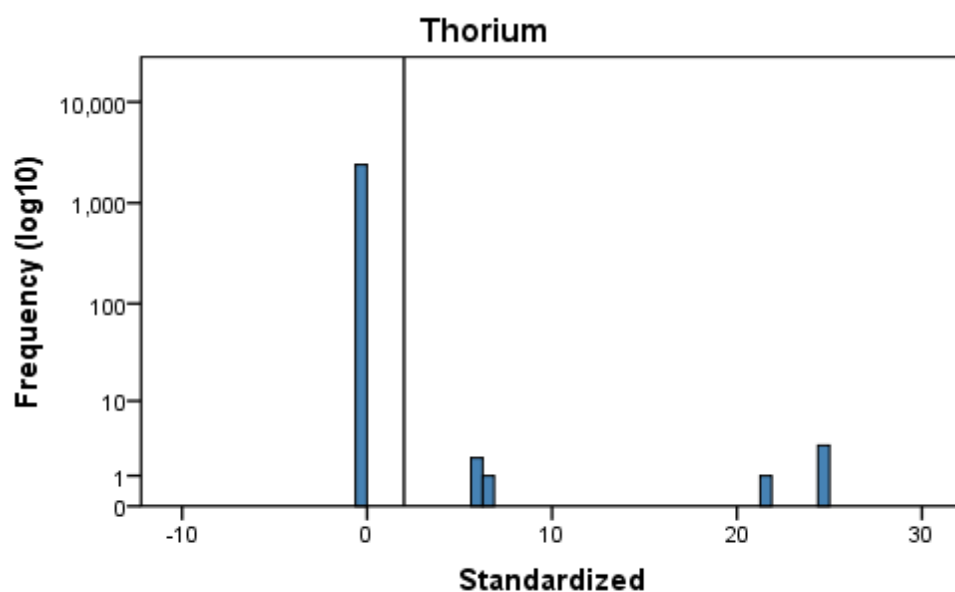


Values greater than reference line are outliers.

Figure 2-34 Tin
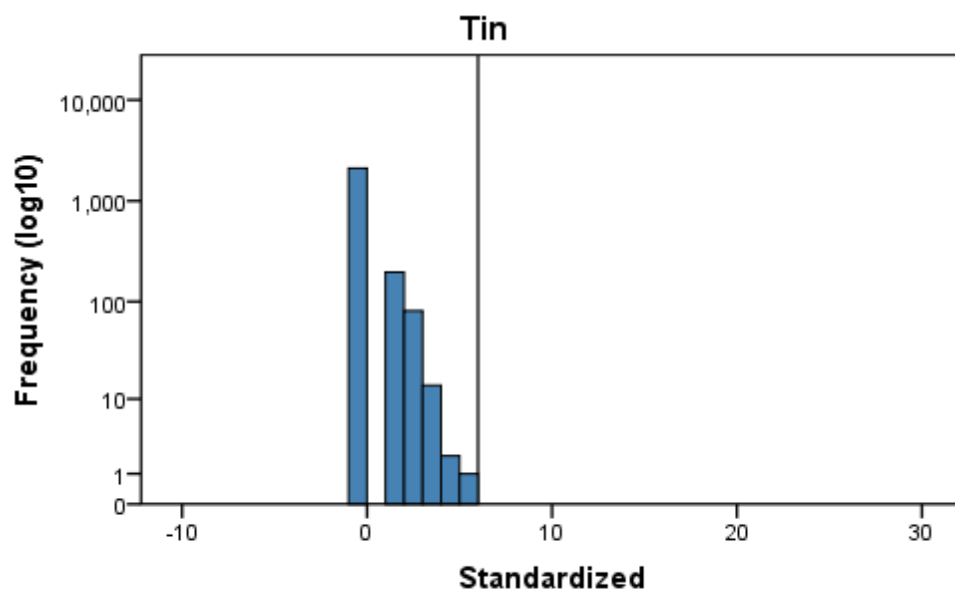


Values greater than reference line are outliers.

Figure 2-35 Titanium



**Titanium**
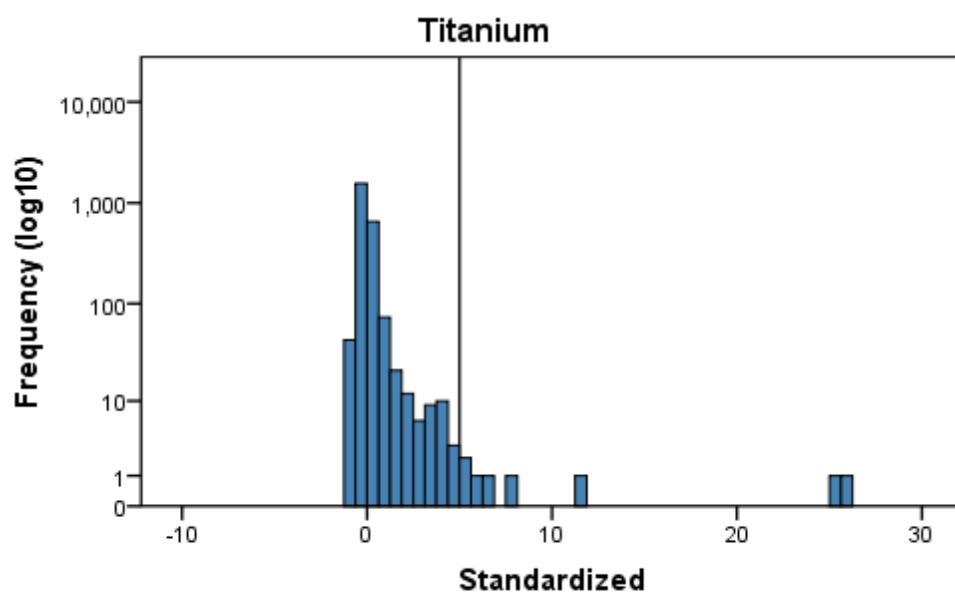
Values greater than reference line are outliers.

Figure 2-36 Tungsten



**Tungsten**
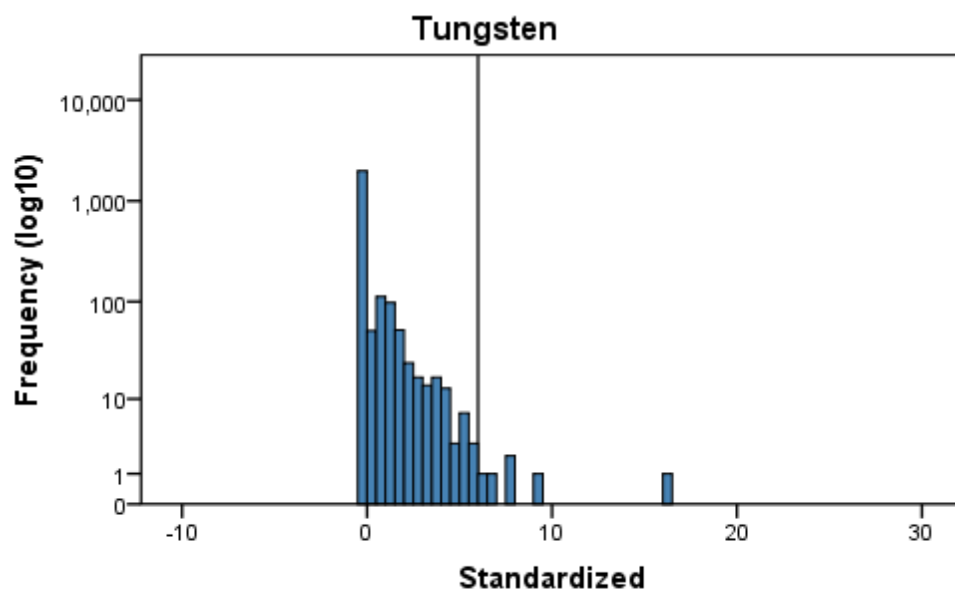
Values greater than reference line are outliers.

Figure 2-37 Uranium



Uranium
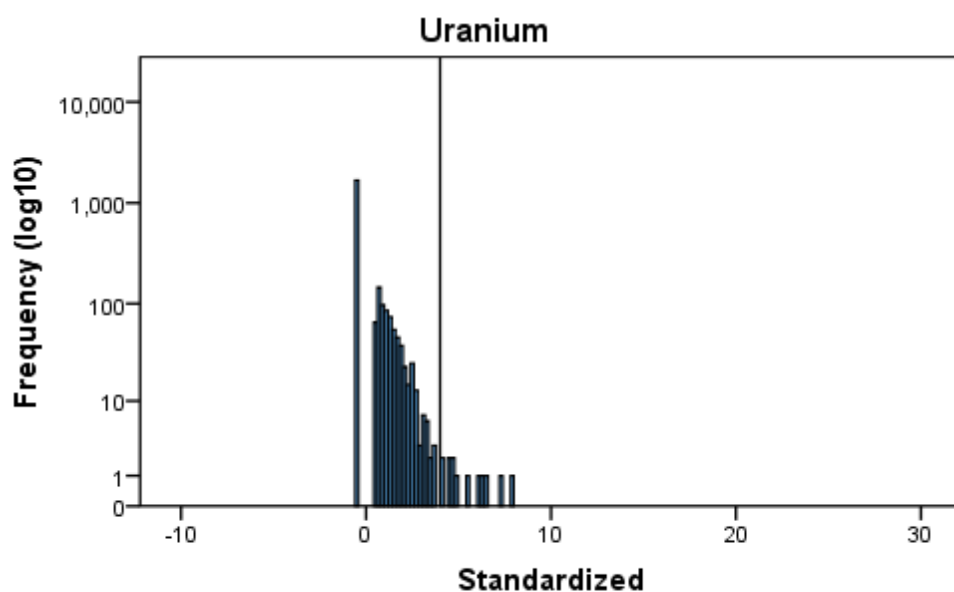
Values greater than reference line are outliers.

Figure 2-38 Vanadium



Vanadium
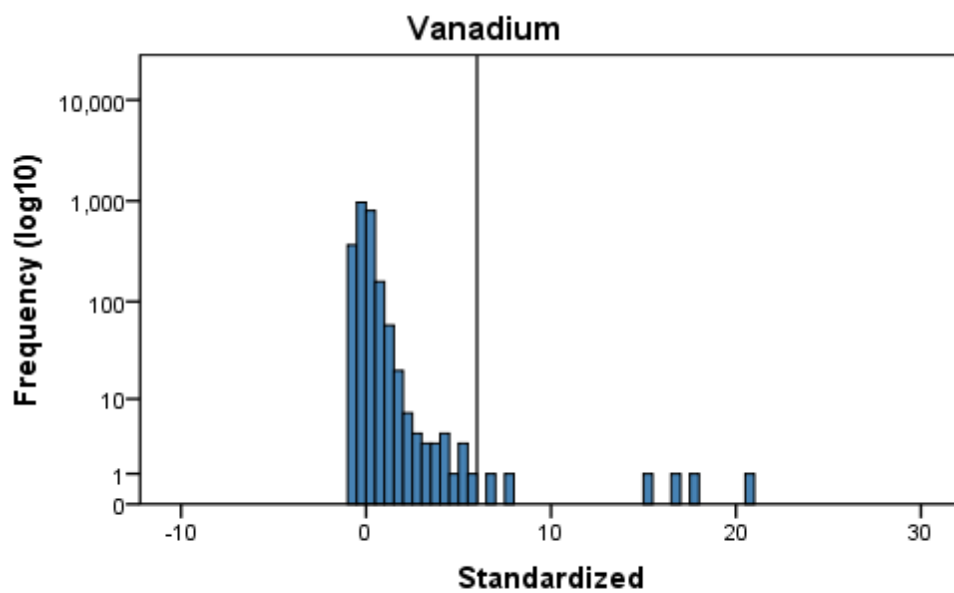
Values greater than reference line are outliers.

Figure 2-39 Zinc



**Zinc**
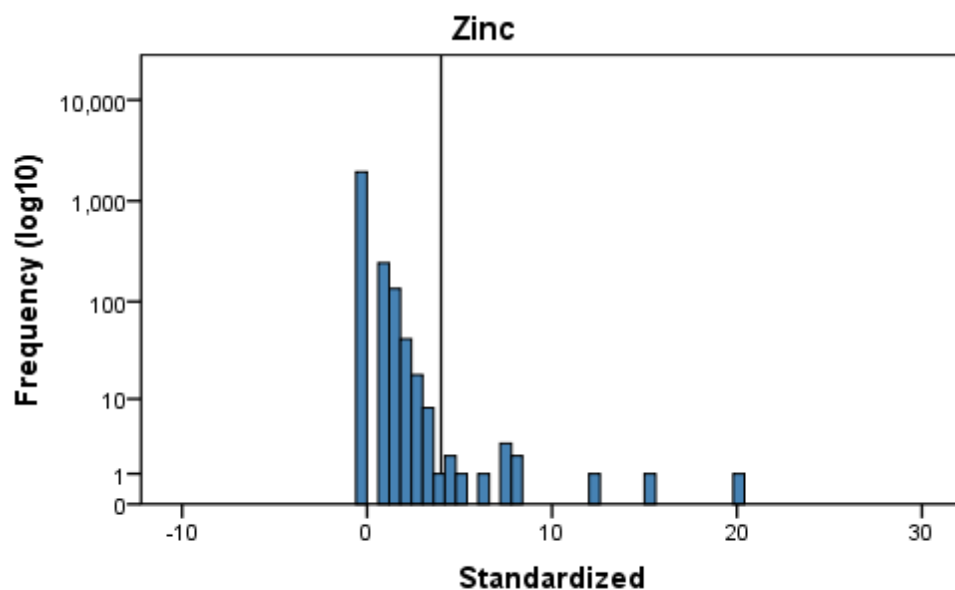
Values greater than reference line are outliers.

Figure 2-40 Zirconium



**Zirconium**
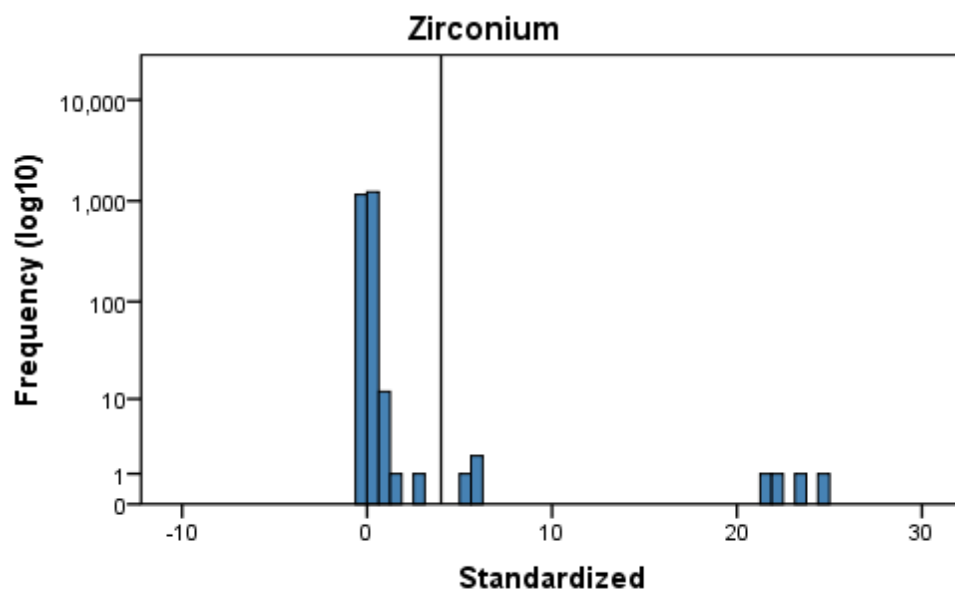
Values greater than reference line are outliers.

**Figure 3-1 Factor Score Outliers (Factors 1 to 5)**
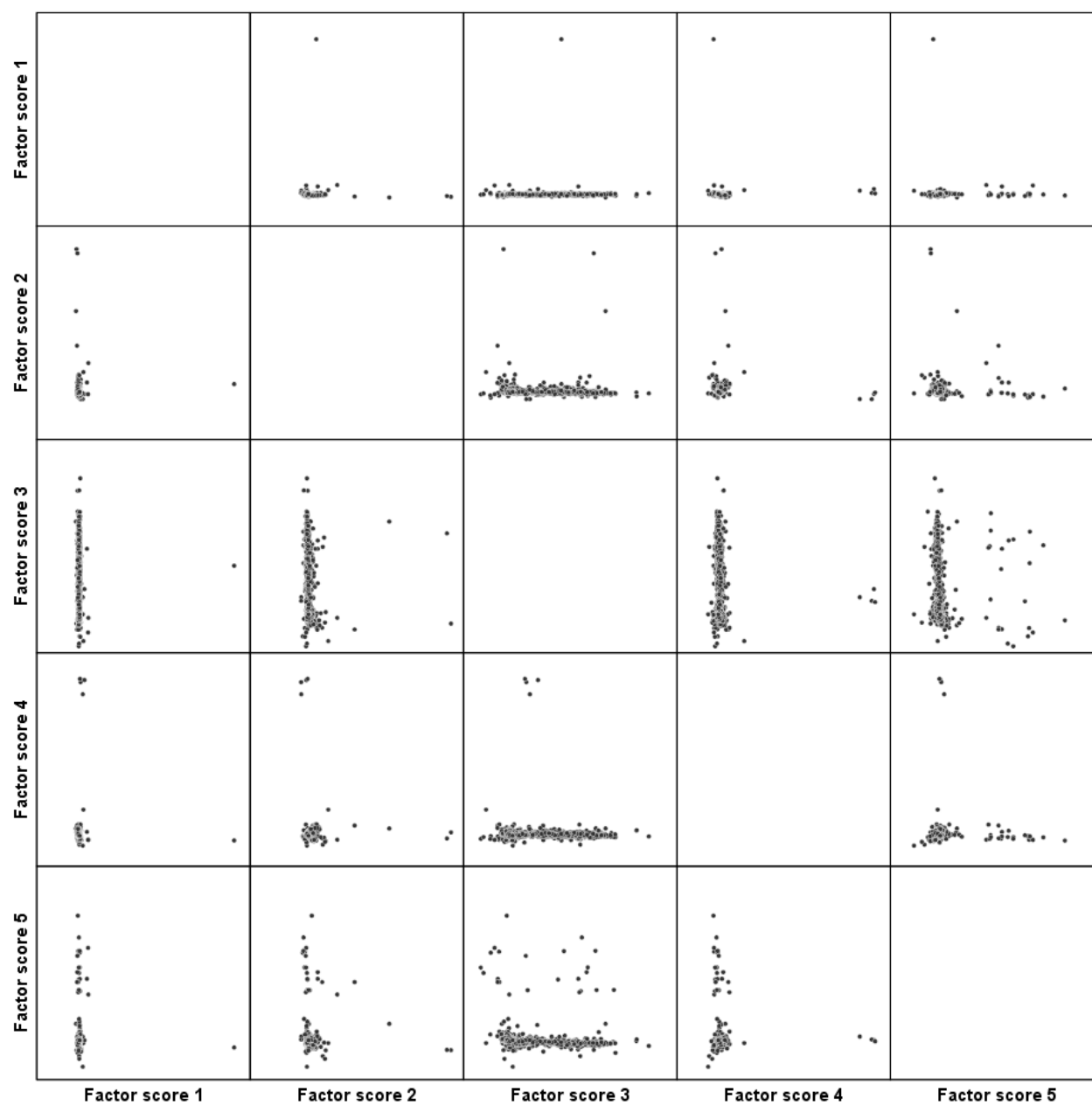
**Figures 4-1 to 4-29 Transformed Element Readings**

Log 10 transformations

Missing Values Imputed and Factor Score Outliers Removed.

