

A Dietary Isotopic Study at Nukuleka, Tonga

by

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Abstract

The aim of this project is to investigate Lapita-age human and faunal remains recovered from the 2007 excavation of Tonga's founder site of Nukuleka (2838 \pm 8 BP) using stable carbon and nitrogen analysis. Results were then used to evaluate the two main Lapita subsistence theories: the strandlooper hypothesis, which states that Lapita people focused primarily on easily foraged marine and terrestrial resources (Groube 1971), and the horticultural hypothesis, which states that Lapita people migrated with a transported landscape, indicating a reliance on horticultural activity (Burley 1998).

Unfortunately, after human remains selected for this research were isotopically analyzed, it became apparent that the vast majority of the samples were poorly preserved and none of the samples were suitable for use in this project. Only one of the fourteen samples yielded viable collagen and it had a $\delta^{13}\text{C}$ signature of -16.0‰ and a $\delta^{15}\text{N}$ signature of 10.4‰. Upon review of Burley et al.'s (2010) Nukuleka excavation report it was found that this sample was likely historic in nature and was rejected for use in this project.

In consideration of the poor collagen preservation of sampled human remains, environmental factors that may have lead to the degradation of the Nukuleka samples are discussed, as well as potential approaches archaeologists could use in future isotopic investigations. To continue with the goal of this project, previous dietary isotopic research in the South Pacific is reviewed, and used as a comparison tool in the evaluation of Nukuleka subsistence strategies. Based on evidence from sites in Remote Oceania, it is likely that Lapita settlers at Nukuleka were employing a subsistence strategy consistent with Groube's (1971) proposed strandlooper hypothesis.

Preface

This thesis is original, unpublished, independent work by the author, Megan B. Wong. Samples used in this project were provided by Professor David Burley of Simon Fraser University from his 2007 excavation at the site of Nukuleka.

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Chapter 1: Introduction

The Kingdom of Tonga is composed of over one-hundred sixty islands that are arranged into three major island groups: the northern islands of Vava'u, the central islands of Ha'apai, and the southern islands of Tongatapu (see Figure 1.1). Archaeological research within Tonga began in the 1920s with excavations of all three island groups by W.C. McKern (1929). In depth archaeological excavations have continued since this initial body of work (Burley 1991; Burley et al. 1995; Burley et al. 1999; Burley et al. 2001; Burley and Dickinson 2001; Burley and Dickinson 2010; Davidson 1969; Dye 1987; Poulsen 1964). The majority of this archaeological work has focused on understanding the Lapita cultural complex, representative of the first settlers of Remote Oceania. The distinctive pottery style associated with Lapita has been the subject of intensive research efforts, the results of which have shed much light on the migration and mobility patterns of Lapita people (Ambrose 2007; Burley et al. 1998, 2002; Connaughton 2007; Dickinson et al. 1996; Poulsen 1987).

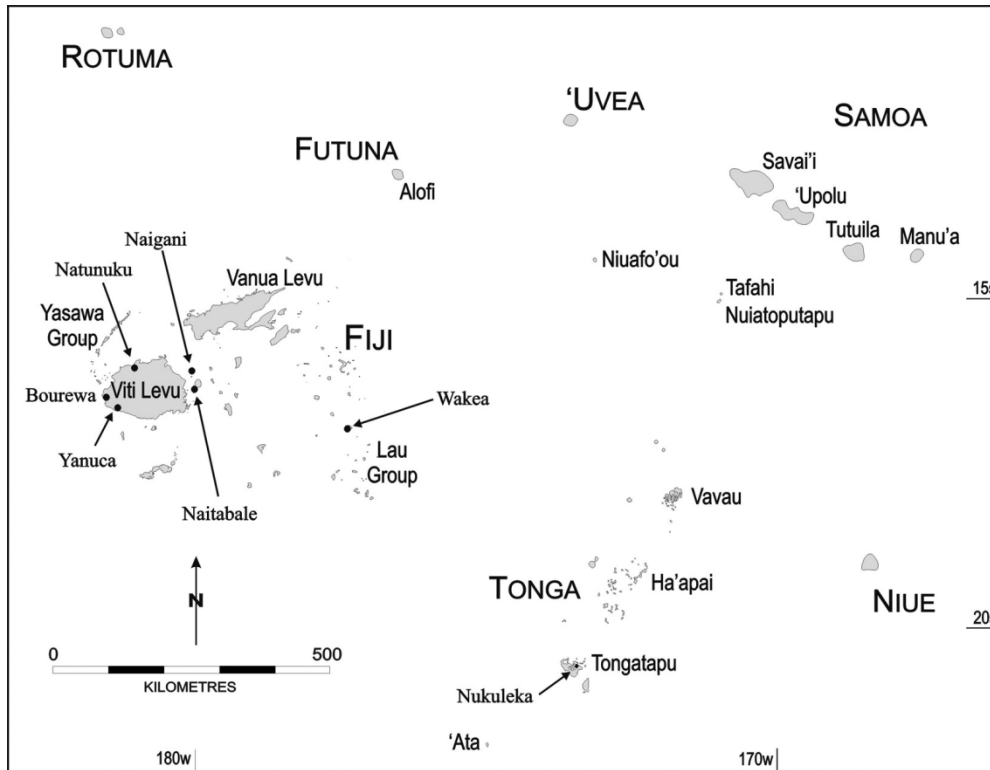


Figure 1.1 Map of Fiji/West Polynesia, including Tonga (Burley et al. 2010)

Despite extensive archaeological investigation into the prehistory of the Kingdom of Tonga, consensus has not yet been reached concerning the primary subsistence strategy of early colonists. Previous research into prehistoric Tongan diet has relied upon evidence derived from indirect methods, such as analysis of zooarchaeological and palaeobotanical assemblages (Schoeninger and Moore 1992). These methods are indirect because they use archaeological evidence that indicate consumption, but do not examine human remains. The fact that these associated fauna and flora were actually consumed is a necessary assumption supported by evidence, such as butchering marks on bone. However, zooarchaeological and palaeobotanical assemblages that are represented in the archaeological record are a biased sample because some types of organic remains preserve better than others (Schoeninger and Moore 1992).

Stable isotope analysis, a direct method of investigation, has yet to be used as a means of determining diet from Lapita-age Tongan remains. The aim of this project was to use stable

carbon and nitrogen analysis on both human and faunal remains from the site of Nukuleka with a focus on two main objectives: (1) to reconstruct prehistoric Tongan diet during the Lapita period at Nukuleka; and (2) to use this reconstruction in evaluating the two most prevalent subsistence theories associated with the Lapita cultural complex, the strandlooper and horticultural hypotheses. The strandlooper hypothesis argues that the Lapita people relied heavily on opportunistically foraged marine and terrestrial resources, while the horticultural hypothesis argues for garden cultivation as a prominent form of subsistence (Burley 1998; Groub 1971; Kirch 1997). The site of Nukuleka was chosen specifically for this analysis because it is considered to be the founder colony of Tonga (Burley et al. 2010, Burley and Dickinson 2001, 2010). Analyzing remains from the initial settlement period in Tonga is essential because it indicates whether Lapita voyagers initially settled Tonga with cultigens for food production or if this was introduced post colonization.

