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# Investigating Prehistoric Exchange in New Zealand: Portable XRF and Spatial Analysis of South Island Obsidian

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INVESTIGATING PREHISTORIC EXCHANGE IN NEW ZEALAND:  
PORTABLE XRF AND SPATIAL ANALYSIS OF SOUTH ISLAND OBSIDIAN

A Thesis

Submitted to the Graduate Faculty of the  
Louisiana State University and  
Agricultural and Mechanical College  
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in

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by  
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*Dedicated to Norman Theriot for his unending and endearing support every step of the way throughout my two years of study that I will never forget.*

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## TABLE OF CONTENTS

ACKNOWLEDGEMENTS.....	iii
ABSTRACT.....	v
CHAPTER 1 - INTRODUCTION.....	1
The First Settlers of Prehistoric New Zealand.....	2
Archaeology in New Zealand.....	4
Trade and Exchange in Prehistoric New Zealand.....	8
Geochemical Characterization.....	16
Cost-Surface Analysis in Archaeology.....	18
CHAPTER 2 - OVERVIEW OF SITES.....	21
Shag River Mouth (S155/5).....	24
Pounawea (S184/1).....	24
Little Papanui (S164/1).....	25
Long Beach (S164/20).....	25
Pleasant River Mouth.....	26
Waitaki River Mouth (S128/1).....	26
Wakanui (L37/8).....	27
Purakanui (S164/18).....	27
Pahia.....	27
Tiwai Point (S181-2/16).....	28
CHAPTER 3 - MATERIALS AND METHODS.....	29
Geochemical Characterization.....	31
Cost-Surface Analysis.....	32
Tobler Function Analysis.....	35
CHAPTER 4 - PORTABLE XRF RESULTS.....	38
Lithic Analysis.....	44
CHAPTER 5 - SPATIAL ANALYSIS RESULTS.....	48
Cost-Surface Analysis Results.....	48
Tobler Function Analysis Results.....	51
CHAPTER 6 - DISCUSSION AND CONCLUSION.....	53
Conclusion.....	55
REFERENCES.....	57
VITA.....	63

## **ABSTRACT**

The Otago Museum in Dunedin, New Zealand currently houses a collection of obsidian artifacts that were once in the possession of ancestral South Island Maori. Although the stone artifacts that reside in the Otago Museum are known to have been collected mostly in the South Island of the New Zealand archipelago, there is not much information as to where the ancestors of South Island Maori originally obtained the raw material to create the stone artifacts. Using portable x-ray fluorescence (XRF) analysis to non-destructively geochemically characterize the obsidian, a study was performed on the collection of stone artifacts to provide a source location of each object based on their geochemical signature and provide further insight into New Zealand's ancient networks of exchange.

The 443 obsidian artifacts that were selected from the Otago Museum collection were recovered from archaeological excavations along the east coast of New Zealand's South Island. For this study, the obsidian artifacts were sorted and assayed using a Bruker AXS portable XRF. Once the obsidian artifacts were assayed, they were assigned a geochemical source and a cost-surface analysis was performed. The geochemical characterization of the obsidian artifacts showed that most of the artifacts originated in the North Island of New Zealand. The cost-surface analysis, along with the obsidian frequencies at each site, provided evidence of two possible exchange networks and possible direct access from the obsidian sources to the sites within the exchange networks. However, further research involving larger obsidian samples and a model for maritime travel analysis from the South Island sites to the obsidian sources would provide a better understanding of the possible exchange networks.

## CHAPTER 1 - INTRODUCTION

Researchers have found that Early Period sites in the North and South Island display wide distribution patterns of obsidian frequencies (Seelenfreund and Bollong 1989) as opposed to the localized obsidian acquisition that occurred during the Late Period (McCoy 2011). In my study, I use obsidian artifacts acquired from Early Period site excavations in the 1870's and 1930's led by H.D Skinner in the South Island of New Zealand (Davidson 1984) to investigate possible exchange networks suggested by Scott (2008). I also will use an anisotropic cost-surface analysis similar to Scott (2008) to calculate possible exchange routes in the South Island by using the results from the sourced obsidian. The cost-surface analysis will be used to eliminate geography as a limiting factor in obsidian exchange and determine if South Island sites along the possible exchange routes were centralized distribution sites in obsidian exchange.

The obsidian data was acquired from a portable x-ray fluorescence (pXRF) analysis of obsidian from an archaeological collection on loan from the Otago Museum in Dunedin, New Zealand. The significance of this collection is that the pXRF analysis will provide accurate geochemical sourcing of the obsidian artifacts from sites along the east coast of the South Island that are near suspected centralized sites of obsidian distribution (Scott 2008). These suspected centralized sites are known to have high frequencies of obsidian obtained from North Island sources (Lawrence et al. 2014; Mosley and McCoy 2010; Scott 2008; Sellenfreund and Bollong 1989). Variation in source frequencies shows that people at Early Period sites usually obtained obsidian by long-distance travel (Walter et al. 2010) before conflict encouraged local exploitation after 1500 A.D. (McCoy et al. 2014).

## **The First Settlers of Prehistoric New Zealand**

New Zealand was the last Polynesian island group to be settled at the end of 1300 A.D. as part of the Austronesian expansion (Kinaston et al. 2013; Walter and Jacomb 2007; Walter et al. 2010) before being rediscovered by James Cook in A.D. 1769 (Davidson 1984). The strongest support for the earliest possible settlement is the lack of archaeological evidence of human settlement and occupation before 1250 A.D. (Smith 1996; Walter et al. 2010). The ancestors of the indigenous people of New Zealand, the Maori, were the first to settle in the archipelago (Smith 1996). These ancestral settlers were Polynesian voyagers known as the tangata whenua, or “people of the land” (Davidson 1984; Smith 1996). The term tangata whenua is a Polynesian concept that is based on the idea of maintaining kin connections throughout the Pacific (Smith 1996).

There is still debate about where the ancestral settlers set out from (Smith 1996; Walter et al. 2010). Frequent stories throughout Polynesia recall a homeland known as Hawaiki as the location where the first settlers made their initial voyage (Smith 1996). According to accounts retold in these Polynesian stories, Hawaiki is believed to be a reference to the Marquesas or the Southern Cook Islands in eastern Polynesia (Smith 1996). The number of settlements that took place during the initial arrival to New Zealand is not clear, but any groups of settlers would have come from the general area in the eastern Pacific and would have been a part of a similar culture (Davidson 1984). By tracing an “ancestral genetic trail” from New Guinea to the eastern Pacific islands, this would indicate that the first settlers of New Zealand are descendants of the Lapita people in the central Pacific (Smith 1996; Vaux 1876; Walter and Jacomb 2010).

During the later phase of the Austronesian expansion around 3300 BP, the Lapita peoples traveled away from New Guinea and towards the Solomon Islands (Walter et al. 2010). In the



northern Solomon Islands, the Lapita peoples interacted with the local inhabitants of this area who had arrived in the Solomon Islands about 47,000 years earlier (Walter et al. 2010). After acquiring new methods of sailing, the Lapita peoples moved eastward in the Oceanic region away from the Solomon Islands and New Zealand became the final settlement by the end of the 13<sup>th</sup> century (Walter and Jacomb 2007, Walter et al 2010).

New Zealand's archaeological record is separated into two periods. The Early Period dates from the initial settlement of New Zealand by the Lapita peoples until 1500 A.D. and the Late Period dates from 1500 A.D. until European contact in 1796 A.D. Major changes such as warfare in the archaeological record occurring at about 1500 A.D. are what mark the divide in time periods (Kinaston et al. 2013; Walter et al. 2010). As the Early Period transitioned into the Late Period, the ancestral Maori transitioned from long-distance modes of settlement and exchange to local exchange networks that were a result of movement restriction caused by more frequent conflict amongst the Maori tribes. (Walter et al 2010).

The first area of settlement in New Zealand by the Lapita people in the Early Period was the North Island, which they named Te Ika a Maui, or "the fish of Maui" (Smith 1996; Walter 2004). Eventually, settlement progressed to the South Island, which was named Te Wai Pounamou, or "the river of greenstone" (Smith 1996). The large, diverse, and temperate landscape in New Zealand facilitated the Lapita peoples' economy of tropical root, tree crops, and fishing (Davidson 1984). When contact with the Lapita peoples' homelands was lost, New Zealand's prehistory proceeded in seclusion (Walter et al. 2010).

## **Archaeology in New Zealand**

The focus of New Zealand's prehistoric archaeology is the Polynesian culture the Lapita people brought with them during their initial settlement in New Zealand (Davidson 1984). This includes the transformation of their culture to the Maori culture, and the conclusion of the prehistoric period ending in A.D. 1796 marked by European contact (Davidson 1984). This focus deals specifically with the first settlers' introduction of horticulture, economy, and the development of warfare, but none of the previously mentioned investigations are considered specific factors in explaining the development of the Maori culture (Davidson 1984).

The earliest known archaeological investigations that took place in New Zealand occurred in the 1840's (Davidson 1984). During this time, major sites such as Waingongoro in South Taranaki and Awamoa in North Otago were investigated for their association of prehistoric human activity along with moa remains (Davidson 1984; Taylor 1873). At this time, the first settlers were recognized only as the "moa-hunters" (Davidson 1984). Several decades later, Sir Julian von Haast with the University of Otago led the first major archaeological excavations in Canterbury, New Zealand in the 1870's investigating moa and moa-hunters (Davidson 1984; Von Haast 1872, 1875). Von Haast had controversially claimed that the moa-hunters and the Maori were two different groups of settlers that had arrived to New Zealand at two different prehistoric periods (Davidson 1984). However, Von Haast's employee, Frederick Wollaston Hutton, had interpreted Von Haast's work differently and proposed that the moa-hunters were the recent ancestors of the Maori (Davidson 1984; Hutton 1876). By the end of the 19<sup>th</sup> century, F.W. Hutton's opinion was generally agreed upon (Davidson 1984).

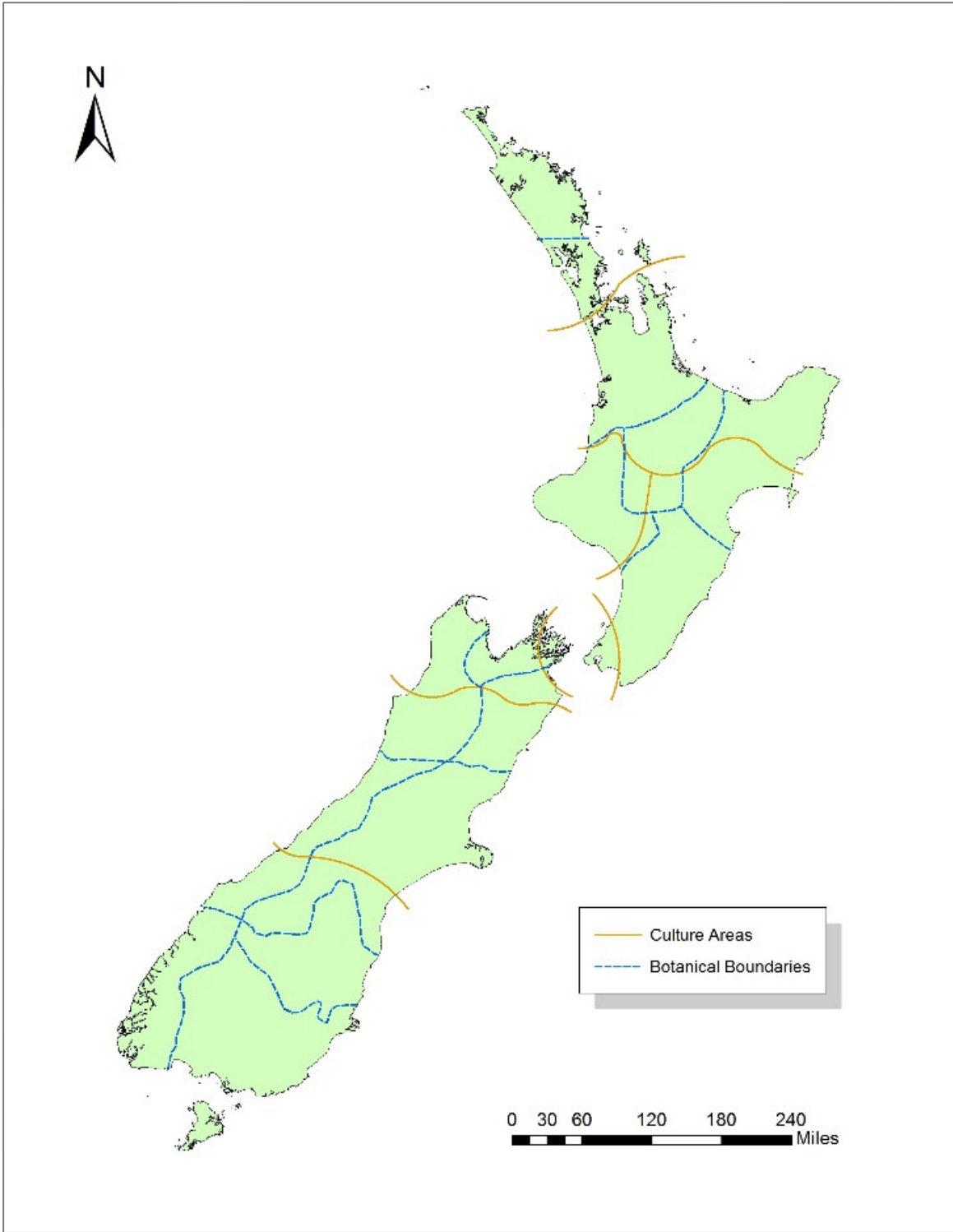


Figure 1. Map of cultural areas defined by Skinner (1921) and botanical districts defined by Cockayne (1926). From Davidson (1984).