Figure 4-1 Aluminium



**Aluminium**

Mean = 3.530736
Std. Dev. = .2333559
N = 2,335

Figure 4-2 Antimony

**Antimony**



Mean = .814592
Std. Dev. = .2251039
N = 2,335

Figure 4-3 Arsenic

**Arsenic**



Mean = 1.550927
Std. Dev. = .4718182
N = 2,335

Figure 4-4 Barium



**Barium**

Mean = 1.550927
Std. Dev. = .4718182
N = 2,335

Figure 4-5 Cadmium



**Cadmium**

Mean = .517337
Std. Dev. = .1680373
N = 2,335

Figure 4-6 Calcium



**Calcium**

Mean = 3.098375
Std. Dev. = .3967284
N = 2,335

Figure 4-7 Copper



**Copper**

Mean = .761892
Std. Dev. = .1626797
N = 2,335

Figure 4-8 Iron



**Iron**

Mean = 3.199629
Std. Dev. = .2732397
N = 2,335

Fe_log

Figure 4-9 Manganese



**Manganese**

Mean = 1.415187
Std. Dev. = .2839989
N = 2,335

Mn_log

Figure 4-10 Mercury



**Mercury**

Mean = .563367
Std. Dev. = .2396617
N = 2,335

Figure 4-11 Molybdenum



**Molybdenum**

Mean = .079879
Std. Dev. = .2886783
N = 2,335

Figure 4-12 Nickel

**Nickel**



Mean = 1.033974
Std. Dev. = .198962
N = 2,335

Figure 4-13 Niobium

**Niobium**



Mean = .076881
Std. Dev. = .3192472
N = 2,335

Figure 4-14 Palladium

**Palladium**



Mean = .233188
Std. Dev. = .1501733
N = 2,335

Figure 4-15 Phosphorus

**Phosphorus**



Mean = 3.383792
Std. Dev. = .1223249
N = 2,335

Figure 4-16 Potassium

## Potassium



Mean = 3.130985
Std. Dev. = .1620159
N = 2,335

Figure 4-17 Rubidium

## Rubidium



Mean = .37185
Std. Dev. = .2564633
N = 2,335

Figure 4-18 Scandium



Figure 4-19 Silicon
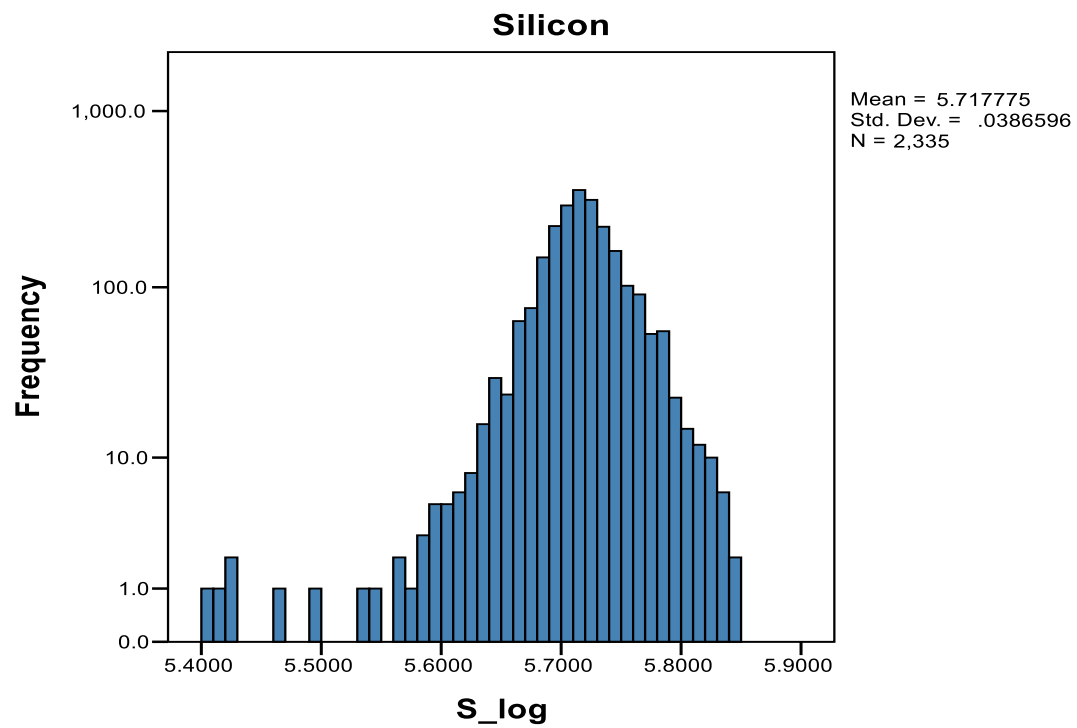
Figure 4-20 Silver
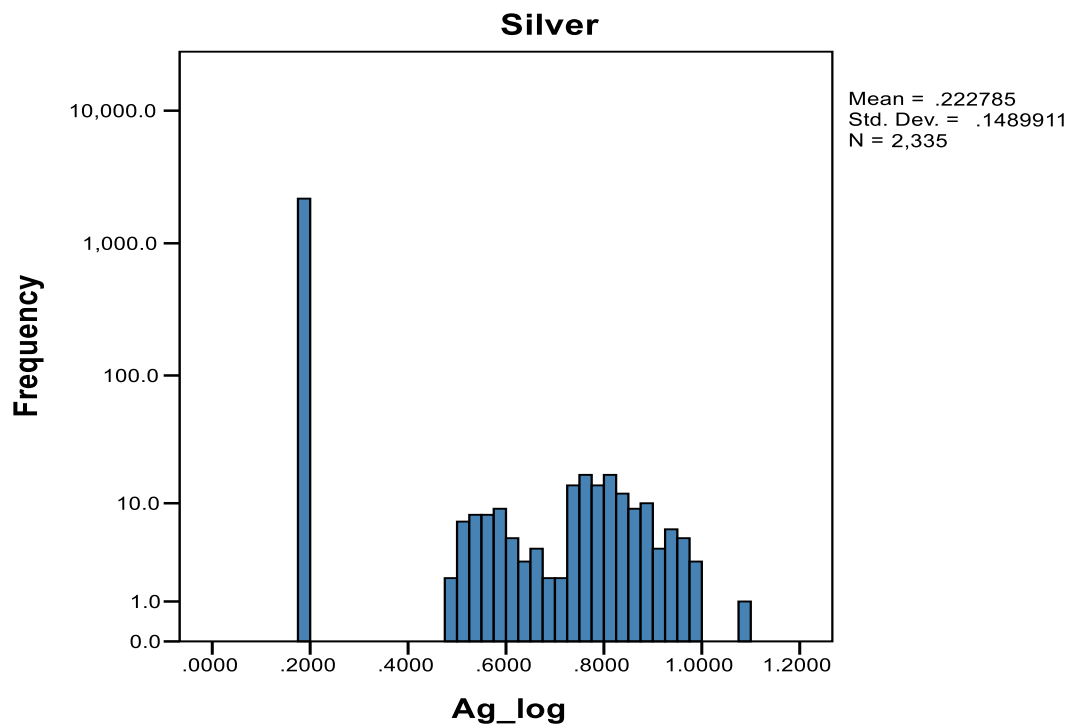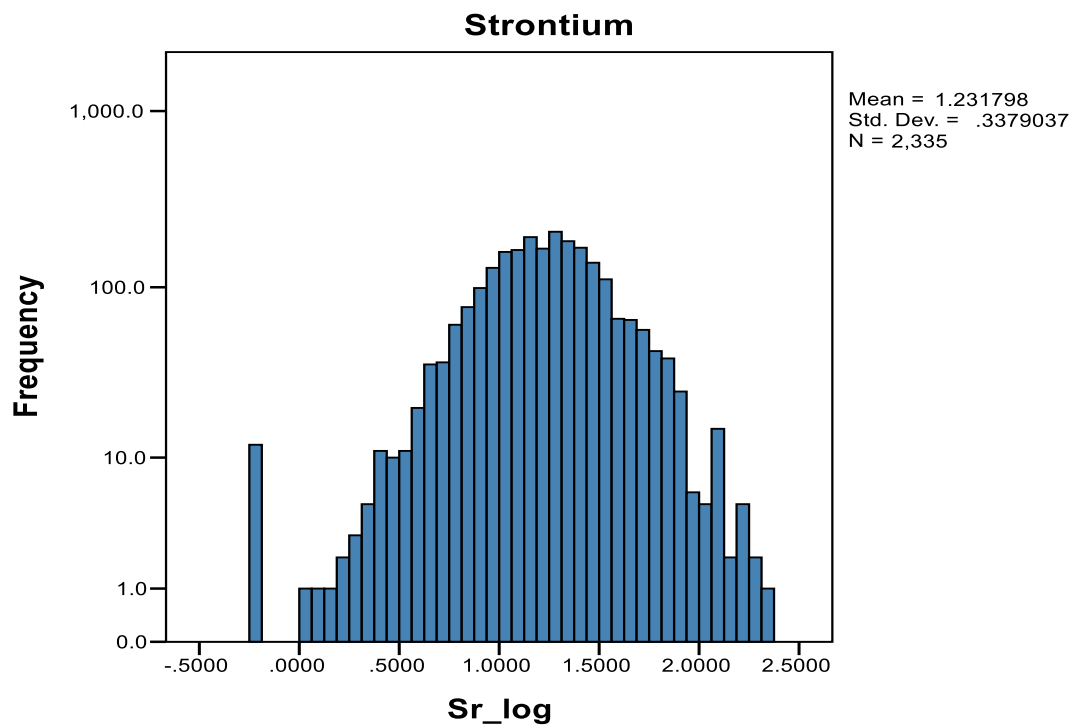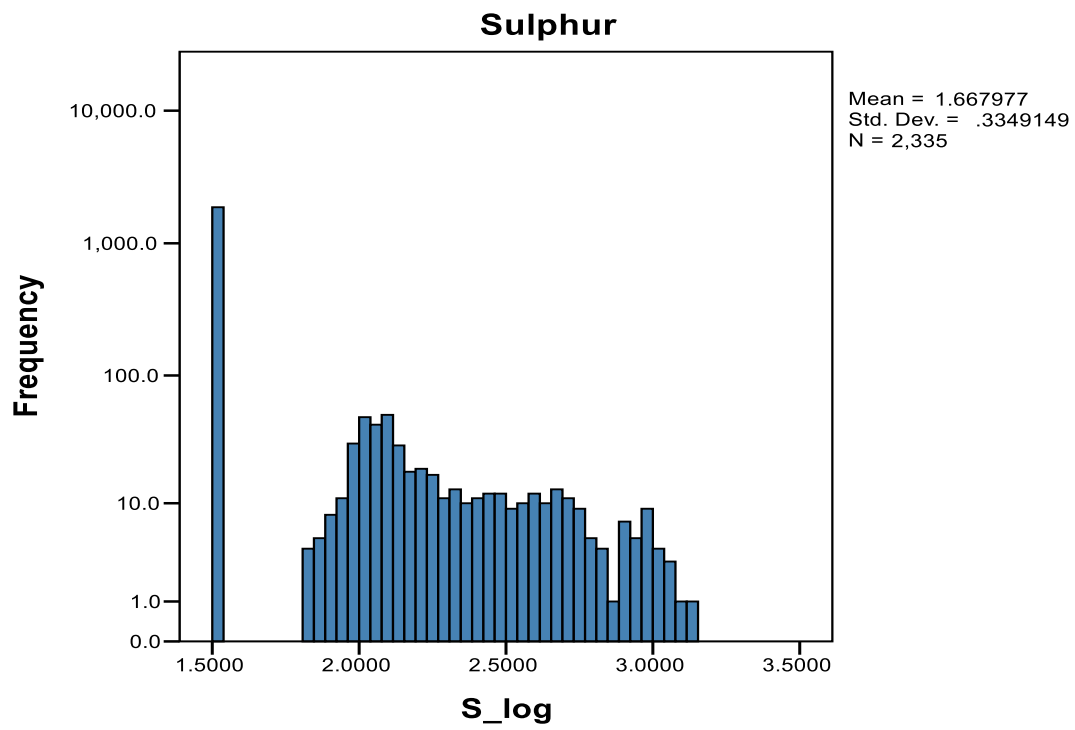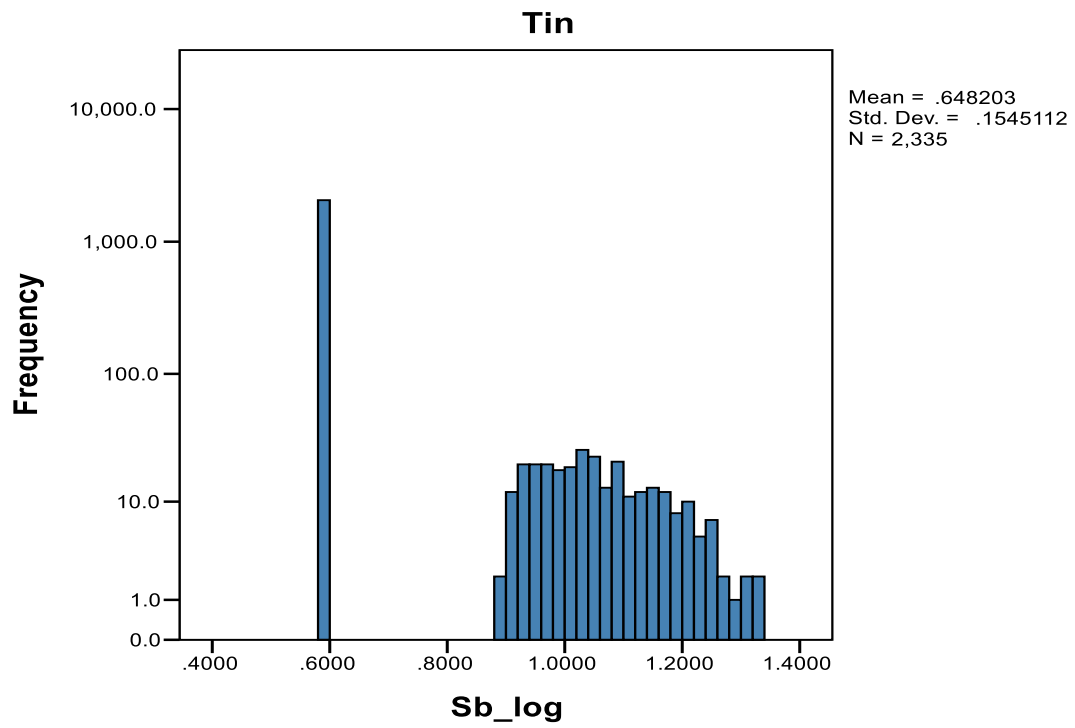
**Silver**

Mean = .222785
Std. Dev. = .1489911
N = 2,335



Figure 4-21 Strontium

**Strontium**

Mean = 1.231798
Std. Dev. = .3379037
N = 2,335

Figure 4-22 Sulphur



**Sulphur**

Mean = 1.667977
Std. Dev. = .3349149
N = 2,335

Figure 4-23 Tin



**Tin**

Mean = .648203
Std. Dev. = .1545112
N = 2,335

Figure 4-24 Titanium

**Titanium**



Mean = 2.295643
Std. Dev. = .25112
N = 2,335

Figure 4-25 Tungsten

**Tungsten**



Mean = 1.133654
Std. Dev. = .2715365
N = 2,335

Figure 4-26 Uranium



**Uranium**

Mean = .301171
Std. Dev. = .2541508
N = 2,335

Figure 4-27 Vanadium



**Vanadium**

Mean = 1.135443
Std. Dev. = .2859535
N = 2,335

Figure 4-28 Zinc

**Zinc**



Mean = .484318
Std. Dev. = .1839171
N = 2,335

Figure 4-29 Zirconium

**Zirconium**



Mean = .493654
Std. Dev. = .3307838
N = 2,335

**Figure 5-1 Model Summary**

| Algorithm | TwoStep |
|-----------|---------|
| Inputs | 6 |
| Clusters | 4 |

### Cluster Quality



Silhouette measure of cohesion and separation

**(Value = 0.68)**
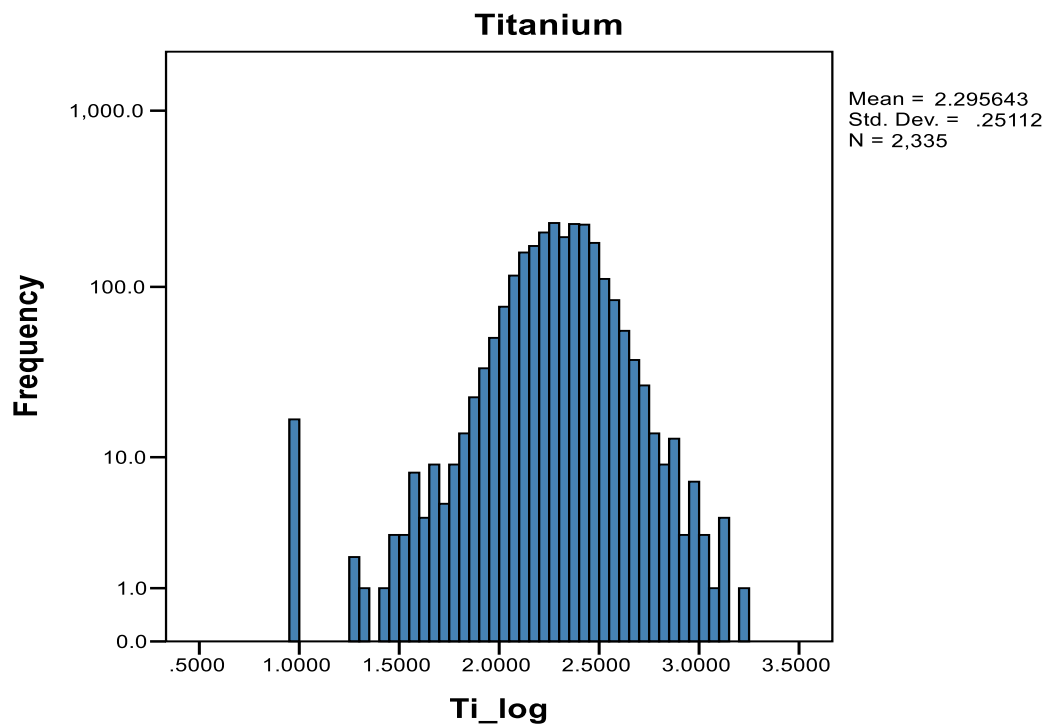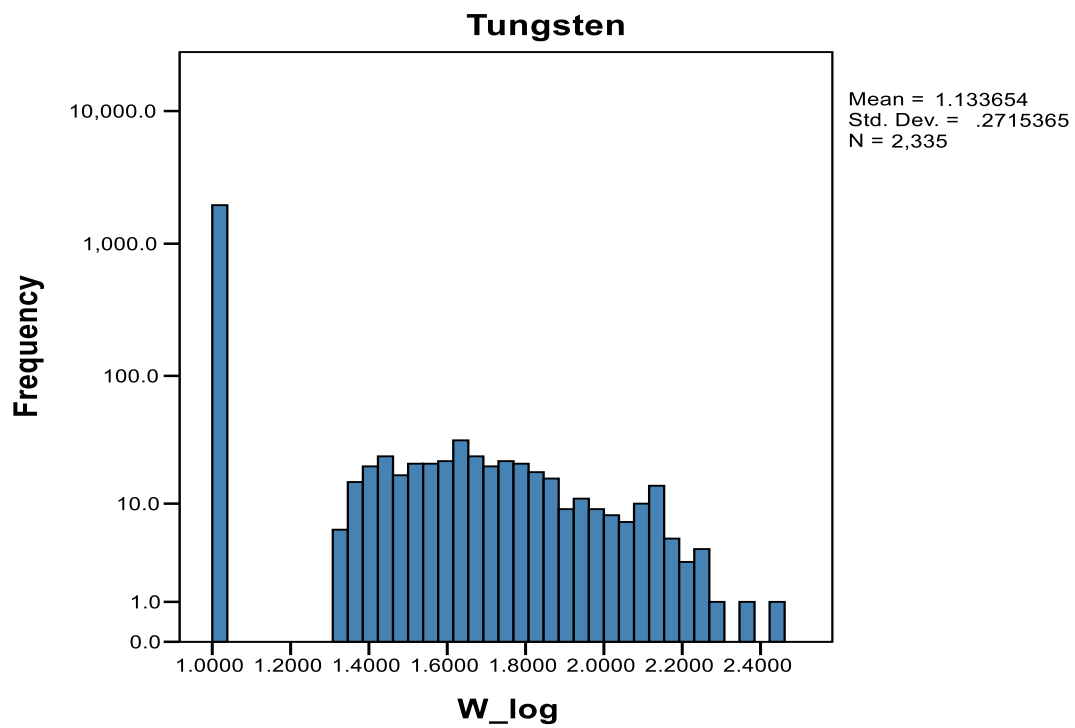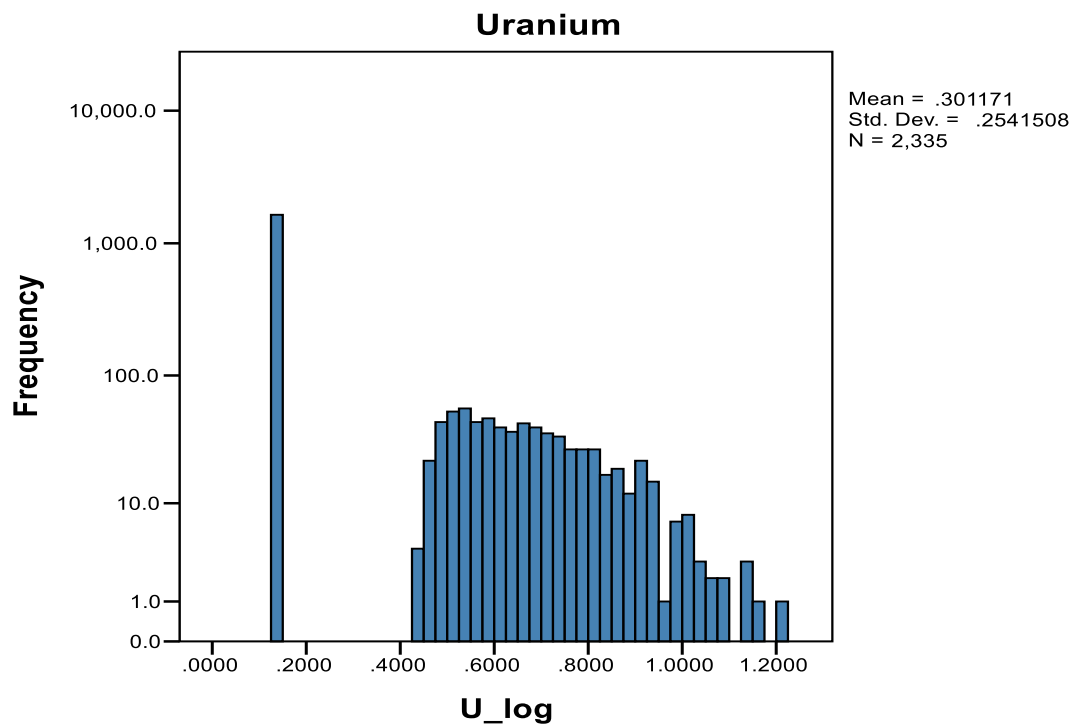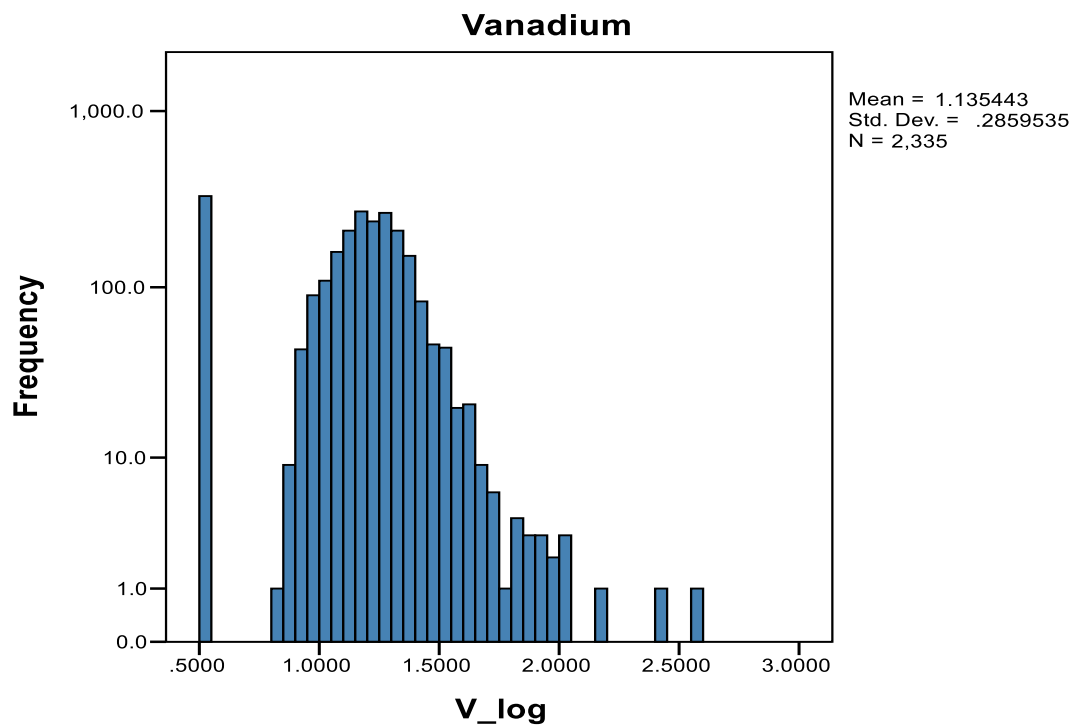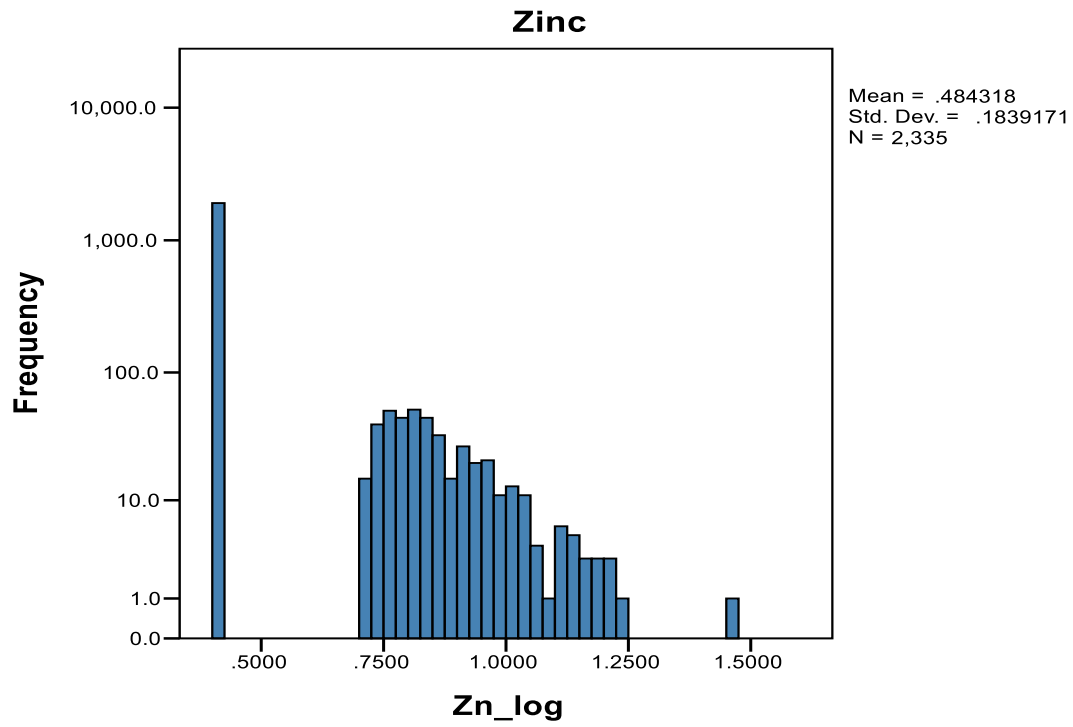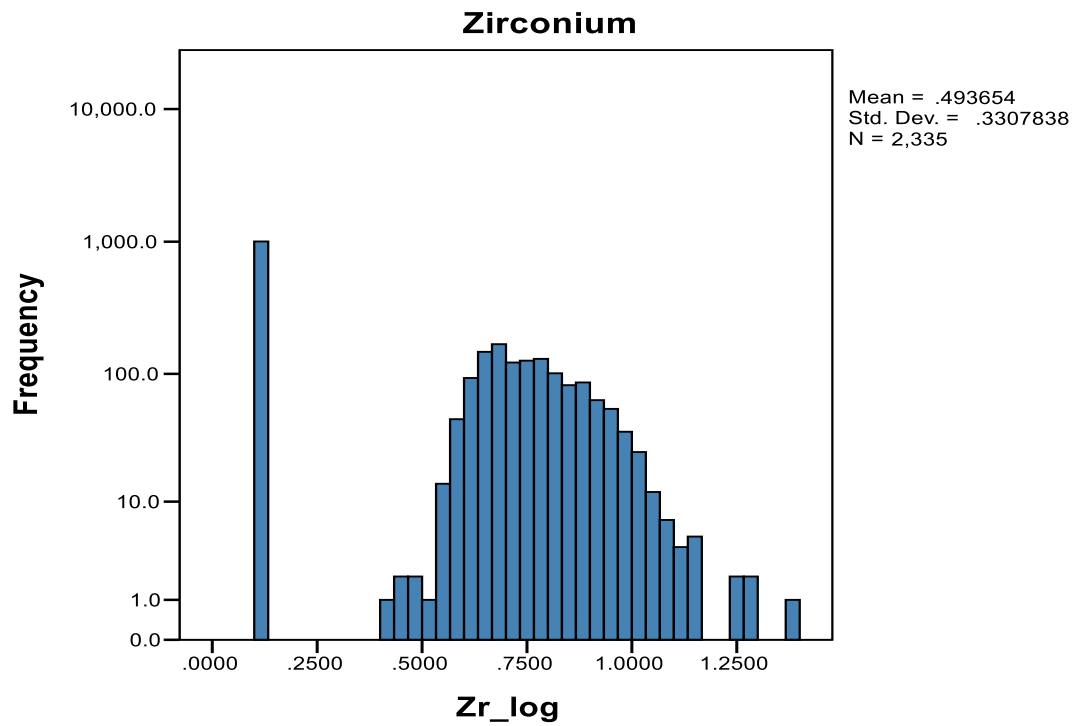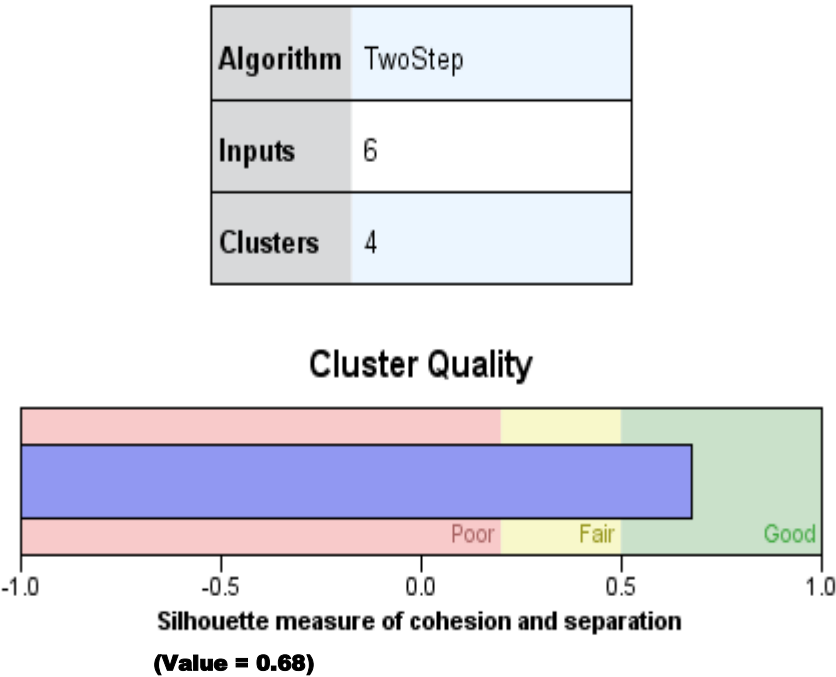
**Figure 5-2 Chart of Cluster Sizes**
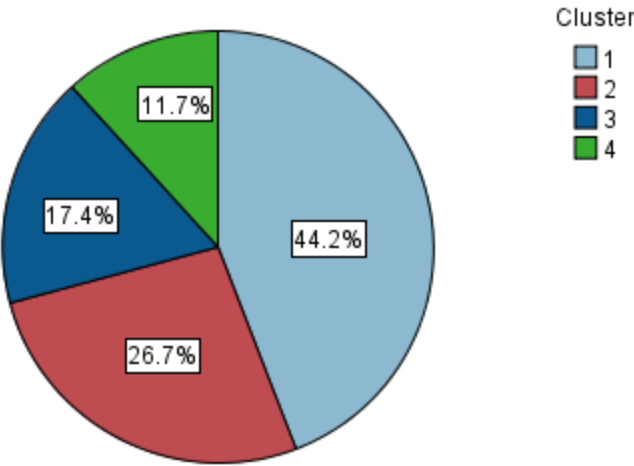
**Figure 5-3 Cluster Centres, Elements by Overall Importance**