While no isotopic data from Lapita-age Tongan sites exists, stable carbon and nitrogen analysis has been used elsewhere, at different sites across Oceania, as a means to understand Lapita diet (Beavan Athfield et al. 2008; Field et al 2009; Leach et al. 2000; Nunn et al. 2007; Valentin et al. 2010). Results from these previous studies will be used in comparison to the results found in this study to evaluate subsistence strategies used at Nukuleka.

Chapter 2: Prehistoric Tonga and Diet

This chapter discusses Lapita migration into the Kingdom of Tonga and identifies key attributes associated with the archaeological sites. Lapita subsistence theories, and the archaeological evidence supporting them, will also be discussed.

2.1 Lapita colonization of the Kingdom of Tonga

As previously mentioned, an extensive amount of archaeological research has focused on the Lapita people's distinctive ceramic tradition (Ambrose 2007; Burley et al. 1998, 2002; Connaughton 2007; Dickinson et al. 1996; Poulsen 1987). At Lapita sites in Tonga, archaeologically recovered ceramics are considered to be part of a ceramic tradition specific to the eastern part of the region (Burley 1998). These ceramics tend to have a more simplified decorative system than western Lapita ceramics and the motifs are more rectilinear (Burley 1998). This research, specifically focusing on motif variability and design simplification, has indicated that Lapita migration into Tonga was an east-to-west progression from Fiji (Burley 1998).

Temporally and spatially, Lapita sites in Tonga are exceptionally consistent. The majority of sites are located close to palaeo-shorelines and are situated on back beach settings, generally facing either a lagoon or a reef (Burley 1998; 1999; Kirch 1997). Lapita sites were also fairly small, less than 1500m², and Burley (1998; 1999; 2007) estimates that these settlements were most likely hamlet-sized communities comprised of three to four families. Occupation of these sites was long term and ceramic assemblages indicate continuous habitation from the early Lapita period through to the Polynesian Plain Ware period, which marks the end of the Lapita phase in Tonga (Burley 1998).

Archaeological assemblages associated with Tongan Lapita sites are also fairly homogenous across all three-island groups. Non-ceramic artifacts tend to be made from local shell material, and are both utilitarian and decorative in nature (Burley 1998). Faunal bone artifacts, such as bird bone needles and tattooing needles, are also frequently found at Lapita sites. Faunal remains associated with Lapita age sites are also consistent across all three-island groups (Burley 1998; Burley 2007; Kirch 1997). Skeletal remains of terrestrial vertebrates, such as birds and lizards, and marine resources, such as shellfish and sea turtle, tend to dominate the Lapita assemblages (Burley 1998). In contrast, there are few flaked stone tools associated with Lapita sites because locally sourced raw material is generally poor in quality (Burley 1998).

While site formation and location is fairly consistent across the three-island groups, the number of Lapita sites distributed across these groups is not. Within the Vava'u group there is a relative paucity of Lapita sites when compared to the density of sites found in the island groups of Tongatapu and Ha'apai, as shown in Table 2.1 (Burley 2007). Tongatapu also has numerous unnamed Lapita sites that are shown on Figure 4.1. Research focusing on inter-site comparisons of ceramic decorative motifs suggests that once colonization of Tonga began, Lapita people migrated through the island groups from south-to-north, and afterwards continued on to settle Niauatoputapu and Samoa (Burley 1998) (see Figure 1.1). Lapita sites found in the Vava'u island group may be less numerous than those from other island groups, because settlers were likely progressively migrating to the north.

Tongatapu	Ha'apai	Vava'u
Nukuleka (To2)	Faleloa	Falevai
To1	Pukotala	Otea
To3	Tongoleleka	Ofu
To4	Mele Havea	
To5	Vaipuna	
To6		

Table 2.1 Excavated Lapita sites in Tongatapu, Ha'apai, and Vava'u

2.2 Prehistoric diet in Tonga

As briefly discussed above, Lapita sites were no larger than the size of a hamlet, and archaeological research has shown that these small groups of colonizers took full advantage of the pristine environmental conditions of the previously uninhabited islands. Faunal remains in the archaeological record strongly indicate that these settlers optimized both terrestrial and marine resources for subsistence purposes (Burley 1998; Dye 1987; Steadman et al. 2002). Groube (1971) proposed that the Lapita people were solely opportunistic foragers with a strandlooper economy. This subsistence strategy suggests a focus on fishing, shellfish gathering, and hunting of marine and terrestrial vertebrates. The location of Lapita sites across the South Pacific and Tonga supports Groube's (1971) ideas since most sites are located along coastlines, close to marine resources (Burley 1998). An abundance of shellfish material, as well as sea turtle and fish bone, in the archaeological record supports the theory that subsistence was largely focused on marine resources.

The Lapita people's dependence on terrestrial vertebrate resources is reflected in the extinction of multiple bird species that were endemic to the Tongan islands before their arrival (Steadman et al. 2002). Steadman et al. (2002) state that Tonga's present day land bird species comprise approximately 40 percent of the original species that the Lapita settlers would have encountered. Extinct land bird species, such as *Pandion haliaetus*, *Megapodius pritchardii*, and *Megapodius molistructor*, were either flightless and/or forest obligates, making them an easily accessible food resource. Heavy predation of this terrestrial resource by Lapita settlers is reflected in the archaeological record through faunal remains, and may explain their extinction (Steadman 2002). The extinction of fruit bats, lizards, and large iguanas due to human predation is also suggested in the archaeological record (Burley 1998).

While Groube's (1971) strandlooper theory is well supported archaeologically, Lapita researchers have also suggested that terrestrial plant resources, harvested through horticultural activity, may have also been a significant component of the Lapita diet. Many archaeologists propose that Lapita settlers migrated to Tonga with a small set of cultivated plants that could have been harvested upon arrival and used as a dependable resource (Kirch 1997; Yen 1992). If this is true, plants cultivated through horticultural practices must have been imported to Tonga, since very few of the approximately 400 indigenous flowering plants are nutritionally viable (Fall and Drezner 2011; Whistler 1991).

Through this transported landscape, Lapita settlers could rely upon a mixture of cultivated plants as well as terrestrial vertebrates and marine resources for subsistence. In the archaeological record, evidence for this theory is found in the form of shell vegetable peelers and scrapers, as well as palaeobotanical remains (Burley 1998). Unfortunately, palaeobotanical remains preserve poorly and are inconsistently found in the archaeological record, making it difficult to confirm the introduction of cultivated plants into prehistoric Tonga.

In order to resolve the debate between strandlooper and transported horticulture economies, South Pacific archaeologists have turned to stable isotope analysis as a means of reconstructing Lapita diet. While no analysis of Tongan Lapita sites have been conducted, previous research has been successful at completing stable isotopic analysis on Lapita age remains.

