Stable Isotopes and Diet: Indications of the Marine and Terrestrial Component in the Diets of Prehistoric Populations from New Zealand and the Pacific

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A thesis submitted for the degree of
Master of Arts in Anthropology
at the University of Otago, Dunedin,
New Zealand.

March, 1990

ABSTRACT

The importance of marine versus terrestrial foods in prehistoric Pacific and New Zealand diets, and the adaptation of the Polynesian diet to new environments, is examined through the analysis of the ratios in human bone of the stable isotopes of carbon, nitrogen and sulphur. In particular, this study seeks to obtain quantitative information which could provide answers to five main questions, relating to the subsistence focus of the early Lapita colonists in the Pacific, the significance of sugar cane in the diets of early Pacific populations, the proportions of reef versus open ocean and terrestrial versus marine foods in these diets, and the identification of populations with pronounced marine or pronounced terrestrial diets.

One hundred and nineteen samples of human bone from 13 sites throughout the Pacific and New Zealand were processed. Nitrogen values were obtained directly from bone powder, while carbon values were determined from collagen produced by digesting bone powder in phosphoric acid. Sulphur evaluations were determined from a $BaSO_4$ precipitate, produced after combustion of the collagen samples in a Parr bomb.

Interpretation of results is approached from a comparative point of view, which enables the proportions of marine and terrestrial foods in the diets of each study group to be assessed in relation to the diets of all the other groups. Additional information on the composition of the diets is gained by

comparing the stable isotope values obtained in this study with published values of other human populations, and of marine and terrestrial plants and animals.

The potential of stable isotope analysis to identify the composition of prehistoric New Zealand and Pacific diets is confirmed. A unique marine adaptation is revealed from the analysis of the Chatham Islands Moriori who appear to have focused almost exclusively on marine resources. In contrast, a highly terrestrial diet is suggested for groups from Nebira in Papua New Guinea and Lake Rotoiti in New Zealand.

PREFACE

This thesis represents part of an ongoing research project relating to dietary analyses of prehistoric New Zealand and Pacific populations. The next stage of this project will involve collection and analysis of a wide range of marine and terrestrial plants and animals, from New Zealand and the Pacific, in order to establish a comprehensive data base of isotope values for this part of the world. The establishment of this data base, in conjunction with the development of multi-dimensional computer modelling and simulation, will enable more detailed analyses of the results in this thesis. Consequently, the interpretations of the results presented here may change for some sites and this should be kept in mind while reading this thesis. For a more up-to-date statement on the diet of any of these groups of people, the reader is requested to contact either the author or the head of this research project, Dr Foss Leach.

ACKNOWLEDGEMENTS

This thesis is part of a wider project of research on bone chemistry and prehistoric diet which has been underway for a number of years. I would like to thank my colleagues for the opportunity to take part in this project (Foss Leach, Graeme Lyon, Tony Haystead and Don Myers). I would also like to thank the following people:

My thesis supervisor, Foss Leach, whose enthusiastic encouragement and constant support was much appreciated.

Don Myers, of the Wellcome Research Institute, University of Otago, who gave expert instruction on sample preparation and the chemical analysis of the 'collagen' extracts.

Tony Haystead, of the Waikato Stable Isotope Unit, Ruakura Agricultural Centre, and technicians George Brier and Rosemary Leigh, under whose expert advice and instruction the practical work associated with the nitrogen analysis was carried out.

Graeme Lyon, of the Institute of Nuclear Sciences, D.S.I.R., who analysed the samples for carbon and sulphur determinations.

Roy Johnston, of the Geology Department, University of Otago, for help with XRF and XRD analysis.

Professor Campbell, who was in 1987 Head of Department of Ch emistry, University of Otago, for the use of the Parr bomb.

Suzanne Mooney, of the Anthropology Department, University of Otago, who cleaned and powdered a large proportion of the bone samples.

Martin Fisher, of the Anthropology Department, University of Otago, for help with the preparation of figures.