Clusters Sorted by Size

## Clusters

Input (Predictor) Importance

■ 1.0 ■ 0.8 ■ 0.6 □ 0.4 □ 0.2 □ 0.0
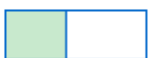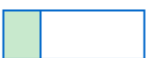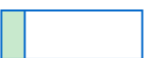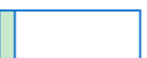
| Cluster | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Label | | | | |
| Description | | | | |
| Size | 44.2% (1032) | 26.7% (623) | 17.4% (406) | 11.7% (274) |
| Inputs | Ba 1.27 | Ba 1.26 | Ba 2.14 | Ba 2.38 |
| | Mo -0.07 | Mo 0.50 | Mo -0.08 | Mo -0.08 |
| | Nb -0.09 | Nb 0.56 | Nb -0.11 | Nb -0.12 |
| | Ni 0.95 | Ni 0.95 | Ni 1.17 | Ni 1.36 |
| | Sb 0.71 | Sb 0.71 | Sb 0.91 | Sb 1.31 |
| | Sn 0.59 | Sn 0.59 | Sn 0.60 | Sn 1.06 |

**Figure 5-4 Cluster Centres, Elements by Within-Cluster Importance**

Clusters Sorted by Size

## Clusters

Input (Predictor) Importance

■ 1.0 ■ 0.8 ☐ 0.6 ☐ 0.4 ☐ 0.2 ☐ 0.0

| Cluster | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Label | | | | |
| Description | | | | |
| Size | 44.2% (1032) | 26.7% (623) | 17.4% (406) | 11.7% (274) |
| Inputs | Ba 1.27 | Ba 1.26 | Mo -0.08 | Ba 2.38 |
| | Mo -0.07 | Nb 0.56 | Ba 2.14 | Mo -0.08 |
| | Ni 0.95 | Mo 0.50 | Nb -0.11 | Sn 1.06 |
| | Nb -0.09 | Ni 0.95 | Sn 0.60 | Sb 1.31 |
| | Sb 0.71 | Sb 0.71 | Ni 1.17 | Ni 1.36 |
| | Sn 0.59 | Sn 0.59 | Sb 0.91 | Nb -0.12 |
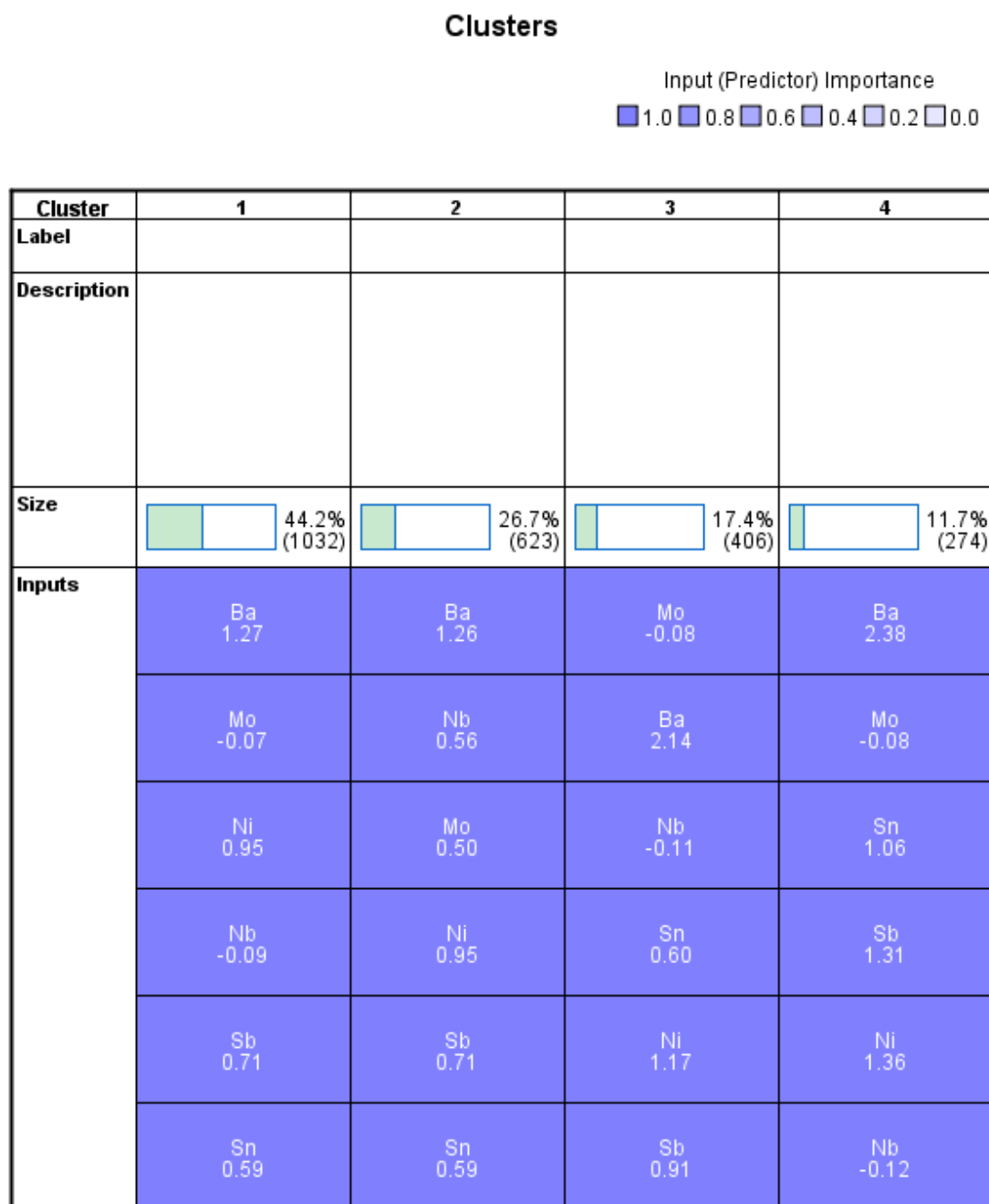
**Figure 5-5 Absolute Cluster Distributions, Elements by Overall Importance**

Clusters Sorted by Size
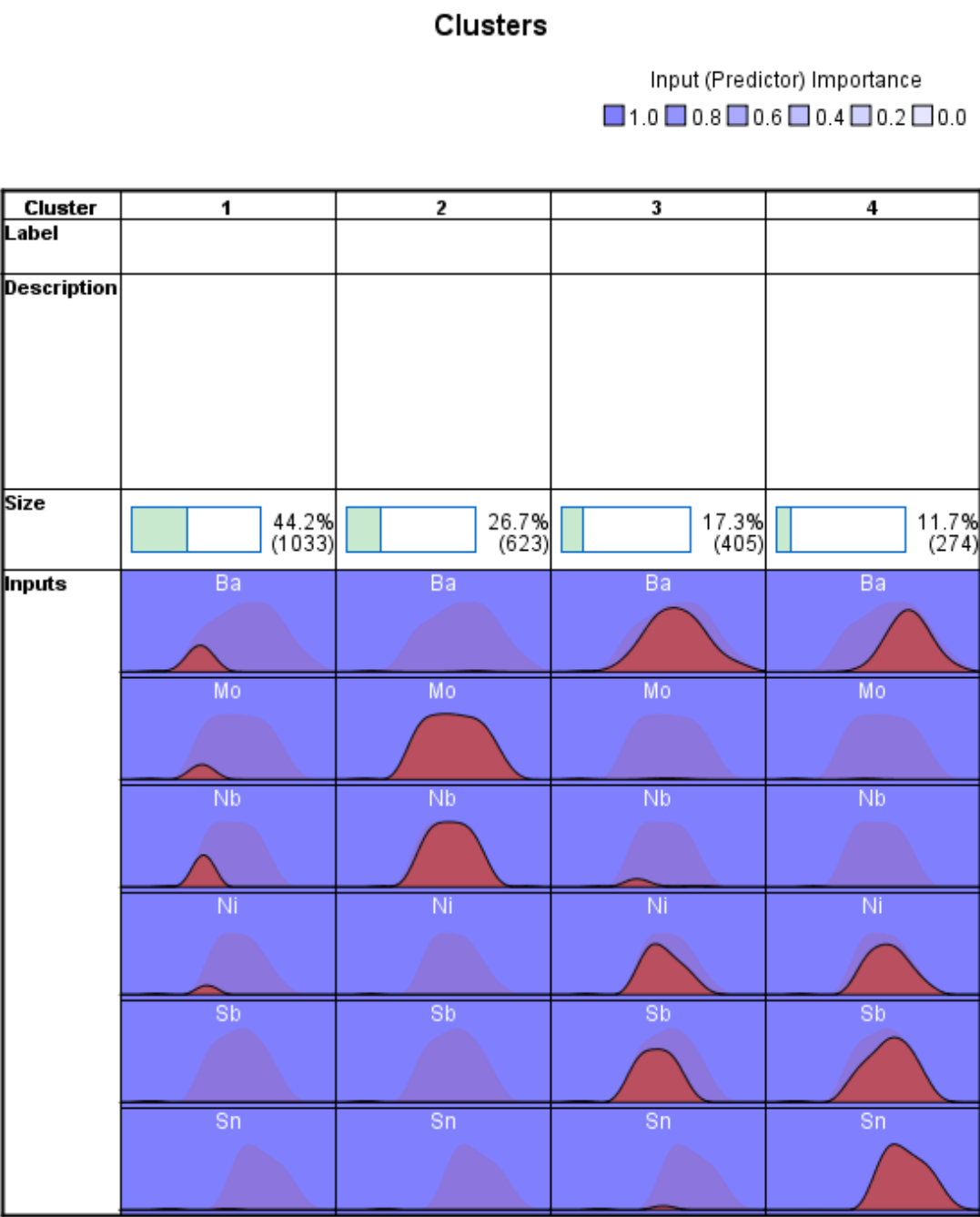
**Figure 5-6 Absolute Cluster Distributions, Elements by Within-Cluster Importance**

Clusters Sorted by Size
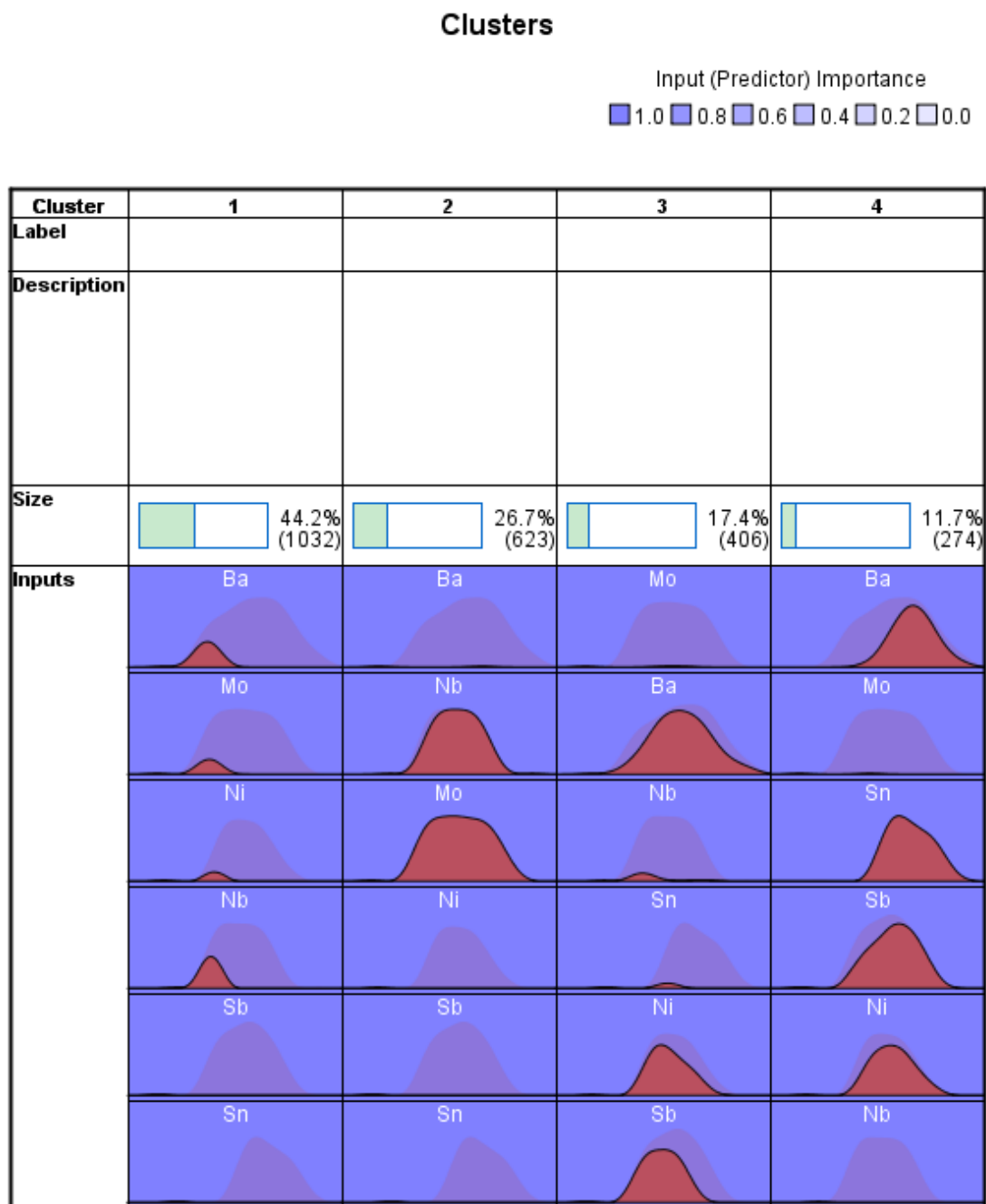
**Figure 5-7 Element Boxplots**
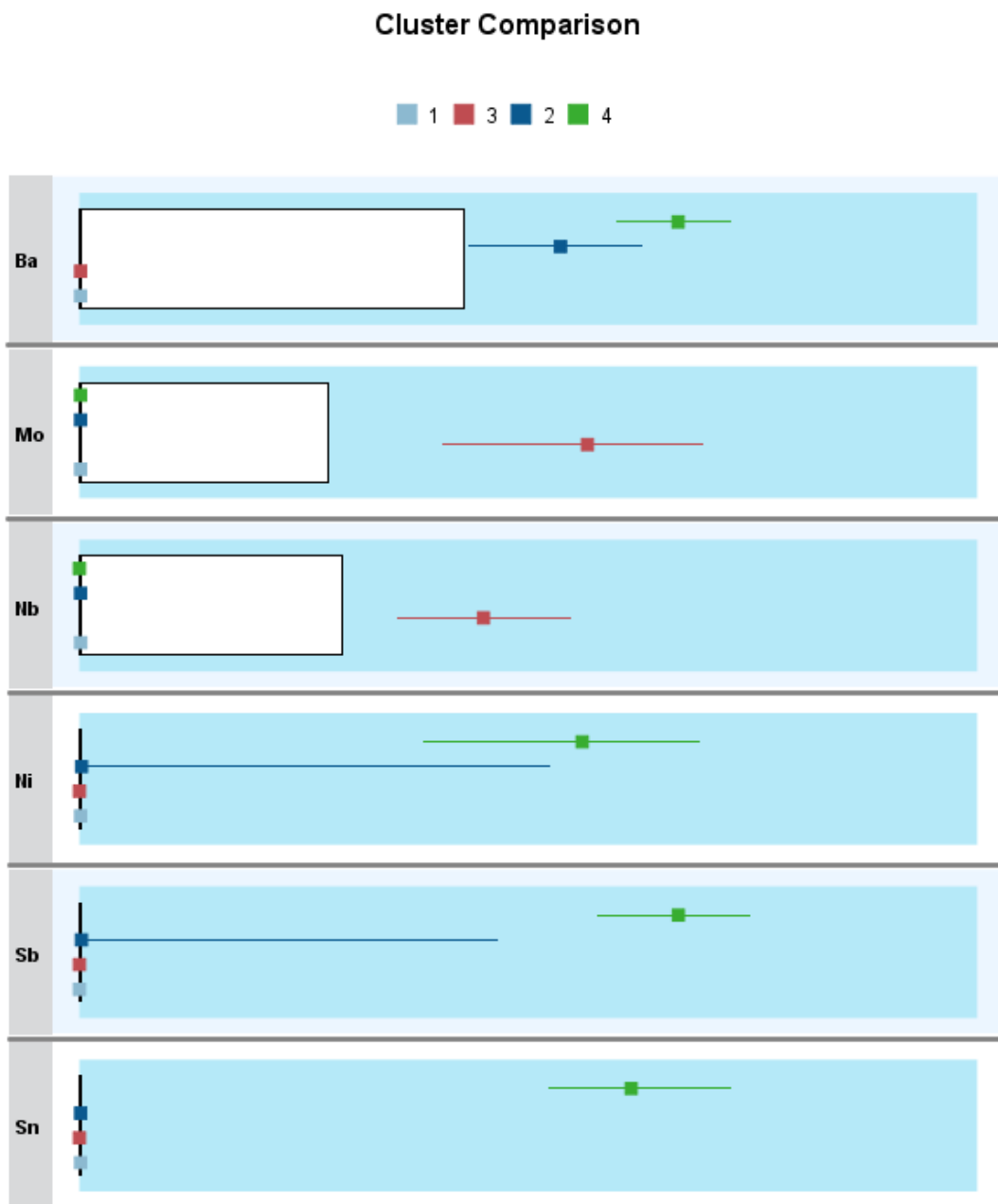


NOTE: The white boxes contain 50% of the element observations, ranging from 25% to 75%.