Chapter 3: Stable Isotope Analysis

Historically, palaeodietary reconstruction has relied on indirect methods such as zooarchaeology and palaeobotany. However, since the development of stable isotope analysis in the 1970s, a direct method of investigation was added to the toolkit of those seeking to reconstruct prehistoric subsistence patterns (Longin 1971). The project that follows proposes to use stable carbon and stable nitrogen analysis on Lapita-age remains from the Tongan settlement site of Nukuleka, dating to 2900 – 2850 cal BP. This chapter provides an overview of the principles of stable carbon and nitrogen analysis.

3.1 Background: stable carbon analysis

Stable carbon isotope analysis examines the ratio of ^{13}C to ^{12}C (expressed as $\delta^{13}\text{C}$ ‰) in faunal and/or human remains. Plants intake carbon through the absorption of carbon dioxide during photosynthesis, and it is during this process that isotopic fractionation occurs (Van Der Merwe and Vogel 1978). Different plant types fractionate carbon by different amounts resulting in different carbon isotope ratios. Amongst terrestrial plants, there are three major photosynthetic plant types: C_3 plants, such as temperate grasses and woody shrubs; C_4 plants, such as maize or sorghum; and crassulacean acid metabolism (CAM) plants, such as cacti (Van Der Merwe and Vogel 1978; Chisholm et al. 1982). The most commonly consumed plants are C_3 plants which trend towards more negative $\delta^{13}\text{C}$ values (-34‰ to -20‰) and C_4 plants which have more positive values (-16‰ to 9‰) (Van Der Merwe and Vogel 1978; Schoeninger and Moore 1992). The $\delta^{13}\text{C}$ signature of marine plants differs from that of terrestrial plants because marine plants uptake their carbon from oceanic bicarbonates, whereas terrestrial plants receive their carbon from the atmosphere. These carbon ratios in plants, once ingested by an animal, are then passed

on to their consumers. Therefore, archaeologists can differentiate between individuals subsisting on C₃ or C₄ plant-based diets.

3.2 Background: stable nitrogen analysis

Stable nitrogen isotope analysis examines the ratio of ¹⁵N to ¹⁴N (expressed as δ¹⁵N‰) in faunal and/or human remains. These nitrogen isotopes vary according to trophic level, and a stepwise enrichment in δ¹⁵N values by 2-6‰ is visible at each trophic step (DeNiro and Epstein 1981). A distinction can then be made between the relationships of plants-to-herbivores, and herbivores-to-carnivores. This stepwise enrichment in δ¹⁵N allows archaeologists to differentiate between herbivores, omnivores and carnivores, as well as marine and terrestrial food webs. Marine food chains are typically longer than terrestrial food chains and, accordingly, result in higher δ¹⁵N values in marine foods and their consumers.

Interpreting the δ¹³C and δ¹⁵N signatures found in prehistoric human remains requires the creation of a baseline for each of these values, using the biota of the site where the remains are found (Chisholm 1989). Use of contemporaneous local fauna is essential because isotopic signatures can vary depending on region and time period (Chisholm 1989). Archaeological remains are preferred when creating this baseline because they existed in the same atmospheric conditions as the human remains with which they are associated (Chisholm 1989). Modern samples are only used when archaeological samples are unavailable, and when used, archaeologists must consider the possible effects of industrialization and climate change on their interpretations.

Chapter 4: The Site of Nukuleka

This chapter places the site of Nukuleka within a larger geographical context, and also briefly details palaeoenvironmental conditions during the Lapita period of occupation. Past excavations at Nukuleka and its importance as a founder colony will also be discussed.

4.1 Geography

Nukuleka is located on the southern Tongan island of Tongatapu at the northeast entrance of Fang'a Uta lagoon (see Figure 4.1). Tongatapu is a raised coralline island, approximately 260km² in area, with fairly rich and fertile land as compared to other islands that are similar in composition (Poulsen 1987). Tongatapu, like all of Tonga, has both a cool-dry season and a hot-humid season, with seasonal rainfall between 150-180cm (Poulsen 1987).

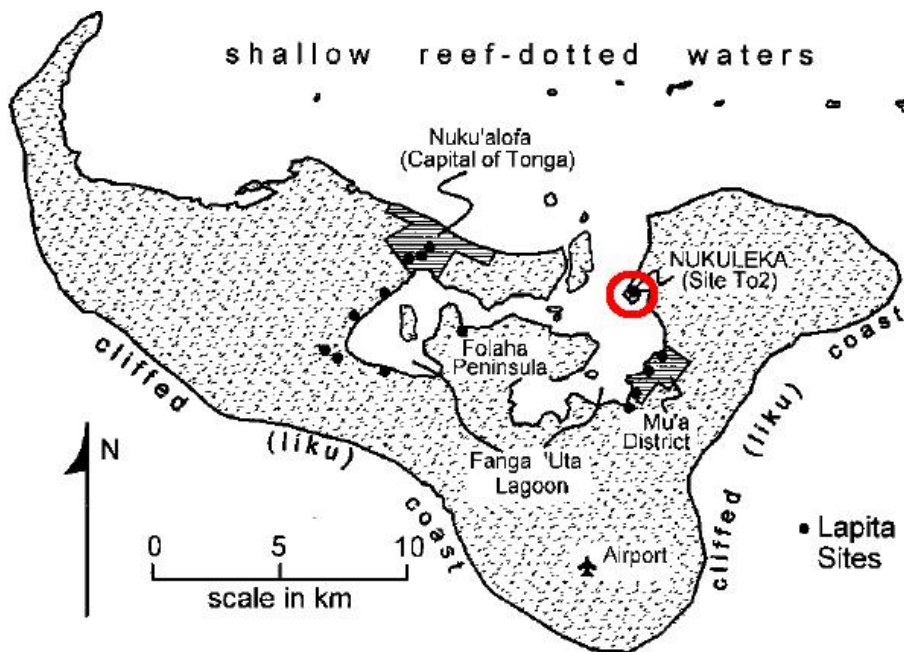


Figure 4.1 Map of Tongatapu highlighting the site of Nukuleka in red (Burley and Dickinson 2001)

Fang'a Uta lagoon contains some of the densest collections of Lapita-age archaeological sites due to the regional palaeoenvironment, which provided circumstances that were conducive

to Lapita settlement and subsistence (Dickinson 2007). During the Lapita occupation period at Nukuleka, sea level would have been 1.2-1.4 m higher, with easy access to the open sea, allowing Lapita settlers to come and go with little difficulty (Burley et al. 2010; Dickinson 2007). Additionally, Fang'a Uta afforded settlers an abundance of shellfish, making the location particularly attractive and important to Lapita people.