For the provision of bone samples I am indebted to the following people: Andrea Seelenfreund (Santiago, Chile); Simon Best (Anthropology Department, University of Auckland); Mike Fleming and Scott Russell (Historic Preservation Office of the Commonwealth of the Northern Marianas Islands); Roger Green (Anthropology Department, University of Auckland); Dimitri Anson (Otago Museum); Phil Houghton (Anatomy Department, Otago Medical School) and Jim Allen (La Trobe University, Melbourne).

I would also like to thank my fellow students in the Department of Anthropology, in particular those from room 2C23, for numerous lively conversations, ranging from the mundane to the bizarre, which confirmed for me that archaeology can be fun. For your camaraderie and support - thank you.

And finally, heartfelt thanks are due to my family. To my children, Jeremy and Ellen, who grew three years during the course of this thesis, learning a little about archaeology in the process and a lot about independence. And to my husband Max who remained supportive throughout and who helped me to keep things in perspective. For your patience and understanding - thank you.

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CHAPTER ONE

INTRODUCTION

Over the last two decades a central debate in Pacific archaeology has been concerned with the relative importance of marine and terrestrial foods to early Pacific populations. The strandlooper hypothesis (Groube 1971) is based on the conclusion that the Lapita colonists initially depended heavily on maritime/lagoonal resources. The development or introduction of horticulture subsequently allowed these people to expand and survive in Fiji and Tonga and eventually colonise the Eastern Pacific. An alternative view suggests that the first settlers of Tonga and Samoa introduced a generalised Oceanic subsistence economy based on seafoods, domestic animals, cultigens and wild plants (Clark and Terrell 1978:311). Some recent research (Kirch 1978; 1979a; Hunt 1981) has produced archaeological evidence which may support the latter view, but this is largely indirect. Best (1984) tends to reject this new evidence for early horticulture, preferring the strandlooper explanation, at least for Lakeba, one of the Fiji Lau Islands.

With the expansion of populations into the Eastern Pacific and to New Zealand the new environmental conditions which they encountered had considerable influence on diets. The extent to which some of these populations had to adapt is not always very clear from the archaeological record. In New Zealand, the much larger land area compared with islands in Eastern Polynesia meant

that for the first time there was the potential for Polynesian populations to develop exclusively terrestrial diets in inland regions. The focus of this thesis is to obtain quantitative evidence for the importance of marine versus terrestrial foods in early Pacific diets and to document any shifts in emphasis between marine and terrestrial sources which may have occurred. This can be done through analysis of the ratios in human bone of the stable isotopes of carbon, nitrogen and sulphur.

SOME PROBLEMS WITH STABLE ISOTOPE ANALYSIS

Before discussing the potential of multiple stable isotope analysis, the problems which have previously been encountered by other researchers should be discussed.

The use of the carbon isotope ratio 13C/12C to distinguish between marine and terrestrial foods, and C3/C4 plants has been well documented. It has also been established that the ratios for C4 plants are very similar to those of many marine organisms and the one may be mistaken for the other (Sealy and van der Merwe 1986:35). This represents a problem for dietary analysis in the Pacific where at least one C4 food plant, sugar cane, indigenous to Papua New Guinea, was widely distributed in prehistoric times (Warner 1962).

This problem can be solved to some extent with the nitrogen isotope ratio 15N/14N. Used in conjunction with carbon isotope

ratios, nitrogen ratios can distinguish between marine and terrestrial foods and eliminate ambiguities caused by the presence of C4 plants in the diet. However, a further complication arises when there is a dietary component which derives from a coral reef environment. This is due to the larger amount of nitrogen fixation by blue-green algae in coral reefs relative to that in the rest of the ocean (Schoeninger and DeNiro 1984:634; DeNiro 1987:189). Fish which feed in a coral reef environment have low δ15N values which fall within the range of values for terrestrial foods (Schoeninger and DeNiro 1984), and therefore an analysis of diets containing reef foods based solely on nitrogen isotopes would produce ambiguous results.