**Figures 6-1 to 6-15 Elements by Scatterplots by Clusters**

**Cluster Numbers and Colours**

● 1    ● 2    ● 3    ● 4

Figure 6-1 Barium (log 10) by Molybdium (log 10) by Clusters
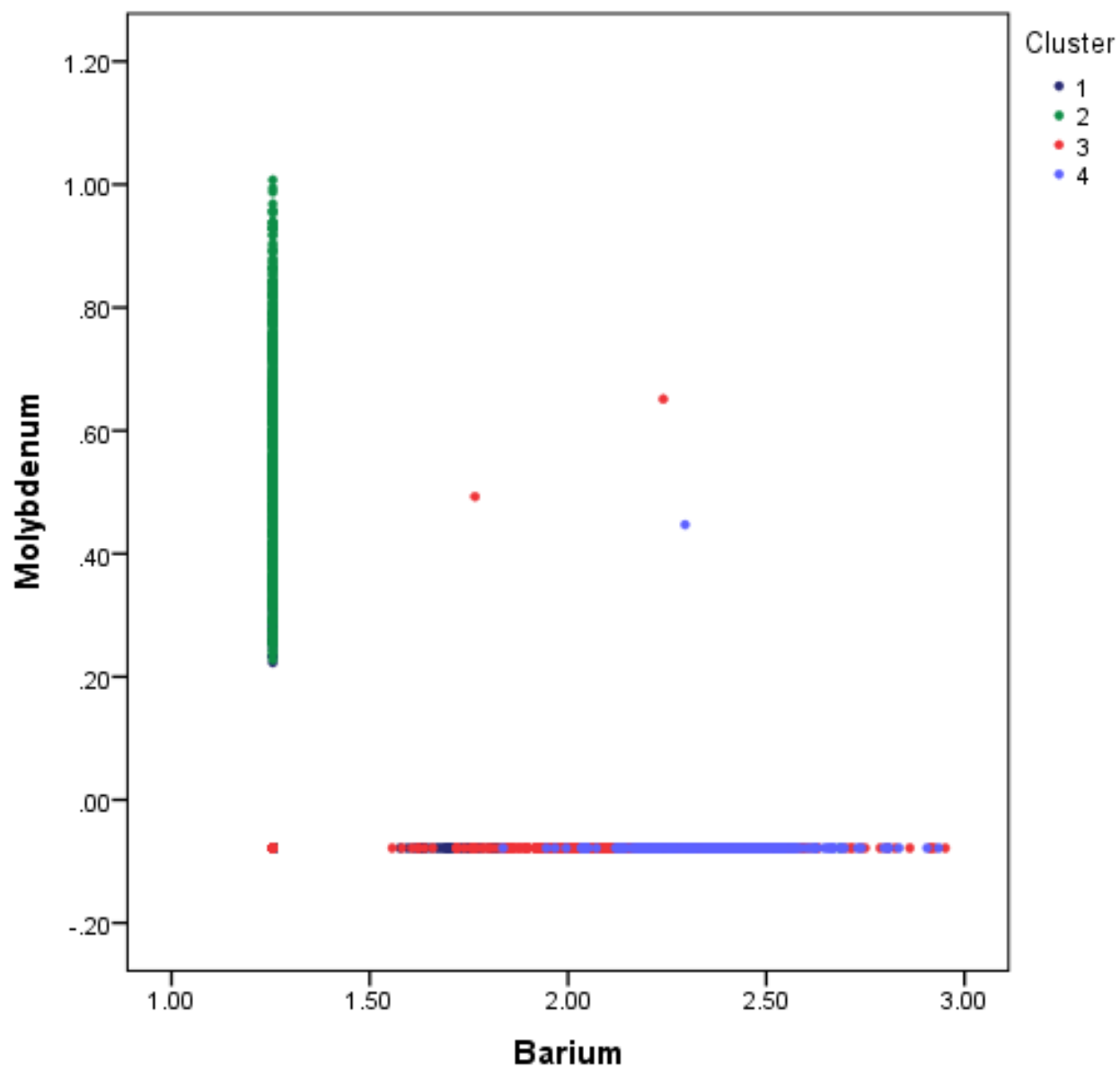
Figure 6-2 Barium (log 10) by Niobium (log 10) by Clusters
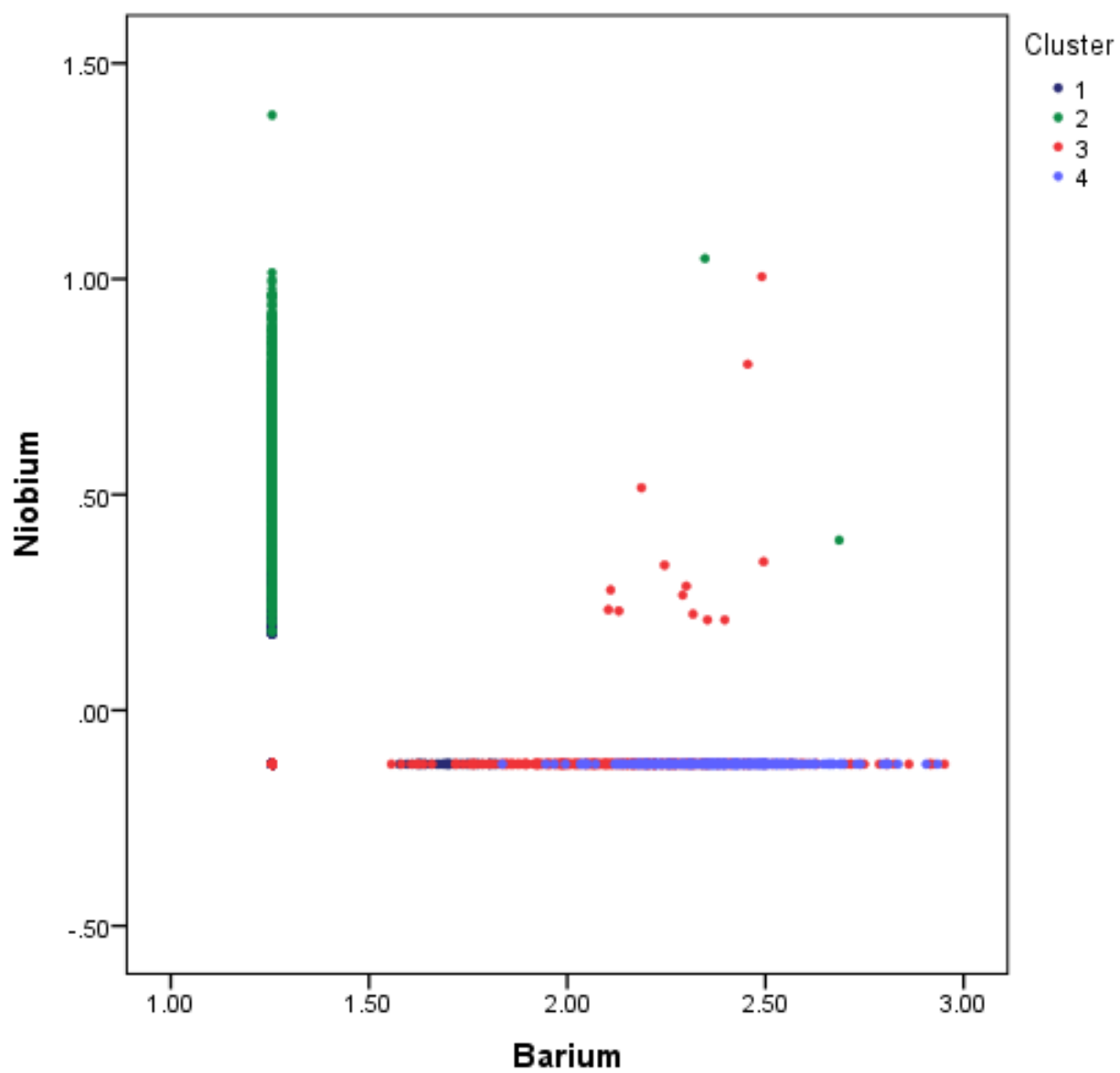
Figure 6-3 Barium (log 10) by Nickel (log 10) by Clusters
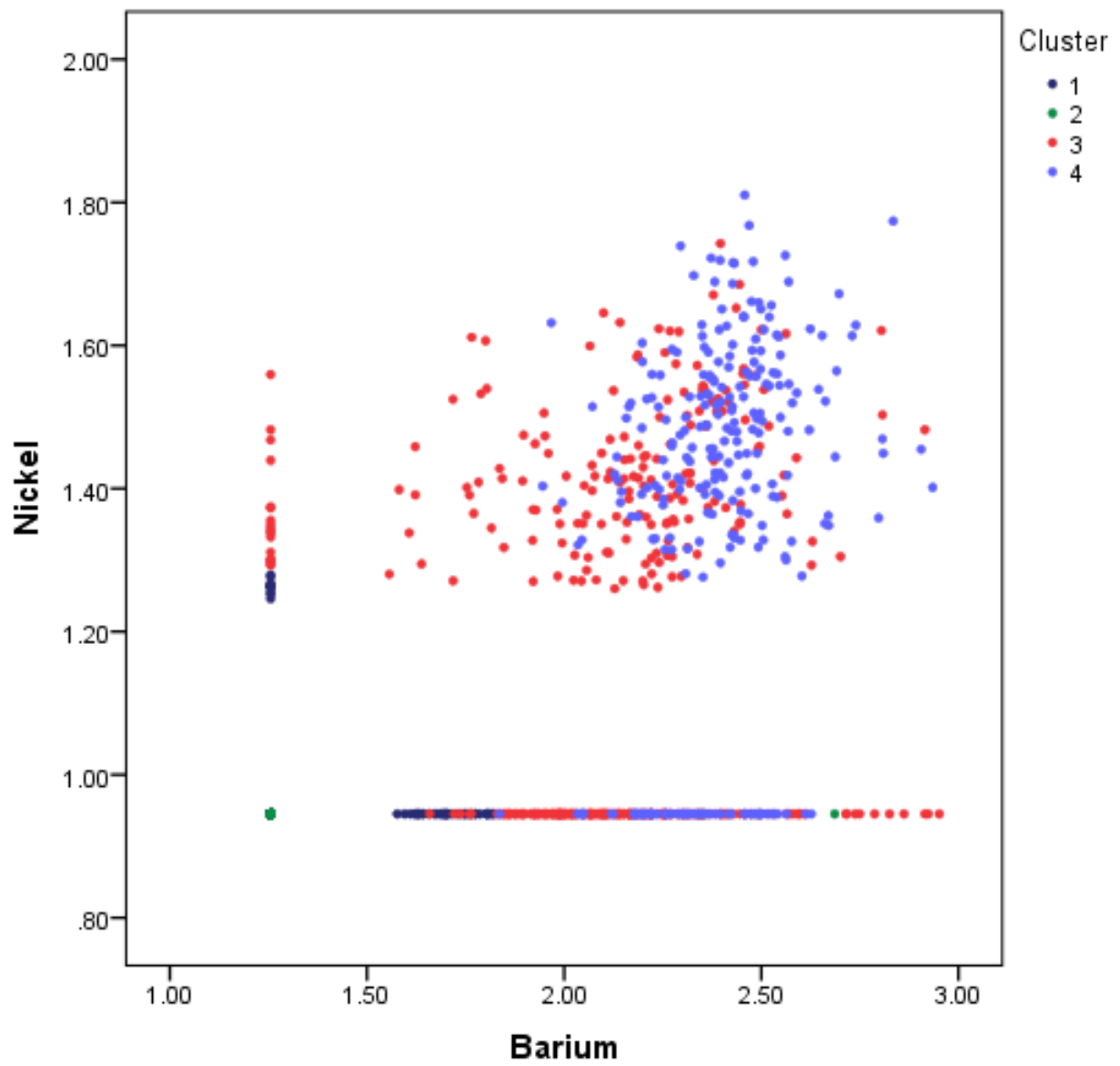
Figure 6-4 Barium (log 10) by Antimony (log 10) by Clusters
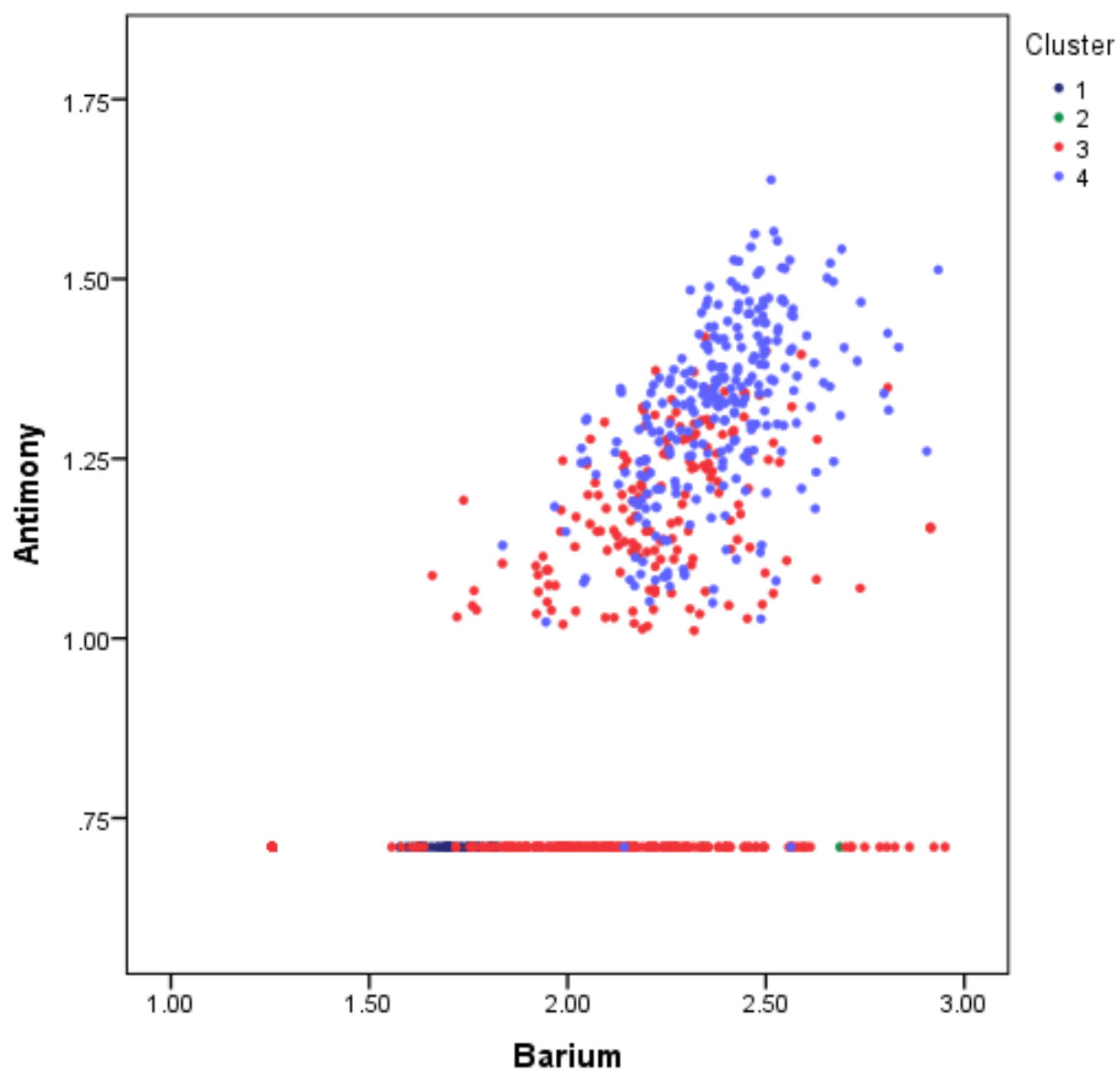
Figure 6-5 Barium (log 10) by Tin (log 10) by Clusters
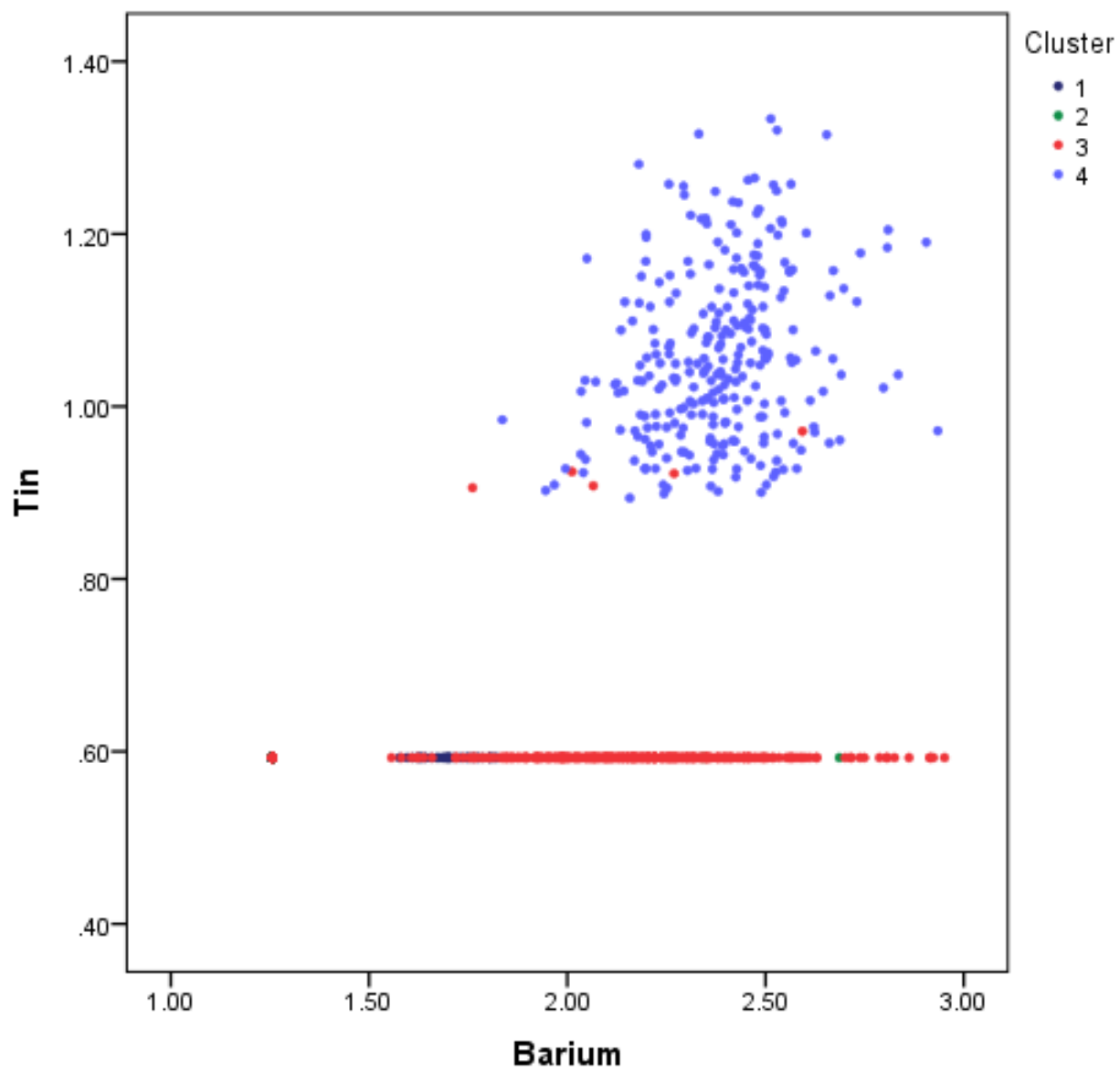
Figure 6-6 Molybdenum (log 10) by Niobium (log 10) by Clusters
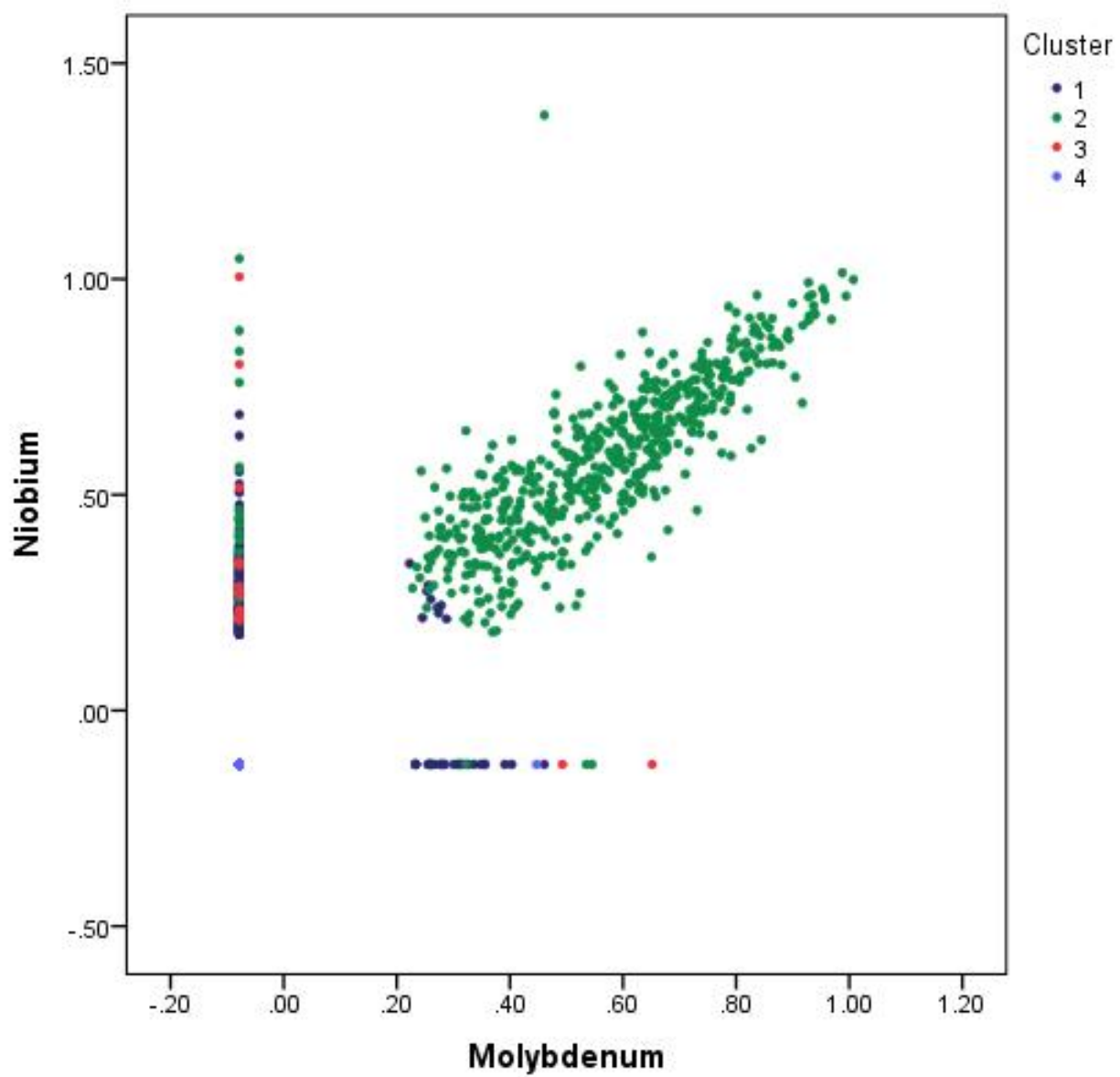
Figure 6-7 Molybdenum (log 10) by Nickel (log 10) by Clusters
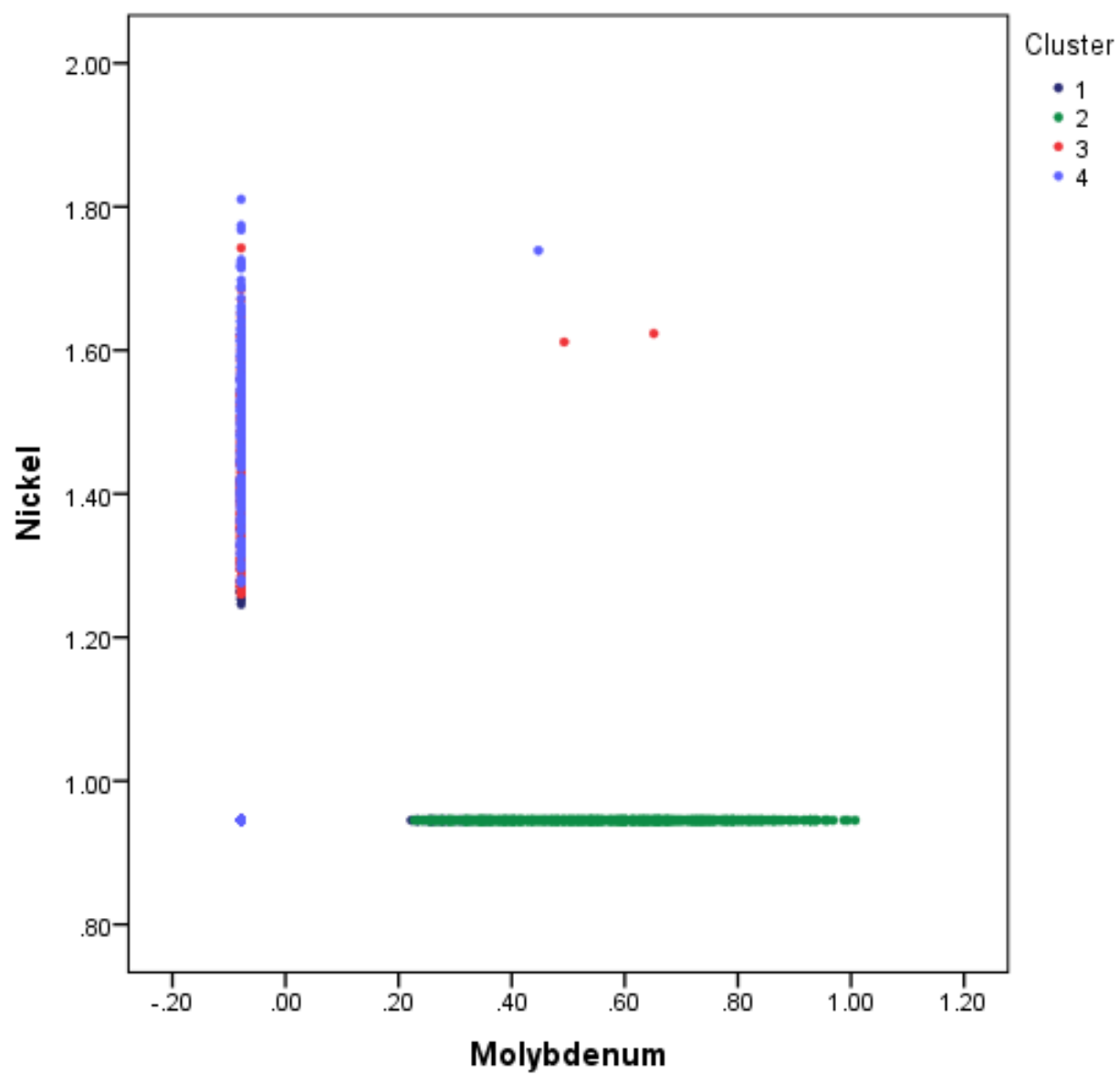
Figure 6-8 Molybdenum (log 10) and Antimony (log 10) by Clusters
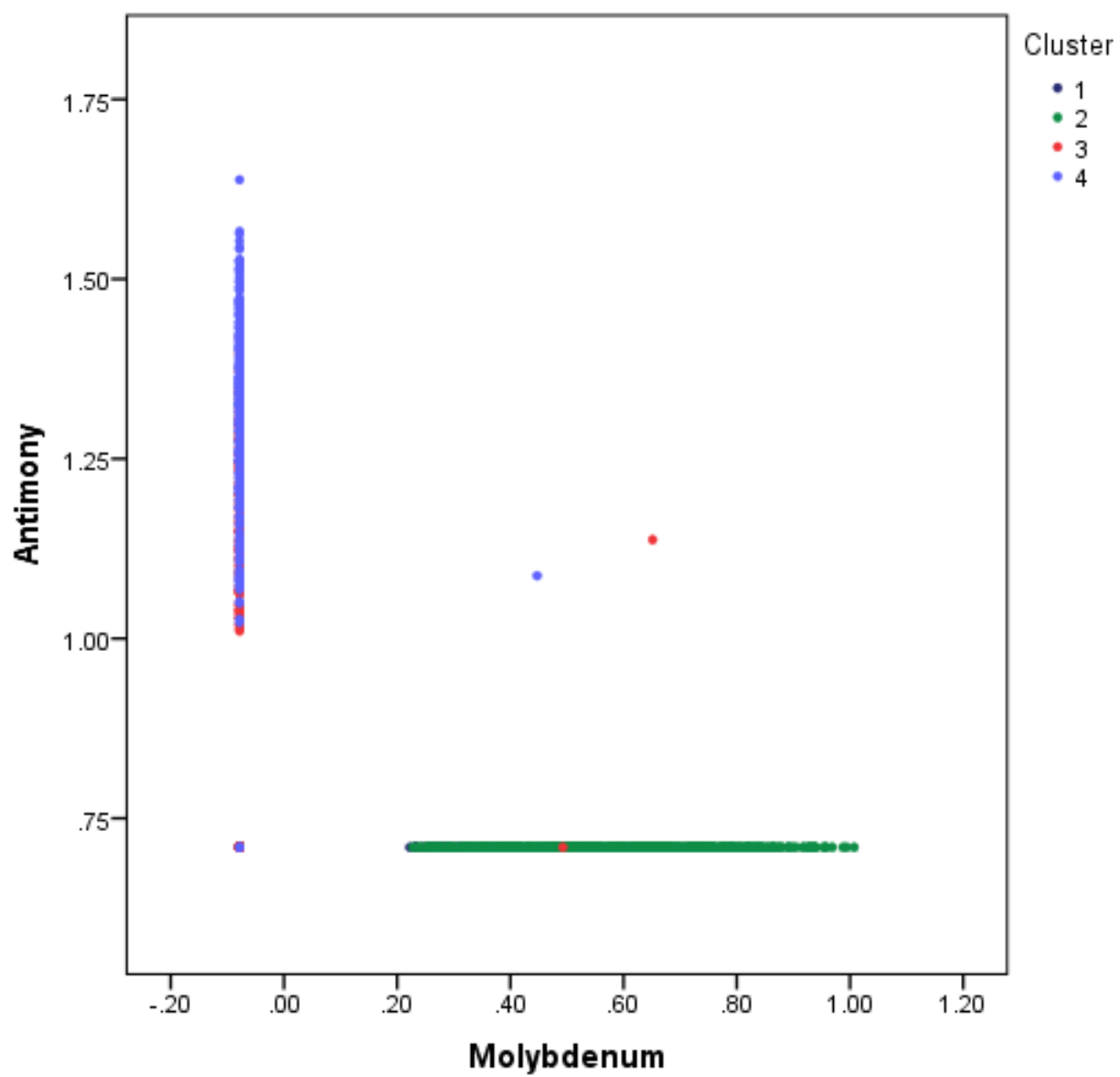
Figure 6-9 Molybdenum (log 10) and Tin (log 10) by Clusters
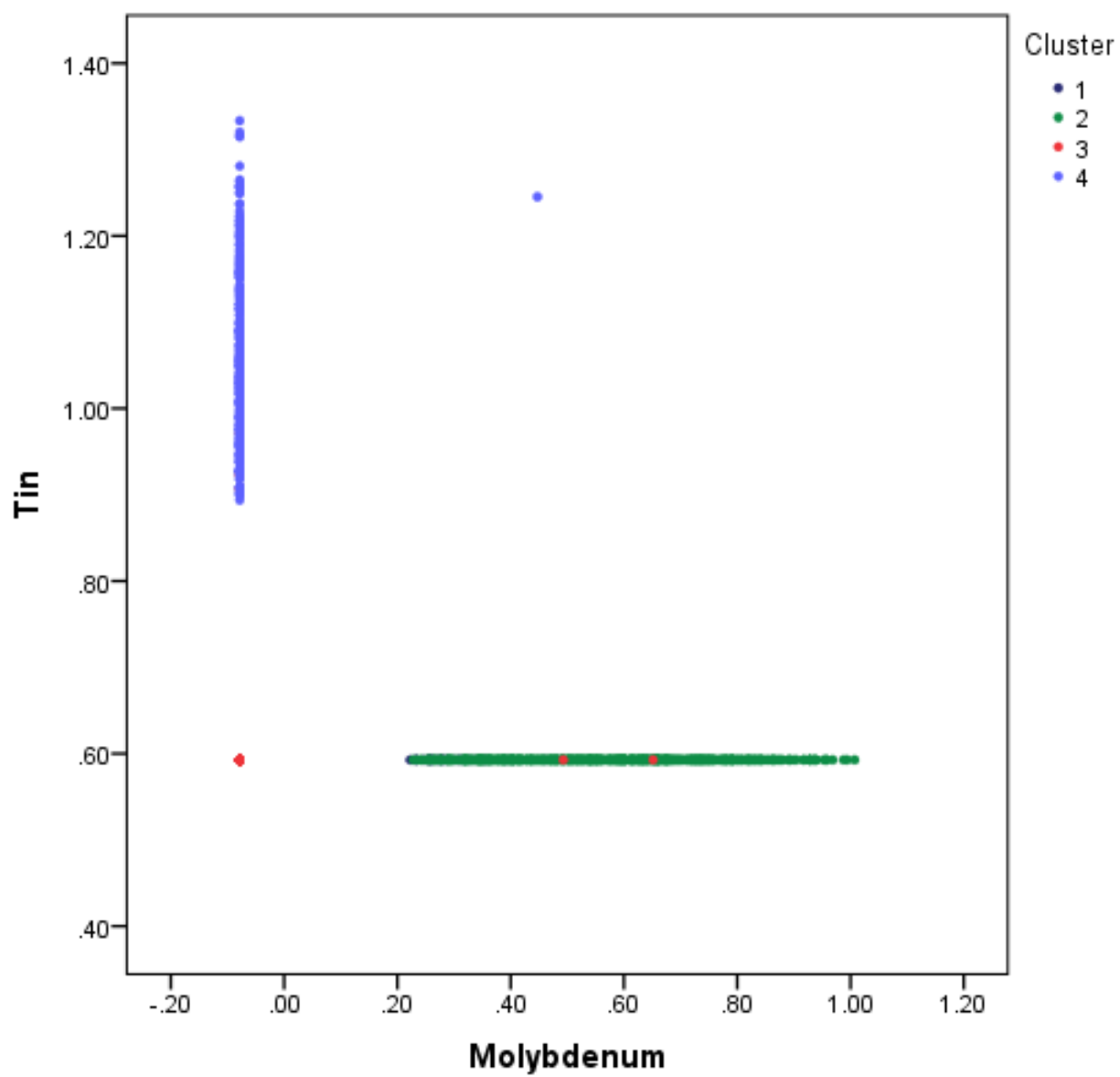
Figure 6-10 Niobium (log 10) and Nickel (log 10) by Clusters
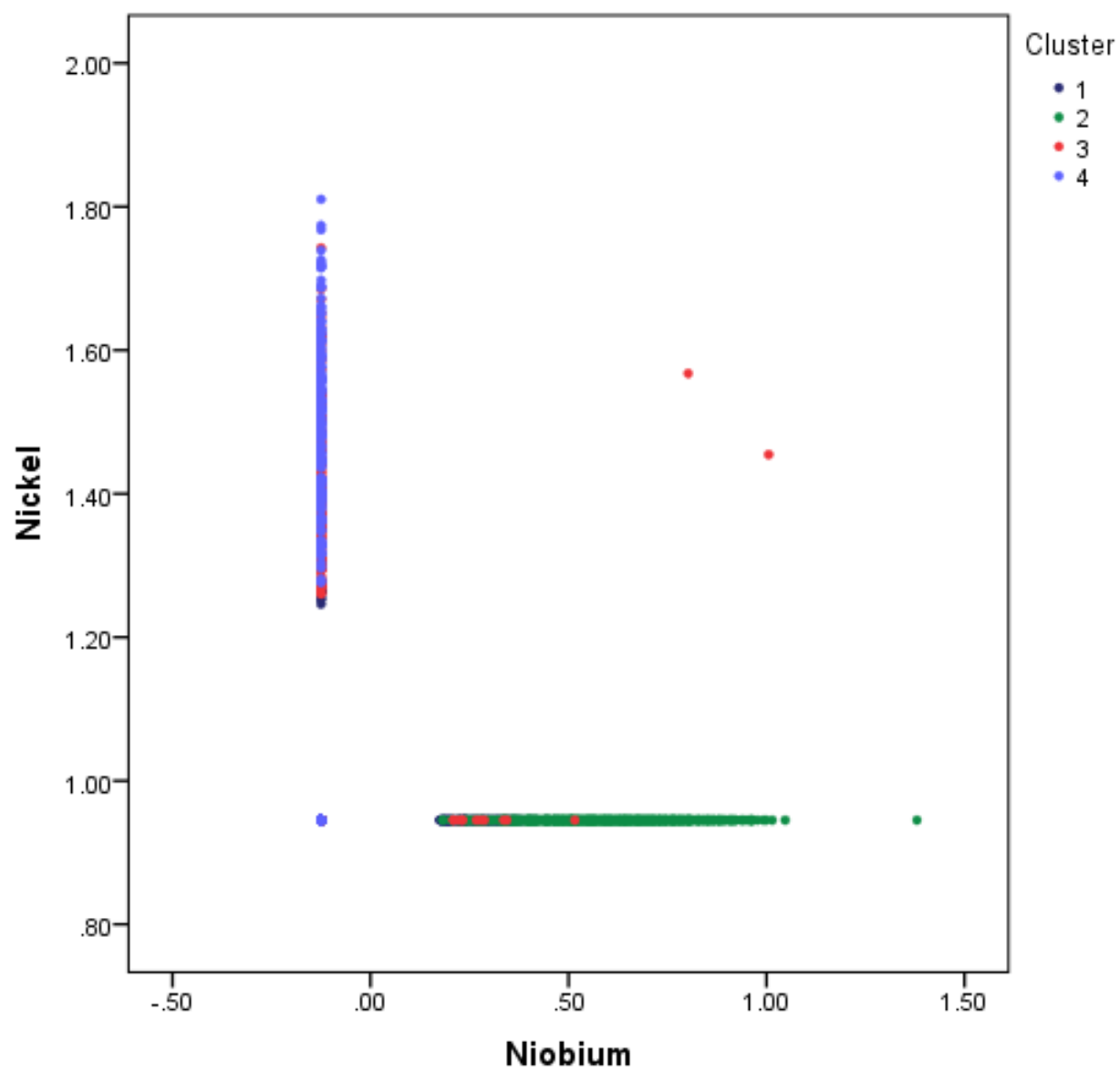
Figure 6-11 Niobium (log 10) and Antimony (log 10) by Clusters
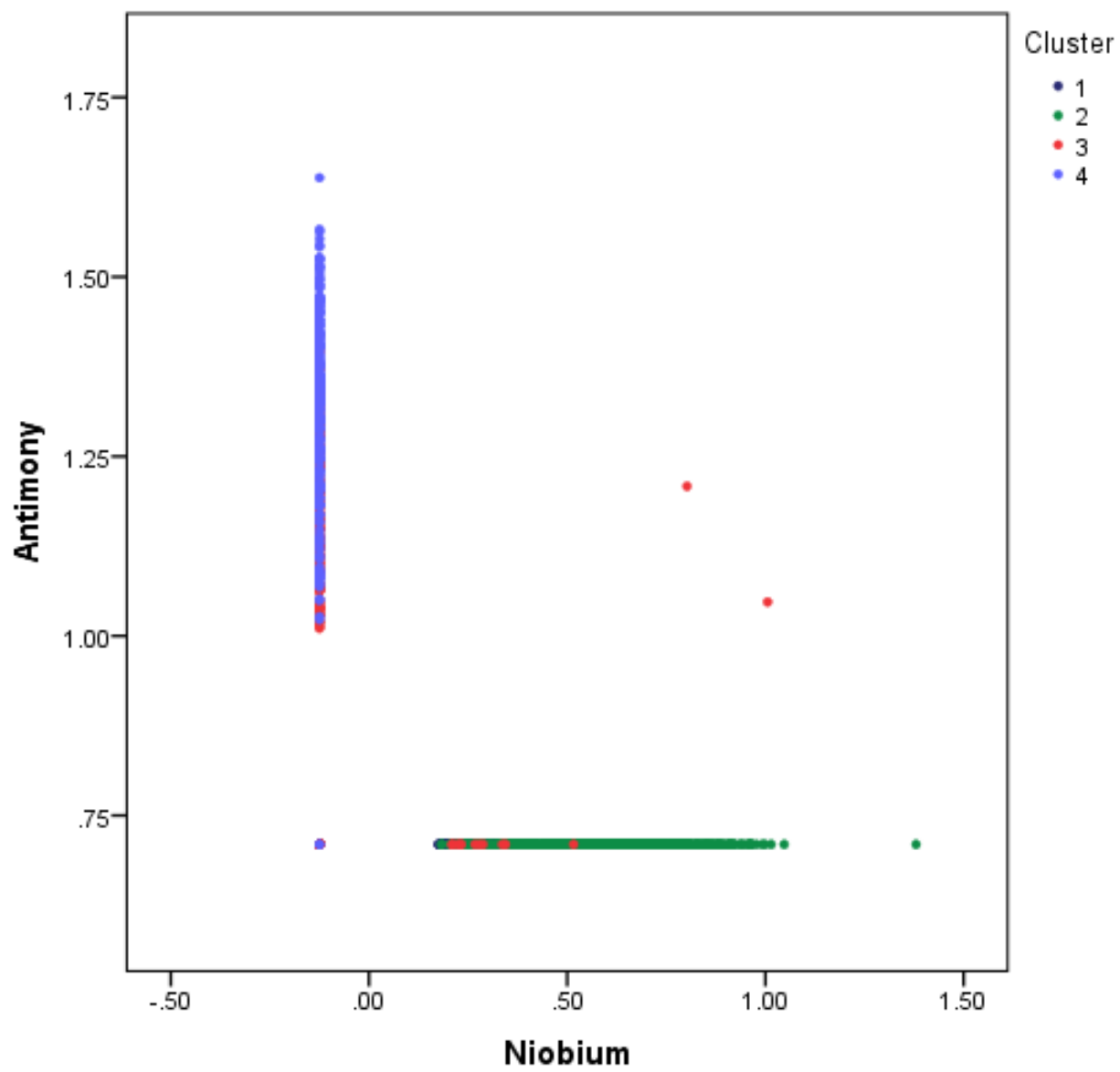
Figure 6-12 Niobium (log 10) and Tin (log 10) by Clusters
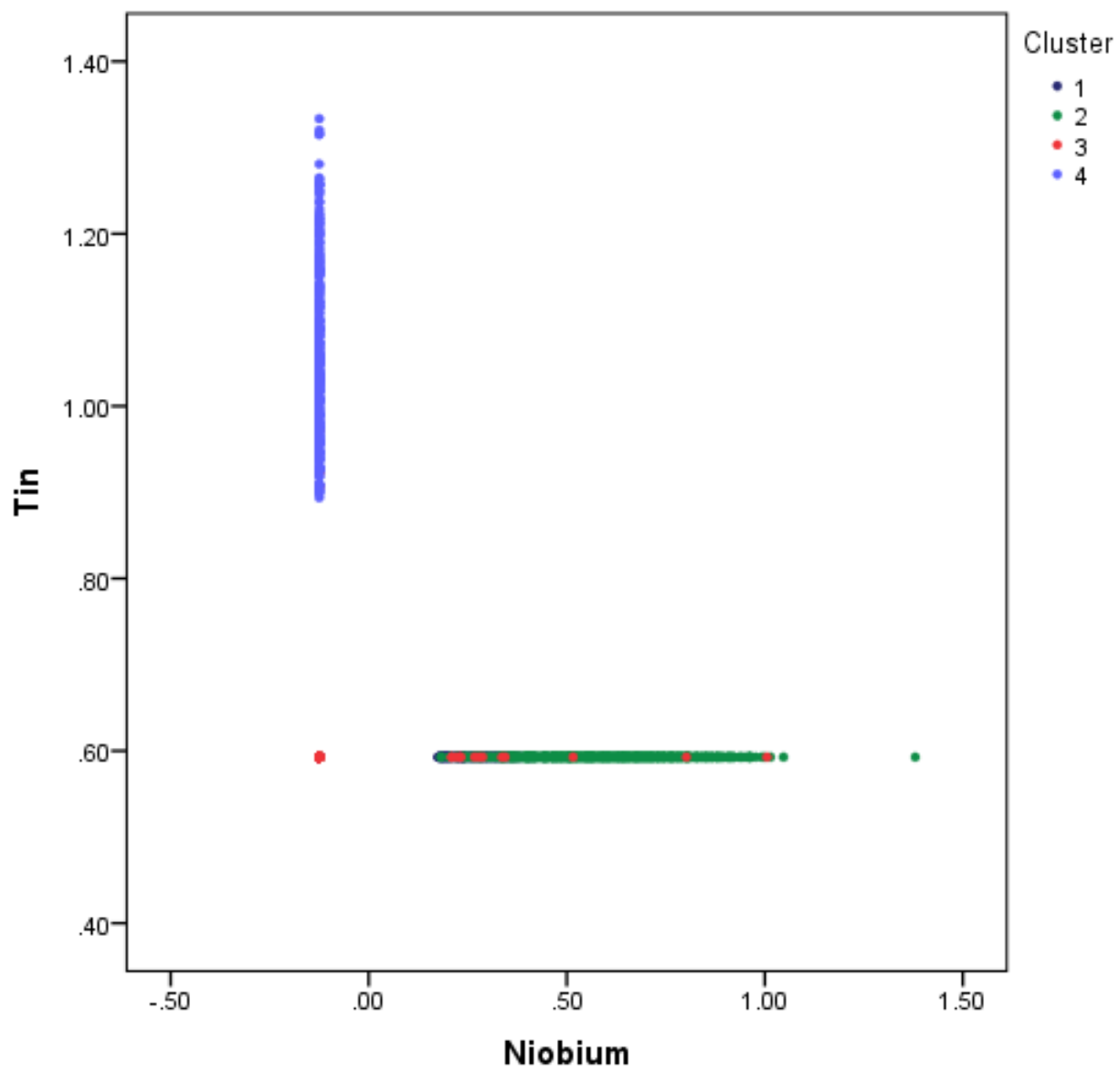
Figure 6-13 Nickel (log 10) and Antimony (log 10) by Clusters
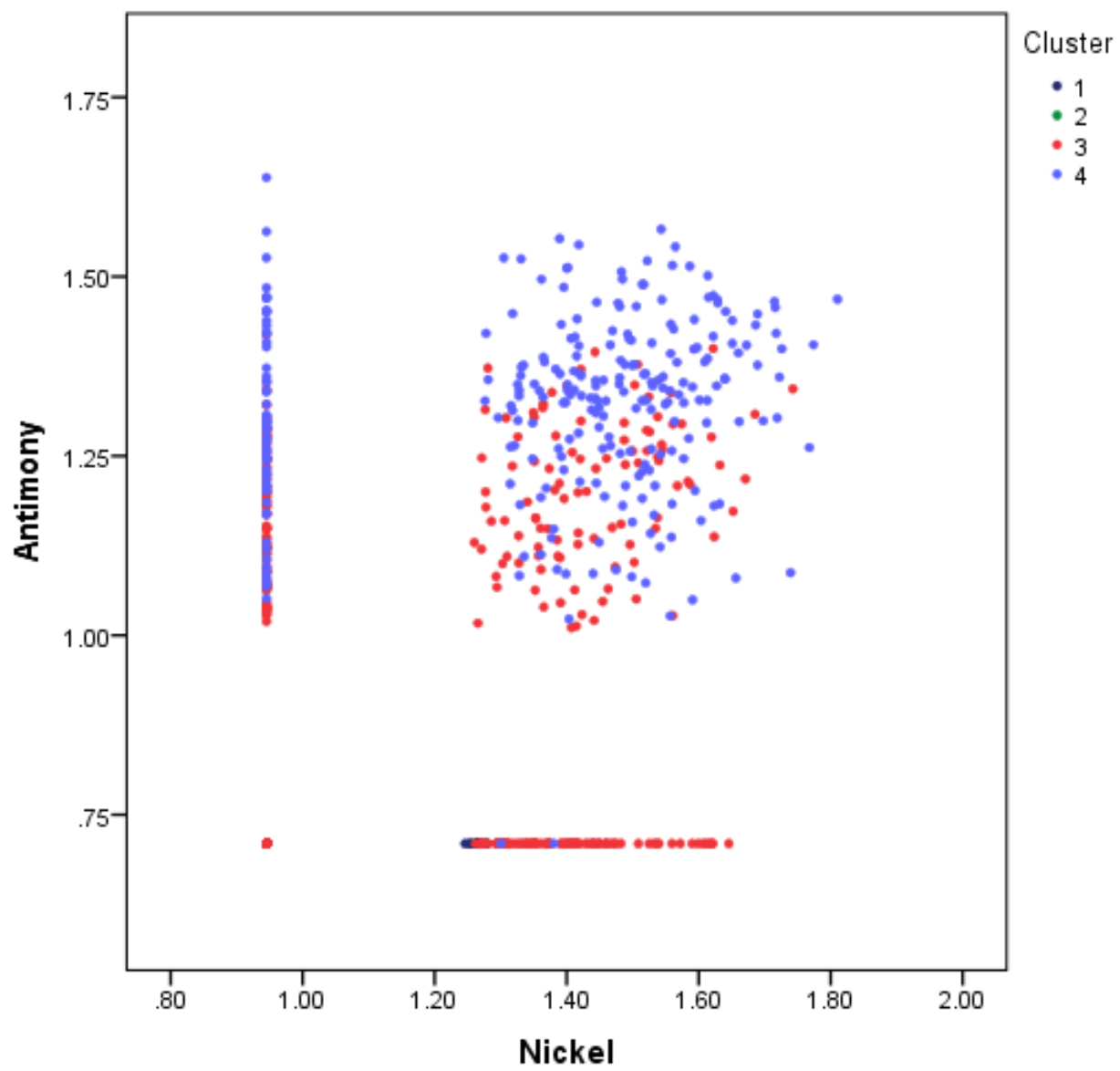
Figure 6-14 Nickel (log 10) and Tin (log 10) by Clusters
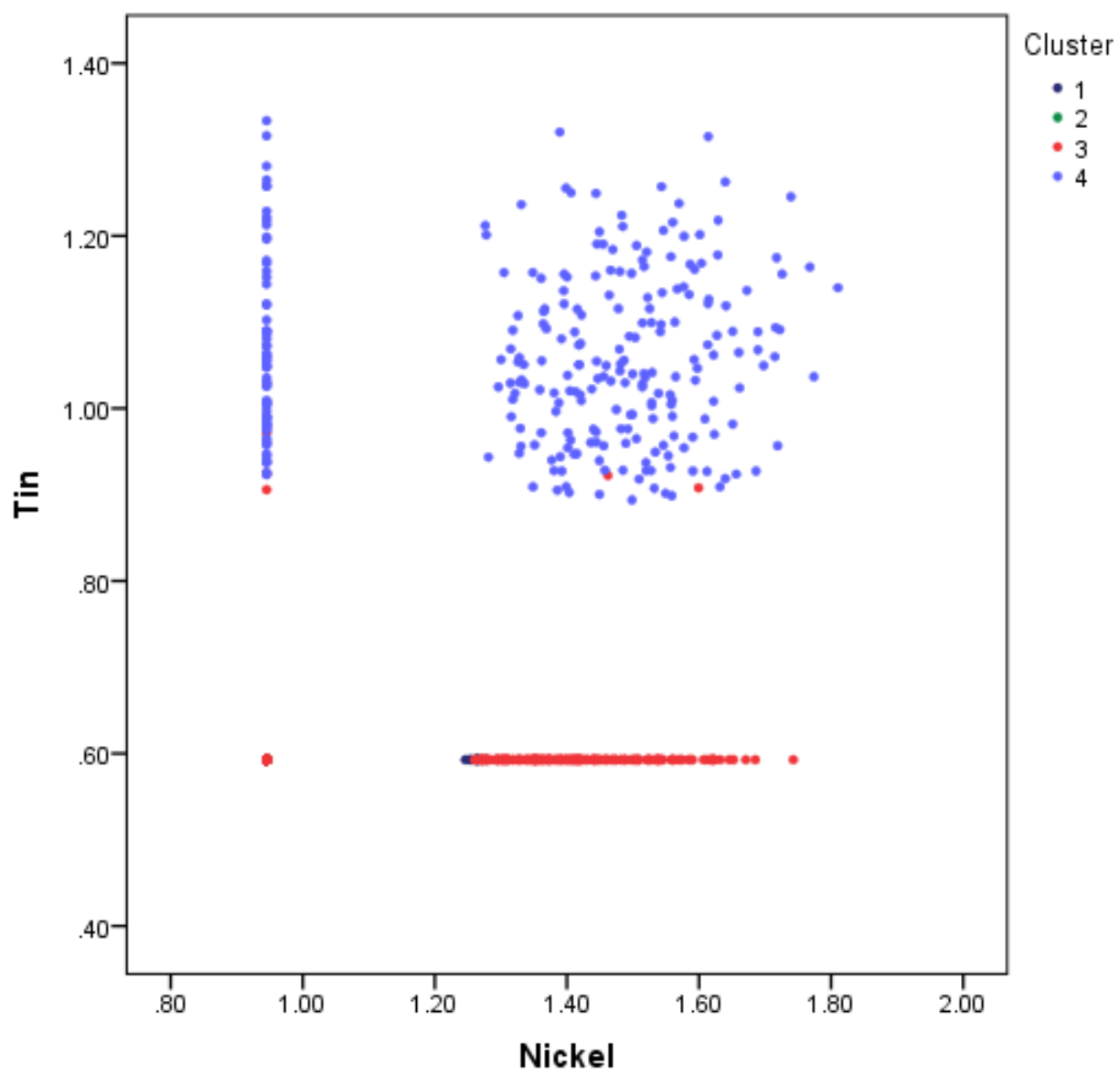
Figure 6-15 Antimony (log 10) and Tin (log 10) by Clusters
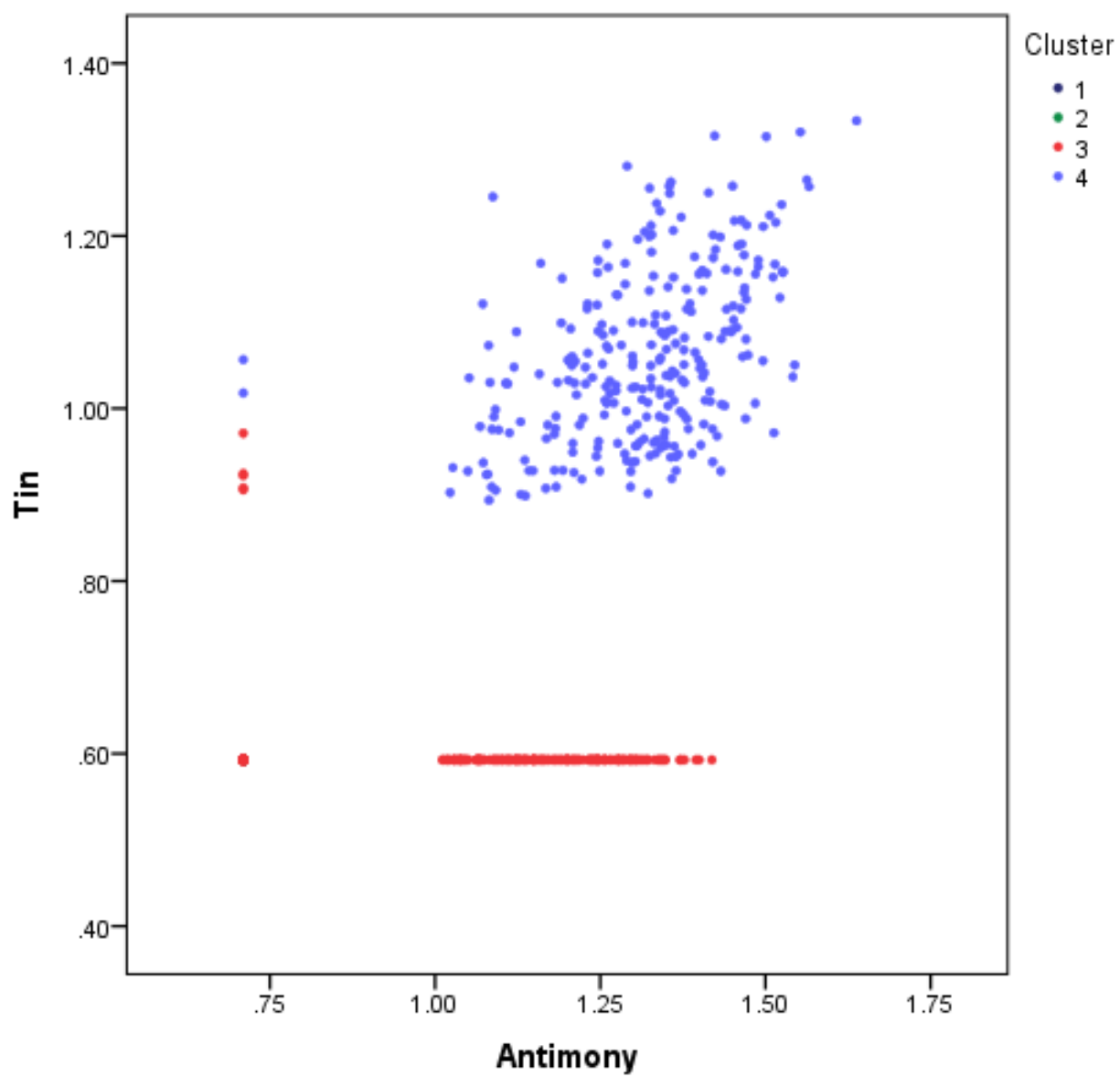
# Appendix 4: Archaeological Sites Broken Down by XU and Plotted Against Available SU Data and GSG Classifications