4.2 Excavations at Nukuleka

Nukuleka was first excavated by Jens Poulsen (1987) in May and June of 1964. Poulsen's excavations focused on a circular mound that was approximately 25m in diameter and 1.5m high. The mound, termed Moala's Mound (named after the present day landowner, Alungia Moala), is located at the southern end of the modern day town of Nukuleka and is about 200m east of the present day beach. The 1964 excavation focused on Moala's Mound because of the incorporation of coral sand, which suggested the possibility of graves within the mound (Poulsen 1987). In typical prehistoric Tongan burials, coral sand is used to fill in a grave after the interment of human remains (Poulsen 1987). During excavation, Poulsen (1987) uncovered eight to ten burials as well as a collection of faunal remains. Another important discovery was the recovery of decorated ceramics, situating the site within the Lapita period.

Research at Nukuleka has continued with subsequent excavations undertaken in 1999, 2001, 2003, and 2007 directed by Professor David Burley (Burley et al. 2010). Burley's research has focused on relocating and excavating Moala's Mound and adjacent areas with the aim of adding to the body of knowledge concerning the course and timing of Lapita migration throughout the Kingdom of Tonga, and subsequent interaction within the archipelago (Burley et al. 2010). A breakthrough occurred during the 2007 excavation when radiocarbon dates not only

confirmed that Nukuleka was an early Lapita site, but that it was the earliest settled Tongan site excavated to date.. Occupation of this founder colony was determined to be between 2838 +/-8 BP (Burley et al. 2012).

Chapter 5: Methods

In this chapter, the laboratory procedures employed during my analysis will be discussed, as well as the samples used for this investigation.

5.1 Sampling

The human and animal samples from Nukuleka used in this project were provided by Prof. David Burley, Department of Archaeology, Simon Fraser University. The human samples consisted of thirteen bone fragments and one tooth. All of these samples, with the exception of one tooth found in unit 56 (see Figure 5.1), were found in units within the main excavation of Moala's Mound during Burley's 2007 excavation (Burley et al. 2010). Due to the fragmentary nature of the skeletal remains, it was not possible to determine sex, nor was it possible to ensure that the multiple samples used in this analysis came from different individuals.

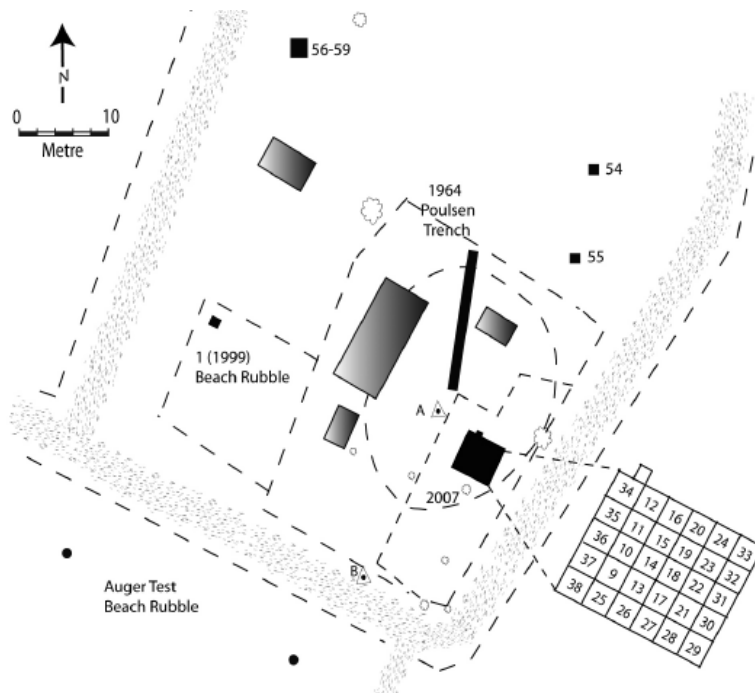


Figure 5.1 Layout of excavation units at Nukuleka (Burley et al. 2010)

All fourteen human samples were prepared for carbon and nitrogen analysis. However, due to poor preservation, only one sample was deemed acceptable for analysis. Because of the inherent difficulty in interpreting an individual sample within the context of a baseline, no zooarchaeological samples were prepared for analysis.

5.2 Sample preparation and measurement

All samples were prepared for carbon and nitrogen analysis at the Archaeological Chemistry Laboratory at the University of British Columbia using a modified Longin (1971) method. An additional ultrafiltration step was used to assist in sample purification (Brown et al. 1988) during preparation process. Six of the samples were processed using an Elementar VarioMirco Cube Elemental Analyzer and an IsoPrime IRMS with an internal precision of +/- 0.190‰ for $\delta^{13}\text{C}$ and +/-0.290‰ for $\delta^{15}\text{N}$. The remaining samples were sent to the Department of Human Evolution at the Max Planck Institute for Evolutionary Anthropology in Leipzig, Germany for isotope measurement using a Thermo E.A. and Delta V IRMS.

The first step in sample preparation involved cleaning the outer bone cortex with a small-mechanized drill to remove possible contaminants. Next, samples were demineralized in 0.5M HCl for two days to three weeks (depending on sample size) in a VWR fridge with the internal dial set to four. Samples were then rinsed using purified water. After the rinsing process, samples were solubilized in a pH3 solution at 75°C for two days. The solution was then filtered using 9ml Ezee filter separators and ultrafiltered using both 30kDa and 10kDa Pall filters. Both the > 30kDa collagen fraction and > 10kDa collagen fraction were kept and lyophilised. Small amounts of the lyophilised collagen (0.5mg or less) were weighed in small tin boats, crushed, and then combusted in the mass spectrometer in order to measure the carbon and nitrogen

isotope values. To ensure that quality collagen was measured during this process, only samples with carbon and nitrogen ratios between 2.9-3.6 were used, as per DeNiro (1985).

5.3 Bone collagen quality

When sampling from human and faunal remains the possibility of postmortem degradation must be considered (van Klinken 1999). Diagenesis, the physical, chemical, and biological processes that occur in the postmortem depositional environment, can lead to the degradation of bone collagen and negatively affect stable isotopic analysis (DeNiro 1985).

The average modern bone contains about 22 percent collagen and this percentage begins to decrease after burial. The rate of collagen loss can vary by climatic region, with collagen loss occurring more rapidly in hot and wet areas when compared to more temperate climates (van Klinken 1999). Once a sample's collagen content has gone below 0.5%, it is regarded as unsuitable for analysis because it becomes too difficult to remove contaminants. The degradation of bone collagen, except in extreme cases, does not mean that the sample cannot be used in isotopic analysis but it does indicate that collecting useable collagen will be more difficult (van Klinken 1999).

To determine if samples used for stable carbon and nitrogen analysis are of good quality and not significantly altered by postmortem processes, archaeologists examine the atomic carbon-to-nitrogen ratio (C:N) in sampled bone collagen (DeNiro 1985). Prehistoric samples with C:N ratios between 2.9 and 3.6 are deemed acceptable for isotope analysis because they reflect C:N ratios of modern collagen samples and indicate that the collagen has not undergone significant diagenetic alterations (DeNiro 1985). Any samples that fell outside of this range were deemed unusable in this study.