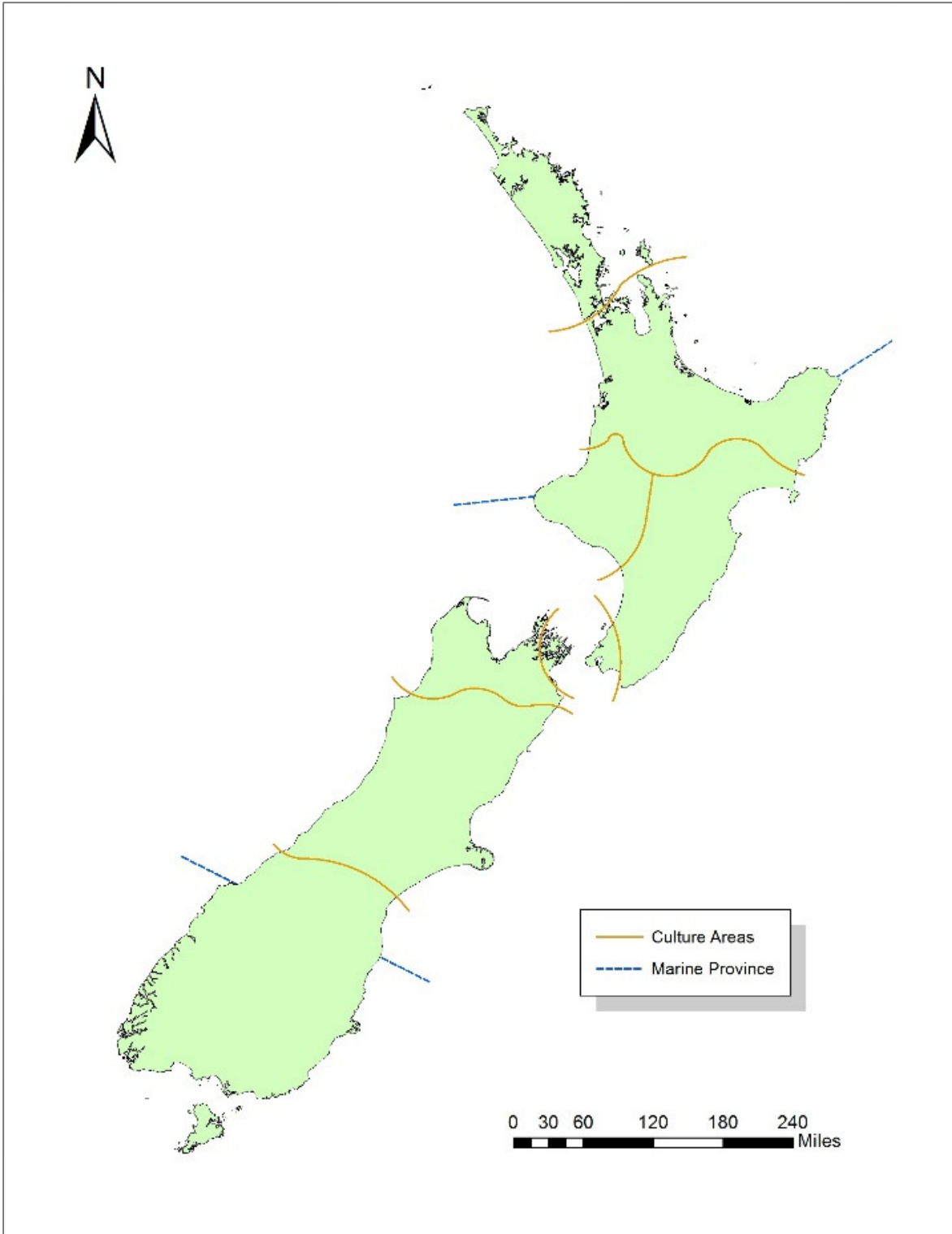


Figure 2. Map showing marine provinces defined by Cumberland (1949) and Lewthwaite (1949). From Davidson (1984).

In 1919, the University of Otago had appointed Henry Devenish Skinner as a Lecturer in Ethnology and Curator of Anthropology at the Otago Museum (Davidson 1984). H.D. Skinner led many major archaeological excavations (Davidson 1984). In 1921, Skinner described and mapped seven areas of New Zealand (Figure 1) defining them as “culture areas” (Davidson 1984; Skinner 1921). Skinner suggested these culture areas were based on constant ethnographic features and archaeological information from earlier and later periods of prehistory (Davidson 1984; Skinner 1921). Skinner describes a culture area as a geographic region where the inhabitants greatly resemble each other and that there is a well-defined physical appearance and dialect (Skinner 1921). Skinner (1921) did note that there was a difference from Southern Island Maori to the Maori of the North Island and that the North Island Maori were more closely related to Melanesians. Surprisingly, the culture areas that Skinner had defined complimented botanical districts described by Leonard Cockayne (1926) and marine provinces (Figure 2) later defined by geographers Kenneth Cumberland (1949) and Gordon Lewthwaite (1949) (Davidson 1984).

However, the archaeological work during the 1920’s did not chronologically account for cultural change (Davidson 1984). Instead, regional differences between sites were favored over chronology differences with stratigraphic positions within sites being disregarded (Davidson 1984; Skinner 1921). Most of the artifacts from this “Skinnerian” era of New Zealand archaeology are of limited use due to the excavation and cataloguing methods from this time (Davidson 1984).

In the 1950’s, higher standards in New Zealand archaeology had been implemented (Davidson 1984). Auckland University had established an anthropology department and an outline for investigating cultural change in prehistoric New Zealand had been created by Jack Golson, a lecturer at the anthropology department of Auckland University (Davidson 1984;

Golson 1959). With the new archaeological methods and ideas that had been formed, New Zealand archaeologists began to focus on Maori origins, Maori traditions, and Maori material culture as time went on (Davidson 1984).

### **Trade and Exchange in Prehistoric New Zealand**

As archaeology in New Zealand progressed, little archaeological discussion on New Zealand's prehistoric trade and exchange had taken place (Knox 2011; Renfrew 1969), an issue that is still present today. Renfrew (1969) emphasizes the importance of investigating trade and exchange in prehistoric communities and their cultural development by stating "Its particular and sometimes crucial importance lies in a dual status: as the indicator for us today that intercultural contact was taking place, and as a prime motive, among prehistoric groups, for such contact." (Renfrew 1969).

A contributing factor to the lack of knowledge on trade and exchange has been the difficulty in reconstructing New Zealand's prehistory through dating of sites. The issue is due to a combination of short archaeological chronology, undesirable site stratification records of earlier excavations, and New Zealand's short prehistory sitting within large ranges of radiocarbon calibration dating errors (Sellenfreund and Bollong 1989; Walter et al. 2010). For instance, a lack of prehistoric artifacts in New Zealand, such as metal and pottery artifacts, causes an issue of constructing a precise chronology for archaeologists (Davidson, 1984; Shawcross 1969s). This makes reconstructing networks of trade and exchange very difficult due to improper chronological alignment of potentially connected sites (Walter et al. 2010). However, Seelenfreund and Bollong (1989) and Green (1964) suggested that the various amounts of obsidian that have been found throughout New Zealand are indicative of a vast system of exchange networks that, with the right amount of quantitative data, can be defined. An

improvement to accurately dating sites in New Zealand is geochemically characterizing stone artifacts, such as obsidian, and analyzing the site to source relation in an attempt to associate those artifacts modes of exchange during certain time periods (Sheppard 2004).

Obsidian has been noted as being a useful medium for evaluating exchange in many parts of the world because obsidian can be chemically sourced (Scott 2008; McCoy and Carpenter 2014). Additionally, obsidian is common at many of New Zealand's archaeological sites, was of value to the prehistoric settlers for its superior quality, and is an excellent indicator of prehistoric communication. (Davidson 1984; Seelenfreund and Bollong 1989; Sheppard 2004; Sheppard 2011). Uses for obsidian in prehistoric New Zealand include flake tools, scrapers, and choppers which were believed to have been used for killing seals (Davidson 1984; Nicholls 1964).



Figure 3. Example of a common piece of black obsidian.

Obsidian flake tools are the most common type of obsidian artifact found in prehistoric New Zealand and were of the informal type when compared to the more formal flake tools found in other obsidian industries from around the world (Davidson 1984; Leach 1969). The second most frequent type of obsidian artifacts are obsidian blades (Davidson 1984) However, these

blades were exclusive to the South Island in an industry known as the Murihuku blade industry (Davidson, 1984). The origins of the industry are not clear and the reason for why the industry was restricted to the South Island is also not clear (Davidson 1984).

Among obsidian, other rock types that have been commonly found in New Zealand's prehistoric sites include Tahanga basalt, metasomatised argillites from the northern part of the South Island, and argillites from the southern part of the South Island used in the construction of flaked adzes (Walter et al. 2010). Materials that also were found to be exchanged in prehistoric New Zealand include fish, birds, rat, sea weed, kumara, shells and canoes (Davidson 1984). The only other material that was preferred over obsidian was greenstone, which was not prevalent until the Late Period (Davidson 1984; Firth 1929). Greenstone, similar to obsidian, has been known to be exchanged across long-distances (Davidson 1984). However, greenstone is not as well-documented as obsidian because not as much greenstone has been found in prehistoric sites in New Zealand (Davidson 1984).

Stone artifacts found in prehistoric New Zealand, such as obsidian, were mostly tools (Davidson 1984). Weapons were not common during the Early Period or Late Period (Davidson, 1984). The most prevalent weapon found in the Late Period of New Zealand's prehistory is the patu, or club (Davidson 1984; Teviotdale and Skinner 1947). These weapons were scarcely found in North Island sites but were commonly found incomplete (Davidson 1984; Teviotdale and Skinner 1947). Patu have been most commonly found in pa sites in the North Island, which were constructed during the Late Period (Davidson 1984).

When the first settlers arrived in New Zealand, most of the stone resources that were important to Polynesian culture were exploited by the 12<sup>th</sup> century (Davidson 1984; Furey 2002; Knox 2011). Many of the popular North Island obsidian sources known today were initially



identified by Ward (1974) and recently updated by Sheppard (2011). The North Island obsidian sources are a result of the volcanic activity caused by the subduction of the Pacific plate (Sheppard et al. 2011). Figure 4 shows some of the major sources that include Kaeo, Huruiki, Fanal Island, Te Ahumata, Cooks Beach, Hahei, Tairua, Whangamata, Onemana, Maratoto, Waihi, Rotorua, Maretai, and Mayor Island. The Northland, Coromandel Volcanic Zone, and Taupo Volcanic Zone source regions contain up to 50 sub-sources (Davidson 1984).

The first area to be settled in New Zealand by the Lapita people was the North Island (Smith 1999). Excavations of initial settlements in Palliser Bay in the southern part of the North Island indicate that the first settlers were obtaining large amounts of obsidian from North Island obsidian sources in the Coromandel volcanic zone, Taupo volcanic zone, and Mayor Island (Davidson 1984; Leach, 1978). The uneven distribution of geological sources granted some prehistoric communities with access to additional sources of high quality raw material (Davidson 1984). Some groups had direct access to obsidian, nephrite and other rocks used for adze construction and other tools (Davidson 1984). Walter et al. (2010) suggest that the settlers of Palliser Bay originally came from a northern part of the North Island and maintained long-distance exchange communications, similar to Polynesian culture, to continue acquisition of obsidian from sources such as Mayor Island, which is located in the northeast coast of the North Island (Davidson 1984).

Mayor Island obsidian was preferred to many of the other obsidians in New Zealand prehistory (Seelenfreund and Bollong 1989). This obsidian has been described as the most important source over the other 20 more common sources from that time (Sheppard 2004; Walter et al. 2010). Preference for Mayor Island obsidian to other types of obsidian may have been

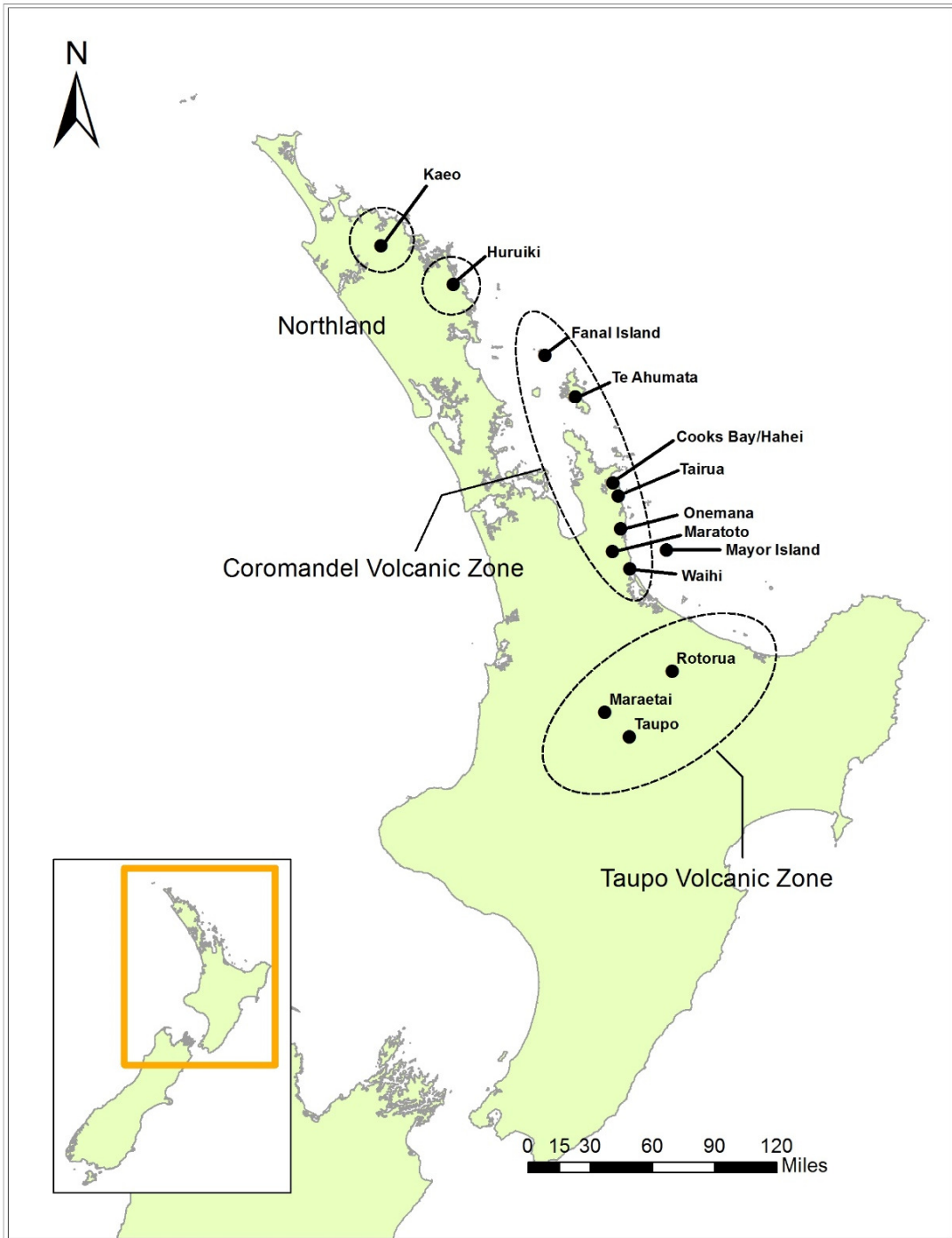


Figure 4. Map showing obsidian sources in the North Island of New Zealand grouped by Northland, Coromandel Volcanic Zone, and Taupo Volcanic Zone regions.

attributed to its central location in the North Island and superior flaking quality (Seelenfreund and Bollong 1989). However, Davidson (1984) suggests that people that lived far from the obsidian sources probably did not know where their obsidian was coming from (Sellenfreund and Bollong 1989). Seeing as Mayor Island obsidian was extremely frequent in many of New Zealand's prehistoric sites, this would make it a good control for the investigation of prehistoric trade and exchange networks in New Zealand as its frequency.