In most situations, analysis of carbon and nitrogen isotope ratios in combination can clarify such ambiguities, but this is not always the case. As an example, a diet based almost exclusively on reef fish would produce low δ15N and high δ13C values. Similar results could be obtained from a diet consisting of a high proportion of C3 and C4 plants and some open ocean marine foods. In the Pacific where the prehistoric distribution of sugar cane is uncertain and its relative contribution to early diets is also unknown, it is difficult to identify positively, or rule out, a C4 component in the diet. In a recent study Owsley, Miles and Gill (1986) have explained the high incidence of caries among prehistoric Easter Islanders as being due to the practice of using the juice from sugar cane as a liquid substitute for water which is rare. The role of sugar cane in the Easter Island diet will be explored in the present study.

It is equally difficult to determine accurately the importance of reef foods in the diet of prehistoric people, even when coral reefs are present. There are ethnographic examples of food prohibitions restricting consumption of some types of fish to certain status groups or to one sex (Fleming 1986:113; 18), and it would not be unrealistic to expect that this was the case in prehistory. The fact that a particular food source existed in a given location will not necessarily mean that it was exploited. Obviously then, it would be difficult to obtain quantitative results for the relative proportions of various foods in the diets of Pacific peoples from carbon and nitrogen isotope analysis alone.

A possible solution to these problems which will be explored in this thesis is to introduce the stable sulphur isotope 34S, which has previously been used to study energy flows in salt marshes and estuaries (Peterson, Howarth and Garritt 1985). Stable sulphur isotope ratios can be used to distinguish between marine algae, upland plants and marsh grasses, particularly if used in combination with 13C and 15N (ibid.:1361). While in general a clear distinction may be made between marine and terrestrial sources using sulphur isotopes, some ambiguities may arise in coastal areas. In such environments the concentration of sea spray sulphates (Mizutani and Rafter 1969) may cause the δ34S values of terrestrial foods to appear marine.

The conclusion reached from the above discussion is that the exclusive use of any one of the three stable isotopes of

carbon, nitrogen or sulphur in dietary analysis would produce ambiguous results. However, the use of all three in combination may provide complementary information which can not only be used to distinguish between marine and terrestrial foods, but can also identify foods from a reef environment and distinguish between C3 and C4 plants.

THE POTENTIAL OF MULTIPLE ISOTOPE ANALYSIS FOR NEW ZEALAND AND PACIFIC MATERIAL

The use of multiple stable isotope analysis in New Zealand and the Pacific has the potential to provide answers to the following questions.

1 Were the early colonists of the Pacific predominantly strandloopers or were they horticulturists?

This is a difficult question to answer because of the dearth of skeletal material from early sites. A small sample (n=6) of Lapita skeletons from Watom in New Britain was available for this study. A recent shell date of 2046 +- 63 BP has been obtained for this site, suggesting a probable calendrical age somewhere in the first four to five centuries BC (Green and Anson 1987:124), but despite the relatively early age of these skeletons they are unlikely to prove useful in confirming or refuting the strandlooper hypothesis. Watom Island lies barely four miles from the coast of New Britain, a large land mass with

a long history of settlement, and the Watom people therefore cannot be considered a colonising group of people in an insular Oceanic environment.

Some additional early skeletons do have the potential to throw some light on this problem. Four individuals which were excavated by Best from Lakeba, in the Lau Islands, in 1976-78 are included in this study. A C14 date of 2840 +- 65 BP was obtained for site 101/7/196, the source of two of these individuals, from a level just below these burials (Best 1984:98). The other two were excavated from site 101/7/197, one dating to around 2250 BP while the other is dated to within the last 500 years (ibid.:75). A fifth Fijian skeleton was excavated by Best in 1987 from the Sigatoka dune site, VL/16/1, on Viti Levu and is thought to be older than c 2000 BP (Best 1987b:5). Using data from these five individuals it may be possible not only to determine whether early Fijian populations were horticulturists, but also to identify any changes in diet which may have occurred over time. Another skeleton included in this study was excavated by Poulsen in 1963/64 from the shell midden To-1 at Pea on Tongatapu, Tonga, and probably belongs to the middle Lapita horizon of Tonga (Poulsen, cited in Spennemann 1985:4), although the stratigraphy of the shell midden was complicated (Spennemann 1985:4). Because of the problem with the stratigraphy at To-1, the Fijian individuals are expected to be of greater reliability in answering the above question.