Chapter 6: Results

Of the fourteen human samples analyzed in this project, only one sample was deemed suitable for stable carbon and nitrogen analysis. The samples that fell outside of the acceptable parameters did not yield the minimum amount of collagen required for analysis (less than 0.5%), or had C:N ratios outside of the 2.9-3.6 range (see Table 6.1). The single viable sample, SUBC 786, had a $\delta^{13}\text{C}$ value of -16.0‰ and a $\delta^{15}\text{N}$ value of 10.4‰. Unfortunately, a review of excavation records indicates that this sample was recovered close to the surface and is most likely historic in nature. Therefore, this sample is not suitable for addressing the hypotheses evaluated in this project.

SUBC	Unit	Level	Initial Mass (mg)	Final Mass (mg)	% Collagen	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	%C	%N	C:N
651	13	9	246	0.944	0.40%	-20.8	8.8	34.8	7.8	5.5
652	16	11	78	0.722	0.92%					
653	17	1	97	0.435	0.40%	-22.7	9.1	35.7	5.8	7.1
654	19	1	256	0.206	0.08%	-24.8	8.7	26.8	2.5	12.5
655	19	1	190	0.015	0.07%	-28.8	0	23.5	0	
657	23	9	212	1.126	0.53%	-27.9	4.7	20.2	0.5	47.7
658	24	9	159	1.221	0.76%	-28.4	0	17.3	0	
659	24	11	94	0.809	0.86%	-27.9	0	21.0	0	
660	24	11	116	0.967	0.83%	-28.0	0	22.2	0	
782	29	4	72.2							
783	29	5	33							
784	28	5	110.9							
785	28	9	172.9							
786	56	2	142.8	1.2	0.84%	-16.0	10.4	37.5	12.9	3.3

Table 6.1 Sample results from carbon and nitrogen isotope analysis. Samples with a blank field could not produce enough material for results.

Chapter 7: Preservation

Unfortunately, due to poor preservation, stable isotope results cannot be used to address the research questions of this study. Preservation issues are a reality that many stable isotope studies must grapple with. This chapter will discuss the environmental factors that likely led to the degradation of human remains used in this study.

7.1 Collagen degradation at the site of Nukuleka

Human bone is composed of both mineral and organic materials, and the degradation of either will negatively impact a bone's viability for isotopic analysis. One of the most important factors in the preservation of both the organic and mineral components of bone is the soil pH. When buried with soil that is either extremely acidic, or extremely neutral, bone collagen hydrolysis may occur. When interred in neutral pH soil, microbial activity may act to break down both mineral and organic components of bone (Collins et al. 2002; Gordon and Buikstra 1981; Von Endt and Ortner 1984).

Microbial attack is the destruction of bone by microorganisms such as fungi and bacteria (Trueman and Martill 2002). During microbial attack, microbes will demineralize the bone, leading to a form of histological destruction, termed microscopic focal destruction (Trueman and Martill 2002). After microscopic focal destruction has occurred, the porosity of bone increases, leaving collagen prone to degradation (Nielsen-Marsh et al. 2007). Collagen degradation is directly impacted by bone porosity, which allows for increased interaction between inorganic ions in groundwater and bone protein, resulting in collagen degradation (Von Endt and Ortner 1984).

Unfortunately, soil samples were not taken at the site of Nukuleka, so the soil pH is unknown. However, burial traditions practiced by the Lapita people may have created a hostile soil environment. In Poulsen's (1987) original excavation of Nukuleka, coral sand was recorded as a component of the burial environment throughout the excavation. During Lapita occupation of Nukuleka, coral sand would have been used to fill in graves after the interment of human remains (Poulsen 1987). Previous research demonstrates that the treatment of bodies with lime (CaCo) or slaked lime (CaCOH) will result in collagen degradation as the collagen becomes significantly more sensitive to alkaline hydrolysis (Collins et al. 2002; Nielsen- Marsh et al. 2007). Coral sand used in prehistoric Tongan burial practices may have leached calcium carbonate into the soil, resulting in a corrosive environment. This may have been a contributing factor to the poor preservation of bone samples in this project.

Another major factor in bone preservation is the climatic conditions under which they are deposited. Bones interred in regions with higher temperatures tend to degrade more quickly than those in more temperate environments (Van Klinken 1999). This is because the process of bone hydrolysis occurs faster at higher temperatures (Von Endt and Ortner 1984). As the extent of bone hydrolysis increases, so too does its susceptibility to chemical alteration and degradation. Thus, higher temperature environments speed up hydrolysis and leave bone vulnerable to the effects of degradation (Von Endt and Ortner 1984). Tonga, being a tropical environment, experiences seasonal highs of well over 32°C, which could contribute to poor bone preservation at Nukuleka. While the exact mechanisms of bone degradation experienced in this project cannot be known, it is highly probable that both soil chemistry and climate negatively affected sample preservation.

7.2 Predicting collagen degradation: thermal age

As discussed above, temperature is a dominant factor in collagen preservation. To address this, a method for predicting the extent of collagen degradation using a site's present-day and prehistoric temperature (palaeotemperature) was developed. This technique relies on the concept that a sample's actual chronological age will differ from its thermal age. Here, thermal age is defined as the time it takes to degrade collagen to a certain degree when the temperature is held at a constant of 10°C (Smith et al. 2003). Using this technique, a sample's specific thermal history is accounted for by adjusting the sample's chronological age using its thermal age (Smith et al. 2003).

When analyzing present day temperatures using mean annual temperatures, site types are grouped into cave and open-air categories. In cave sites, mean annual temperature is generally considered to be a good approximation of deep cave air temperatures (Smith et al. 2003). However, samples buried in open-air sites, such as Lapita age sites found across the South Pacific, are more difficult to evaluate because additional issues affect thermal age. These issues involve seasonal fluctuation in soil, burial depth, and local effects such as vegetation. Unfortunately, this information is difficult to acquire and many of these issues cannot be easily extrapolated back into the past (Smith et al. 2003). While adequate estimates of mean soil temperature can be made using mean air temperature (Smith et al. 2003), archaeologists should always be cognizant of the possible issues affecting their site. Once a site is assigned to a contemporary temperature, it is then averaged with palaeotemperature to reconstruct the site's thermal history and achieve thermal age.

Using this procedure, Dobberstein et al. (2009) found that samples with a thermal age of approximately $8_{\text{kyr}@10^{\circ}\text{C}}$ or less are more likely to produce useable collagen. This approach would

be beneficial to South Pacific archaeologists, as applying this method would inform them of the likelihood that the collagen in their samples has been destroyed due to temperature-related depurination. However, as previously stated, preservation at open-air sites is extremely variable and relies on a number of site-specific processes. The thermal age for one of the samples used in this project was calculated in order to estimate the effects of temperature on collagen degradation using Collins and Harker's (2009) Thermal Age Web Tool. The sample chosen for this analysis was found at the base of the mound, implying it was among the oldest considered in this study, in context with Lapita age ceramics. This sample was calculated to have an approximate thermal age of $32_{\text{kyr}@10^{\circ}\text{C}}$, indicating that this sample likely had very poor collagen preservation.