Before arriving to New Zealand, obsidian was found at many prehistoric Lapita sites throughout the Pacific and had originally been brought from long distances (Davidson 1984). One example includes obsidian that originated in the north coast of New Britain was found in southeast Solomons Lapita sites (Davidson 1984). In a study by Walter et al. (2010), prehistoric Lapita exchange systems involving obsidian from Melanesia were compared to prehistoric New Zealand exchange systems involving lithics in the settlement period. Walter et al. (2010) found that the early exchange networks in Melanesia were very similar to prehistoric exchange systems in New Zealand that had long-distance exchange.

In the study by Walter et al. (2010), they described two modes of exchange that occurred in early western Melanesia 3000 years ago based on differences observed by Irwin (1991). The first mode of exchange is the "colonizer mode" (Walter et al. 2010). The colonizer mode of exchange is defined by Walter et al. (2010) as a sudden increase in the exchange of exotic obsidian that occurred during a colonization event. Walter et al. (2010) attribute this mode of exchange to a high frequency of communication to establish local and long-distance contact with kinship communities during a time of expansion. During this time, obsidian may not have held a value as a commodity item (Walter et al. 2010). The second mode of exchange described by Walter et al. (2010) is the "trader mode". This mode of exchange occurred later in western

Melanesia when obsidian was traded as a commodity through coastal trade networks (Walter et al. 2010).

During the Early Period in New Zealand, there was long-distance movements of Mayor Island obsidian in a colonizer mode of exchange as described by Walter et al. (2010). Mayor Island obsidian was exchanged thousands of kilometers from the source to the Kermadecs and Chatham Islands (Sheppard et al. 2011) and is observed in high abundance in many Early Period sites (Seelenfreund and Bollong 1989). This mode of exchange that took place in the Early Period of New Zealand is comparable to early the colonizer mode Lapita exchange networks found in Melanesia as a result of exploration and long-distance networks (Irwin 1991; Walter 2007). Additionally, the prevalence of long-distance exchange during the Early Period likely was to establish long-distance social networks in New Zealand similar to the long-distance homeland connections in earlier Lapita systems (Green and Kirch 1997; Green and Anson 2000; Walter et al. 2010). As settlement expansion continued in New Zealand, modes of exchange as described by Walter (2007) also changed.

Near the end of the Early Period of New Zealand, Walter et al. (2010) suggest that a change from colonizer to trader modes of exchange occurred in New Zealand with notable rock types, such as nephrite, marking the shift. These changes in modes of exchange observed in New Zealand were very similar to modes of exchange that occurred in the use of obsidian in Lapita and other regions of western Melanesia (Walter et al. 2010). During the early Late Period, there is a reduction of Mayor Island obsidian frequency in the North Island of New Zealand (Seelenfreund and Bollong 1989; Walter et al. 2010) and an even higher reduction of Mayor Island obsidian frequency in the South Island (Walter et al. 2010). This reduction in Mayor Island obsidian frequency has been attributed to the increase in conflict and warfare that marks

the beginning of the Late Period (Walter et al. 2010). During this time, there is an increase of nephrite as a commodity over obsidian suggesting the emergence of a trade system (Walter et al. 2010). This change from an exchange network involving mostly obsidian to a commodity trade network involving mostly nephrite is very similar to the colonizer mode observed in west Melanesia shifting to a trader mode (Walter et al. 2010).

Walter et al.'s (2010) suggestion of these two modes of exchange compliments Scott's (2008) suggestion that a down-the-line mode of exchange was occurring somewhere between the Early and Late Periods. Scott (2008) also suggests that there were two different modes of exchange that occurred in the Early and Late Periods. This suggestion would be supported by having the colonizer mode of exchange discussed by Walter et al. (2010) in the Early Period that involved exchange of long-distance acquired obsidian and the trader mode of exchange that occurred in the Late Period that marked the introduction of a trade system involving commodity goods.

The beginning of the trader mode of exchange was also accompanied by introduction of conflict and the formation of Maori chiefdoms in the Late Period (Sutton 1990). Maori chiefdoms are also suggested to have formed almost exclusively in the North Island (Sutton 1990). This would support the idea that there was no sociopolitical influence on exchange during the Early Period, especially in the South Island (Sutton 1990). Sutton (1990) also discusses the errors in assumptions made when comparing Polynesian societies and chiefdoms to other prehistoric societies and their respective hierarchies. For instance, Sutton (1990) suggests that Kirch (1984) is incorrect in assuming that the societies of the ancestral Polynesians already had in place a hierarchal chiefdom based on heredity. Sutton's (1990) argument is that if this were the case, this would mean the Maori chiefdoms would have been in place since the initial

settlement of New Zealand. Sutton (1990) also argues that the New Zealand Maori are often compared to an “idealized” version of 19<sup>th</sup> century Polynesian societies due to the late Polynesian society influence that authors such as Buck (1950), Goldman (1970), and Firth (1972) had on the interpretation of the Maori and their culture in general.

### **Geochemical Characterization**

Geochemical characterization of stone artifacts in New Zealand was not frequently used in the early 1900's due to costs and destructive and complicated techniques (Seelenfreund and Bollong 1989). Before the use of characterization studies, physical identification of stone artifacts was the preferred method of sourcing (Seelenfreund and Bollong 1989). Some obsidian, like Mayor Island obsidian, could be recognized by the stone's color (Seelenfreund and Bollong 1989). For instance, holding Mayor Island obsidian under light would show a translucent green color (Seelenfreund and Bollong 1989).

Studies from around the world have contributed to the increase in analysis of geochemically characterizing obsidian stone artifacts (Sheppard 2004; McCoy et al. 2011; Mosley and McCoy 2010; Taliaferro et al. 2011). Geochemical characterization is mentioned as being one of the fastest growing areas of study in archaeology (Knox 2011; Glascock 2002). The study of geochemical characterization in archaeology has been performed using a variety of technologies and methods such as atomic absorption, emission spectrometry, proton induced x-ray emission absorption and proton induced gamma ray emission (PIXE-PIGME), and wavelength dispersive and energy dispersive x-ray fluorescence (XRF) (Knox 2011; Sheppard 2004). The most notable technique has been the use of x-ray fluorescence analysis (XRF) in archaeology since it provides a non-destructive method to accurately geochemically characterize stone artifacts such as obsidian (Sheppard 2004; Sheppard 2011; McCoy et al 2011).

Early studies of geochemical characterization involving XRF analysis on obsidian artifacts, such as Green et al.'s (1967) study using emission spectrometry, were undesirable since the methods were destructive to the samples and costly (Knox 2011; Green et al. 1967; Armitage et al. 1972; Reeves and Armitage 1973). By the 1970's, methods were simplified with neutron activation analysis and its non-destructive techniques made it desirable amongst the archaeological community (Knox 2011; Smith et al. 1977). Neutron activation analysis also had overshadowed other techniques, such as non-destructive characterization analysis by Coote et al. (1972) that had potential in the archaeological community. This new method used a scattering of beam protons from a 3 MeV Van de Graff accelerator to derive readings of sodium, fluorine, and aluminum. Another method that was overshadowed was isoprobe analysis by Charles Bollong (1983). Bollong created an automated, non-destructive obsidian sourcing laboratory in the Department of Archaeology using isoprobe analysis at Otago University in Dunedin but its accuracy limited its usefulness (Bollong 1983; Sellenfreund and Bollong 1989). This method of analysis could only distinguish between New Zealand sources such as Mayor Island and a general group of North Island sources that includes the Coromandel, Great Barrier, and Inland obsidian sources (Bollong 1983; Seelenfreund and Bollong 1989).

The non-destructive use of portable x-ray fluorescence analysis (pXRF) involving the investigation of obsidian during pre-European contact in New Zealand has recently increased (Sheppard 2004; Sheppard 2011; Mosley and McCoy 2010; McCoy and Carpenter 2014, Lawrence et al. 2014). Prior to the use of pXRF and similar methods in New Zealand, most materials were characterized by their physical appearance (Knox 2011; Moore 1988). Recent studies of pXRF on obsidian collections in the past decade have proven that the ease of use, non-destructive preparation and analysis methods, and cheap cost, make pXRF analysis an excellent

characterization method alternative to the previous method of physical characterization (Sheppard 2004; Sheppard 2011; Mosley and McCoy 2010; McCoy and Carpenter, 2014, Lawrence et al., 2014). In a call for more sourcing work to begin, Green (1962) suggests that sourcing studies provide a greater understanding of prehistoric colonization and settlement (Sheppard et al., 2011).

In a recent study on the revitalization of using non-destructive pXRF techniques to source pre-European obsidian in New Zealand, Sheppard et al. (2011) compare methods and results of pXRF analysis to other geochemical characterization methods. The study provided a new perspective on the use of pXRF analysis as a quick, efficient, accurate, and cheap method of providing geochemical information on large datasets compared to other methods of geochemical characterization (Sheppard et al. 2011). However, Sheppard et al. (2011) noted that methods to distinguish between homogenously sourced material and assignment of unknown sources is yet to be created.

### **Cost-Surface Analysis in Archaeology**

Using chemically characterized obsidian, researchers have established methods on how to best reconstruct prehistoric networks of trade and exchange in New Zealand by using spatial analysis (Mosley and McCoy 2010; McCoy and Carpenter 2014; Scott 2008; Lawrence et al. 2014). In a study by Scott (2008), prehistoric exchange of obsidian was investigated by using geographic information systems (GIS) methods to map possible routes of exchange. Cost-surface analysis was implemented to derive calculated paths of least-cost in order to visualize possible paths of prehistoric obsidian exchange in New Zealand.

Cost-surface analysis is the term for a set of GIS techniques that calculate and create a cost-surface to estimate the least-cost path of travel across the cost-surface raster map (Scott



2008; Van Leusen 2002). There are generally two methods of performing a cost-surface analysis (Scott 2008; Wheatley and Gillings 2002). The first method is using an isotropic algorithm which takes into consideration the cost of movement across a cost-surface but does not take into consideration the direction of movement (Scott 2008; Wheatley and Gillings 2002). The second method is using an anisotropic algorithm that takes into consideration the direction of movement across a cost-surface, which would be important when slope is taken into account (Scott 2008; Wheatley and Gillings 2002).

Scott (2008) used an anisotropic cost-surface derived from a digital elevation model (DEM) to calculate possible exchange paths from obsidian sources in the North Island of New Zealand to sites in the South Island. Since the study by Scott (2008) involved travel across waterways from the North Island to the South Island, the cost-surface raster was created using the DEM and adjusted cost for environmental variables and barriers (Scott 2008). For instance, Wheatley and Gillings (2002) suggest assigning low-cost values to cells where water transportation was common but surrounding the body of water with a thin barrier of high-cost to account for the time taken to acquire transportation (Scott 2008). However, as Scott (2008) notes, canoe transport was common in prehistoric New Zealand and the method of applying a barrier was not applied. Scott (2008) did adjust the cost of travelling across water in different analyses by having low-cost marine travel analysis and high-cost marine travel analysis included in his results.

By comparing the resulting least-cost paths to obsidian frequencies in South Island sites, Scott (2008) suggested coastal sites such as Wairu Bar and Redcliffs having been centralized nodes of distribution for obsidian in prehistoric New Zealand if the cost of travelling the ocean was low-cost. This suggested prehistoric obsidian exchange movement by Scott (2008) coincides

with most inland sites in the South Island lacking obsidian material (Sellenfreund and Bollong, 1989). If the cost for traveling the ocean was high-cost, most of the sites along the coast of the South Island could be accessed directly from the North Island obsidian sources or from the North Island in general (Scott 2008).

In the mid 1990's, cost-surface analysis was introduced and there was skepticism about its use in archaeology due to cost-surface analysis results creating finite environmentally deterministic conclusions about what it is being applied to (Van Leusen 1993). Van Leusen (1993) argues against this suggesting that, archaeologically, results derived from cost-surface analysis can be considered invalid if they have been applied incorrectly or if there has been misinterpretation with the results.

## CHAPTER 2 – OVERVIEW OF SITES

The obsidian collections that were investigated in this study are from Early Period sites from the South Island of New Zealand (Figure 5). These sites were chosen to expand and compare the resulting pXRF analysis data to other previously published pXRF analysis data from nearby sites such as Wakanui and Purakanui. The sites discussed in this section are labeled with their respective archaeological imperial site numbers that are derived from the Central Index of New Zealand Archaeological Sites (CINZAS). Each site is labeled according to their North Island (NI) or South Island (SI) position and their position on the numbered imperial map index. All site numbers were obtained from a 2008 CINZAS spatial database acquired from the University of Otago but a site number was not found for Pleasant River Mouth or Pahia. Radiocarbon dates discussed in this study have also been included (Table 1). However, as Seelenfreund and Bollong (1989) mention, radiocarbon dates for New Zealand archaeological material are difficult to interpret with large errors of  $\pm 150$  years at 95% confidence due to New Zealand's prehistory only spanning less than 1000 years.

Table 1. Radiocarbon dates for the sites discussed in this study.

Site	Radiocarbon Dates (years BP)
Shag River Mouth	845 $\pm$ 55 to 823 $\pm$ 45
Pounaweia	590 $\pm$ 40 to 450 $\pm$ 50
Little Papanui	Unspecified
Long Beach	712 $\pm$ 57 to 311 $\pm$ 86
Pleasant River Mouth	Unspecified
Waitaki River Mouth	600 $\pm$ 80
Wakanui	421 $\pm$ 51 to 672 $\pm$ 56
Purakanui	562 $\pm$ 30 to 571 $\pm$ 34
Pahia	490 $\pm$ 50
Tiwai Point	770 $\pm$ 90 to 640 $\pm$ 40

In the past, conflicting discussion about each of the sites mentioned in this study has involved site function and settlement frequency (Smith 1999; Anderson 1982; Anderson et al. 1996; Teal 1975; Knight 1965). Pleasant River Mouth, Little Papanui, Purakanui, and Long Beach have all been described as seasonal settlements (Smith 1999; Anderson 1982; Anderson et al. 1996; Knight 1965; Teal 1975) that functioned as campsites for cyclical mobility when Maori made their way down to hunt from large, permanent settlements such as Shag River Mouth (Anderson 1982; Smith 1999). Sites that were located in the northern region of the South Island, like Shag River Mouth, are believed to have been sites with more permanent settlement (Smith 1999). However, sites in the southern part of the South Island, such as Pounaweia, have shown evidence for permanent settlement as well (Hamel 1977). Sites that are believed to have functioned as temporary campsites may have served as satellite camps for sites with permanent settlement functionality (Smith 1999).