2 How significant was sugar cane in the diets of early Pacific peoples?

The original domestication of the sweet sugar canes probably occurred in New Guinea (Warner 1962:407) where they became a prominent component of subsistence gardens and of diet (ibid.:409). The presence of agriculturally associated drainage systems in the Wahgi Valley dating back 9000 years points to the extreme antiquity of horticulture in Melanesia (Yen 1982:291). Although these drainage systems have been associated with taro cultivation, Yen (ibid.:292) has inferred that there may have been equally early cultivation of other highland domesticates, including sugar cane (Saccharum officinarum, Setaria palmifolia).

Sugar cane was reported in the gardens of Hawaii and other Polynesian Islands by Captain Cook in the early 18th Century and is presumed to have been dispersed throughout the Pacific by the early Polynesian colonists (Yen 1982). It is known to have been an important component in the diet of Easter Islanders at contact (Owsley, Miles and Gill 1986:419), but its prehistoric significance in other areas is largely unknown. The extent to which sugar cane contributed to the diets of the groups being studied in this thesis should become apparent through stable isotope analysis, with the qualification that sugar cane is assumed to be the only C4 plant likely to have been eaten in the Pacific.

3 Is it possible to identify the proportions of reef versus open ocean components in diets?

It is difficult to assess reliably the proportions of reef versus open ocean (pelagic) fish in diets through midden analysis alone, because the contents of the midden do not necessarily reflect the true composition of the diet. The δ15N values of fish from a reef environment fall within the terrestrial range, but both their δ13C and δ34S values will indicate their marine origin. It should therefore be possible to identify the proportions of marine foods which are derived from coral reefs as opposed to the open ocean using carbon and sulphur values to first eliminate the terrestrial component of the diet.

4 Is it possible to identify correctly the proportions of marine and terrestrial foods in prehistoric diets in New Zealand and the Pacific?

Quantitative values for marine and terrestrial dietary components can be obtained using carbon or nitrogen ratios alone, provided there were respectively no C4 plants or coral reefs in the vicinity of the food sources of the individuals in question. Since both C4 plants and coral reefs are present in the Pacific, it is necessary to employ a third isotope, 34S, which unambiguously differentiates between terrestrial and marine food sources. Using these three isotopes in combination it should be possible to identify accurately the proportion of marine and terrestrial foods in the diet of any given individual.

5 Is it possible to identify diets which were exclusively terrestrial or exclusively marine?

Theoretically, there should be a distinct combination of values of the stable isotopes of carbon, nitrogen and sulphur which would indicate that an individual was eating exclusively terrestrial or exclusively marine foods. For most of the groups in this study it is probably unlikely that such a marine or terrestrial 'signature' would be found as most Pacific populations would be expected to have dietary components from both sources. However, two groups from New Zealand may show such dietary signatures. The group of people from Lake Rotoiti may have had an exclusively terrestrial based diet, while the Chatham Islands Moriori are thought to have had an almost exclusively marine diet (Sutton 1979:236). Horwood's recent study (1989) of trace element levels for these prehistoric Chatham Islanders has shown a high reliance on marine foods by these people, and this should be reflected in their isotope ratios.

SUMMARY

Multiple stable isotope analysis has the potential to identify the proportions of marine and terrestrial foods in prehistoric New Zealand and Pacific diets, and to provide evidence for continuity and change in subsistence strategies over time. Stable isotope analysis should not be used in isolation, but rather should be seen as providing complementary information

to that gained from traditional archaeological methods of dietary analysis, and the more recently developed method of trace element analysis. Various traditional methods of dietary analysis are discussed in the following chapter.