| Table 1: Edubu 1, XU by GSG Cluster | | | | | | 28 XUs | |
|---|---|---|---|---|---|---|---|
| **XU** | **Cluster** | | | | **Total** | **3 SUs** | **Chronological Period** |
| | **1** | **2** | **3** | **4** | | | |
| 1 Count | 9 | 2 | 6 | 0 | 17 | SU1 (XU 1-16) | Upper Cultural concentration (ca.2350 cal BP)(SU1, XU 1-16) |
| % within XU | 52.9% | 11.8% | 35.3% | 0.0% | 100.0% | | |
| % within Cluster | 6.3% | 2.9% | 11.5% | 0.0% | 5.7% | | |
| 2 Count | 14 | 2 | 4 | 5 | 25 | | |
| % within XU | 56.0% | 8.0% | 16.0% | 20.0% | 100.0% | | |
| % within Cluster | 9.7% | 2.9% | 7.7% | 14.7% | 8.4% | | |
| 3 Count | 16 | 6 | 3 | 2 | 27 | | |
| % within XU | 59.3% | 22.2% | 11.1% | 7.4% | 100.0% | | |
| % within Cluster | 11.1% | 8.8% | 5.8% | 5.9% | 9.1% | | |
| 4 Count | 15 | 4 | 7 | 5 | 31 | | |
| % within XU | 48.4% | 12.9% | 22.6% | 16.1% | 100.0% | | |
| % within Cluster | 10.4% | 5.9% | 13.5% | 14.7% | 10.4% | | |
| 5 Count | 5 | 7 | 5 | 2 | 19 | | |
| % within XU | 26.3% | 36.8% | 26.3% | 10.5% | 100.0% | | |
| % within Cluster | 3.5% | 10.3% | 9.6% | 5.9% | 6.4% | | |
| 6 Count | 25 | 11 | 4 | 3 | 43 | | |
| % within XU | 58.1% | 25.6% | 9.3% | 7.0% | 100.0% | | |
| % within Cluster | 17.4% | 16.2% | 7.7% | 8.8% | 14.4% | | |
| 7 Count | 6 | 5 | 0 | 0 | 11 | | |
| % within XU | 54.5% | 45.5% | 0.0% | 0.0% | 100.0% | | |
| % within Cluster | 4.2% | 7.4% | 0.0% | 0.0% | 3.7% | | |
| 8 Count | 3 | 6 | 3 | 3 | 15 | | |
| % within XU | 20.0% | 40.0% | 20.0% | 20.0% | 100.0% | | |
| % within Cluster | 2.1% | 8.8% | 5.8% | 8.8% | 5.0% | | |
| 9 Count | 12 | 2 | 3 | 2 | 19 | | |
| % within XU | 63.2% | 10.5% | 15.8% | 10.5% | 100.0% | | |
| % within Cluster | 8.3% | 2.9% | 5.8% | 5.9% | 6.4% | | |
| 10 Count | 5 | 3 | 3 | 2 | 13 | | |
| % within XU | 38.5% | 23.1% | 23.1% | 15.4% | 100.0% | | |
| % within Cluster | 3.5% | 4.4% | 5.8% | 5.9% | 4.4% | | |
| 11 Count | 6 | 3 | 1 | 1 | 11 | | |
| % within XU | 54.5% | 27.3% | 9.1% | 9.1% | 100.0% | | |
| % within Cluster | 4.2% | 4.4% | 1.9% | 2.9% | 3.7% | | |
| 12 Count | 5 | 2 | 4 | 1 | 12 | | |
| % within XU | 41.7% | 16.7% | 33.3% | 8.3% | 100.0% | | |
| % within Cluster | 3.5% | 2.9% | 7.7% | 2.9% | 4.0% | | |
| 13 Count | 2 | 0 | 0 | 1 | 3 | | |
| % within XU | 66.7% | 0.0% | 0.0% | 33.3% | 100.0% | | |
| % within Cluster | 1.4% | 0.0% | 0.0% | 2.9% | 1.0% | | |
| 14 Count | 2 | 0 | 0 | 0 | 2 | | |
| % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% | | |
| % within Cluster | 1.4% | 0.0% | 0.0% | 0.0% | .7% | | |