Other sites included in this study from previously published studies are Wakanui, Purakanui, Tiwai Point, and Pahia. Recently, pXRF analysis data was acquired from obsidian assayed from Wakanui and Purakanui (Lawrence et al. 2014; Mosley and McCoy 2010) and are used in this study for comparative analysis. Both Wakanui and Purakanui are considered Early Period sites with Purakanui excavations indicating seasonal settlement functionality and Wakanui being a large permanent settlement (Lawrence et al. 2014; Mosley and McCoy 2010). Tiwai Point and Pahia are also both Early Period sites but very little is known on their settlement functionality (Davidson 1989; Seelenfreund and Bollong 1989).

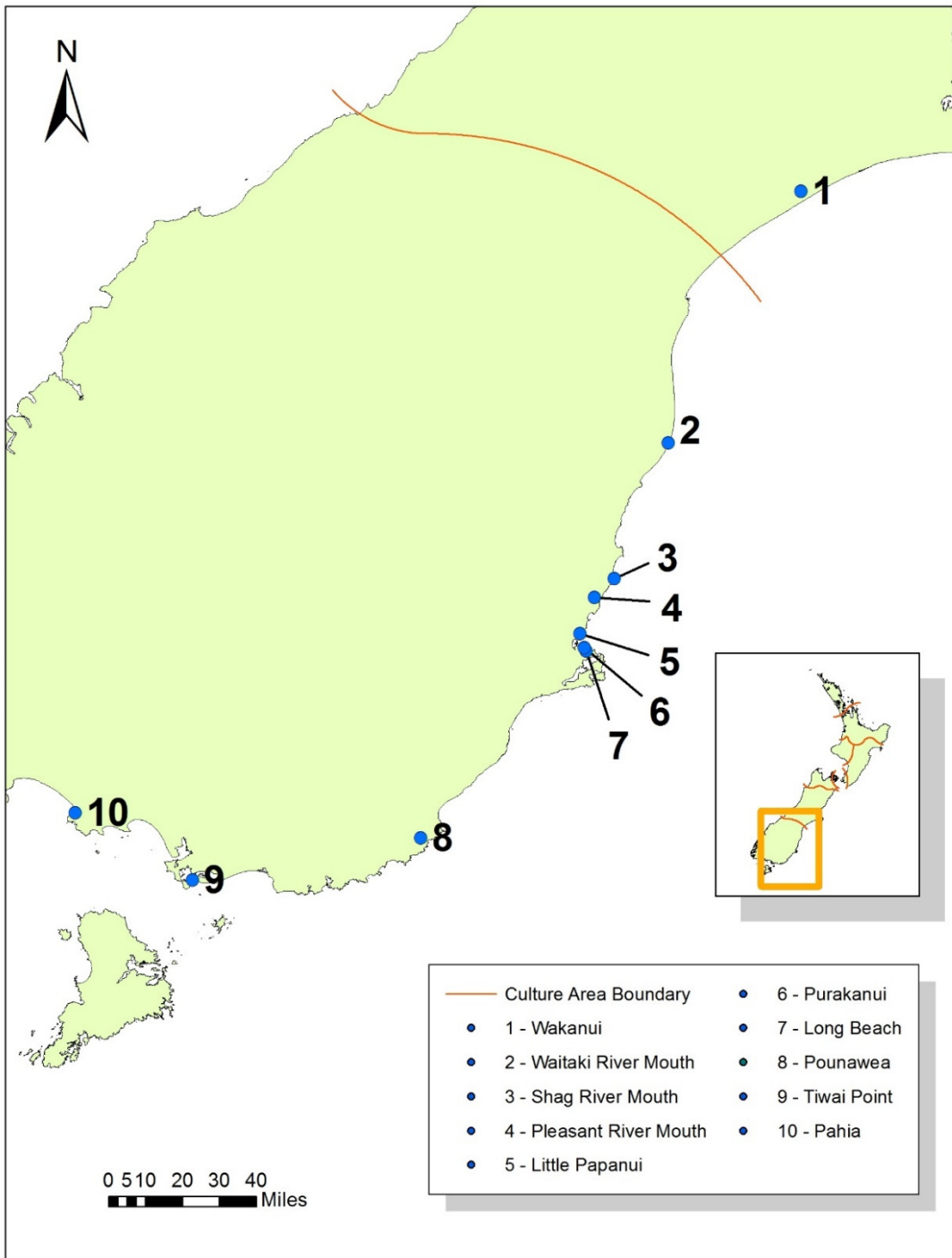


Figure 5. Map showing all sites that have assayed obsidian discussed in this study. A Cultural Area Boundary digitized from Skinner (1921) is also shown separating Wakanui and Waitaki River Mouth. This is the same boundary that corresponds closely to the marine province of this area.

### **Shag River Mouth (S155/5)**

Shag River Mouth is one of the earliest major sites that was investigated during the early beginnings of New Zealand's archaeology in the 1870's (Davidson 1984; Manning 1875). Shag River Mouth was first investigated by Sir Julius von Haast and Frederick Wollaston Hutton who were both lecturers at the University of Otago at the time (Davidson 1984). This site lies on the inland side of the sand spit at the river mouth of Shag River in North Otago and features a large area of shell midden, an abundance of Moa remains, and East Polynesian artifacts (Davidson 1984). Radiocarbon samples of charcoal from the site date Shag River Mouth at about  $845 \pm 55$  to  $825 \pm 45$  years BP (Davidson 1984; Seelenfreund and Bollong 1989). Recent excavations indicate that Shag River Mouth was a site with permanent settlement functionality (Smith 1999).

### **Pounaweia (S184/1)**

Pounaweia is located in the Caitlins River estuary in South Otago. The site was initially investigated by Lockerbie (1959) in the 1950's and revisited by Hamel (1977) in the 1970's. Pounaweia features a shell midden with moa remains and other bones (Davidson 1984). Pounaweia is considered a permanent settlement site (Smith 1999) that was occupied 500-800 years BP but is debated as possibly having been a temporary campsite during earlier occupation (Seelenfreund and Bollong 1989; Lockerbie 1959; Hamel 1977; Smith 1999). Subsistence activity at Pounaweia consisted mostly of fishing indicated by the bone hook and shell hook assemblages found at the site (Davidson 1984; Lockerbie 1959). Bone implements similar to those found in the Marquesas were also found at Pounaweia during excavations (Davidson 1984; Lockerbie 1959).

### **Little Papanui (S164/1)**

Little Papanui is a hillside site located in the Otago Peninsula (Davidson 1984; Simmons 1967). Little Papanui was initially investigated in the 1930's by David Teviotdale (1932) and later revisited by H.D. Skinner (Skinner 1960). An inland midden, moa remains, bone hook artifact assemblages, and several burials were excavated (Teviotdale 1932; Skinner 1960). Subsistence activity at Little Papanui consisted of mostly fishing (Davidson 1984; Teviotdale 1932). Unspecified radiocarbon dating has dated Little Papanui in the Early Period (Skinner 1960; Teviotdale 1932). Most artifacts obtained from the Otago region were excavated from Little Papanui (Skinner 1960).

### **Long Beach (S164/20)**

Long Beach is another site found in the Otago region near Dunedin. This open-bay site features an extensive area of occupation with large assemblages and the inclusion of burials (Davidson 1984; Leach and Hamel 1981). The study by Leach and Hamel in 1981 was part of a controlled investigation in the early 1980's that involved excavation of several layers underneath a 17<sup>th</sup> century Maori settlement (Leach and Hamel 1981). Five radiocarbon dates from charcoal found in two different stratigraphic layers provide dates ranging from  $712 \pm 57$  years BP to  $311 \pm 86$  years BP indicating that Long Beach was occupied during the Early Period and Late period (Seelenfreund Bollong 1989) and is believed to have been a permanent settlement with cultural continuity (Leach and Hamel 1981). Excavations indicate that subsistence activity consisted mostly of fishing due to the large bone hook artifact assemblages found at this site (Leach and Hamel 1981).

## **Pleasant River Mouth**

Pleasant River Mouth is a large site along the east coast of the south island of New Zealand in east Otago (Smith 1999). The first archaeological remains from Pleasant River Mouth were found in the 1890's and reported by Renata (1894). The site was officially excavated in the 1950's with more recent excavations occurring in the 1990's (Smith 1999). Pleasant River Mouth is believed to have been used as a seasonal campsite from the 14<sup>th</sup> century until the 16<sup>th</sup> century during the late Early Period (Smith 1999). Activity at Pleasant River Mouth mostly consisted of moa hunting and fishing but it has been suggested that it is a multi-functional site (Knight 1965; Smith 1999). Pleasant River Mouth is believed to have been one of the larger satellite sites of Shag River Mouth (Smith 1999).

## **Waitaki River Mouth (S128/1)**

Waitaki River Mouth is a large site north of Shag River Mouth on the southern side of the Waitaki River mouth (Davidson 1984). Excavations revealed an extensive area of ovens, moa remains, stone adzes, quartzite, and evidence of cortical flakes that indicate most obsidian cores were not reduced at the quarry site for transportation (Davidson 1984; Knight 1965). Excavations also recovered a rare quartzite double-edged knife (Knight 1965). This double-edged knife is one of two knives of its kind recovered in New Zealand with the other knife having been found in Murihiku, another South Island site (Knight 1965). The extensive oven area indicates that Waitaki River Mouth was a permanent settlement (Davidson 1984; Knight 1965). Radiocarbon dating of moa bone have dated Waitaki River Mouth  $600 \pm 80$  years BP (Davidson 1984).



### **Wakanui (L37/8)**

Wakanui is located on river plain on the east coast of the South Island of New Zealand in South Canterbury and was first excavated by the Canterbury Museum Archaeological society in the 1970's (Mosley and McCoy 2010). Excavations revealed oven features with moa remains, flake tools, and adzes indicating that Wakanui was a large, permanent settlement. Radiocarbon dates of moa remains indicates have dated Wakanui at  $421 \pm 51$  to  $672 \pm 56$  years BP (Davidson 1984; Mosley and McCoy, 2010). Excavations at Wakanui also contained rare examples of harpoon heads (Davidson 1984). The artifacts recovered from Wakanui indicate that subsistence activity consisted mostly of fishing.

### **Purakanui (S164/18)**

Purakanui is located in the Purakanui inlet near Dunedin on the east coast of the South Island of New Zealand and was first excavated in the late 1970's by Anderson (1981). Excavations at Purakanui revealed stratified midden within the sand dunes and indicate that Purakanui subsistence consisted of mostly fishing. Purakanui was considered a seasonal camp with radiocarbon dated shells dating Purakanui at  $562 \pm 30$  to  $571 \pm 34$  years BP.

### **Pahia**

Little information on Pahia is available in literature. Most of what is known comes from the archaeological collections derived from early excavations (Seelenfreund Bollong 1989). Pahia is located in the south-west end of the South Island of New Zealand. Radiocarbon dates indicate that Pahia is  $490 \pm 50$  years BP, indicating that Pahia may have been a late Early period site (Seelenfreund Bollong 1989).

### **Tiwai Point (S181-2/16)**

Tiwai Point is located near the entrance of Bluff Harbour in the South Island of New Zealand (Davidson 1984). Tiwai Point was initially excavated in the late 1960's and consists of middens and areas indicating argillite-working (Davidson 1984; Sutton and Marshall 1980).

Tiwai point is also one of the earliest sites that began mutton-birding (Davidson 1984).

Radiocarbon dates of charcoal date Tiwai Point at  $770 \pm 90$  to  $640 \pm 40$  years BP indicating that it is an Early Period site.

### CHAPTER 3 – MATERIALS AND METHODS

A collection of more than 1,300 stone artifacts was loaned by the Otago Museum's Humanities department under the supervision of Scott Reeves, the Humanities Collection Manager. Of the stone artifacts that were loaned, 443 artifacts were selected to be assayed by pXRF. The selection was made by choosing sites on the east coast that would provide a target sample size of at least 30 obsidian stone artifacts. The stone artifacts were tested using a Bruker AXS portable XRF (Figure 6) machine from six sites along the east coast of the South Island in New Zealand. The sites include Waitaki River Mouth (S128/1), Shag River Mouth (S155/5), Pleasant River Mouth, Little Papanui (S164/1), Long Beach (S164/20), and Pounaweia (S184/1). The material was mostly received from excavations that took place in the Otago region of the South Island (Figure 7) in the 1870's and 1930's by the University of Otago led by Henry D. Skinner (Davidson 1986). The eight sites date to New Zealand's Early Period before 1500 A.D. (Davidson 1984; Walter et al. 2010; Seelenfreund and Bollong 1989).



Figure 6. One of two Bruker AXS portable x-ray fluorescence machines used in sourcing of the obsidian.

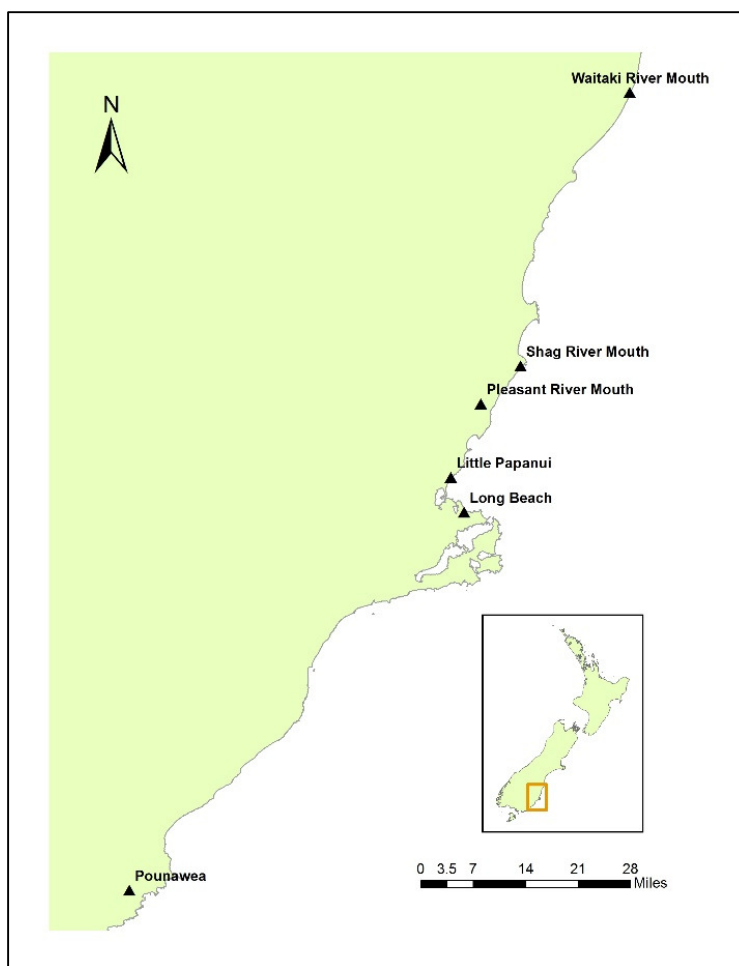


Figure 7. Map of the east coast of the South Island of New Zealand of the obsidian collections that were sourced in this study.