CHAPTER TWO

METHODS OF DIETARY ANALYSIS

A. TRADITIONAL ARCHAEOLOGICAL ANALYSIS OF DIET

Traditional archaeological methods of dietary analysis are fraught with problems and characteristically limited in their application. In many instances the archaeologist is faced with limited evidence on which to base dietary reconstructions, and all too often must resort to speculations about what might or might not have been eaten. While midden analysis gives some useful information on some of the foods which may have been eaten, it cannot for instance tell us what was eaten and discarded elsewhere, or what vegetable foods may have been eaten. This is particularly so in the Pacific where root crops, the remains of which seldom survive in archaeological contexts, were the main vegetable foods. More direct methods, such as coprolite and pollen analysis, have some useful applications but are limited in their scope, generally being too specific to reconstruct an overall diet.

Some of the more commonly used methods of dietary analysis will now be discussed and an evaluation of their usefulness in this respect will be made.

The analysis of midden remains is an invaluable means of providing general information about prehistoric diet, but even with the most rigorous analysis it is not possible to determine whether the food remains in a particular midden reflect the total diet of the people responsible for their deposition. There are three main reasons for this. Firstly, the differential preservation of food remains in archaeological sites usually results in a loss of most soft foods, especially the remains of root crops. A proportion of the plant component of the diet may survive in the form of seeds, such remains having been identified from several New Zealand archaeological sites (for example see Leach 1976:255). The presence of seeds from a particular species, however, does not necessarily provide evidence of the consumption of that species, but may instead reflect its use as firewood, as raw material for making mats and baskets etc. (McFadgen 1972:80), or the seeds may have been deposited in the soil by natural processes unrelated to the cultural activity there. Secondly, a significant proportion of food remains may have been discarded elsewhere, either where the food was consumed, or at specialised butchering sites. Cultural and social practices which sometimes lead to food remains being discarded away from living areas may also be important here. For example, on Naigani Island it is customary for all the remains of carangid fish to be thrown back into the sea before nightfall (Best 1984:508). The third complicating factor is that midden remains may have been disturbed since deposition, either by scavenging animals such as

dogs, pigs or rodents, or simply by cultural activity such as the movement of people through the area, gardening activities and the like. A detailed discussion of factors affecting midden composition can be found in Horwood's thesis (1988:10-15).

In theory, with these limitations recognised, it is possible to gain valuable information about prehistoric diet from midden analysis. However, in practice this rarely happens, because many archaeologists fail to employ appropriate excavation strategies and recovery methods. Accurate dietary reconstruction will not be possible unless particular attention is paid to sampling methods and recovery of floral and faunal remains during excavations, followed by thorough analysis and quantification of all excavated material.

Sampling methods

In a review of midden analysis and the economic approach in New Zealand archaeology, Davidson (1967) discusses the problem of intra-site variation in midden composition at Kauri Point, where work suggested that "the range of variation between different areas of a single midden was as great as that between different middens, and that any ordering or comparison based on single small samples would be unreliable" (ibid.:222). Great care must be taken when excavating to ensure that the sample removed is representative of the whole. This is easy to say, virtually impossible to achieve, and often a totally unrealistic objective, given limitations on time and resources, the condition of the

site itself, and the nature and extent of previous archaeological investigation. McFadgen (1972:48) discusses the problems associated with collecting random samples of cockle shells from the Foxton midden. A series of excavations undertaken over a period of eight years (during which aims and methods and hence excavation strategies had changed) resulted in insufficient shells from some lenses for an analysis of the variation in mean shell size between different lenses and layers. Furthermore, the previous excavations precluded any resampling of the lenses in question (ibid.:49).