Regardless of the results of thermal age calculations, the investigation of Lapita age remains using stable isotope analysis is worthwhile because preservation in open-air sites is highly variable. Lapita age remains at other sites across the South Pacific have been analyzed successfully using stable isotope analysis (Beavan Athfield et al. 2008; Field et al. 2009; Leach et al. 2000, Leach et al. 2005; Nunn et al. 2007; Valentin et al. 2010). Since human remains of comparable age, buried in environments with similar mean temperatures, yielded viable bone collagen it was possible that Nukuleka may also have yielded well-preserved samples. Unfortunately, this was not the case. At sites where Lapita age remains were suitable for isotopic analysis, other local factors that were not present at Nukuleka must have acted to preserve bone collagen. Regrettably, site composition and environment were not discussed in enough detail within the original excavation site reports to allow comparison between Nukuleka and those sites that had well preserved Lapita age remains.

Chapter 8: Discussion

As a direct application of stable isotope analysis to the founder site in Tonga was not possible, previous isotopic research at Lapita sites across the South Pacific will be used to approach Lapita subsistence at Nukuleka. Specifically, this chapter discusses stable isotopic results from Vanuatu, Papua New Guinea, and Fiji, and examines how they can be applied to the site of Nukuleka.

8.1 Stable isotope analysis in Vanuatu

At the cemetery site of Teouma, Vanuatu, Valentin et al. (2010) used stable carbon and nitrogen analysis on 23 human samples and five faunal samples, which is currently the largest amount of data available on isotopically analyzed Lapita-aged remains. The human remains yielded $\delta^{13}\text{C}$ signatures that ranged between -18‰ and -14‰, with a mean value of -15.8‰, and $\delta^{15}\text{N}$ signatures that ranged between 10.6‰ and 16.1‰, with a mean value of 12.4‰ (see Table 8.1). Valentin and colleagues concluded that, at Teouma, Lapita people subsisted on mainly terrestrial proteins and marine resources, such as shellfish and crustaceans (Valentin et al. 2010).

Burial	$\delta^{13}\text{C}\text{‰}$	$\delta^{15}\text{N}\text{‰}$
TEO1	-15.0	11.8
TEO2A	-15.6	12.9
TEO5A	-14.9	11.5
TEO6	-15.5	13.1
TEO7	-14.3	12.1
TEO8	-14.5	11.8
TEO10E	-15.6	12.7
TEO15	-15.8	12.5
TEO16	-16.2	10.6
TEO18	-15.2	11.5
TEO19	-16.1	12.0
TEO20	-17.4	16.1
TEO25	-16.7	14.3
TEO31	-17.0	13.0
TEO32	-16.1	11.0
TEO33	-17.0	12.1
TEO34	-16.1	13.0
TEO36	-14.0	11.5
TEO37	-16.0	12.5
TEO38	-15.8	11.6
TEO40	-15.4	12.9
TEO44	-18.2	13.4
TEO48	-14.4	11.4

Table 8.1 Human collagen isotopic data at Teouma, Vanuatu (Valentin et al. 2010)

The authors also argue for some low-level food production. However, this argument relies on osteological data, such as dental caries and periodontal disease, and is not substantiated by isotopic evidence (Valentin et al. 2010). Unfortunately, the methodology employed in the construction of their isotopic baseline may call Valentin et al.'s (2010) findings into question. The authors relied heavily on modern material from islands that are geographically distant and environmentally distinct from Teouma, such as Japan (Valentin et al. 2010). While they admitted that this was problematic, only eight faunal samples were prepared for isotopic analysis and only five of those samples were well enough preserved to use in their study (Valentin et al. 2010). Since the bulk of their baseline data was non-local, a greater analysis of local modern, and archaeological, faunal remains would have resulted in a more reliable data set.

The type of site analyzed also impacts the applicability of Valentin et al.'s (2010) results to Nukuleka. The Teouma site is a cemetery with complex funerary treatments of the Lapita

people interred there. This could imply that the individuals analyzed are not representative of the community. Additionally, during occupation, the site was used solely for human burial. The faunal remains used by Valentin et al. (2010) in their analyses were taken from a more recent village site overlaying the Lapita cemetery, which post-dates the Lapita occupation period by at least 200 years. Research has shown that environmental conditions can greatly affect stable isotope signatures in plants and animals (Heaton 1987; Britton et al. 2008). Modern and non-local samples are problematic because environmental conditions can fluctuate through time and vary between regions. For example, nitrogen values can drastically change depending on difference in aridity (Heaton et al. 1986).

8.2 Stable isotope analysis in Papua New Guinea

Isotopic investigations at Watom Island, Papua New Guinea have been conducted by multiple South Pacific archaeologists (Beavan Athfield et al. 2008; Leach et al. 2000; Leach et al. 2003; Petchey and Green 2005). Most of these investigations examine the same burials (numbered 01 through 05) at the same site and, as such, only articles analyzing different burials will be discussed here. In Leach et al.'s (2000) investigation, seven burials were analyzed. However, issues of preservation, similar to those outlined above in this project, resulted in only three of the seven burials yielding acceptable collagen. Burials 03, 04, and 05 had $\delta^{13}\text{C}$ values ranging from -18.3‰ to -17.6‰ and $\delta^{15}\text{N}$ values ranging from 11.9‰ to 10.2‰ (Leach et al. 2000, see Table 8.2).

Burial	$\delta^{13}\text{C}\text{‰}$	$\delta^{15}\text{N}\text{‰}$
Burial 03	-18.2	11.9
Burial 04	-18.3	10.2
Burial 05	-17.6	10.6

Table 8.2 Human collagen isotopic data at Watom Island, Papua New Guinea (Leach et al. 2000)

Leach et al. (2000) found that Lapita people in this region had a diet consisting mainly of land-based foods, with a smaller component of marine-based foods that consisted largely of non-reef fish. Interestingly, the authors also discuss the possibility that C₄ plants, and browsing animals consuming C₄ plants, may constitute a small portion of the land-based foods consumed at this site (Leach et al. 2000).

Continuing with this research, Beavan Athfield et al. (2008) reanalyzed Burials 01 and 03. Burial 03 was sampled twice, as one of the samples, designated WK-15568, is under debate as to whether it belonged to Burial 03 or Burial 05 (Beavan Athfield et al. 2008). These samples had $\delta^{13}\text{C}$ values between -18.1‰ and -17.6‰ and $\delta^{15}\text{N}$ values between of 12.5‰ to 10.9‰ (see Table 8.3). With these values Beavan Athfield et al. (2008) argue for a diet that relies heavily on horticultural activities and the consumption of terrestrial animals, with less focus on marine resources.