Results of chemically-sourced obsidian from two previously published South Island sites were also included in this study for extended and comparative analysis of obsidian distribution. These sites are Purakanui (Lawrence et al. 2014) and Wakanui (Mosley and McCoy 2011), both Early Period sites along the east coast. Published information on sourced obsidian from Redcliffs also was used (Seelenfreund and Bollong 1989) for the purpose of comparing Redcliff's obsidian source frequencies to the obsidian frequencies obtained in this study. The samples from Purakanui (n=118) (Lawrence et al. 2014), Wakanui (n=87) (Mosley and McCoy 2011), and Redcliffs (n=86) (Seelenfreund and Bollong 1989) creating a total sample size of 734 artifacts.

The artifact attributes were assigned a unique accession number and stored in a Microsoft Excel spreadsheet database for the Otago Museum's referencing purposes and for analysis purposes. Most of the obsidian artifacts already had museum accession numbers but in the cases where the accession number could not be determined, a new accession number was assigned to the artifact beginning with D2014.10 and ending with D2014.169. After the stone artifacts were sorted, the geochemical characterization by way of portable XRF was performed.

### **Geochemical Characterization**

For over 40 years, XRF has been used to non-destructively geochemically characterize stone artifacts from prehistoric sites in New Zealand (Sheppard 2004). The method has proven to be useful in accurately sourcing obsidian (McCoy et al 2011; McCoy and Carpenter 2014) and has increased in use in the archaeological community in the last decade. This study involved the use of two BrukerAXS™ pXRF's provided by the archaeology laboratories of the University of Otago. Geochemical characterization of the stone artifacts was performed at the Otago Museum's laboratory. Two separate pXRF handhelds were used so that the stone artifacts could be efficiently scanned using two separate filter settings using established laboratory protocols (McCoy and Carpenter 2014; Sheppard et al. 2011).

The BrukerAXS™ pXRF is an x-ray tube powered by lithium batteries or a standard power brick. The pXRF unit also runs an Ag anode at a voltage range of 10-40 kV. The results can either be downloaded to a PDA or the pXRF unit can be plugged into a COM serial port. For this study, the pXRF units were each connected to a separate laptop via COM serial port. All of the obsidian was assayed using the optimal settings for 'mid-z' trace elements that include Rb, Sr, Y, Zr, and Nb using what the manufacturer refers to as the "green" filter. This filter specifically uses the settings of 40 kv and 8 microamps at a 300 second live time and with a filter

(12milAl+1milTi+6milCu) and provides better accuracy in identifying any green obsidians typically found in Mayor Island. This would further help in sorting out any obsidians that may not have been sourced from Mayor Island. A second filter setting was then used in the examination of lighter elements that include Si, Ti, Al, Fe, Mn, Mg, Ca,Na, and K, which required using the Bruker pXRF's vacuum. The settings were set to 15 kv and 45 microamps without the use of a filter.

As mentioned in Sheppard et al. (2011), maintaining consistent operating conditions and protocols for the pXRF units is important to avoid inaccurate results in the geochemical analysis. Before beginning each analysis session each day at the Otago Museum's laboratory, the two BrukerAXS™ pXRF's had a pelletized USGS basalt standard assayed as a control. This control was also assayed at a 300 second live time. Each artifact was placed over the detector window with the flattest side of the artifact on the detector window of the pXRF unit to obtain the most accurate reading. Once the obsidian was assayed, the readings were converted to parts-per-million (ppm) and grouped using principal components analysis into similar geochemical categories. The principal component analysis was carried out by Mark McCoy.

### **Cost-Surface Analysis**

A cost-surface analysis was performed in ESRI's ArcGIS involving Waitaki River Mouth, Shag River Mouth, Pleasant River Mouth, Little Papanui, Purakanui, Long Beach, Pounaweia, Tiwai Point, to determine if they are part of the same prehistoric exchange network. These sites are believed to be part of the same culture area (Skinner 1921). The Mayor Island obsidian frequencies also suggest that they may have been part of the same prehistoric exchange network along the east coast of the South Island of New Zealand.

The analysis was used to calculate a least-cost path from Waitaki River Mouth, the northern-most site in one of the suspected prehistoric exchange networks, to each of its southward sites that are thought to have been connected to Waitaki as satellite sites within the same exchange network. A separate cost analysis was also performed from Tiwai Point and outward towards Pounaweia and Pahia. These sites were analyzed separately from the eight previously mentioned sites because of their distance and the large increase in Mayor Island obsidian from Purakanui and Long Beach to Pounaweia. The first southern-most suspected exchange network involves Pounaweia, Tiwai Point, and Pahia which are all Early Period sites that may have been occupied around the same time (Davidson 1984). The Mayor Island obsidian frequencies in previously published papers (Seelenfreund and Bollong 1989) and suggestions by Scott (2008) on centralized sites, suggest that Tiwai Point was the centralized distribution site with Mayor Island obsidian frequencies dropping proportionately to distance at the satellite sites, which would be Pounaweia and Pahia. The second suspected exchange network involves Waitaki River Mouth, Shag River Mouth, Pleasant River Mouth, Little Papanui, Purakanui, and Long Beach, with Waitaki River Mouth acting as the centralized distribution site due to the higher Mayor Island obsidian frequencies observed at this site compared to the other five sites.

The cost-surface analysis will be used to determine if Pounaweia, Pahia, and Tiwai were part of their own exchange network separate from the other eight sites, if all 11 sites were part of the same exchange network, or if they were part of a separate time series. The cost-surface analysis should indicate separate exchange systems that occurred within the same time series if there is a greater difference in distance between sites such as Pounaweia and Purakanui that may have been separated by a geographical obstruction. A geographical obstruction would make travel between two sites more costly.

A friction surface is required to perform a cost-surface analysis and determine the least-cost path from site to site. To create the friction surface, datasets such as the starting point, a cost-distance raster, a cost backlink raster, and a slope raster are required. The rasters are calculated simultaneously by ArcMap to create a cost-surface grid that assigns a cost to each cell in an image raster. Using the created datasets, the shortest path from the source site to the destination sites is calculated by ArcMap by determining which path across the cell grid will accumulate the least amount of cost.

A digital elevation map (DEM) was obtained from Land Elevation New Zealand (LINZ) at a resolution of 8 meters. The DEM was used to create a slope raster using ArcMap's Surface Slope tool. The slope raster is created by ArcMap by analyzing the increase or decrease in elevation along a distance range and recalculating those changes in elevation along a change in distance as slope angles measured in degrees. Next, a cost backlink raster is required to determine a set of best possible routes to travel along the slope raster from a starting point, which will be Waitaki River Mouth and Tiwai point in each separate analysis, to their subsequent destinations. ArcMap calculates the cost backlink raster by defining the neighbor cell that will be the next cell traveled along the cell grid to accumulate the least cost by distance and also takes into account from which direction each upward and downward slope is approached to reduce cost. The slope DEM that is created is then used to create the cost distance raster. ArcMap calculates the cost distance raster by calculating the least amount of cost that can be accumulated to the nearest source along the cell grid in the slope raster. The cost distance and cost backlink rasters are both used in the cost path analysis tool to calculate the least-cost path from a starting site to subsequent destination sites.



## **Tobler Function Analysis**

Travel-time was calculated using Tobler's (1993) "hiking function" using a method outlined in McCoy et al. (2011). This method commonly has been used in archaeological research involving mobility (McCoy et al. 2011; Kantner 2004; Taliaferro et al. 2010; Wheatley and Gillings 2002). The time functions were calculated as direct person hours that would be required to travel from origin to destination and does not take into account factors such as going off-trail, carrying of cargo, or maritime travel (McCoy et al. 2011). The sites that were involved in this analysis have been determined to be Early Period sites so beasts of burden such as horses were not introduced until the early 19<sup>th</sup> century (Davidson 1984; Smith 1996; Nicholas 1817). When integrated with tools in ArcMap, the function parameters take the slope variations of the slope raster into account and converts the slope variations into a walking velocity as it moves along the raster cells (Tobler 1993). This function operates similar to the cost-surface analysis by finding the best least-cost path and then accumulating time while passing through cells that have been assigned time values relative to slope.

The significance of using the Tobler function in this study was to obtain travel times along a least-cost path to determine if there was a time factor that would impede travel from one site to another in the case that a geographical obstruction was not observed in the cost path analysis. Although an efficient least-cost path may occur between sites, there may be a greater time impedance on travel that the cost-surface analysis might not show. In this study, least-cost path with accumulated time was calculated from a starting site that is suspected of being a centralized distribution site to subsequent satellite sites (Figure 8). The calculated least-cost-path also assumes that the prehistoric New Zealand land cover and small riverways were not an impedance on travel.

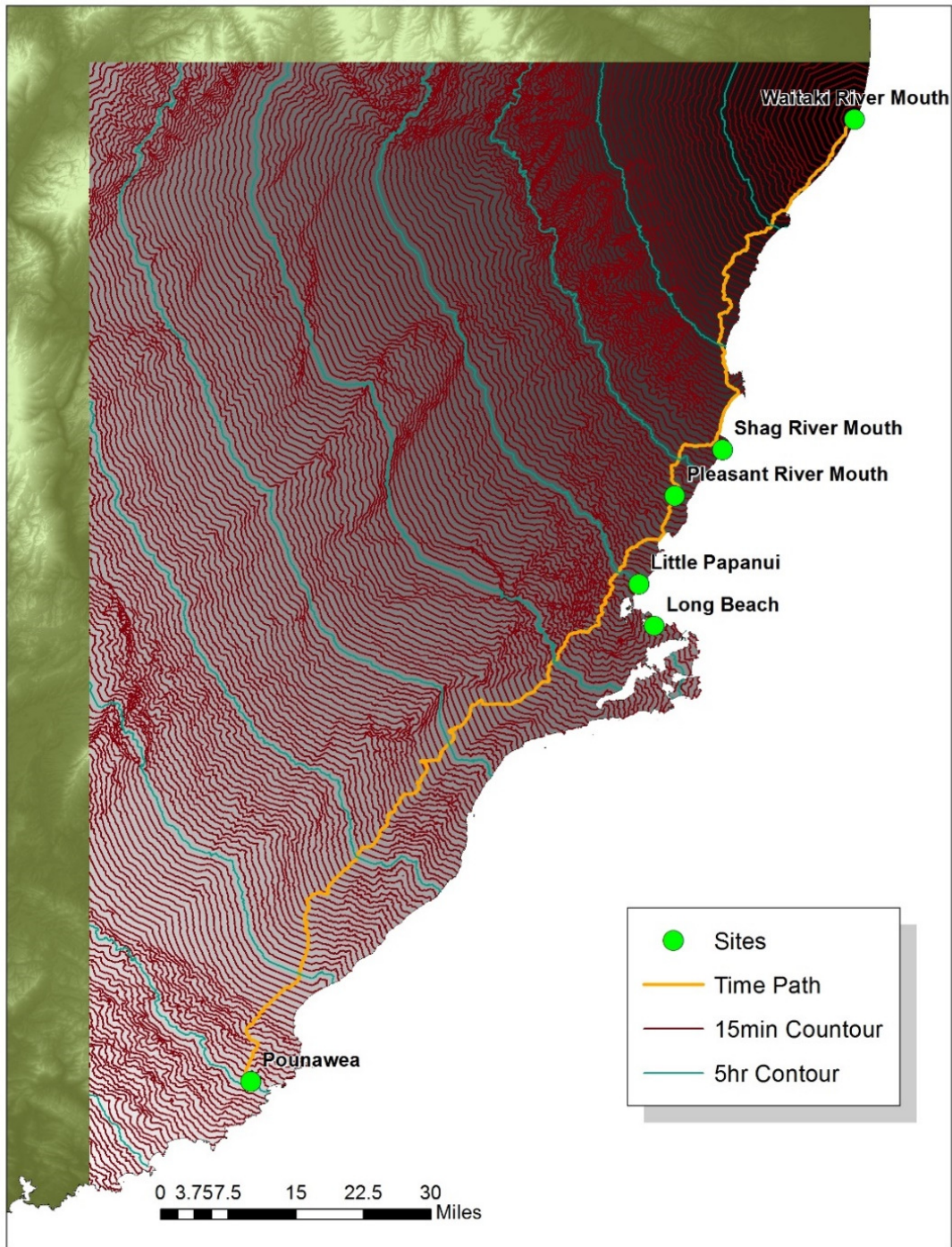


Figure 8. Map of the sites discussed in this study on the east coast of the South Island of New Zealand showing contour lines representing travel time across a slope cost distance raster in 15 minute and 5 hour intervals.

The slope raster that was used in the cost-surface analysis also was used for the Tobler function analysis. Similar to the cost path analysis, an anisotropic cost-surface is created using the slope raster to calculate cost across each cell that is traveled. Instead of using the Cost Path tool in ArcMap, the Path Distance tool is used for the Tobler function. Using a vertical factor table based on slope-affected walking velocity (Tobler 1993) acquired from [mapaspects.org](http://mapaspects.org), the vertical factor parameters are from the table are used in the Path Distance tool along with the cost raster that was created. The distance raster that is created can then be used to create a line with accumulated time costs across the raster.

## CHAPTER 4 – PORTABLE XRF RESULTS

Of the 443 obsidian artifacts that were assayed using the Bruker AXS portable XRF, 383 were assigned a geological source in the North Island as seen in the bivariate plots (Figures 9 and 10) resulting from the principle component analysis performed by Dr. Mark McCoy. Additionally, 53 obsidian artifacts were found to be from an obsidian source in New Zealand but their exact source location could not be determined (Figure 11). Obsidian frequencies from Early Period sites should also display patterns of wide distribution of sources (Seelenfreund and Bollong 1989) as opposed to the more localized obsidian acquisition that occurred during the later period (McCoy, 2011) before conflict encouraged local exploitation after 1500 A.D. (McCoy et al. 2014).