| XU | | Cluster 1 | 2 | 3 | 4 | Total | SU | Description |
|---|---|---|---|---|---|---|---|---|
| 15 | Count | 4 | 4 | 1 | 0 | 9 | | |
| | % within XU | 44.4% | 44.4% | 11.1% | 0.0% | 100.0% | | |
| | % within Cluster | 2.8% | 5.9% | 1.9% | 0.0% | 3.0% | | |
| 16 | Count | 1 | 1 | 0 | 2 | 4 | SU2 (XU16-23) | Middle Cultural concentration (ca.2500 cal BP) (SU2, XU 16-23) |
| | % within XU | 25.0% | 25.0% | 0.0% | 50.0% | 100.0% | | |
| | % within Cluster | .7% | 1.5% | 0.0% | 5.9% | 1.3% | | |
| 18 | Count | 2 | 2 | 1 | 0 | 5 | | |
| | % within XU | 40.0% | 40.0% | 20.0% | 0.0% | 100.0% | | |
| | % within Cluster | 1.4% | 2.9% | 1.9% | 0.0% | 1.7% | | |
| 19 | Count | 3 | 2 | 4 | 0 | 9 | | |
| | % within XU | 33.3% | 22.2% | 44.4% | 0.0% | 100.0% | | |
| | % within Cluster | 2.1% | 2.9% | 7.7% | 0.0% | 3.0% | | |
| 20 | Count | 3 | 1 | 0 | 4 | 8 | | |
| | % within XU | 37.5% | 12.5% | 0.0% | 50.0% | 100.0% | | |
| | % within Cluster | 2.1% | 1.5% | 0.0% | 11.8% | 2.7% | | |
| 21 | Count | 1 | 0 | 0 | 0 | 1 | | |
| | % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% | | |
| | % within Cluster | .7% | 0.0% | 0.0% | 0.0% | .3% | | |
| 22 | Count | 2 | 0 | 0 | 0 | 2 | | |
| | % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% | | |
| | % within Cluster | 1.4% | 0.0% | 0.0% | 0.0% | .7% | | |
| 24 | Count | 1 | 1 | 0 | 0 | 2 | | |
| | % within XU | 50.0% | 50.0% | 0.0% | 0.0% | 100.0% | | |
| | % within Cluster | .7% | 1.5% | 0.0% | 0.0% | .7% | | |
| 26 | Count | 0 | 0 | 1 | 0 | 1 | | |
| | % within XU | 0.0% | 0.0% | 100.0% | 0.0% | 100.0% | | |
| | % within Cluster | 0.0% | 0.0% | 1.9% | 0.0% | .3% | | |
| 27 | Count | 0 | 1 | 0 | 1 | 2 | SU3 (XU27-32) | Lower Cultural concentration (ca. 2500-2750 cal BP) (SU3, XU 27-32) |
| | % within XU | 0.0% | 50.0% | 0.0% | 50.0% | 100.0% | | |
| | % within Cluster | 0.0% | 1.5% | 0.0% | 2.9% | .7% | | |
| 28 | Count | 0 | 2 | 1 | 0 | 3 | | |
| | % within XU | 0.0% | 66.7% | 33.3% | 0.0% | 100.0% | | |
| | % within Cluster | 0.0% | 2.9% | 1.9% | 0.0% | 1.0% | | |
| 29 | Count | 1 | 0 | 1 | 0 | 2 | | |
| | % within XU | 50.0% | 0.0% | 50.0% | 0.0% | 100.0% | | |
| | % within Cluster | .7% | 0.0% | 1.9% | 0.0% | .7% | | |
| 31 | Count | 1 | 0 | 0 | 0 | 1 | | |
| | % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% | | |
| | % within Cluster | .7% | 0.0% | 0.0% | 0.0% | .3% | | |
| 32 | Count | 0 | 1 | 0 | 0 | 1 | | |
| | % within XU | 0.0% | 100.0% | 0.0% | 0.0% | 100.0% | | |
| | % within Cluster | 0.0% | 1.5% | 0.0% | 0.0% | .3% | | |
| Total | Count | 144 | 68 | 52 | 34 | 298 | | |
| | % within XU | 48% | 23% | 17% | 11% | 100.0% | | |
| | % within Cluster | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | | |

| Table 2: ABCE, XU by GSG Cluster | | | | | | 15 XUs | |
|---|---|---|---|---|---|---|---|
| XU | Cluster | | | | Total | 1 SU | Chonological Period |
| | 1 | 2 | 3 | 4 | | | |
| 1 Count | 6 | 1 | 6 | 1 | 14 | Square C is all related to Occupation 1, no other SU s recorded. | Occupation 1 |
| % within XU | 42.9% | 7.1% | 42.9% | 7.1% | 100.0% | | |
| % within Cluster | 8.2% | 2.3% | 21.4% | 5.9% | 8.6% | | |
| 2 Count | 7 | 4 | 4 | 3 | 18 | | |
| % within XU | 38.9% | 22.2% | 22.2% | 16.7% | 100.0% | | |
| % within Cluster | 9.6% | 9.1% | 14.3% | 17.6% | 11.1% | | |
| 3 Count | 10 | 5 | 5 | 4 | 24 | | |
| % within XU | 41.7% | 20.8% | 20.8% | 16.7% | 100.0% | | |
| % within Cluster | 13.7% | 11.4% | 17.9% | 23.5% | 14.8% | | |
| 4 Count | 14 | 6 | 3 | 4 | 27 | | |
| % within XU | 51.9% | 22.2% | 11.1% | 14.8% | 100.0% | | |
| % within Cluster | 19.2% | 13.6% | 10.7% | 23.5% | 16.7% | | |
| 5 Count | 6 | 8 | 1 | 1 | 16 | | |
| % within XU | 37.5% | 50.0% | 6.3% | 6.3% | 100.0% | | |
| % within Cluster | 8.2% | 18.2% | 3.6% | 5.9% | 9.9% | | |
| 6 Count | 11 | 4 | 1 | 1 | 17 | | |
| % within XU | 64.7% | 23.5% | 5.9% | 5.9% | 100.0% | | |
| % within Cluster | 15.1% | 9.1% | 3.6% | 5.9% | 10.5% | | |
| 7 Count | 7 | 5 | 2 | 1 | 15 | | |
| % within XU | 46.7% | 33.3% | 13.3% | 6.7% | 100.0% | | |
| % within Cluster | 9.6% | 11.4% | 7.1% | 5.9% | 9.3% | | |
| 8 Count | 5 | 2 | 4 | 2 | 13 | | |
| % within XU | 38.5% | 15.4% | 30.8% | 15.4% | 100.0% | | |
| % within Cluster | 6.8% | 4.5% | 14.3% | 11.8% | 8.0% | | |
| 9 Count | 2 | 3 | 0 | 0 | 5 | | Jerome's lithic break point |
| % within XU | 40.0% | 60.0% | 0.0% | 0.0% | 100.0% | | |
| % within Cluster | 2.7% | 6.8% | 0.0% | 0.0% | 3.1% | | |
| 10 Count | 1 | 1 | 1 | 0 | 3 | | |
| % within XU | 33.3% | 33.3% | 33.3% | 0.0% | 100.0% | | |
| % within Cluster | 1.4% | 2.3% | 3.6% | 0.0% | 1.9% | | |
| 11 Count | 3 | 2 | 1 | 0 | 6 | | |
| % within XU | 50.0% | 33.3% | 16.7% | 0.0% | 100.0% | | |
| % within Cluster | 4.1% | 4.5% | 3.6% | 0.0% | 3.7% | | |
| 12 Count | 0 | 1 | 0 | 0 | 1 | | |
| % within XU | 0.0% | 100.0% | 0.0% | 0.0% | 100.0% | | |
| % within Cluster | 0.0% | 2.3% | 0.0% | 0.0% | .6% | | |
| 13 Count | 0 | 1 | 0 | 0 | 1 | | |
| % within XU | 0.0% | 100.0% | 0.0% | 0.0% | 100.0% | | |
| % within Cluster | 0.0% | 2.3% | 0.0% | 0.0% | .6% | | |
| 14 Count | 1 | 0 | 0 | 0 | 1 | | |
| % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% | | |
| % within Cluster | 1.4% | 0.0% | 0.0% | 0.0% | .6% | | |
| 18 Count | 0 | 1 | 0 | 0 | 1 | | |
| % within XU | 0.0% | 100.0% | 0.0% | 0.0% | 100.0% | | |
| % within Cluster | 0.0% | 2.3% | 0.0% | 0.0% | .6% | | |
| Total Count | 73 | 44 | 28 | 17 | 162 | | |
| % within XU | 45.1% | 27.2% | 17.3% | 10.5% | 100.0% | | |
| % within Cluster | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | | |

| Table 3: Bogy 1, XU by GSG Cluster | | | | | | 76 XUs | |
|---|---|---|---|---|---|---|---|
| XU | Cluster | | | | Total | 3 SUs | Chonological Period |
| | 1 | 2 | 3 | 4 | | | |
| 1 Count | 1 | 0 | 1 | 0 | 2 | | |
| % within XU | 50.0% | 0.0% | 50.0% | 0.0% | 100.0% | | |
| % within Cluster | .2% | 0.0% | .6% | 0.0% | .2% | | |
| 2 Count | 13 | 2 | 7 | 1 | 23 | | |
| % within XU | 56.5% | 8.7% | 30.4% | 4.3% | 100.0% | | |
| % within Cluster | 3.0% | 1.0% | 4.0% | .9% | 2.5% | | |
| 3 Count | 19 | 8 | 17 | 6 | 50 | | |
| % within XU | 38.0% | 16.0% | 34.0% | 12.0% | 100.0% | | |
| % within Cluster | 4.4% | 4.2% | 9.6% | 5.6% | 5.5% | | |
| 4 Count | 38 | 7 | 17 | 5 | 67 | | |
| % within XU | 56.7% | 10.4% | 25.4% | 7.5% | 100.0% | | |
| % within Cluster | 8.8% | 3.7% | 9.6% | 4.7% | 7.4% | | |
| 5 Count | 29 | 24 | 12 | 0 | 65 | SU5-6 | |
| % within XU | 44.6% | 36.9% | 18.5% | 0.0% | 100.0% | | |
| % within Cluster | 6.7% | 12.6% | 6.8% | 0.0% | 7.2% | | |
| 6 Count | 25 | 10 | 10 | 0 | 45 | | |
| % within XU | 55.6% | 22.2% | 22.2% | 0.0% | 100.0% | | Phase 3·2000-2150 cal BP, XUs 5-35a |
| % within Cluster | 5.8% | 5.2% | 5.6% | 0.0% | 5.0% | | |
| 7 Count | 35 | 12 | 14 | 2 | 63 | | |
| % within XU | 55.6% | 19.0% | 22.2% | 3.2% | 100.0% | | |
| % within Cluster | 8.1% | 6.3% | 7.9% | 1.9% | 6.9% | | |
| 8 Count | 22 | 5 | 6 | 8 | 41 | | |
| % within XU | 53.7% | 12.2% | 14.6% | 19.5% | 100.0% | | |
| % within Cluster | 5.1% | 2.6% | 3.4% | 7.5% | 4.5% | | |
| 9 Count | 1 | 3 | 1 | 0 | 5 | | |
| % within XU | 20.0% | 60.0% | 20.0% | 0.0% | 100.0% | | |
| % within Cluster | .2% | 1.6% | .6% | 0.0% | .6% | | |
| 10 Count | 10 | 2 | 3 | 6 | 21 | | |
| % within XU | 47.6% | 9.5% | 14.3% | 28.6% | 100.0% | | |
| % within Cluster | 2.3% | 1.0% | 1.7% | 5.6% | 2.3% | | |
| 11 Count | 13 | 8 | 6 | 8 | 35 | | |
| % within XU | 37.1% | 22.9% | 17.1% | 22.9% | 100.0% | | |
| % within Cluster | 3.0% | 4.2% | 3.4% | 7.5% | 3.9% | | |
| 12 Count | 15 | 6 | 5 | 6 | 32 | | |
| % within XU | 46.9% | 18.8% | 15.6% | 18.8% | 100.0% | | |
| % within Cluster | 3.5% | 3.1% | 2.8% | 5.6% | 3.5% | | |
| 13 Count | 18 | 5 | 5 | 9 | 37 | | |
| % within XU | 48.6% | 13.5% | 13.5% | 24.3% | 100.0% | | |
| % within Cluster | 4.1% | 2.6% | 2.8% | 8.4% | 4.1% | | |
| 14 Count | 24 | 7 | 11 | 12 | 54 | | |
| % within XU | 44.4% | 13.0% | 20.4% | 22.2% | 100.0% | | |
| % within Cluster | 5.5% | 3.7% | 6.2% | 11.2% | 5.9% | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 15 | Count | 27 | 10 | 13 | 8 | 58 |
| | % within XU | 46.6% | 17.2% | 22.4% | 13.8% | 100.0% |
| | % within Cluster | 6.2% | 5.2% | 7.3% | 7.5% | 6.4% |
| 16 | Count | 21 | 12 | 6 | 4 | 43 |
| | % within XU | 48.8% | 27.9% | 14.0% | 9.3% | 100.0% |
| | % within Cluster | 4.8% | 6.3% | 3.4% | 3.7% | 4.7% |
| 17 | Count | 19 | 12 | 8 | 5 | 44 |
| | % within XU | 43.2% | 27.3% | 18.2% | 11.4% | 100.0% |
| | % within Cluster | 4.4% | 6.3% | 4.5% | 4.7% | 4.8% |
| 18 | Count | 12 | 3 | 2 | 5 | 22 |
| | % within XU | 54.5% | 13.6% | 9.1% | 22.7% | 100.0% |
| | % within Cluster | 2.8% | 1.6% | 1.1% | 4.7% | 2.4% |
| 19 | Count | 5 | 3 | 1 | 1 | 10 |
| | % within XU | 50.0% | 30.0% | 10.0% | 10.0% | 100.0% |
| | % within Cluster | 1.2% | 1.6% | .6% | .9% | 1.1% |
| 20 | Count | 6 | 2 | 2 | 3 | 13 |
| | % within XU | 46.2% | 15.4% | 15.4% | 23.1% | 100.0% |
| | % within Cluster | 1.4% | 1.0% | 1.1% | 2.8% | 1.4% |
| 21 | Count | 7 | 7 | 3 | 3 | 20 |
| | % within XU | 35.0% | 35.0% | 15.0% | 15.0% | 100.0% |
| | % within Cluster | 1.6% | 3.7% | 1.7% | 2.8% | 2.2% |
| 22 | Count | 5 | 0 | 2 | 1 | 8 |
| | % within XU | 62.5% | 0.0% | 25.0% | 12.5% | 100.0% |
| | % within Cluster | 1.2% | 0.0% | 1.1% | .9% | .9% |
| 23 | Count | 10 | 1 | 2 | 0 | 13 |
| | % within XU | 76.9% | 7.7% | 15.4% | 0.0% | 100.0% |
| | % within Cluster | 2.3% | .5% | 1.1% | 0.0% | 1.4% |
| 24 | Count | 3 | 6 | 0 | 0 | 9 |
| | % within XU | 33.3% | 66.7% | 0.0% | 0.0% | 100.0% |
| | % within Cluster | .7% | 3.1% | 0.0% | 0.0% | 1.0% |
| 25 | Count | 2 | 1 | 2 | 4 | 9 |
| | % within XU | 22.2% | 11.1% | 22.2% | 44.4% | 100.0% |
| | % within Cluster | .5% | .5% | 1.1% | 3.7% | 1.0% |
| 26 | Count | 4 | 5 | 1 | 1 | 11 |
| | % within XU | 36.4% | 45.5% | 9.1% | 9.1% | 100.0% |
| | % within Cluster | .9% | 2.6% | .6% | .9% | 1.2% |
| 27 | Count | 2 | 1 | 2 | 0 | 5 |
| | % within XU | 40.0% | 20.0% | 40.0% | 0.0% | 100.0% |
| | % within Cluster | .5% | .5% | 1.1% | 0.0% | .6% |
| 28 | Count | 3 | 0 | 2 | 2 | 7 |
| | % within XU | 42.9% | 0.0% | 28.6% | 28.6% | 100.0% |
| | % within Cluster | .7% | 0.0% | 1.1% | 1.9% | .8% |
| 29 | Count | 6 | 2 | 4 | 0 | 12 |
| | % within XU | 50.0% | 16.7% | 33.3% | 0.0% | 100.0% |
| | % within Cluster | 1.4% | 1.0% | 2.3% | 0.0% | 1.3% |

| | | | | | | |
|---|---|---|---|---|---|---|
| 30 Count | 3 | 2 | 1 | 0 | 6 | |
| % within XU | 50.0% | 33.3% | 16.7% | 0.0% | 100.0% | |
| % within Cluster | .7% | 1.0% | .6% | 0.0% | .7% | |
| 31 Count | 3 | 0 | 0 | 0 | 3 | |
| % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% | |
| % within Cluster | .7% | 0.0% | 0.0% | 0.0% | .3% | |
| 32 Count | 1 | 2 | 1 | 0 | 4 | |
| % within XU | 25.0% | 50.0% | 25.0% | 0.0% | 100.0% | |
| % within Cluster | .2% | 1.0% | .6% | 0.0% | .4% | |
| 33 Count | 0 | 2 | 0 | 0 | 2 | |
| % within XU | 0.0% | 100.0% | 0.0% | 0.0% | 100.0% | |
| % within Cluster | 0.0% | 1.0% | 0.0% | 0.0% | .2% | |
| 34 Count | 2 | 1 | 1 | 1 | 5 | |
| % within XU | 40.0% | 20.0% | 20.0% | 20.0% | 100.0% | |
| % within Cluster | .5% | .5% | .6% | .9% | .6% | |
| 35 Count | 2 | 1 | 1 | 0 | 4 | |
| % within XU | 50.0% | 25.0% | 25.0% | 0.0% | 100.0% | |
| % within Cluster | .5% | .5% | .6% | 0.0% | .4% | |
| 36 Count | 2 | 0 | 0 | 0 | 2 | |
| % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% | |
| % within Cluster | .5% | 0.0% | 0.0% | 0.0% | .2% | |
| 37 Count | 1 | 1 | 1 | 0 | 3 | |
| % within XU | 33.3% | 33.3% | 33.3% | 0.0% | 100.0% | |
| % within Cluster | .2% | .5% | .6% | 0.0% | .3% | |
| 39 Count | 1 | 0 | 0 | 0 | 1 | |
| % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% | |
| % within Cluster | .2% | 0.0% | 0.0% | 0.0% | .1% | |
| 42 Count | 0 | 0 | 0 | 1 | 1 | |
| % within XU | 0.0% | 0.0% | 0.0% | 100.0% | 100.0% | |
| % within Cluster | 0.0% | 0.0% | 0.0% | .9% | .1% | |
| 43 Count | 1 | 0 | 0 | 0 | 1 | |
| % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% | |
| % within Cluster | .2% | 0.0% | 0.0% | 0.0% | .1% | |
| 45 Count | 0 | 1 | 0 | 0 | 1 | |
| % within XU | 0.0% | 100.0% | 0.0% | 0.0% | 100.0% | |
| % within Cluster | 0.0% | .5% | 0.0% | 0.0% | .1% | |
| 47 Count | 0 | 1 | 0 | 0 | 1 | |
| % within XU | 0.0% | 100.0% | 0.0% | 0.0% | 100.0% | |
| % within Cluster | 0.0% | .5% | 0.0% | 0.0% | .1% | |
| 48 Count | 1 | 1 | 0 | 0 | 2 | SU7a |
| % within XU | 50.0% | 50.0% | 0.0% | 0.0% | 100.0% | |
| % within Cluster | .2% | .5% | 0.0% | 0.0% | .2% | |
| 52 Count | 0 | 0 | 2 | 0 | 2 | |
| % within XU | 0.0% | 0.0% | 100.0% | 0.0% | 100.0% | |
| % within Cluster | 0.0% | 0.0% | 1.1% | 0.0% | .2% | |

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| | | | | | | |
|---|---|---|---|---|---|---|
| 53 | Count | 1 | 0 | 0 | 2 | 3 |
| | % within XU | 33.3% | 0.0% | 0.0% | 66.7% | 100.0% |
| | % within Cluster | .2% | 0.0% | 0.0% | 1.9% | .3% |
| 55 | Count | 0 | 0 | 0 | 1 | 1 |
| | % within XU | 0.0% | 0.0% | 0.0% | 100.0% | 100.0% |
| | % within Cluster | 0.0% | 0.0% | 0.0% | .9% | .1% |
| 59 | Count | 3 | 0 | 1 | 0 | 4 |
| | % within XU | 75.0% | 0.0% | 25.0% | 0.0% | 100.0% |
| | % within Cluster | .7% | 0.0% | .6% | 0.0% | .4% |
| 61 | Count | 1 | 1 | 0 | 0 | 2 |
| | % within XU | 50.0% | 50.0% | 0.0% | 0.0% | 100.0% |
| | % within Cluster | .2% | .5% | 0.0% | 0.0% | .2% |
| 62 | Count | 0 | 1 | 0 | 0 | 1 |
| | % within XU | 0.0% | 100.0% | 0.0% | 0.0% | 100.0% |
| | % within Cluster | 0.0% | .5% | 0.0% | 0.0% | .1% |
| 63 | Count | 0 | 2 | 0 | 0 | 2 |
| | % within XU | 0.0% | 100.0% | 0.0% | 0.0% | 100.0% |
| | % within Cluster | 0.0% | 1.0% | 0.0% | 0.0% | .2% |
| 64 | Count | 0 | 1 | 0 | 0 | 1 |
| | % within XU | 0.0% | 100.0% | 0.0% | 0.0% | 100.0% |
| | % within Cluster | 0.0% | .5% | 0.0% | 0.0% | .1% |
| 65 | Count | 1 | 1 | 0 | 0 | 2 |
| | % within XU | 50.0% | 50.0% | 0.0% | 0.0% | 100.0% |
| | % within Cluster | .2% | .5% | 0.0% | 0.0% | .2% |
| 66 | Count | 0 | 0 | 0 | 1 | 1 |
| | % within XU | 0.0% | 0.0% | 0.0% | 100.0% | 100.0% |
| | % within Cluster | 0.0% | 0.0% | 0.0% | .9% | .1% |
| 67 | Count | 1 | 0 | 0 | 0 | 1 |
| | % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% |
| | % within Cluster | .2% | 0.0% | 0.0% | 0.0% | .1% |
| 69 | Count | 1 | 1 | 0 | 0 | 2 |
| | % within XU | 50.0% | 50.0% | 0.0% | 0.0% | 100.0% |
| | % within Cluster | .2% | .5% | 0.0% | 0.0% | .2% |
| 70 | Count | 3 | 0 | 0 | 0 | 3 |
| | % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% |
| | % within Cluster | .7% | 0.0% | 0.0% | 0.0% | .3% |
| 75 | Count | 0 | 3 | 0 | 0 | 3 |
| | % within XU | 0.0% | 100.0% | 0.0% | 0.0% | 100.0% |
| | % within Cluster | 0.0% | 1.6% | 0.0% | 0.0% | .3% |
| 76 | Count | 1 | 0 | 0 | 0 | 1 |
| | % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% |
| | % within Cluster | .2% | 0.0% | 0.0% | 0.0% | .1% |
| 78 | Count | 0 | 0 | 1 | 0 | 1 |
| | % within XU | 0.0% | 0.0% | 100.0% | 0.0% | 100.0% |
| | % within Cluster | 0.0% | 0.0% | .6% | 0.0% | .1% |

| XU | | | | | | Total | |
|---|---|---|---|---|---|---|---|
| 79 | Count | 0 | 0 | 1 | 0 | 1 | SU8? |
| | % within XU | 0.0% | 0.0% | 100.0% | 0.0% | 100.0% | |
| | % within Cluster | 0.0% | 0.0% | .6% | 0.0% | .1% | |
| 80 | Count | 0 | 0 | 1 | 0 | 1 | |
| | % within XU | 0.0% | 0.0% | 100.0% | 0.0% | 100.0% | |
| | % within Cluster | 0.0% | 0.0% | .6% | 0.0% | .1% | |
| 81 | Count | 0 | 0 | 0 | 1 | 1 | |
| | % within XU | 0.0% | 0.0% | 0.0% | 100.0% | 100.0% | |
| | % within Cluster | 0.0% | 0.0% | 0.0% | .9% | .1% | |
| 84 | Count | 1 | 0 | 0 | 0 | 1 | |
| | % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% | |
| | % within Cluster | .2% | 0.0% | 0.0% | 0.0% | .1% | |
| 88 | Count | 0 | 1 | 0 | 0 | 1 | |
| | % within XU | 0.0% | 100.0% | 0.0% | 0.0% | 100.0% | |
| | % within Cluster | 0.0% | .5% | 0.0% | 0.0% | .1% | |
| 91 | Count | 3 | 0 | 0 | 0 | 3 | |
| | % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% | |
| | % within Cluster | .7% | 0.0% | 0.0% | 0.0% | .3% | |
| 93 | Count | 1 | 0 | 0 | 0 | 1 | |
| | % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% | |
| | % within Cluster | .2% | 0.0% | 0.0% | 0.0% | .1% | |
| 96 | Count | 0 | 1 | 0 | 0 | 1 | |
| | % within XU | 0.0% | 100.0% | 0.0% | 0.0% | 100.0% | |
| | % within Cluster | 0.0% | .5% | 0.0% | 0.0% | .1% | |
| 97 | Count | 1 | 0 | 0 | 0 | 1 | |
| | % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% | |
| | % within Cluster | .2% | 0.0% | 0.0% | 0.0% | .1% | |
| 98 | Count | 1 | 0 | 0 | 0 | 1 | |
| | % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% | |
| | % within Cluster | .2% | 0.0% | 0.0% | 0.0% | .1% | |
| 100 | Count | 0 | 1 | 0 | 0 | 1 | |
| | % within XU | 0.0% | 100.0% | 0.0% | 0.0% | 100.0% | |
| | % within Cluster | 0.0% | .5% | 0.0% | 0.0% | .1% | |
| 101 | Count | 1 | 0 | 0 | 0 | 1 | |
| | % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% | |
| | % within Cluster | .2% | 0.0% | 0.0% | 0.0% | .1% | |
| 102 | Count | 1 | 0 | 0 | 0 | 1 | |
| | % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% | |
| | % within Cluster | .2% | 0.0% | 0.0% | 0.0% | .1% | |
| 108 | Count | 1 | 0 | 0 | 0 | 1 | |
| | % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% | |
| | % within Cluster | .2% | 0.0% | 0.0% | 0.0% | .1% | |
| 122 | Count | 0 | 1 | 0 | 0 | 1 | |
| | % within XU | 0.0% | 100.0% | 0.0% | 0.0% | 100.0% | |
| | % within Cluster | 0.0% | .5% | 0.0% | 0.0% | .1% | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 141 Count | 0 | 1 | 0 | 0 | 1 | |
| % within XU | 0.0% | 100.0% | 0.0% | 0.0% | 100.0% | |
| % within Cluster | 0.0% | .5% | 0.0% | 0.0% | .1% | |
| 144 Count | 0 | 0 | 1 | 0 | 1 | |
| % within XU | 0.0% | 0.0% | 100.0% | 0.0% | 100.0% | |
| % within Cluster | 0.0% | 0.0% | .6% | 0.0% | .1% | |
| Total Count | 434 | 191 | 177 | 107 | 909 | |
| % within XU | 47.7% | 21.0% | 19.5% | 11.8% | 100.0% | |
| % within Cluster | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | |

| Table 4: Ataga 1, XU by GSG Cluster | | | | | | 23 XUs | |
| --- | --- | --- | --- | --- | --- | --- | --- |
| XU | Cluster | | | | Total | SUs | Chonological Period |
| | 1 | 2 | 3 | 4 | | | |
| 1 Count | 2 | 8 | 0 | 0 | 10 | | |
| % within XU | 20.0% | 80.0% | 0.0% | 0.0% | 100.0% | | |
| % within Cluster | 2.9% | 9.4% | 0.0% | 0.0% | 5.5% | | |
| 2 Count | 7 | 11 | 1 | 0 | 19 | | |
| % within XU | 36.8% | 57.9% | 5.3% | 0.0% | 100.0% | | |
| % within Cluster | 10.3% | 12.9% | 5.9% | 0.0% | 10.4% | | |
| 3 Count | 5 | 4 | 4 | 0 | 13 | | |
| % within XU | 38.5% | 30.8% | 30.8% | 0.0% | 100.0% | | |
| % within Cluster | 7.4% | 4.7% | 23.5% | 0.0% | 7.1% | | |
| 4 Count | 6 | 5 | 1 | 2 | 14 | | |
| % within XU | 42.9% | 35.7% | 7.1% | 14.3% | 100.0% | | |
| % within Cluster | 8.8% | 5.9% | 5.9% | 16.7% | 7.7% | | |
| 5 Count | 2 | 3 | 1 | 1 | 7 | | |
| % within XU | 28.6% | 42.9% | 14.3% | 14.3% | 100.0% | | |
| % within Cluster | 2.9% | 3.5% | 5.9% | 8.3% | 3.8% | | |
| 6 Count | 4 | 11 | 1 | 0 | 16 | | |
| % within XU | 25.0% | 68.8% | 6.3% | 0.0% | 100.0% | | |
| % within Cluster | 5.9% | 12.9% | 5.9% | 0.0% | 8.8% | | |
| 7 Count | 2 | 5 | 0 | 1 | 8 | | |
| % within XU | 25.0% | 62.5% | 0.0% | 12.5% | 100.0% | | |
| % within Cluster | 2.9% | 5.9% | 0.0% | 8.3% | 4.4% | | |
| 8 Count | 2 | 4 | 0 | 0 | 6 | | |
| % within XU | 33.3% | 66.7% | 0.0% | 0.0% | 100.0% | | |
| % within Cluster | 2.9% | 4.7% | 0.0% | 0.0% | 3.3% | | |
| 9 Count | 7 | 5 | 2 | 1 | 15 | | |
| % within XU | 46.7% | 33.3% | 13.3% | 6.7% | 100.0% | | |
| % within Cluster | 10.3% | 5.9% | 11.8% | 8.3% | 8.2% | | |
| 10 Count | 7 | 4 | 3 | 3 | 17 | | |
| % within XU | 41.2% | 23.5% | 17.6% | 17.6% | 100.0% | | |
| % within Cluster | 10.3% | 4.7% | 17.6% | 25.0% | 9.3% | | |
| 11 Count | 6 | 9 | 1 | 2 | 18 | | |
| % within XU | 33.3% | 50.0% | 5.6% | 11.1% | 100.0% | | |
| % within Cluster | 8.8% | 10.6% | 5.9% | 16.7% | 9.9% | | |
| 12 Count | 5 | 4 | 1 | 0 | 10 | | |
| % within XU | 50.0% | 40.0% | 10.0% | 0.0% | 100.0% | | |
| % within Cluster | 7.4% | 4.7% | 5.9% | 0.0% | 5.5% | | |
| 13 Count | 1 | 3 | 0 | 0 | 4 | | |
| % within XU | 25.0% | 75.0% | 0.0% | 0.0% | 100.0% | | |
| % within Cluster | 1.5% | 3.5% | 0.0% | 0.0% | 2.2% | | |
| 14 Count | 4 | 1 | 1 | 1 | 7 | | |
| % within XU | 57.1% | 14.3% | 14.3% | 14.3% | 100.0% | | |
| % within Cluster | 5.9% | 1.2% | 5.9% | 8.3% | 3.8% | | |

| | | | | | | |
|---|---|---:|---:|---:|---:|---:|
| 15 | Count | 2 | 0 | 0 | 0 | 2 |
| | % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% |
| | % within Cluster | 2.9% | 0.0% | 0.0% | 0.0% | 1.1% |
| 16 | Count | 1 | 4 | 0 | 1 | 6 |
| | % within XU | 16.7% | 66.7% | 0.0% | 16.7% | 100.0% |
| | % within Cluster | 1.5% | 4.7% | 0.0% | 8.3% | 3.3% |
| 17 | Count | 2 | 1 | 0 | 0 | 3 |
| | % within XU | 66.7% | 33.3% | 0.0% | 0.0% | 100.0% |
| | % within Cluster | 2.9% | 1.2% | 0.0% | 0.0% | 1.6% |
| 18 | Count | 1 | 0 | 0 | 0 | 1 |
| | % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% |
| | % within Cluster | 1.5% | 0.0% | 0.0% | 0.0% | .5% |
| 19 | Count | 0 | 1 | 0 | 0 | 1 |
| | % within XU | 0.0% | 100.0% | 0.0% | 0.0% | 100.0% |
| | % within Cluster | 0.0% | 1.2% | 0.0% | 0.0% | .5% |
| 20 | Count | 1 | 1 | 0 | 0 | 2 |
| | % within XU | 50.0% | 50.0% | 0.0% | 0.0% | 100.0% |
| | % within Cluster | 1.5% | 1.2% | 0.0% | 0.0% | 1.1% |
| 22 | Count | 0 | 1 | 0 | 0 | 1 |
| | % within XU | 0.0% | 100.0% | 0.0% | 0.0% | 100.0% |
| | % within Cluster | 0.0% | 1.2% | 0.0% | 0.0% | .5% |
| 23 | Count | 0 | 0 | 1 | 0 | 1 |
| | % within XU | 0.0% | 0.0% | 100.0% | 0.0% | 100.0% |
| | % within Cluster | 0.0% | 0.0% | 5.9% | 0.0% | .5% |
| 24 | Count | 1 | 0 | 0 | 0 | 1 |
| | % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% |
| | % within Cluster | 1.5% | 0.0% | 0.0% | 0.0% | .5% |
| Total | Count | 68 | 85 | 17 | 12 | 182 |
| | % within XU | 37.4% | 46.7% | 9.3% | 6.6% | 100.0% |
| | % within Cluster | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |

| Table 5: AAUG, XU by GSG Cluster | | | | | | 14 XUs | |
|---|---|---|---|---|---|---|---|
| **XU** | **Cluster** | | | | **Total** | **2 SUs** | **Chonological Period** |
| | **1** | **2** | **3** | **4** | | | |
| 1 Count | 2 | 3 | 0 | 0 | 5 | SU1 (XU1-9) | |
| % within XU | 40.0% | 60.0% | 0.0% | 0.0% | 100.0% | | |
| % within Cluster | 1.4% | 4.4% | 0.0% | 0.0% | 1.9% | | |
| 2 Count | 2 | 3 | 0 | 0 | 5 | | |
| % within XU | 40.0% | 60.0% | 0.0% | 0.0% | 100.0% | | |
| % within Cluster | 1.4% | 4.4% | 0.0% | 0.0% | 1.9% | | |
| 3 Count | 9 | 1 | 2 | 3 | 15 | | |
| % within XU | 60.0% | 6.7% | 13.3% | 20.0% | 100.0% | | |
| % within Cluster | 6.1% | 1.5% | 6.7% | 15.8% | 5.7% | | |
| 4 Count | 6 | 0 | 0 | 0 | 6 | | |
| % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% | | |
| % within Cluster | 4.1% | 0.0% | 0.0% | 0.0% | 2.3% | | |
| 5 Count | 10 | 7 | 2 | 1 | 20 | | |
| % within XU | 50.0% | 35.0% | 10.0% | 5.0% | 100.0% | | |
| % within Cluster | 6.8% | 10.3% | 6.7% | 5.3% | 7.5% | | |
| 6 Count | 13 | 6 | 6 | 1 | 26 | SU2 (XU 6-13) | Major occupation 2350-1950 cal BP. |
| % within XU | 50.0% | 23.1% | 23.1% | 3.8% | 100.0% | | |
| % within Cluster | 8.8% | 8.8% | 20.0% | 5.3% | 9.8% | | |
| 7 Count | 11 | 8 | 2 | 1 | 22 | | |
| % within XU | 50.0% | 36.4% | 9.1% | 4.5% | 100.0% | | |
| % within Cluster | 7.4% | 11.8% | 6.7% | 5.3% | 8.3% | | |
| 8 Count | 18 | 14 | 2 | 2 | 36 | | |
| % within XU | 50.0% | 38.9% | 5.6% | 5.6% | 100.0% | | |
| % within Cluster | 12.2% | 20.6% | 6.7% | 10.5% | 13.6% | | |
| 9 Count | 32 | 7 | 4 | 6 | 49 | | |
| % within XU | 65.3% | 14.3% | 8.2% | 12.2% | 100.0% | | |
| % within Cluster | 21.6% | 10.3% | 13.3% | 31.6% | 18.5% | | |
| 10 Count | 14 | 9 | 6 | 1 | 30 | | |
| % within XU | 46.7% | 30.0% | 20.0% | 3.3% | 100.0% | | |
| % within Cluster | 9.5% | 13.2% | 20.0% | 5.3% | 11.3% | | |
| 11 Count | 6 | 1 | 2 | 0 | 9 | | |
| % within XU | 66.7% | 11.1% | 22.2% | 0.0% | 100.0% | | |
| % within Cluster | 4.1% | 1.5% | 6.7% | 0.0% | 3.4% | | |
| 12 Count | 5 | 2 | 1 | 2 | 10 | | |
| % within XU | 50.0% | 20.0% | 10.0% | 20.0% | 100.0% | | |
| % within Cluster | 3.4% | 2.9% | 3.3% | 10.5% | 3.8% | | |
| 13 Count | 12 | 5 | 1 | 1 | 19 | | |
| % within XU | 63.2% | 26.3% | 5.3% | 5.3% | 100.0% | | |
| % within Cluster | 8.1% | 7.4% | 3.3% | 5.3% | 7.2% | | |
| 14 Count | 8 | 2 | 2 | 1 | 13 | | |
| % within XU | 61.5% | 15.4% | 15.4% | 7.7% | 100.0% | | |
| % within Cluster | 5.4% | 2.9% | 6.7% | 5.3% | 4.9% | | |
| Total Count | 148 | 68 | 30 | 19 | 265 | | |
| % within XU | 55.8% | 25.7% | 11.3% | 7.2% | 100.0% | | |
| % within Cluster | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | | |

| Table 6: AASI, XU by GSG Cluster | | | | | | 9 XUs | |
|---|---|---|---|---|---|---|---|
| **XU** | **Cluster** | | | | **Total** | **3 SUs** | **Chonological Period** |
| | **1** | **2** | **3** | **4** | | | |
| 1 Count | 7 | 1 | 6 | 2 | 16 | SU1 (XU1-6) / SU2 (XU1-11) / SU3 (XU 8-22) - not cultural | One Occupation phase |
| % within XU | 43.8% | 6.3% | 37.5% | 12.5% | 100.0% | | |
| % within Cluster | 46.7% | 16.7% | 85.7% | 100.0% | 53.3% | | |
| 2 Count | 3 | 0 | 1 | 0 | 4 | | |
| % within XU | 75.0% | 0.0% | 25.0% | 0.0% | 100.0% | | |
| % within Cluster | 20.0% | 0.0% | 14.3% | 0.0% | 13.3% | | |
| 3 Count | 0 | 1 | 0 | 0 | 1 | | |
| % within XU | 0.0% | 100.0% | 0.0% | 0.0% | 100.0% | | |
| % within Cluster | 0.0% | 16.7% | 0.0% | 0.0% | 3.3% | | |
| 4 Count | 2 | 2 | 0 | 0 | 4 | | |
| % within XU | 50.0% | 50.0% | 0.0% | 0.0% | 100.0% | | |
| % within Cluster | 13.3% | 33.3% | 0.0% | 0.0% | 13.3% | | |
| 5 Count | 0 | 1 | 0 | 0 | 1 | | |
| % within XU | 0.0% | 100.0% | 0.0% | 0.0% | 100.0% | | |
| % within Cluster | 0.0% | 16.7% | 0.0% | 0.0% | 3.3% | | |
| 6 Count | 1 | 0 | 0 | 0 | 1 | | |
| % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% | | |
| % within Cluster | 6.7% | 0.0% | 0.0% | 0.0% | 3.3% | | |
| 8 Count | 0 | 1 | 0 | 0 | 1 | | |
| % within XU | 0.0% | 100.0% | 0.0% | 0.0% | 100.0% | | |
| % within Cluster | 0.0% | 16.7% | 0.0% | 0.0% | 3.3% | | |
| 9 Count | 1 | 0 | 0 | 0 | 1 | | |
| % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% | | |
| % within Cluster | 6.7% | 0.0% | 0.0% | 0.0% | 3.3% | | |
| 13 Count | 1 | 0 | 0 | 0 | 1 | | |
| % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% | | |
| % within Cluster | 6.7% | 0.0% | 0.0% | 0.0% | 3.3% | | |
| Total Count | 15 | 6 | 7 | 2 | 30 | | |
| % within XU | 50.0% | 20.0% | 23.3% | 6.7% | 100.0% | | |
| % within Cluster | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | | |

| Table 7: Tanamu 1, XU by GSG Cluster | | | | | | 54 XUs | |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **XU** | **Cluster** | | | | **Total** | **8 SUs** | **Chonological Period** |
| | **1** | **2** | **3** | **4** | | | |
| 1 Count | 1 | 1 | 0 | 0 | 2 | SU1a ( XU 1-6) | Upper Horizon A- c.100-200 cal BP, XU1-6 |
| % within XU | 50.0% | 50.0% | 0.0% | 0.0% | 100.0% | | |
| % within Cluster | 1.5% | 3.6% | 0.0% | 0.0% | 1.3% | | |
| 2 Count | 2 | 1 | 1 | 3 | 7 | | |
| % within XU | 28.6% | 14.3% | 14.3% | 42.9% | 100.0% | | |
| % within Cluster | 3.1% | 3.6% | 3.4% | 10.3% | 4.6% | | |
| 3 Count | 8 | 6 | 5 | 0 | 19 | | |
| % within XU | 42.1% | 31.6% | 26.3% | 0.0% | 100.0% | | |
| % within Cluster | 12.3% | 21.4% | 17.2% | 0.0% | 12.6% | | |
| 4 Count | 8 | 3 | 2 | 1 | 14 | | |
| % within XU | 57.1% | 21.4% | 14.3% | 7.1% | 100.0% | | |
| % within Cluster | 12.3% | 10.7% | 6.9% | 3.4% | 9.3% | | |
| 5 Count | 6 | 3 | 1 | 4 | 14 | | |
| % within XU | 42.9% | 21.4% | 7.1% | 28.6% | 100.0% | | |
| % within Cluster | 9.2% | 10.7% | 3.4% | 13.8% | 9.3% | | |
| 7 Count | 0 | 0 | 0 | 1 | 1 | SU1b (XU 7-10) | |
| % within XU | 0.0% | 0.0% | 0.0% | 100.0% | 100.0% | | |
| % within Cluster | 0.0% | 0.0% | 0.0% | 3.4% | .7% | | |
| 12 Count | 0 | 0 | 0 | 1 | 1 | SU2 (XU 11-21) | |
| % within XU | 0.0% | 0.0% | 0.0% | 100.0% | 100.0% | | |
| % within Cluster | 0.0% | 0.0% | 0.0% | 3.4% | .7% | | |
| 14 Count | 1 | 1 | 3 | 0 | 5 | | |
| % within XU | 20.0% | 20.0% | 60.0% | 0.0% | 100.0% | | |
| % within Cluster | 1.5% | 3.6% | 10.3% | 0.0% | 3.3% | | |
| 15 Count | 1 | 0 | 0 | 0 | 1 | | |
| % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% | | |
| % within Cluster | 1.5% | 0.0% | 0.0% | 0.0% | .7% | | |
| 16 Count | 1 | 0 | 1 | 1 | 3 | | |
| % within XU | 33.3% | 0.0% | 33.3% | 33.3% | 100.0% | | |
| % within Cluster | 1.5% | 0.0% | 3.4% | 3.4% | 2.0% | | |
| 18 Count | 2 | 1 | 0 | 0 | 3 | | |
| % within XU | 66.7% | 33.3% | 0.0% | 0.0% | 100.0% | | |
| % within Cluster | 3.1% | 3.6% | 0.0% | 0.0% | 2.0% | | |
| 19 Count | 2 | 3 | 0 | 0 | 5 | | |
| % within XU | 40.0% | 60.0% | 0.0% | 0.0% | 100.0% | | |
| % within Cluster | 3.1% | 10.7% | 0.0% | 0.0% | 3.3% | | |
| 20 Count | 1 | 0 | 1 | 0 | 2 | | |
| % within XU | 50.0% | 0.0% | 50.0% | 0.0% | 100.0% | | |
| % within Cluster | 1.5% | 0.0% | 3.4% | 0.0% | 1.3% | | |
| 21 Count | 2 | 0 | 2 | 0 | 4 | | |
| % within XU | 50.0% | 0.0% | 50.0% | 0.0% | 100.0% | | |
| % within Cluster | 3.1% | 0.0% | 6.9% | 0.0% | 2.6% | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 23 | Count | 1 | 0 | 0 | 0 | 1 | | |
| | % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% | | |
| | % within Cluster | 1.5% | 0.0% | 0.0% | 0.0% | .7% | | |
| 25 | Count | 1 | 0 | 1 | 0 | 2 | SU3 (XU24-34) | Middle Horizon-c.2800-2750 cal BP, XU 24-34 |
| | % within XU | 50.0% | 0.0% | 50.0% | 0.0% | 100.0% | | |
| | % within Cluster | 1.5% | 0.0% | 3.4% | 0.0% | 1.3% | | |
| 26 | Count | 1 | 0 | 0 | 0 | 1 | | |
| | % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% | | |
| | % within Cluster | 1.5% | 0.0% | 0.0% | 0.0% | .7% | | |
| 27 | Count | 0 | 0 | 0 | 1 | 1 | | |
| | % within XU | 0.0% | 0.0% | 0.0% | 100.0% | 100.0% | | |
| | % within Cluster | 0.0% | 0.0% | 0.0% | 3.4% | .7% | | |
| 29 | Count | 0 | 1 | 1 | 0 | 2 | | |
| | % within XU | 0.0% | 50.0% | 50.0% | 0.0% | 100.0% | | |
| | % within Cluster | 0.0% | 3.6% | 3.4% | 0.0% | 1.3% | | |
| 31 | Count | 1 | 0 | 2 | 1 | 4 | | |
| | % within XU | 25.0% | 0.0% | 50.0% | 25.0% | 100.0% | | |
| | % within Cluster | 1.5% | 0.0% | 6.9% | 3.4% | 2.6% | | |
| 32 | Count | 0 | 1 | 0 | 0 | 1 | | |
| | % within XU | 0.0% | 100.0% | 0.0% | 0.0% | 100.0% | | |
| | % within Cluster | 0.0% | 3.6% | 0.0% | 0.0% | .7% | | |
| 34 | Count | 1 | 0 | 0 | 0 | 1 | | |
| | % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% | | |
| | % within Cluster | 1.5% | 0.0% | 0.0% | 0.0% | .7% | | |
| 36 | Count | 1 | 0 | 0 | 0 | 1 | SU4 (XU35-47) | |
| | % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% | | |
| | % within Cluster | 1.5% | 0.0% | 0.0% | 0.0% | .7% | | |
| 38 | Count | 0 | 0 | 1 | 0 | 1 | | |
| | % within XU | 0.0% | 0.0% | 100.0% | 0.0% | 100.0% | | |
| | % within Cluster | 0.0% | 0.0% | 3.4% | 0.0% | .7% | | |
| 39 | Count | 2 | 0 | 0 | 0 | 2 | | |
| | % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% | | |
| | % within Cluster | 3.1% | 0.0% | 0.0% | 0.0% | 1.3% | | |
| 40 | Count | 0 | 1 | 0 | 0 | 1 | | |
| | % within XU | 0.0% | 100.0% | 0.0% | 0.0% | 100.0% | | |
| | % within Cluster | 0.0% | 3.6% | 0.0% | 0.0% | .7% | | |
| 43 | Count | 3 | 0 | 0 | 1 | 4 | | |
| | % within XU | 75.0% | 0.0% | 0.0% | 25.0% | 100.0% | | |
| | % within Cluster | 4.6% | 0.0% | 0.0% | 3.4% | 2.6% | | |
| 44 | Count | 1 | 0 | 1 | 1 | 3 | | |
| | % within XU | 33.3% | 0.0% | 33.3% | 33.3% | 100.0% | | |
| | % within Cluster | 1.5% | 0.0% | 3.4% | 3.4% | 2.0% | | |
| 47 | Count | 1 | 0 | 0 | 0 | 1 | | |
| | % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% | | |
| | % within Cluster | 1.5% | 0.0% | 0.0% | 0.0% | .7% | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 51 | Count | 1 | 0 | 0 | 0 | 1 |
| | % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% |
| | % within Cluster | 1.5% | 0.0% | 0.0% | 0.0% | .7% |
| 53 | Count | 1 | 0 | 0 | 0 | 1 |
| | % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% |
| | % within Cluster | 1.5% | 0.0% | 0.0% | 0.0% | .7% |
| 54 | Count | 0 | 0 | 0 | 1 | 1 |
| | % within XU | 0.0% | 0.0% | 0.0% | 100.0% | 100.0% |
| | % within Cluster | 0.0% | 0.0% | 0.0% | 3.4% | .7% |
| 55 | Count | 2 | 0 | 2 | 3 | 7 |
| | % within XU | 28.6% | 0.0% | 28.6% | 42.9% | 100.0% |
| | % within Cluster | 3.1% | 0.0% | 6.9% | 10.3% | 4.6% |
| 56 | Count | 0 | 1 | 0 | 2 | 3 |
| | % within XU | 0.0% | 33.3% | 0.0% | 66.7% | 100.0% |
| | % within Cluster | 0.0% | 3.6% | 0.0% | 6.9% | 2.0% |
| 58 | Count | 0 | 1 | 0 | 0 | 1 |
| | % within XU | 0.0% | 100.0% | 0.0% | 0.0% | 100.0% |
| | % within Cluster | 0.0% | 3.6% | 0.0% | 0.0% | .7% |
| 60 | Count | 1 | 1 | 0 | 1 | 3 |
| | % within XU | 33.3% | 33.3% | 0.0% | 33.3% | 100.0% |
| | % within Cluster | 1.5% | 3.6% | 0.0% | 3.4% | 2.0% |
| 63 | Count | 1 | 0 | 0 | 1 | 2 |
| | % within XU | 50.0% | 0.0% | 0.0% | 50.0% | 100.0% |
| | % within Cluster | 1.5% | 0.0% | 0.0% | 3.4% | 1.3% |
| 64 | Count | 1 | 1 | 1 | 0 | 3 |
| | % within XU | 33.3% | 33.3% | 33.3% | 0.0% | 100.0% |
| | % within Cluster | 1.5% | 3.6% | 3.4% | 0.0% | 2.0% |
| 66 | Count | 0 | 0 | 1 | 1 | 2 |
| | % within XU | 0.0% | 0.0% | 50.0% | 50.0% | 100.0% |
| | % within Cluster | 0.0% | 0.0% | 3.4% | 3.4% | 1.3% |
| 67 | Count | 0 | 0 | 0 | 2 | 2 |
| | % within XU | 0.0% | 0.0% | 0.0% | 100.0% | 100.0% |
| | % within Cluster | 0.0% | 0.0% | 0.0% | 6.9% | 1.3% |
| 70 | Count | 1 | 0 | 0 | 0 | 1 |
| | % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% |
| | % within Cluster | 1.5% | 0.0% | 0.0% | 0.0% | .7% |
| 71 | Count | 0 | 0 | 0 | 1 | 1 |
| | % within XU | 0.0% | 0.0% | 0.0% | 100.0% | 100.0% |
| | % within Cluster | 0.0% | 0.0% | 0.0% | 3.4% | .7% |
| 72 | Count | 1 | 0 | 0 | 0 | 1 |
| | % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% |
| | % within Cluster | 1.5% | 0.0% | 0.0% | 0.0% | .7% |
| 74 | Count | 0 | 0 | 1 | 0 | 1 |
| | % within XU | 0.0% | 0.0% | 100.0% | 0.0% | 100.0% |
| | % within Cluster | 0.0% | 0.0% | 3.4% | 0.0% | .7% |

SU5 (XU48-69)

SU6 (XU 70-113)