Lab No.	Burial	$\delta^{13}\text{C}\text{‰}$	$\delta^{15}\text{N}\text{‰}$
WK-15567	Burial 01	-18.1	10.9
WK-15568	Burial 03	-17.8	11.1
WK-13685	Burial 03	-17.6	12.5

Table 8.3 Human collagen isotopic data at Watom Island, Papua New Guinea (Beavan Athfield et al. 2008)

Both of these studies provide evidence against the strandlooper hypothesis and are in favour of a Lapita diet, with increased reliance on horticultural foods. This fits with previous indirect archaeological investigations in Papua New Guinea and throughout Near Oceania (Kirch 1997; Clark and Anderson 2001). However, the sample sizes in these studies are quite small and drawing overarching conclusions from a dataset of this size is problematic. It would be beneficial to conduct more isotopic analyses on human remains from other Lapita sites in Near Oceania, so that the findings at Watom Island can be further evaluated.

Isotopic research at Watom Island is similar to that at Teouma, in that the baseline data established relies on too many non-local sources and is too temporally broad. Beavan Athfield et

al. (2008) included eight archaeological faunal samples in their data set; however, only one of these samples is local and contemporaneous with the human samples from Watom Island. The authors' modern samples are also problematic in this regard, being collected largely from non-local sources throughout the South Pacific (Beavan Athfield et al. 2008). The questionable nature of Beavan Athfield and colleagues' methodology in baseline construction is exceeded only by that of Leach et al. (2000), where these authors failed to note not only location, but also the contemporaneity of their sample data. The only baseline data discussed in Leach et al.'s (2000) research concerned a limited amount of modern C₄ samples, one of which was collected by the authors, and the others taken from previous publications concerning Papua New Guinea (Leach et al. 2000). This lack of information makes it impossible to verify Leach and colleagues' interpretation of the human samples' stable carbon and nitrogen isotope signatures.

8.3 Stable isotope analysis in Fiji

In Fiji, only two sites have been analyzed using stable isotopic methods (Field et al. 2009; Nunn et al. 2007). Field et al. (2009) examined Lapita remains from the site of Olo, Waya Island and Nunn et al. (2007) focused on a Lapita skeleton from Naitabale, Moturiki Island. At Olo, 12 Lapita age human samples with good collagen preservation were recovered (numbered F01-F38). These samples exhibited a greater range of $\delta^{13}\text{C}$ values than those observed in Papua New Guinea, falling between -16.8‰ and -13.5‰, and perhaps showing more intra-individual variability than seen at other sites (Field et al. 2009). The $\delta^{15}\text{N}$ values of sampled human remains range between 8.6‰ and 11.0‰ (Field et al. 2009). Interestingly, five of the samples show characteristics of cannibalism, which was common throughout Fijian prehistory (Cochrane et al. 2004). Field et al. (2009) argue that it is likely that cannibalized individuals were non-local and

and may exhibit different stable isotopic dietary signatures. Therefore, samples F12 to F34 were likely not representative of the Lapita community at Olo and were removed from the data set before the authors made their interpretations (see Table 8.4). With these samples removed, Field et al. (2009) place the non-cannibalized individuals as subsisting on a diet similar to that argued for by the strandlooper hypothesis; i.e. a mixing of terrestrial and marine resources with a greater focus on marine foods (Field et al. 2009).

Lab No.	$\delta^{13}\text{C}\text{‰}$	$\delta^{15}\text{N}\text{‰}$
F01	-16.8	9.8
F02	-16.4	9.9
F04	-15.9	10.8
F05	-14.0	10.8
F06	-15.0	10.5
F12	-15.1	9.1
F13	-15.4	10.4
F20	-15.1	9.2
F28	-15.5	9.0
F29	-15.4	8.8
F34	-15.3	8.9
F38	-13.5	11.0

Table 8.4 Human collagen isotopic data at Waya Island, Olo (Field et al. 2009)

In Nunn et al.'s (2007) research, only one Lapita age skeleton was uncovered at Naitabale, Moturiki Island. Three samples from different skeletal elements were analyzed and their stable carbon values found to range between -16.0‰ and -15.8‰ and their stable nitrogen values range between 9.8‰ and 9.3‰ (see Table 8.5, Nunn et al. 2007). Nunn et al. (2007) interpreted these signatures as an individual with a diet of mixed terrestrial and marine foods with a focus on fish and shellfish. As with the other Fijian case study, this supports the strandlooper hypothesis rather than a mixed diet with horticultural activities.

Sample	$\delta^{13}\text{C}\text{‰}$	$\delta^{15}\text{N}\text{‰}$
MANA-4	-15.8	9.3
MANA-7	-16.0	9.4
MANA-11	-15.8	9.8

Table 8.5 Human collagen isotopic data at Natabale, Moturiki (Nunn et al. 2007)

However, both of these investigations follow the trend of previous South Pacific isotopic studies by presenting interpretations based on weak baseline data. Field et al. (2009) rely heavily on four modern fish samples for their interpretations, and draw on terrestrial data from published works pertaining to other islands, such as the Marianas Islands located in the North Pacific Ocean. Nunn et al. (2007) present no data in regards to their baseline information, which makes it impossible to verify their interpretations of Fijian Lapita diet. Furthermore, Nunn et al. (2007) relied solely on samples from a single burial. While the isotopic data may be interesting when compared to a zooarchaeological analysis, extrapolating the isotopic values of a single individual to the community or population level remains problematic.

8.4 Application of previous isotopic research at Nukuleka, Tonga

Before using the previous isotopic research, as discussed above, to address subsistence hypotheses at Nukuleka, it is important to consider the differences in Lapita cultural traditions between Remote and Near Oceania (see Figure 8.1). Near Oceania was first colonized sometime in the Late Pleistocene, with the Lapita tradition appearing around 3500 cal BP in the Bismarck Archipelago (Sheppard 2011). There is evidence, such as the translocation of some plant species, for some low level food-resource management and production during the beginning of the Pleistocene (Sheppard 2011). Conversely, Remote Oceania was previously uninhabited before the expansion of the Lapita people (Sheppard 2011). Since the previous inhabitants of Near Oceania may have relied on existing food management techniques, many archaeologists believe that early settlers of Fiji-West Polynesia may have employed a different subsistence strategy as they colonized previously uninhabited lands. Specifically, these colonists are argued to have relied heavily on foraged foods from marine and terrestrial resources as opposed to management

strategies that would require transportation of cultivated plant (Davidson and Leach 2001; Kirch 1997; Sheppard 2011; Valentin et al. 2010).

The archaeological sites in Near Oceania are also environmentally different when compared to those in Vanuatu, Fiji, and Tonga. In Papua New Guinea, there are more C₄ plants, which could be incorporated into the diet, either through direct consumption or through the consumption of wild browsing herbivores (Beavan Athfield et al. 2008; Leach et al. 2000). The incorporation of C₄ plants would lead to more positive $\delta^{13}\text{C}$ signatures. With these variables in mind, the stable isotopic results from sites within Remote Oceania are a more useful comparator for the subsistence strategies used at Nukuleka.