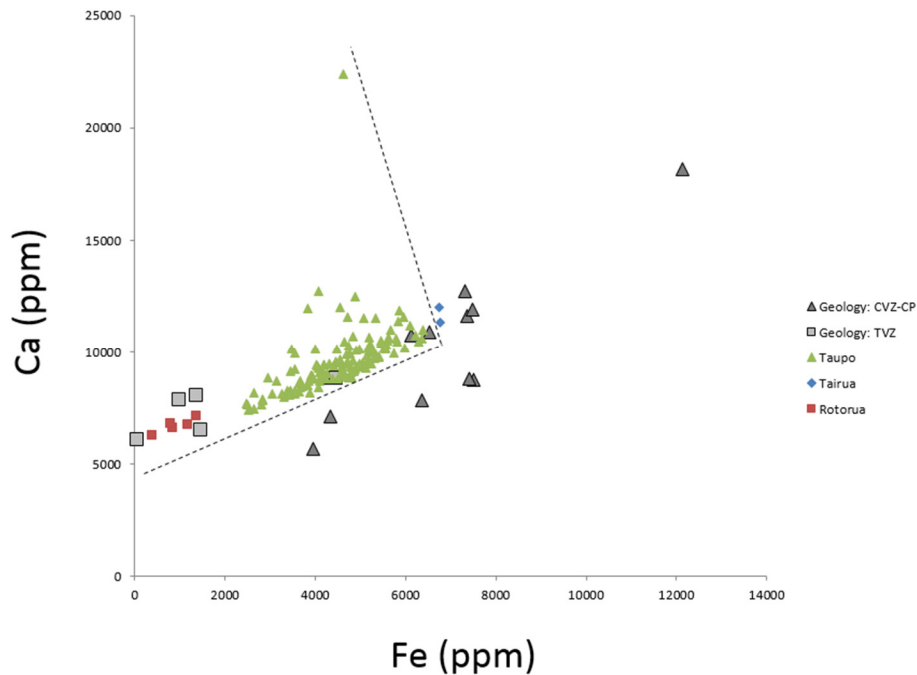


Figure 9. Bivariate plot produced by Dr. Mark McCoy of Calcium (Ca) and Iron (Fe) geochemical composition (ppm) of assayed obsidian assigned to Taupo, Cooks Bay, and Hahei Sources using principal component analysis

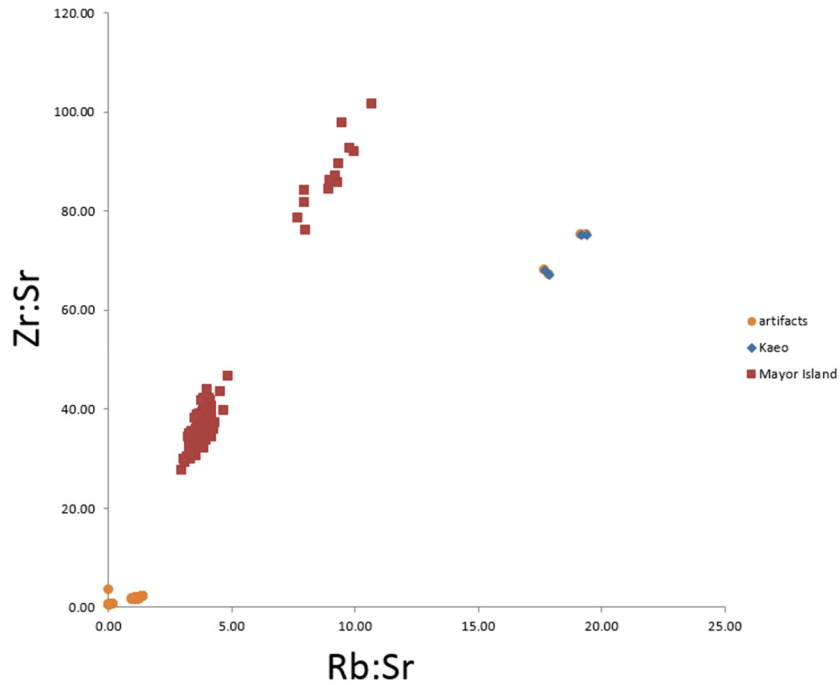


Figure 10. Bivariate plot produced by Dr. Mark McCoy of Zirconium (Zr) to Strontium (Sr) and Rubidium (Rb) to Strontium (Sr) geochemical composition (ppm) ratios of assayed obsidian assigned to Mayor Island and Kao sources using principle component analysis.

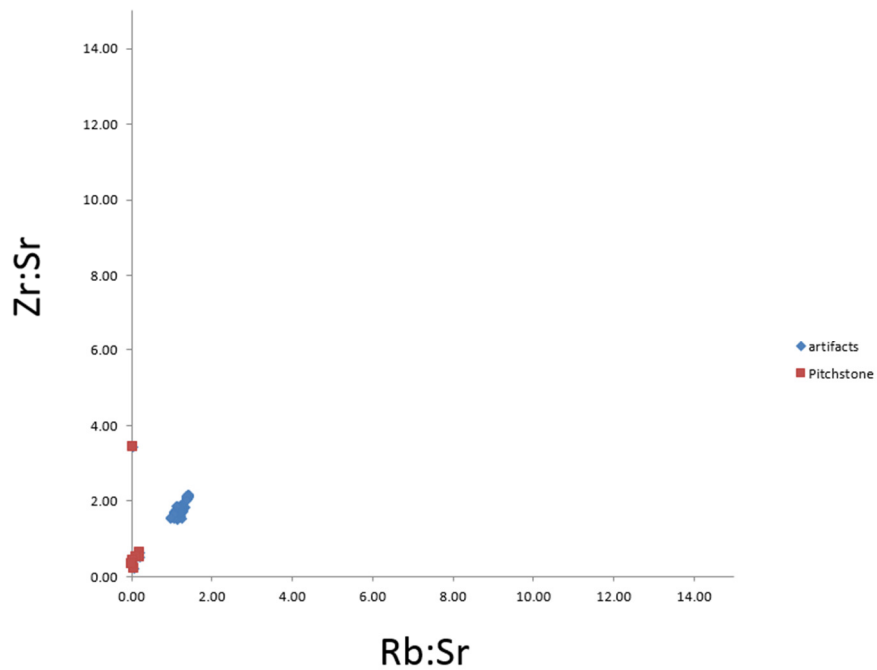


Figure 11. Bivariate plot produced by Dr. Mark McCoy of Zirconium (Zr) to Strontium (Sr) and Rubidium (Rb) to Strontium (Sr) geochemical composition (ppm) ratios of assayed artifacts determined to be pitchstone and obsidian sources other than Mayor Island and Kao.

As expected, most of the sites exhibited a high frequency of Mayor Island obsidian (Figure 12). The majority of sourced obsidian artifacts (n=383) come from Mayor Island (n=243, 63.4% of sourced obsidian) and Taupo (n=129, 33.7% of sourced obsidian). The remaining sourced obsidian was assayed in low frequencies from other regions such as Kaeo (n=4, 1% of sourced obsidian), Rotorua (n=5, 1.0% of sourced obsidian), and the Coromandel Peninsula (Tairua source, n=2, 0.5% of sourced obsidian). The results from this study also showed slightly increased accuracy of readings in Ca and Fe over previous studies (McCoy and Carpenter 2014). Some of the geological reference material from Tairua used in the McCoy and Carpenter (2014) study was misclassified with the Taupo source. Also noted in this study are high concentrations of Ca within the Taupo obsidian. Although we cannot account for the high Ca concentration using the data, we believe the results may reflect natural trends in the geochemistry of the sources.

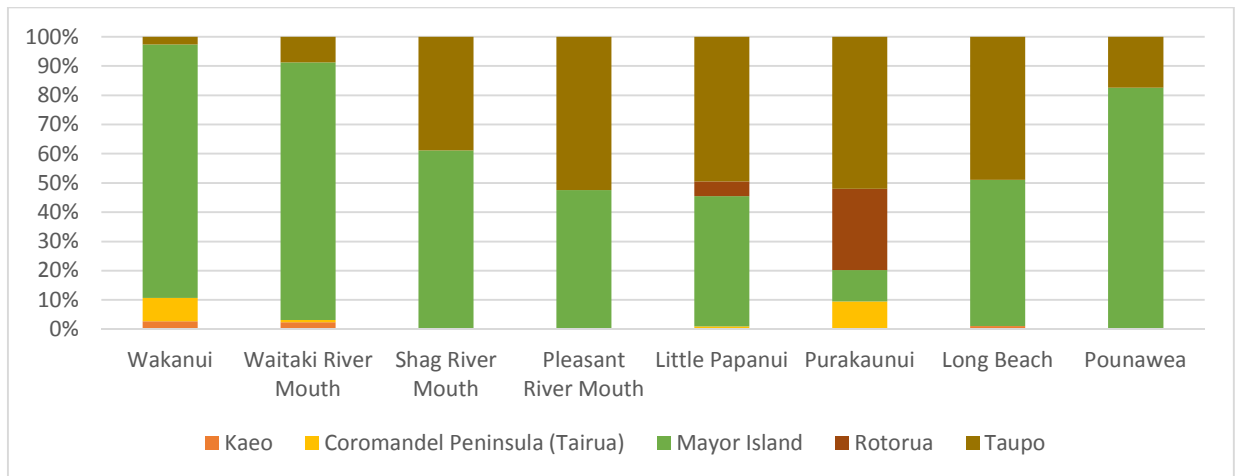


Figure 12. Frequency of New Zealand obsidian at the site locations sourced using portable XRF and ordered by distance. This includes the obsidian frequencies assayed in this study from the Otago Museum’s collections and previously-published obsidian frequencies from Wakanui (Lawrence et al. 2014) and Purakanui (Mosley and McCoy 2010).

Previously published Mayor Island obsidian frequency data from Wakanui (Mosley and McCoy 2011) and Purakanui (Lawrence et al. 2014) display a correlation in distance decay similar to the Mayor Island obsidian frequencies observed at the other six sites in this study (Figures 12 and 13). Beginning at Wakanui or Waitaki River Mouth, the Mayor Island obsidian frequencies are high at Wakanui (n=65, 80% of sourced obsidian) and are less frequent as distance increases on the east coast of the South Island. Down the coast from Purakanui and Long Beach Long Beach (n=48, 50% of sourced obsidian), the Mayor Island obsidian frequencies increase dramatically moving towards Pounaweia (n=19, 83% of sourced obsidian). Other types of obsidian such as Kaeo, Rotorua, and Tairua region obsidian are low in frequency at all of the sites that were studied due to the availability of higher quality obsidian, such as Mayor Island obsidian, in the Coromandel area. (Mosley and McCoy 2011).

Table 2. Table showing sourced New Zealand obsidian (n) from the Otago Museum’s Collection for each site.

Source	Site								Total
	Wakanui	Puraka unui	Shag River Mouth	Waitaki River Mouth	Pleasant River Mouth	Little Papanui	Long Beach	Pounaweia	
Kaeo	2	0	0	3	0	0	1	0	6
Coromandel (Tairua)	6	14	0	1	0	1	0	0	22
Mayor Island	65	16	11	111	10	44	48	19	324
Rotorua	0	41	0	0	0	5	0	0	46
Taupo	2	77	7	11	11	49	47	4	208
<b>Total</b>	<b>75</b>	<b>148</b>	<b>18</b>	<b>126</b>	<b>21</b>	<b>99</b>	<b>96</b>	<b>23</b>	<b>606</b>

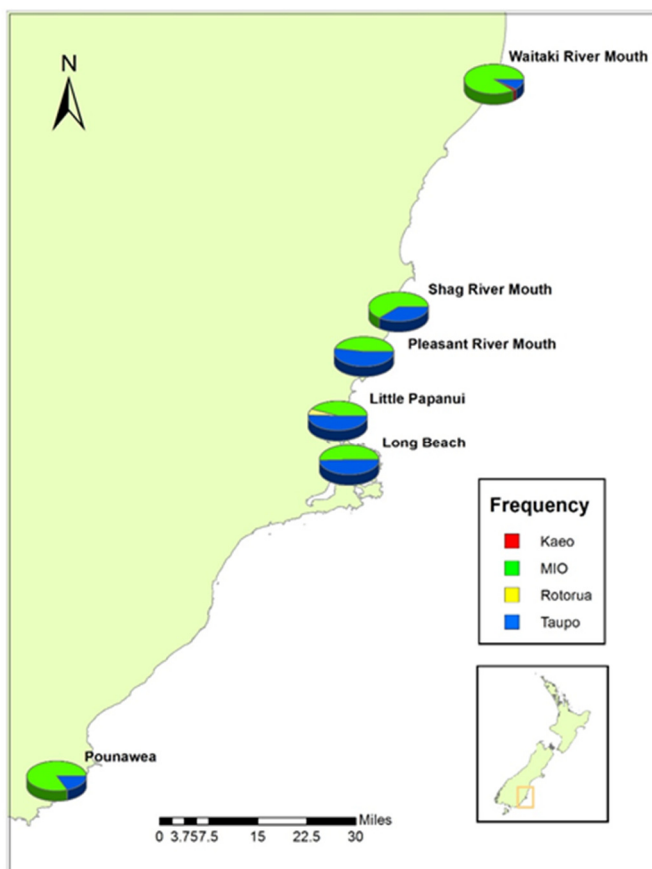


Figure 13. Map of the sites discussed in this study on the east coast of the South Island of New Zealand showing obsidian frequencies by percentage for each site from the Otago Museum collections.

Although the sample size for Pounawea is relatively low, the pattern is supported by similar previously-published Mayor Island obsidian frequencies (Seelenfreund and Bollong 1989). In my study, the sourced obsidian at Pounawea consisted of 83% Mayor Island obsidian compared to the 75% Mayor Island obsidian frequency in a previous study (Seelenfreund and Bollong 1989). This finding raises the question if Pounawea was part of the distance decay that ran southwards beginning at Waitaki River Mouth or if Pounawea was part of another centralized node of distribution in the second suspected exchange system with Tiwai point acting as the centralized distribution site.