Lower Horison-c.4350-4050 cal BP, XU48-69

| | | | | | | |
|---|---|---|---|---|---|---|
| 75 Count | 0 | 0 | 1 | 0 | 1 | |
| % within XU | 0.0% | 0.0% | 100.0% | 0.0% | 100.0% | |
| % within Cluster | 0.0% | 0.0% | 3.4% | 0.0% | .7% | |
| 79 Count | 0 | 0 | 1 | 0 | 1 | |
| % within XU | 0.0% | 0.0% | 100.0% | 0.0% | 100.0% | |
| % within Cluster | 0.0% | 0.0% | 3.4% | 0.0% | .7% | |
| 81 Count | 2 | 0 | 0 | 1 | 3 | |
| % within XU | 66.7% | 0.0% | 0.0% | 33.3% | 100.0% | |
| % within Cluster | 3.1% | 0.0% | 0.0% | 3.4% | 2.0% | |
| 82 Count | 3 | 0 | 0 | 0 | 3 | |
| % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% | |
| % within Cluster | 4.6% | 0.0% | 0.0% | 0.0% | 2.0% | |
| 83 Count | 0 | 1 | 0 | 0 | 1 | |
| % within XU | 0.0% | 100.0% | 0.0% | 0.0% | 100.0% | |
| % within Cluster | 0.0% | 3.6% | 0.0% | 0.0% | .7% | |
| 91 Count | 0 | 1 | 0 | 0 | 1 | |
| % within XU | 0.0% | 100.0% | 0.0% | 0.0% | 100.0% | |
| % within Cluster | 0.0% | 3.6% | 0.0% | 0.0% | .7% | |
| 93 Count | 1 | 0 | 0 | 0 | 1 | |
| % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% | |
| % within Cluster | 1.5% | 0.0% | 0.0% | 0.0% | .7% | |
| 99 Count | 1 | 0 | 0 | 0 | 1 | |
| % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% | |
| % within Cluster | 1.5% | 0.0% | 0.0% | 0.0% | .7% | |
| 110 Count | 0 | 0 | 0 | 1 | 1 | |
| % within XU | 0.0% | 0.0% | 0.0% | 100.0% | 100.0% | |
| % within Cluster | 0.0% | 0.0% | 0.0% | 3.4% | .7% | |
| 113 Count | 1 | 0 | 0 | 0 | 1 | SU7 (XU 114-134) - not artifacts tested |
| % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% | |
| % within Cluster | 1.5% | 0.0% | 0.0% | 0.0% | .7% | |
| Total Count | 65 | 28 | 29 | 29 | 151 | |
| % within XU | 43.0% | 18.5% | 19.2% | 19.2% | 100.0% | |
| % within Cluster | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | |

| Table 8: Tanamu 2, XU by GSG Cluster | | | | | | 25 XUs | |
|---|---|---|---|---|---|---|---|
| **XU** | **Cluster** | | | | **Total** | **4 SUs** | **Chonological Period** |
| | **1** | **2** | **3** | **4** | | | |
| 2 Count | 0 | 1 | 1 | 1 | 3 | SU1-phase 2 (XU1-5) | very minor occupation |
| % within XU | 0.0% | 33.3% | 33.3% | 33.3% | 100.0% | | |
| % within Cluster | 0.0% | 7.1% | 4.2% | 5.3% | 4.0% | | |
| 4 Count | 0 | 1 | 0 | 0 | 1 | | |
| % within XU | 0.0% | 100.0% | 0.0% | 0.0% | 100.0% | | |
| % within Cluster | 0.0% | 7.1% | 0.0% | 0.0% | 1.3% | | |
| 5 Count | 0 | 2 | 1 | 1 | 4 | | |
| % within XU | 0.0% | 50.0% | 25.0% | 25.0% | 100.0% | | |
| % within Cluster | 0.0% | 14.3% | 4.2% | 5.3% | 5.3% | | |
| 6 Count | 4 | 2 | 4 | 4 | 14 | SU2a - Phase 2 (XU6-15) 2500-2400 cal BP | PHASE 2 - Main occupation period |
| % within XU | 28.6% | 14.3% | 28.6% | 28.6% | 100.0% | | |
| % within Cluster | 22.2% | 14.3% | 16.7% | 21.1% | 18.7% | | |
| 7 Count | 5 | 0 | 2 | 1 | 8 | | |
| % within XU | 62.5% | 0.0% | 25.0% | 12.5% | 100.0% | | |
| % within Cluster | 27.8% | 0.0% | 8.3% | 5.3% | 10.7% | | |
| 8 Count | 1 | 0 | 2 | 1 | 4 | | |
| % within XU | 25.0% | 0.0% | 50.0% | 25.0% | 100.0% | | |
| % within Cluster | 5.6% | 0.0% | 8.3% | 5.3% | 5.3% | | |
| 9 Count | 0 | 2 | 2 | 4 | 8 | | |
| % within XU | 0.0% | 25.0% | 25.0% | 50.0% | 100.0% | | |
| % within Cluster | 0.0% | 14.3% | 8.3% | 21.1% | 10.7% | | |
| 10 Count | 1 | 1 | 2 | 2 | 6 | | |
| % within XU | 16.7% | 16.7% | 33.3% | 33.3% | 100.0% | | |
| % within Cluster | 5.6% | 7.1% | 8.3% | 10.5% | 8.0% | | |
| 11 Count | 0 | 0 | 2 | 1 | 3 | | |
| % within XU | 0.0% | 0.0% | 66.7% | 33.3% | 100.0% | | |
| % within Cluster | 0.0% | 0.0% | 8.3% | 5.3% | 4.0% | | |
| 12 Count | 0 | 0 | 1 | 0 | 1 | | |
| % within XU | 0.0% | 0.0% | 100.0% | 0.0% | 100.0% | | |
| % within Cluster | 0.0% | 0.0% | 4.2% | 0.0% | 1.3% | | |
| 13 Count | 1 | 3 | 1 | 1 | 6 | | |
| % within XU | 16.7% | 50.0% | 16.7% | 16.7% | 100.0% | | |
| % within Cluster | 5.6% | 21.4% | 4.2% | 5.3% | 8.0% | | |
| 14 Count | 1 | 0 | 0 | 0 | 1 | | |
| % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% | | |
| % within Cluster | 5.6% | 0.0% | 0.0% | 0.0% | 1.3% | | |
| 16 Count | 2 | 0 | 0 | 0 | 2 | SU2b - Phase 2 (X | |
| % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% | | |
| % within Cluster | 11.1% | 0.0% | 0.0% | 0.0% | 2.7% | | |
| 17 Count | 0 | 0 | 1 | 0 | 1 | | |
| % within XU | 0.0% | 0.0% | 100.0% | 0.0% | 100.0% | | |
| % within Cluster | 0.0% | 0.0% | 4.2% | 0.0% | 1.3% | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 19 | Count | 1 | 0 | 0 | 0 | 1 | |
| | % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% | |
| | % within Cluster | 5.6% | 0.0% | 0.0% | 0.0% | 1.3% | XU 16-31) 2500-2400 cal BP |
| 22 | Count | 0 | 0 | 1 | 0 | 1 | |
| | % within XU | 0.0% | 0.0% | 100.0% | 0.0% | 100.0% | |
| | % within Cluster | 0.0% | 0.0% | 4.2% | 0.0% | 1.3% | |
| 24 | Count | 0 | 1 | 0 | 0 | 1 | |
| | % within XU | 0.0% | 100.0% | 0.0% | 0.0% | 100.0% | |
| | % within Cluster | 0.0% | 7.1% | 0.0% | 0.0% | 1.3% | |
| 29 | Count | 0 | 0 | 1 | 0 | 1 | |
| | % within XU | 0.0% | 0.0% | 100.0% | 0.0% | 100.0% | |
| | % within Cluster | 0.0% | 0.0% | 4.2% | 0.0% | 1.3% | |
| 31 | Count | 0 | 0 | 1 | 0 | 1 | |
| | % within XU | 0.0% | 0.0% | 100.0% | 0.0% | 100.0% | |
| | % within Cluster | 0.0% | 0.0% | 4.2% | 0.0% | 1.3% | |
| 32 | Count | 1 | 0 | 0 | 0 | 1 | |
| | % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% | |
| | % within Cluster | 5.6% | 0.0% | 0.0% | 0.0% | 1.3% | SU2b-phase 1 (XU 32-50) 6940-2715? cal BP |
| 33 | Count | 0 | 0 | 0 | 1 | 1 | |
| | % within XU | 0.0% | 0.0% | 0.0% | 100.0% | 100.0% | |
| | % within Cluster | 0.0% | 0.0% | 0.0% | 5.3% | 1.3% | |
| 35 | Count | 0 | 1 | 0 | 0 | 1 | |
| | % within XU | 0.0% | 100.0% | 0.0% | 0.0% | 100.0% | |
| | % within Cluster | 0.0% | 7.1% | 0.0% | 0.0% | 1.3% | |
| 39 | Count | 0 | 0 | 1 | 1 | 2 | |
| | % within XU | 0.0% | 0.0% | 50.0% | 50.0% | 100.0% | |
| | % within Cluster | 0.0% | 0.0% | 4.2% | 5.3% | 2.7% | |
| 47 | Count | 0 | 0 | 0 | 1 | 1 | |
| | % within XU | 0.0% | 0.0% | 0.0% | 100.0% | 100.0% | |
| | % within Cluster | 0.0% | 0.0% | 0.0% | 5.3% | 1.3% | |
| 48 | Count | 1 | 0 | 1 | 0 | 2 | |
| | % within XU | 50.0% | 0.0% | 50.0% | 0.0% | 100.0% | |
| | % within Cluster | 5.6% | 0.0% | 4.2% | 0.0% | 2.7% | |
| Total | Count | 18 | 14 | 24 | 19 | 75 | |
| | % within XU | 24.0% | 18.7% | 32.0% | 25.3% | 100.0% | |
| | % within Cluster | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | |

| Table 9: Tanamu 3, XU by GSG Cluster | | | | | | 15 XUs | |
|---|---|---|---|---|---|---|---|
| XU | Cluster | | | | Total | 3 SUs | Chonological Period |
| | 1 | 2 | 3 | 4 | | | |
| 2 Count | 0 | 1 | 1 | 0 | 2 | SU1 | Phase C (XU 1-7) c.1800-1891 cal BP - not cultural? |
| % within XU | 0.0% | 50.0% | 50.0% | 0.0% | 100.0% | | |
| % within Cluster | 0.0% | 12.5% | 16.7% | 0.0% | 6.7% | | |
| 3 Count | 2 | 0 | 0 | 1 | 3 | | |
| % within XU | 66.7% | 0.0% | 0.0% | 33.3% | 100.0% | | |
| % within Cluster | 18.2% | 0.0% | 0.0% | 20.0% | 10.0% | | |
| 4 Count | 1 | 1 | 1 | 0 | 3 | | |
| % within XU | 33.3% | 33.3% | 33.3% | 0.0% | 100.0% | | |
| % within Cluster | 9.1% | 12.5% | 16.7% | 0.0% | 10.0% | | |
| 5 Count | 0 | 0 | 1 | 0 | 1 | | |
| % within XU | 0.0% | 0.0% | 100.0% | 0.0% | 100.0% | | |
| % within Cluster | 0.0% | 0.0% | 16.7% | 0.0% | 3.3% | | |
| 6 Count | 0 | 1 | 0 | 0 | 1 | | |
| % within XU | 0.0% | 100.0% | 0.0% | 0.0% | 100.0% | | |
| % within Cluster | 0.0% | 12.5% | 0.0% | 0.0% | 3.3% | | |
| 7 Count | 0 | 1 | 0 | 0 | 1 | | |
| % within XU | 0.0% | 100.0% | 0.0% | 0.0% | 100.0% | | |
| % within Cluster | 0.0% | 12.5% | 0.0% | 0.0% | 3.3% | | |
| 8 Count | 0 | 0 | 0 | 1 | 1 | | Phase B (XU 8-19) - 2265-2545 cal BP - major occupation |
| % within XU | 0.0% | 0.0% | 0.0% | 100.0% | 100.0% | | |
| % within Cluster | 0.0% | 0.0% | 0.0% | 20.0% | 3.3% | | |
| 10 Count | 1 | 0 | 0 | 0 | 1 | | |
| % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% | | |
| % within Cluster | 9.1% | 0.0% | 0.0% | 0.0% | 3.3% | | |
| 13 Count | 2 | 1 | 1 | 0 | 4 | SU2 | |
| % within XU | 50.0% | 25.0% | 25.0% | 0.0% | 100.0% | | |
| % within Cluster | 18.2% | 12.5% | 16.7% | 0.0% | 13.3% | | |
| 14 Count | 1 | 1 | 0 | 0 | 2 | | |
| % within XU | 50.0% | 50.0% | 0.0% | 0.0% | 100.0% | | |
| % within Cluster | 9.1% | 12.5% | 0.0% | 0.0% | 6.7% | | |
| 15 Count | 2 | 0 | 0 | 0 | 2 | SU3 | |
| % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% | | |
| % within Cluster | 18.2% | 0.0% | 0.0% | 0.0% | 6.7% | | |
| 16 Count | 1 | 1 | 2 | 1 | 5 | | |
| % within XU | 20.0% | 20.0% | 40.0% | 20.0% | 100.0% | | |
| % within Cluster | 9.1% | 12.5% | 33.3% | 20.0% | 16.7% | | |
| 17 Count | 0 | 1 | 0 | 1 | 2 | | |
| % within XU | 0.0% | 50.0% | 0.0% | 50.0% | 100.0% | | |
| % within Cluster | 0.0% | 12.5% | 0.0% | 20.0% | 6.7% | | |
| 21 Count | 0 | 0 | 0 | 1 | 1 | | Phase A (XU 19-32) - 3046-3173 cal BP - minor occupation |
| % within XU | 0.0% | 0.0% | 0.0% | 100.0% | 100.0% | | |
| % within Cluster | 0.0% | 0.0% | 0.0% | 20.0% | 3.3% | | |
| 31 Count | 1 | 0 | 0 | 0 | 1 | | |
| % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% | | |
| % within Cluster | 9.1% | 0.0% | 0.0% | 0.0% | 3.3% | | |
| Total Count | 11 | 8 | 6 | 5 | 30 | | |
| % within XU | 36.7% | 26.7% | 20.0% | 16.7% | 100.0% | | |
| % within Cluster | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | | |

| Table 10: ABKF, XU by GSG Cluster | | | | | | 10 XUs | |
|---|---|---|---|---|---|---|---|
| **XU** | **Cluster** | | | | **Total** | **SUs** | **Chonological Period** |
| | **1** | **2** | **3** | **4** | | | |
| 3 Count | 1 | 0 | 0 | 0 | 1 | | |
| % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% | | |
| % within Cluster | 20.0% | 0.0% | 0.0% | 0.0% | 6.7% | | |
| 5 Count | 1 | 1 | 0 | 0 | 2 | | |
| % within XU | 50.0% | 50.0% | 0.0% | 0.0% | 100.0% | | |
| % within Cluster | 20.0% | 25.0% | 0.0% | 0.0% | 13.3% | | |
| 9 Count | 0 | 1 | 0 | 0 | 1 | | |
| % within XU | 0.0% | 100.0% | 0.0% | 0.0% | 100.0% | | |
| % within Cluster | 0.0% | 25.0% | 0.0% | 0.0% | 6.7% | | |
| 10 Count | 1 | 0 | 0 | 0 | 1 | | |
| % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% | | |
| % within Cluster | 20.0% | 0.0% | 0.0% | 0.0% | 6.7% | | |
| 11 Count | 0 | 0 | 0 | 2 | 2 | | |
| % within XU | 0.0% | 0.0% | 0.0% | 100.0% | 100.0% | | |
| % within Cluster | 0.0% | 0.0% | 0.0% | 50.0% | 13.3% | | |
| 12 Count | 0 | 0 | 1 | 1 | 2 | | |
| % within XU | 0.0% | 0.0% | 50.0% | 50.0% | 100.0% | | |
| % within Cluster | 0.0% | 0.0% | 50.0% | 25.0% | 13.3% | | |
| 13 Count | 0 | 1 | 0 | 0 | 1 | | |
| % within XU | 0.0% | 100.0% | 0.0% | 0.0% | 100.0% | | |
| % within Cluster | 0.0% | 25.0% | 0.0% | 0.0% | 6.7% | | |
| 14 Count | 1 | 1 | 1 | 0 | 3 | | |
| % within XU | 33.3% | 33.3% | 33.3% | 0.0% | 100.0% | | |
| % within Cluster | 20.0% | 25.0% | 50.0% | 0.0% | 20.0% | | |
| 15 Count | 1 | 0 | 0 | 0 | 1 | | |
| % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% | | |
| % within Cluster | 20.0% | 0.0% | 0.0% | 0.0% | 6.7% | | |
| 18 Count | 0 | 0 | 0 | 1 | 1 | | |
| % within XU | 0.0% | 0.0% | 0.0% | 100.0% | 100.0% | | |
| % within Cluster | 0.0% | 0.0% | 0.0% | 25.0% | 6.7% | | |
| Total Count | 5 | 4 | 2 | 4 | 15 | | |
| % within XU | 33.3% | 26.7% | 13.3% | 26.7% | 100.0% | | |
| % within Cluster | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | | |

| Table 11: Nese 1, XU by GSG Cluster | | | | | | 7 XUs | |
|---|---|---|---|---|---|---|---|
| XU | Cluster | | | | Total | SUs | Chonological Period |
| | 1 | 2 | 3 | 4 | | | |
| 6 Count | 4 | 4 | 0 | 1 | 9 | | |
| % within XU | 44.4% | 44.4% | 0.0% | 11.1% | 100.0% | | |
| % within Cluster | 8.2% | 21.1% | 0.0% | 9.1% | 10.0% | | |
| 7 Count | 7 | 4 | 1 | 1 | 13 | | |
| % within XU | 53.8% | 30.8% | 7.7% | 7.7% | 100.0% | | |
| % within Cluster | 14.3% | 21.1% | 9.1% | 9.1% | 14.4% | | |
| 8 Count | 7 | 4 | 4 | 0 | 15 | | |
| % within XU | 46.7% | 26.7% | 26.7% | 0.0% | 100.0% | | |
| % within Cluster | 14.3% | 21.1% | 36.4% | 0.0% | 16.7% | | |
| 9 Count | 8 | 1 | 0 | 4 | 13 | | |
| % within XU | 61.5% | 7.7% | 0.0% | 30.8% | 100.0% | | |
| % within Cluster | 16.3% | 5.3% | 0.0% | 36.4% | 14.4% | | |
| 10 Count | 10 | 2 | 2 | 3 | 17 | | |
| % within XU | 58.8% | 11.8% | 11.8% | 17.6% | 100.0% | | |
| % within Cluster | 20.4% | 10.5% | 18.2% | 27.3% | 18.9% | | |
| 11 Count | 13 | 3 | 4 | 2 | 22 | | |
| % within XU | 59.1% | 13.6% | 18.2% | 9.1% | 100.0% | | |
| % within Cluster | 26.5% | 15.8% | 36.4% | 18.2% | 24.4% | | |
| 12 Count | 0 | 1 | 0 | 0 | 1 | | |
| % within XU | 0.0% | 100.0% | 0.0% | 0.0% | 100.0% | | |
| % within Cluster | 0.0% | 5.3% | 0.0% | 0.0% | 1.1% | | |
| Total Count | 49 | 19 | 11 | 11 | 90 | | |
| % within XU | 54.4% | 21.1% | 12.2% | 12.2% | 100.0% | | |
| % within Cluster | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | | |

| Table 12: Moiapu 2, XU by GSG Cluster | | | | | | 11 XUs | | |
|---|---|---|---|---|---|---|---|---|
| XU | Cluster | | | | Total | 3 SUs | Chonological Period | |
| | 1 | 2 | 3 | 4 | | | | |
| 1 Count | 2 | 0 | 0 | 0 | 2 | SU1 (XU 1-6) c.1700-1590 cal BP | | Major Cultural material (XU 3 to 12) c.2720-2530 call BP |
| % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% | | | |
| % within Cluster | 3.6% | 0.0% | 0.0% | 0.0% | 1.6% | | | |
| 3 Count | 1 | 1 | 0 | 0 | 2 | | SU2 (XU 3 to 18) c.2660-2230 call BP | |
| % within XU | 50.0% | 50.0% | 0.0% | 0.0% | 100.0% | | | |
| % within Cluster | 1.8% | 3.0% | 0.0% | 0.0% | 1.6% | | | |
| 4 Count | 3 | 3 | 1 | 0 | 7 | | | |
| % within XU | 42.9% | 42.9% | 14.3% | 0.0% | 100.0% | | | |
| % within Cluster | 5.4% | 9.1% | 4.2% | 0.0% | 5.5% | | | |
| 5 Count | 7 | 3 | 3 | 2 | 15 | | | |
| % within XU | 46.7% | 20.0% | 20.0% | 13.3% | 100.0% | | | |
| % within Cluster | 12.5% | 9.1% | 12.5% | 13.3% | 11.7% | | | |
| 6 Count | 13 | 8 | 5 | 9 | 35 | | | |
| % within XU | 37.1% | 22.9% | 14.3% | 25.7% | 100.0% | | | |
| % within Cluster | 23.2% | 24.2% | 20.8% | 60.0% | 27.3% | | | |
| 7 Count | 19 | 8 | 7 | 4 | 38 | | | |
| % within XU | 50.0% | 21.1% | 18.4% | 10.5% | 100.0% | | | |
| % within Cluster | 33.9% | 24.2% | 29.2% | 26.7% | 29.7% | | | |
| 8 Count | 3 | 5 | 3 | 0 | 11 | | | |
| % within XU | 27.3% | 45.5% | 27.3% | 0.0% | 100.0% | | | |
| % within Cluster | 5.4% | 15.2% | 12.5% | 0.0% | 8.6% | | | |
| 9 Count | 5 | 3 | 3 | 0 | 11 | | | |
| % within XU | 45.5% | 27.3% | 27.3% | 0.0% | 100.0% | | | |
| % within Cluster | 8.9% | 9.1% | 12.5% | 0.0% | 8.6% | | | |
| 10 Count | 2 | 2 | 1 | 0 | 5 | | | |
| % within XU | 40.0% | 40.0% | 20.0% | 0.0% | 100.0% | | | |
| % within Cluster | 3.6% | 6.1% | 4.2% | 0.0% | 3.9% | | | |
| 11 Count | 1 | 0 | 0 | 0 | 1 | | SU3 (XU11 to 23) c.2720-2530 cal | |
| % within XU | 100.0% | 0.0% | 0.0% | 0.0% | 100.0% | | | |
| % within Cluster | 1.8% | 0.0% | 0.0% | 0.0% | 0.8% | | | |
| 16 Count | 0 | 0 | 1 | 0 | 1 | | | |
| % within XU | 0.0% | 0.0% | 100.0% | 0.0% | 100.0% | | | |
| % within Cluster | 0.0% | 0.0% | 4.2% | 0.0% | 0.8% | | | |
| Count | 56 | 33 | 24 | 15 | 128 | | | |
| % within XU | 43.8% | 25.8% | 18.8% | 11.7% | 100.0% | | | |
| % within Cluster | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | | | |

**Appendix 5: Periodic Table of Elements**

# Periodic Table of the Elements

| 1A | | | | | | | | | | | | | | | | | | 8A |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 **H** 1.00794 | 2A | | | | | | | | | | | 3A | 4A | 5A | 6A | 7A | | 2 **He** 4.002602 |
| 3 **Li** 6.941 | 4 **Be** 9.012182 | | | | | | | | | | | 5 **B** 10.811 | 6 **C** 12.0107 | 7 **N** 14.0067 | 8 **O** 15.9994 | 9 **F** 18.9984032 | | 10 **Ne** 20.1797 |
| 11 **Na** 22.989769 | 12 **Mg** 24.3050 | 3B | 4B | 5B | 6B | 7B | 8B | 8B | 8B | 1B | 2B | 13 **Al** 26.9815386 | 14 **Si** 28.0855 | 15 **P** 30.973762 | 16 **S** 32.065 | 17 **Cl** 35.453 | | 18 **Ar** 39.948 |
| 19 **K** 39.0983 | 20 **Ca** 40.078 | 21 **Sc** 44.955912 | 22 **Ti** 47.867 | 23 **V** 50.9415 | 24 **Cr** 51.9961 | 25 **Mn** 54.938045 | 26 **Fe** 55.845 | 27 **Co** 58.933195 | 28 **Ni** 58.6934 | 29 **Cu** 63.546 | 30 **Zn** 65.38 | 31 **Ga** 69.723 | 32 **Ge** 72.64 | 33 **As** 74.92160 | 34 **Se** 78.96 | 35 **Br** 79.904 | | 36 **Kr** 83.798 |
| 37 **Rb** 85.4678 | 38 **Sr** 87.62 | 39 **Y** 88.90585 | 40 **Zr** 91.224 | 41 **Nb** 92.90638 | 42 **Mo** 95.96 | 43 **Tc** [98] | 44 **Ru** 101.07 | 45 **Rh** 102.90550 | 46 **Pd** 106.42 | 47 **Ag** 107.8682 | 48 **Cd** 112.411 | 49 **In** 114.818 | 50 **Sn** 118.710 | 51 **Sb** 121.760 | 52 **Te** 127.60 | 53 **I** 126.90447 | | 54 **Xe** 131.293 |
| 55 **Cs** 132.9054519 | 56 **Ba** 137.327 | 57-71 Lanthanides | 72 **Hf** 178.49 | 73 **Ta** 180.94788 | 74 **W** 183.84 | 75 **Re** 186.207 | 76 **Os** 190.23 | 77 **Ir** 192.217 | 78 **Pt** 195.084 | 79 **Au** 196.966569 | 80 **Hg** 200.59 | 81 **Tl** 204.3833 | 82 **Pb** 207.2 | 83 **Bi** 208.98040 | 84 **Po** [209] | 85 **At** [210] | | 86 **Rn** [222] |
| 87 **Fr** [223] | 88 **Ra** [226] | 89-103 Actinides | 104 **Rf** [267] | 105 **Db** [268] | 106 **Sg** [271] | 107 **Bh** [272] | 108 **Hs** [270] | 109 **Mt** [276] | 110 **Ds** [281] | 111 **Rg** [280] | 112 **Cn** [285] | 113 **Uut** [284] | 114 **Uuq** [289] | 115 **Uup** [288] | 116 **Uuh** [293] | 117 **Uus** [294] | | 118 **Uuo** [294] |

**Lanthanides**

| 57 **La** 138.90547 | 58 **Ce** 140.116 | 59 **Pr** 140.90765 | 60 **Nd** 144.242 | 61 **Pm** [145] | 62 **Sm** 150.36 | 63 **Eu** 151.964 | 64 **Gd** 157.25 | 65 **Tb** 158.92535 | 66 **Dy** 162.500 | 67 **Ho** 164.93032 | 68 **Er** 167.259 | 69 **Tm** 168.93421 | 70 **Yb** 173.054 | 71 **Lu** 174.9668 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

**Actinides**

| 89 **Ac** [227] | 90 **Th** 232.03806 | 91 **Pa** 231.03588 | 92 **U** 238.02891 | 93 **Np** [237] | 94 **Pu** [244] | 95 **Am** [243] | 96 **Cm** [247] | 97 **Bk** [247] | 98 **Cf** [251] | 99 **Es** [252] | 100 **Fm** [257] | 101 **Md** [258] | 102 **No** [259] | 103 **Lr** [262] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|