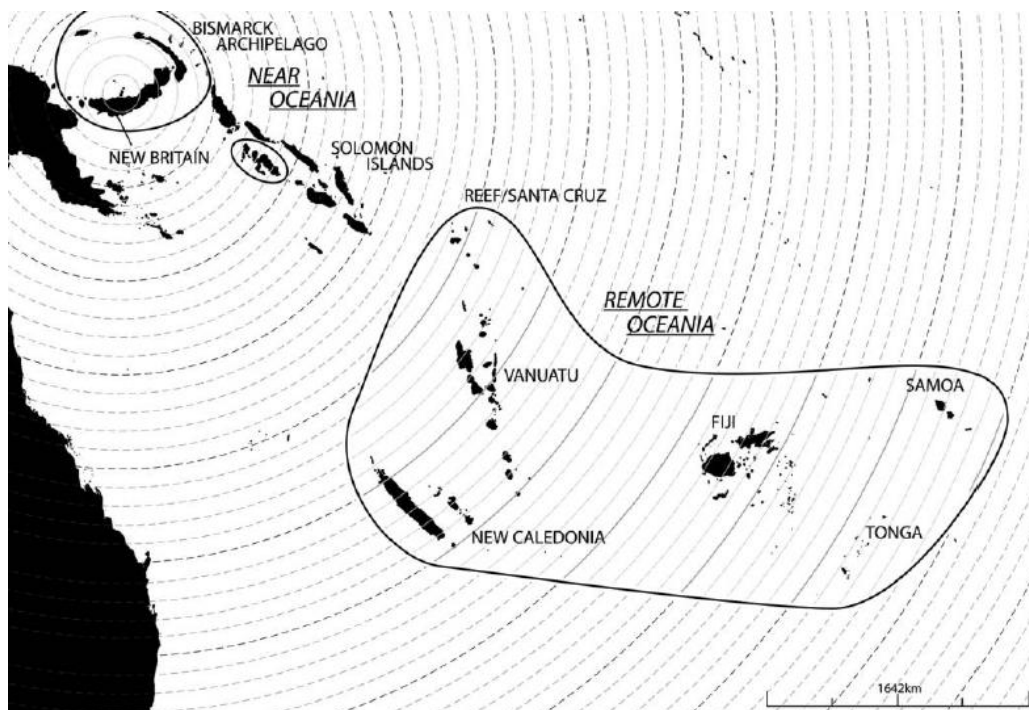


Figure 8.1 Map of Near and Remote Oceania (Sheppard 2011)

The sites in Vanuatu and Fiji are comparable to that of Nukuleka in that a limited amount of wild C₄ plants are available for consumption. All of these sites are also coastally located, and both Fijian sites have faunal assemblages similar to those found at Nukuleka (Nunn et al. 2007; Burley et al. 2010). Isotopic results from the three sites in Vanuatu and Fiji all show a strong

signal indicating the optimal foraging of marine and terrestrial resources (Field et al. 2009; Nunn et al. 2007; Valentin et al. 2010). This would imply that the Lapita colonizers of Nukuleka would have followed Groube's (1971) proposed strandlooper hypothesis, in maximizing readily available marine and terrestrial foods rather than transporting cultigens for food production. Additionally, it is feasible that they abandoned any planned horticultural investment when presented with easier subsistence options upon arrival. In Clark and Anderson's (2001) analysis of Fiji/Western Lapita expansion, they proposed that the subject of agricultural practices should be considered "absent until demonstrated" (Clark and Anderson 2001:84). Evidence from Nukuleka fits this criterion, and the null hypothesis that Lapita people here adopted a strandlooper subsistence strategy, remains the more likely scenario.

Chapter 9: Summary and Conclusion

The aim of this project was to reconstruct prehistoric Tongan diet at Nukuleka and to evaluate the two main subsistence theories associated with the Lapita cultural complex through stable carbon and nitrogen analysis and comparison with previous isotopic evidence throughout Oceania. Fourteen human samples from Nukuleka were prepared for collagen extraction and run for stable carbon and nitrogen isotope analysis. Unfortunately, only one sample yielded good quality collagen and it was later found to date after the Lapita occupation period.

In spite of poor sample preservation, an evaluation of subsistence strategies employed at Nukuleka was still possible through comparison with previous dietary isotopic research in the South Pacific. Sites within Remote Oceania were found to be more comparable to conditions at Nukuleka than with previously occupied sites in Near Oceania. This comparative analysis suggests that Groube's (1971) strandlooper hypothesis, which predicts a reliance on foraged marine and terrestrial foods, is the stronger candidate for modelling the subsistence strategies of the early colonizers of Tonga.

This research has led to some important points of discussion when attempting to use stable isotope analysis to investigate Lapita diet. First, a more critical approach to the planning of excavations in the South Pacific should emphasize the importance of mitigating issues related to skeletal preservation. In Nielsen-Marsh et al.'s (2007) paper on taphonomic and environmental considerations in the European Holocene, they recommend that analysis of site components, such as soil chemistry, be taken into consideration when organizing excavation strategies and time frames. In certain environments, sites should be excavated rapidly to help preserve bone integrity. In the South Pacific, many archaeologists will excavate a single site over a number of

years; however, it may be beneficial to excavate all human remains immediately upon discovery rather than allowing skeletal material to remain in corrosive soil.

Second, additional information on site formation and composition should be published more consistently when useable collagen can be extracted from human remains. Understanding the environmental circumstances that are conducive to collagen preservation can be extremely beneficial to archaeologists conducting research involving isotopic methods, particularly within less temperate environments like that of the South Pacific. With this information, future archaeologists will be better able to predict the sites where bone samples, if recovered, may be suitable for isotopic analysis.

Third, South Pacific archaeologists would benefit from using thermal age, in conjunction with environmental factors, to assist in predicting collagen degradation. The thermal age calculator is user-friendly and processes data at a high speed, allowing archaeologists to gain insight into the feasibility of employing stable isotope analysis at their sites. By taking into consideration degradation factors and applying preventative and predictive measures, more productive research using stable isotope analysis can be done on the Lapita people and their subsistence methods.

Finally, review of previous isotopic analysis on Lapita-age human remains has highlighted the need for a more extensive collection of baseline data across the South Pacific. There is a consistent reliance on non-local datasets, and on samples that are modern rather than archaeological in nature. There is extensive research on Lapita-age faunal collections (Burley 1998; Dye 1987; Poulsen 1987; Hunt 1999; Nunn et al. 2007; Steadman et al. 2002) and it would be extremely beneficial to derive from these a baseline for stable carbon and nitrogen analysis. A

comprehensive Lapita-age faunal database from a multitude of South Pacific islands would remedy the current situation of poorly constructed baseline data.

Evaluating Lapita subsistence theories is a complex task and one that is made more difficult as a result of poor collagen preservation and a lack of baseline data. However, isotopic analysis has worked at different sites across the South Pacific and it is recommended that future researchers continue to attempt to use this method at other Lapita burial sites, in the hopes of adding to what is currently a small body of data.

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