Figures 14 and 15 display the trend comparisons between Mayor Island obsidian frequency against straight-line distance of all sites, and a trimmed Mayor Island obsidian frequency that does not include Pounawea to observe any differences in trend if Pounawea were part of a separate time series since it's frequency is higher than the sites adjacent to Pounawea. The trend is slightly stronger in the trimmed Mayor Island obsidian frequency compared to straight-line distance to source ( $r^2 = .5955$ ) compared to the weaker trend in the Mayor Island obsidian frequency compared against the straight-line distance to source that does not include Pounawea ( $r^2 = .1273$ ).

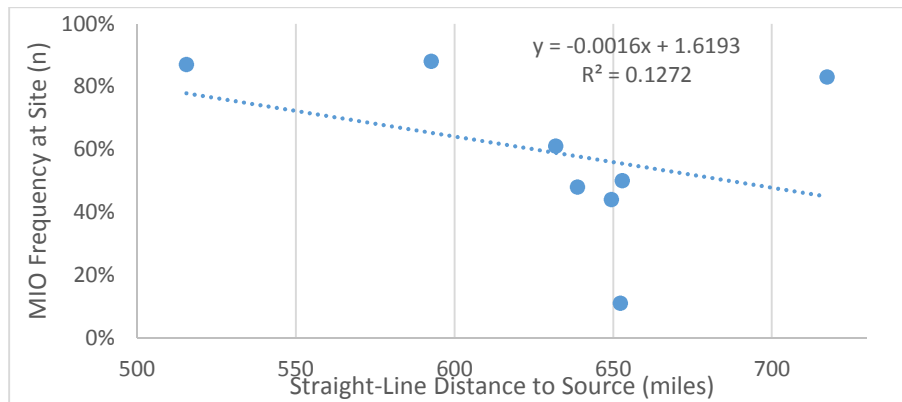


Figure 14. Mayor Island obsidian (MIO) frequency of all sites against straight-line distance from site to source.

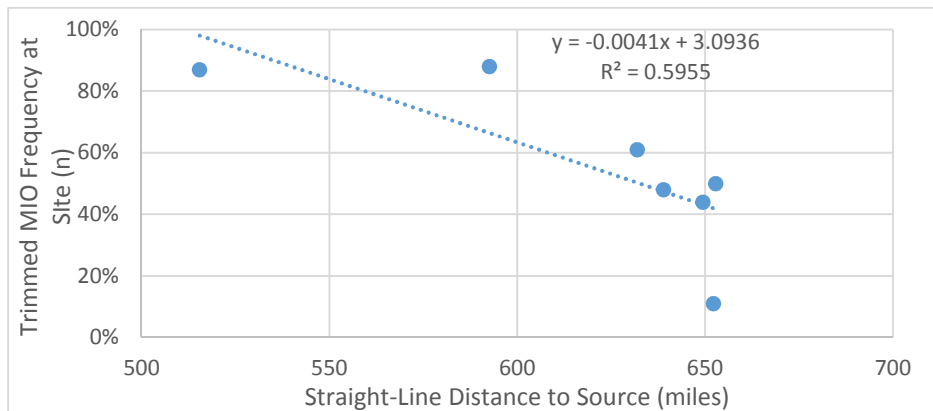


Figure 15. Trimmed Mayor Island obsidian (MIO) frequency against straight-line distance from site to source that excludes Pounawea.

The shift from lower Mayor Island obsidian frequency in Long Beach and Purakanui to higher Mayor Island obsidian frequency in Pounaweia could be explained by a geographic restraint that restricted continued distance decay to Pounaweia from other sites such as Waitaki River Mouth or Wakanui. Another explanation would be that Pounaweia is part of an earlier phase of the Early Period as speculated in previous studies using radio carbon dating (Seelenfreund and Bollong 1989). It was also interesting to see that Waitaki River Mouth did not display any obsidian from nearby sources considering it is known for having had unworked obsidian cortex flakes from nearby sources found at Waitaki River Mouth during earlier excavations (Knight 1965).

### **Lithic Analysis**

Qualitative and quantitative attributes of recorded artifacts were analyzed (Tables 4 and 5) for Waitaki River Mouth, Shag River Mouth, Pleasant River Mouth, Little Papanui, Long Beach, and Pounaweia to obtain a finer understanding of exchange in the South Island along the east coast. The attributes for the obsidian artifacts for the six sites include weight (g), length (cm), width (cm), thickness (cm), presence of cortex, and analysis of use-wear based on methods outlined in previous studies of New Zealand obsidian (McCoy and Carpenter 2014; Andrefsky 1998).

The obsidian artifacts were observed for characteristics that would categorize them as debitage, flake, tool, or core (Table 3) using artifact classification guidelines from Andrefsky (1998). Obsidian artifacts that were identified as shatter were defined as debitage that were the result of tool working and flakes (Andrefsky 1998). Debitage also lacked a striking platform or bulb of percussion (Andrefsky 1998). Obsidian artifacts that indicated presence of a striking platform or bulb of percussion were defined as flakes (Andrefsky 1998). Partial flakes were

recorded in this study but were included in the percentage counts for the general flake category. Tools were defined as any obsidian artifact that indicated use-wear along an edge or a serrated edge (Andrefsky 1998). Cores were defined as any obsidian artifact that had raw, blocky features with indication of striking platforms (Andrefsky 1998).

Table 3. Table showing the frequency of obsidian artifact types found at each site investigated in this study from the Otago Museum’s collections.

Site	Artifact Type			
	Debitage	Flake	Tool	Core
Waitaki River Mouth	25%	14%	56%	5%
Shag River Mouth	21%	59%	10%	10%
Pleasant River Mouth	55%	23%	19%	3%
Little Papanui	28%	13%	55%	4%
Long Beach	32%	61%	1%	6%
Pounaweia	30%	44%	13%	13%

Most of the sites that were investigated had cores. However, most apparent is the high frequency of flakes anddebitage at Long Beach with a smaller frequency of tools. There was no indication of a distinct “community-wide design” or “specification to which the artisans conformed” as defined by Rouse (1989) of obsidian artisan work in the six collections that were investigated in this study. Most of the obsidian artifacts that were identified as tools were large flakes that may have been used as cutting tools.

Analyzing the attributes of the obsidian artifacts will determine varying modes of exchange that include direct access, informal exchange, and long-distance formal exchange (McCoy et al. 2011; McCoy and Carpenter 2014). Since the sites are located beyond the direct

supply zone from any of the North Island obsidian sources (Walter et al. 2010; Torrence 1981: 51; Scott 2008), most of the methods outlined in McCoy et al. (2011) do not apply.

For direct access, there will generally be a significant presence of unaltered raw material at about 25-50% (McCoy et al. 2011). In the case of informal exchange, artifacts should exhibit low frequency of cortex and a decrease in average size the further the obsidian is exchanged away from its source (McCoy and Carpenter 2014) or centralized site of distribution. This mode of exchange would be attributed to the obsidian being reduced as the obsidian is exchanged down-the-line to subsequent sites. Formal exchange, on the other hand, would rarely exhibit any amount of cortex due to the reduction of the raw material at the time of collection to reduce unnecessary weight when traveling.

Table 4. Descriptive statistics of obsidian by site and distance to source.

Source	Site Location	Straight-Line Distance (miles)	Frequency	Avg Weight (g)	Cortex	Use	Method
Taupo	Waitaki River Mouth	504.85	9%	3.43	0%	73%	formal
Taupo	Shag River Mouth	543.94	39%	5.35	0%	86%	formal
Taupo	Pleasant River Mouth	551.06	53%	1.99	0%	9%	formal
Taupo	Little Papanui	561.52	50%	3.95	8%	67%	informal
Taupo	Long Beach	564.72	49%	2.84	1%	32%	formal
Mayor Island	Waitaki River Mouth	592.62	88%	7.48	6%	68%	formal
Rotorua	Little Papanui	599.2	5%	3.15	0%	80%	formal
Taupo	Pounaweia	629.92	17%	2.21	0%	50%	formal
Mayor Island	Shag River Mouth	631.93	61%	5.72	0%	73%	formal
Mayor Island	Pleasant River Mouth	638.97	48%	1.26	0%	30%	formal
Mayor Island	Little Papanui	649.45	44%	3.62	14%	45%	informal
Mayor Island	Long Beach	652.81	50%	3.44	4%	42%	formal
Kaero	Waitaki River Mouth	687.1	2%	8.89	0%	100%	formal
Mayor Island	Pounaweia	717.44	83%	4.86	5%	48%	formal
Kaero	Long Beach	746.66	1%	18.55	0%	0%	formal

Table 5. Descriptive statistics of sites with only Mayor Island Obsidian and distance to source.

Source	Site Location	Straight-Line Distance (miles)	Frequency	Avg Weight (g)	Cortex	Use	Method
Mayor Island	Waitaki River Mouth	592.62	88%	7.48	6%	68%	formal
Mayor Island	Shag River Mouth	631.93	61%	5.72	0%	73%	formal
Mayor Island	Pleasant River Mouth	638.97	48%	1.26	0%	30%	formal
Mayor Island	Little Papanui	649.45	44%	3.62	14%	45%	informal
Mayor Island	Long Beach	652.81	50%	3.44	4%	42%	formal
Mayor Island	Pounaweia	717.44	83%	4.86	5%	48%	formal

Most of the sites and obsidian sets are in the category of formal exchange (Tables 4 and 5). This finding makes sense considering there would have been a reduction in any unnecessary weight when traveling, therefore reducing cortex frequency. However, assuming that there is a possibility of direct access by way of maritime travel to several suspected centralized distribution sites, the lack of cortex in movement of obsidian could signal direct access.

The relation between Mayor Island obsidian frequencies increasing away from the centralized distribution site such as Waitaki River Mouth and Mayor Island obsidian frequencies increasing at sites such as Long Beach that are further away could be explained by observations made in earlier studies (Walter et al. 2010; Seelenfreund 1985). In a study by Seelenfreund-Hirsch (1985) involving Mayor Island obsidian distribution, an increase of Mayor Island obsidian weight along with an increase in Mayor Island obsidian frequency was also observed. When the relative abundance of Mayor Island obsidian is considered by weight, there is an apparent increase in relative abundance with distance. Seelenfreund-Hirsch believed this relation was due to Mayor Island obsidian's higher value in sites that were further away from the source (Seelenfreund 1985). However, when use of Mayor Island obsidian compared against distance from the Mayor Island source, an economic use of the available Mayor Island obsidian decreases as distance from the source increases.

## CHAPTER 5 – SPATIAL ANALYSIS RESULTS

### Cost-Surface Analysis Results

An anisotropic least-cost path analysis was performed within the immediate area of the sites suspected to be part of two prehistoric exchange networks. The first suspected exchange network consists of the sites that were investigated in this study beginning at Waitaki River Mouth and creating a least-cost path ending at Long Beach, with Waitaki River Mouth acting as the centralized distribution node for Mayor Island obsidian. The second suspected prehistoric exchange network consists of Pounaweia, Tiwai Point, and Pahia, with Tiwai Point acting as the centralized distribution node for Mayor Island obsidian. A least-cost path analysis from Long Beach to Pounaweia also was created. This path was created to rule out any possible geographic constraints that might explain Pounaweia's outlying distance from the first suspected exchange network and increase in Mayor Island obsidian frequency compared to the lower Mayor Island obsidian frequency at Long Beach and Purakanui (Figure 16).

The cost-surface analysis was restricted to inland travel along the east coast since much of the expected exchange movement in the South Island of New Zealand is thought to have occurred in inland routes along the coast (Scott 2008; Walter et al. 2010). Water traversal through rivers and lakes was not accounted for in this study since, according to Scott (2008), canoes were common and acquisition of a canoe would not be costly (Wheatley and Gillings 2002). The area that was mapped was based on a cost-surface analysis that accounted for variations in slope and direction of travel from suspected centralized distribution sites such as Waitaki River Mouth and Tiwai Point. Figure 16 shows the least-cost path that was calculated between the centralized distribution sites and their respective satellite sites.

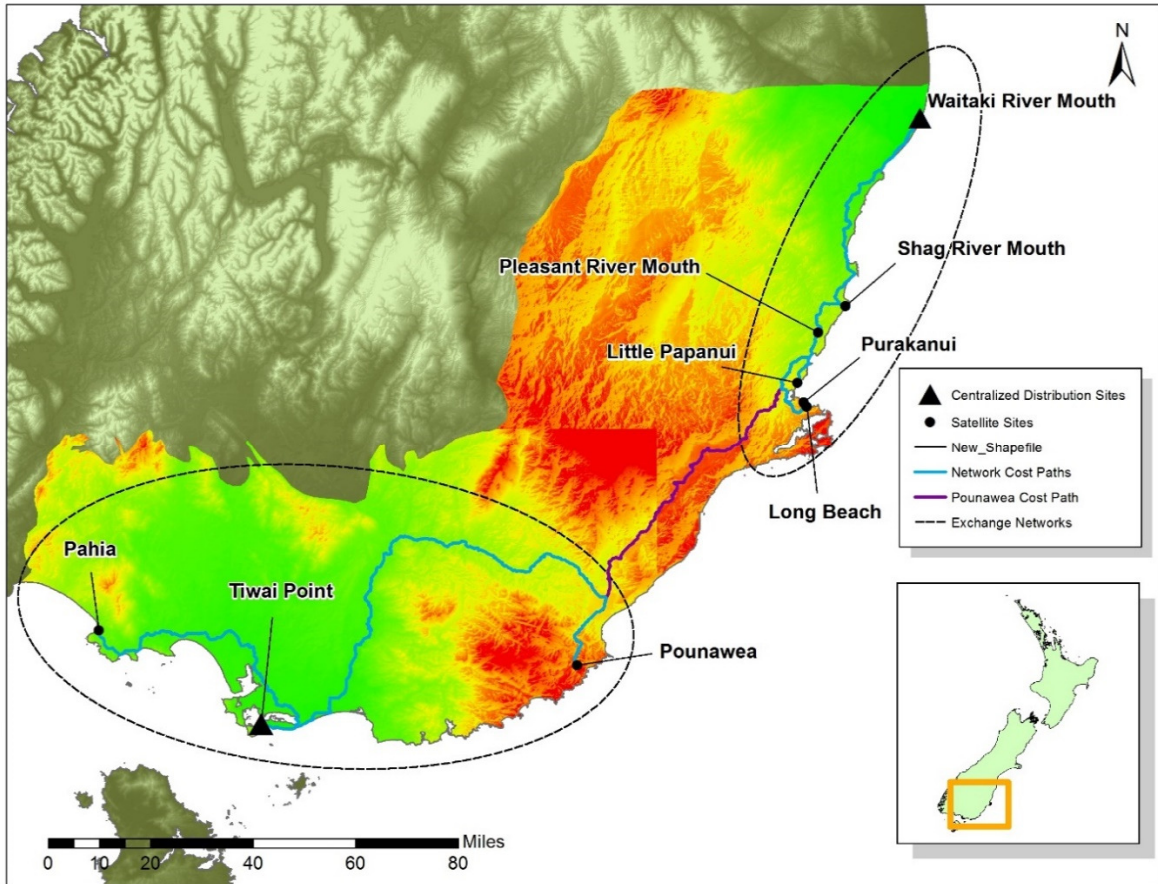


Figure 16. Map of the east and south coast of the South Island of New Zealand showing least-cost paths of two possible exchange networks and a least-cost path from Long Beach to Pounawea. The green-red gradient is based on a cost raster adjusted to show higher costs of traversal in red areas against lower costs of traversal in green areas.

Figure 16 shows a least-cost path beginning at Long Beach and ending at Pounawea without any visible geographic obstructions that may have restricted access between either site. The least-cost path from Waitaki River Mouth and all of the subsequent sites to Pounawea also did not demonstrate any apparent geographical constraints or obstructions that would cause any noticeable and inefficient changes in direction (Figure 16). However, there did appear to be a costly traversal leaving from Tiwai Point heading towards Pounawea (Figure 16). This leaves

Pounaweia as an outlier, especially considering that the frequency of Mayor Island obsidian at Long Beach (n=48, 50%) is reinforced by similar Mayor Island obsidian frequencies of neighboring sites such as Little Papanui (n=44, 44%), Pleasant River Mouth (n=10, 48%), and Purakanui (n=16, 11%) that generally follow the expected distance decay of Mayor Island obsidian as distance increases from the centralized distribution site. A proportional distance decay of Mayor Island obsidian becomes more apparent along the southern coast if the suspected exchange network at the southern end of the South Island area is limited to only Pahia (75%), Tiwai Point (85%), and Pounaweia (83%) Mayor Island obsidian frequencies (Figure 18).

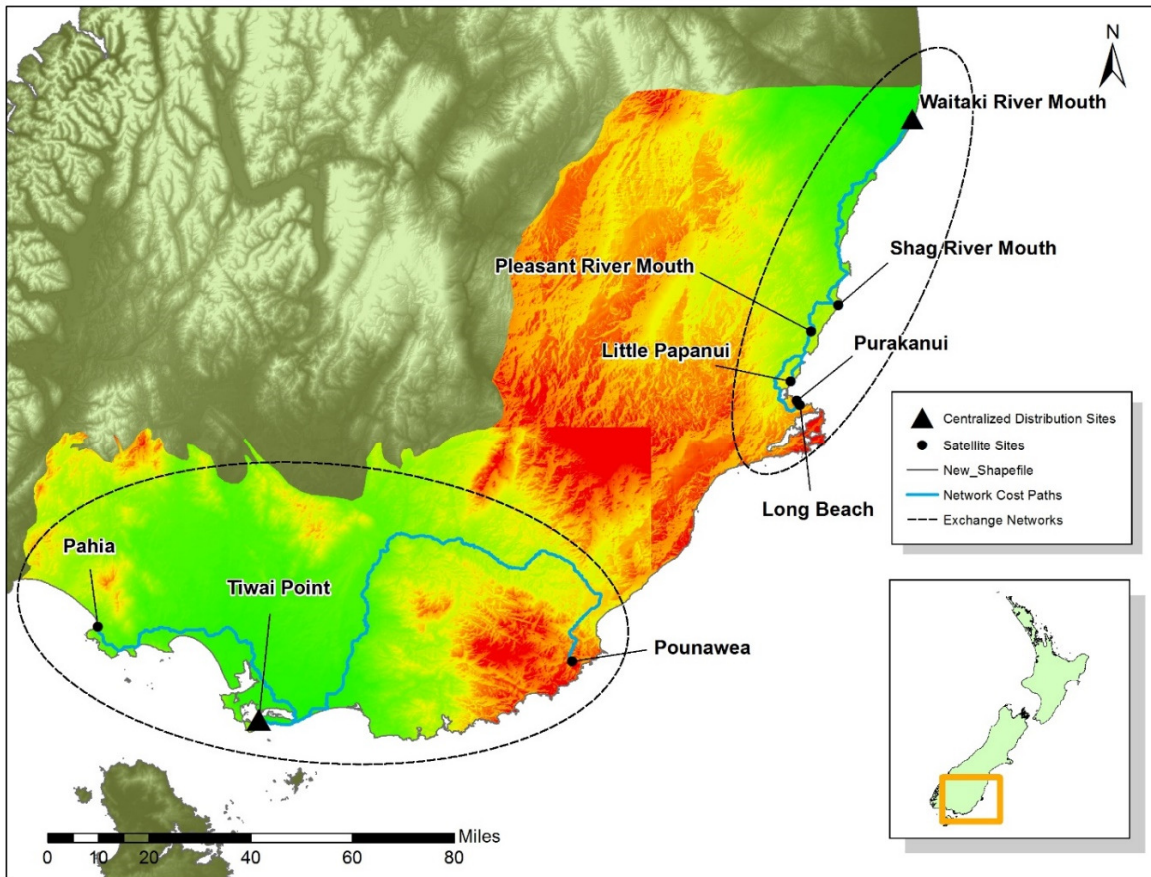


Figure 17. Map of the east and south coast of the South Island of New Zealand only showing the least-cost paths for the two exchange systems. The green-red gradient is based on a cost raster adjusted to show higher costs of traversal in red areas against lower costs of traversal in green areas.



As obsidian supplies are exchanged from Tiwai point, the centralized distribution site, to either Pounaweia or Pahia, there is a slight decrease in Mayor Island obsidian frequency. The exchange system along the east coast beginning at Waitaki Rover Mouth and ending south at Long Beach also displays a proportional Mayor Island obsidian frequency. Separating Pounaweia from the east coast exchange system results in two distinct areas of Mayor Island obsidian diffusion with Waitaki River Mouth and Tiwai Point acting as two separate centralized distribution sites. Although the three sites are Early Period sites, Tiwai Point and Pahia have been speculated to be occupied at a later period than Pounaweia (Seelenfreund and Bollong 1989).

### **Tobler Function Analysis Results**

After applying the vertical factor table derived from Tobler's equation (1993), the travel time was estimated along the calculated least-cost paths. Table 6 shows the one-way distance travel-time for all sites originating from Waitaki River Mouth in the east coast exchange network and the travel-time to Pahia and Pounaweia leaving from Tiwai Point. The east coast exchange network also includes the travel time from Long Beach to Pounaweia to determine if there was a costly time impedance along the least-cost path despite the absence of any geographic obstructions on the way to Pounaweia. This form of mobility investigation does not take into consideration other possible means of travel that we might not be aware of, such as maritime travel or other possible routes from site to site. However, mentioned in other studies (McCoy et al. 2011; Renfrew 1977), travel-time analysis is an important preliminary investigation into mobility of prehistoric communities.

Table 6. Distance in miles and travel time from suspected centralized distribution sites.

<b>Site</b>	<b>One-Way Distance from Centralized Site (Waitaki River Mouth)</b>	<b>Travel Time (Hrs)</b>
Shag River Mouth	42.81 miles	14.2
Pleasant River Mouth	50.33 miles	16.5
Little Papanui	61.01 miles	20
Long Beach	65.36 miles	22.2
Pounawea	133.96 miles	44.9

<b>Site</b>	<b>One-Way Distance from Centralized Site (Tiwai Point)</b>	<b>Travel Time</b>
Pahia	90.09 miles	25.1
Pounawea	110.91 miles	41.3

Most apparent is that the time required to travel from Long Beach to Pounawea from the east coast exchange system is half the travel time than the travel-time calculated to get to Pounawea from Tiwai from the southern exchange system. Leaving from Long Beach, the time is about 22.7 hours at a distance of about 68.6 miles compared to a travel time of 41.3 hours traveling from Tiwai Point to Pounawea at a distance of 110.91 miles. This coincides with the long cost path around a high slope and high cost area that was calculated from Tiwai Point to Pounawea. These estimates, along with the general cost path analysis and general distance assumption, contradicts Pounawea belonging to the southern exchange system in favor of the more efficient distance and travel time from Long Beach.

## CHAPTER 6 – DISCUSSION AND CONCLUSION

In Chapter 1 of my thesis, I discussed the archaeological history, ideas, and questions that came to be in the early 1900's. H.D. Skinner had proposed separate cultural areas throughout New Zealand in an effort to better understand linguistic and cultural differences amongst the Maori tribes (Davidson 1984; Skinner 1921). However, questions regarding the origins of the Maori, their ancestors, and site chronology remained unanswered. As archaeological methods became more advanced around the world as the years progressed, the application of XRF studies and GIS allowed archaeologists in New Zealand to gain a better understanding of the communities, settlement patterns, and exchange networks that were present in prehistoric New Zealand.

In Chapter 2, the sites that were investigated in my study were detailed. Larger sites along the east coast of the South Island, such as Shag River Mouth and Waitaki River Mouth, are believed to have been centralized distribution sites to smaller satellite sites south of Shag River Mouth (Davidson 1984; Maning 1875; Scott 2008). The literature that was reviewed for the remaining sites investigated in this study further supported the idea that sites such as Tiwai Point, Pahia, and Pounaweia may have belonged to one exchange network and that sites along the east coast of the South Island may have been a part of a different exchange network.

In Chapter 3, the spatial analysis and geochemical methods were discussed. Geochemically characterizing the obsidian obtained from the Otago Museum's collections by way of portable XRF provided a better understanding of mobility throughout prehistoric New Zealand. The portable XRF and spatial analysis results from Chapters 4 and 5 further supported the idea that there existed two separate exchange networks in the South Island. Placing the sites that were investigated in this study within the cultural boundaries proposed by Skinner (1921)

and marine provinces proposed by Cumberland (1949) and Lewthwaite (1949) showed that there was a correlation in geochemically characterized obsidian distance decay as distance increased from the suspected centralized distribution sites.

Focusing on Mayor Island obsidian at all sites in this study, and in the previously published sites, we can see that there was a steady, expected distance decay of Mayor Island obsidian beginning with Wakanui and Waitaki River Mouth with Waitaki River Mouth being the suspected centralized distribution node to Shag River Mouth, Pleasant River Mouth, Little Papanui, Purakanui, and Long Beach. As distance is increased from Waitaki River Mouth, the Mayor Island obsidian frequency decreases before it begins to increase at Long Beach. The possibility of Shag River Mouth acting as a centralized distribution node is reinforced by recent excavations that indicate Shag River Mouth functioned as a permanent settlement (Smith 1999). Pleasant River Mouth, Little Papanui, Purakanui, and Long Beach are considered temporary seasonal campsites that may have been used as satellite camps for sites such as Shag River Mouth or Waitaki River Mouth that had a more permanent settlement purpose (Smith 1999).

North of Waitaki River Mouth, Redcliffs has been speculated as acting as a centralized distribution node, as noted by Scott (2008) in his cost-surface analysis of obsidian exchange. However, he did not take into account the obsidian frequencies of Redcliffs and its surrounding sites. When taking these frequencies into consideration, Waitaki River Mouth (88%) and Wakanui (90%) both display a slightly greater frequency of Mayor Island obsidian as Redcliffs (88%) and could have been the next distribution nodes further south from Redcliffs. Considering the distance between Waitaki River Mouth and Wakanui, each of the two sites most likely acted as their own centralized distribution nodes with distribution taking place south of Waitaki River Mouth and trade taking place north of Wakanui. Wakanui may have acted as a centralized

distribution node whereas Redcliffs was a part of its northerly distance decay and Waitaki River Mouth would have been the next centralized distribution node south of Wakanui.

The spatial analysis shows a similar costly traversal from east-coast sites to Pounawea, as well as from Tiwai Point to Pounawea. After viewing the Mayor Island obsidian distance decay of the two suspected exchange networks, Pounawea makes more sense being viewed as originating from Tiwai point rather than part of the distance decay exchange system stemming along the east coast of the south island. The Tobler function that was applied to estimate time along the calculated least-cost path shows an efficient travel time leaving from Long Beach to Pounawea, which contradicts the notion that Pounawea belongs to the southern exchange system connected to Tiwai Point. Pounawea may have been part of the east coast exchange system, but the high amount of Mayor Island obsidian is higher than expected when comparing Long Beach's Mayor Island obsidian frequency to Pounawea's Mayor Island obsidian frequency.

As mentioned before, H.D. Skinner mapped out what he suggested were cultural boundaries consistent throughout New Zealand's prehistory. If these cultural boundaries are indicative of common tribe relationships, then this would suggest that most, if not all, of these sites are part of the same time series but not part of the same exchange network. The higher than expected Mayor Island obsidian frequency observed at Pounawea would suggest that it is not part of the same exchange system observed in the east coast of the South Island. However, the travel time and calculated cost paths suggest otherwise.

## **Conclusion**

The path distances, travel time, and Mayor Island obsidian frequency distance decay support Waitaki River Mouth and Tiwai Point as being centralized nodes of distribution for materials such as Mayor Island obsidian. This analysis could imply that Waitaki River Mouth

and Tiawai Point may have acted as separate centralized distribution nodes in maritime direct access. This direct access could have occurred in the form of reducing cortex before leaving the source and then traveling back south, as the lack of cortex in most sites shows. McCoy and Carpenter (2014) suggest that sea travel was the preferred mode of transportation. This is also supported by the absence of Maori chiefdoms in the South Island during the Early Period (Sutton 1990) which could have explained a restriction in exchange across certain regions, such as between Long Beach and Pounaweia. Direct access of long-distance sources is also supported by Walter et al.'s (2010) suggestion of a colonizer mode of exchange similar to the Lapita colonizer mode of exchange.

Pounaweia has been suggested as having been an early Late Period site (Smith 1999) and that could mean Pounaweia was part of a separate time series. This would explain the inconsistent distance-decay frequencies in the occurrence of Mayor Island obsidian along the east coast down to Pounaweia. Larger sourced obsidian samples, from sites between Tiwai point and Pounaweia and the sites south of Waitaki, would be beneficial to obtaining a better resolution of Mayor Island obsidian frequencies between sites. Additionally, further maritime travel analysis may help support the idea of some of these sites acting as centralized nodes. Scott (2008) performed two separate analyses that included low-cost marine travel and high-cost marine travel. In both models, North Island travel was unaffected but when a low-cost marine travel model that had a low accumulative cost for ocean travel was used, most of the South Islands coastal sites were bypassed, with the exception of the lower South Island (Scott 2008). However, a more dynamic and detailed model must be developed to properly analyze direct-to-source travel from these coastal sites on the South Island.

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## **VITA**

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