Excavation strategies designed for specific purposes, such as recovery of pottery and other artefacts, establishing occupation sequences, or obtaining stratigraphic information, in many cases prove inadequate for the purpose of specific dietary reconstruction. On Tikopia Kirch and Yen (1982) excavated a stratified random sample of twelve one-square-metre units at the Kiki site. On the basis of information recovered, the areas of greatest concentration of cultural material were identified, and at these sites three larger areal excavations were carried out (Kirch and Yen 1982:112). The combined area covered from both the areal and test excavations represented 1.04% of the total site (ibid.). As a means of justifying this excavation strategy, Kirch and Yen employed a mathematical formula to calculate a 'negative hypergeometric distribution' which confirmed that a representative sample of items contained in the midden would be recovered in their sample size (Kirch and Yen 1982:114). This sort of strategy would be of little or no benefit in

reconstruction of diet, because while the sampling strategy may be unbiased there will be an inherent bias in any midden sample because the material is not uniformly distributed in the first place (Anderson 1973:121). It is unfortunate that, often with the best of intentions, our knowledge of prehistoric diet is not usually increased by such an approach as that employed by Kirch and Yen (1982). The real cost of such excavation strategies is often the disturbance of the site to the extent that valuable evidence pertaining to diet is irretrievably lost, for the sake of a general overview of the economy.

In circumstances where it is impractical to excavate an entire site, a more common sense approach has been advocated (Anderson 1973:123) in which an areal excavation of a portion of the site is carried out. Some degree of bias immediately would be introduced because a choice would have to be made about where to excavate, but provided the subsequent analysis of the excavated material was thorough, and the information recovered was not extrapolated to produce an overall interpretation of the whole site, this approach would be preferable to one which involved excavating several randomly sampled discontinuous squares (ibid.). Obviously, for the purposes of dietary reconstruction, a partial excavation would not provide a complete picture, but such a method could give some useful indications of local subsistence patterns. This could then be confirmed by more direct methods of dietary analysis.

Innaccurate dietary reconstruction may also be the result

of selecting an unrepresentative sample of sites for excavation. Sutton's (1980) reconstruction of the diet of the Waihora people on the Chatham Islands is based on midden analysis from four excavated sites within a two kilometre radius of the Waihora mound, and three shellfish middens excavated elsewhere. Anderson (1981) has criticised this approach, arguing that the excavated sites are not representative of the 80 sites within two kilometres of Waihora (ibid.:151). He also suggests that activities such as catching ducks and eels may have been carried out some distance from Waihora and the remains discarded at specialised butchering sites. While such foods may have made a considerable contribution to the diet, their true proportions would not be revealed by analysis of middens in close proximity to the site.

Smith's (1985) analysis of sea mammal hunting in prehistoric New Zealand has confirmed that seal bones were often discarded at kill sites. Ethnographic observations suggested that different butchering techniques were employed, depending on whether the seals were being butchered for immediate consumption, or for preservation of the meat (ibid.:464). The preservation strategy involved separating the flesh from the bone at or near the kill site, resulting in few bones being returned to living sites. Conversely, Smith suggests that butchering for immediate consumption would involve some initial separation of the carcass into easily transportable units at the kill site, with all useable parts being carried to living sites (ibid.:465). A reconstruction of primary butchering procedures revealed that an

adult fur seal carcass could be reduced conveniently to 10 butchering units, while lower limbs, which had little food or other value, were likely to be discarded (ibid.:469). Young seals could be transported as a single unit (idid.:468). Therefore, while an assemblage with higher proportions of upper limb bones to lower limb bones could be interpreted as representing a site where seal flesh was consumed, the consumption of preserved seal flesh would be difficult to detect from analysis of a living site alone. Even if other sites in the area could be identified as kill sites, it would still be difficult to determine whether animals butchered for preservation at those kill sites were consumed at the living site in question. To do this, detailed knowledge of tribal ownership of resources would be needed and this is rarely available for pre-contact populations. Ethnographic observations of one South Island Maori group revealed that "the Temuka Maoris nominally resided in one permanent village, Waiateruati, but possessed ownership rights, enforced by rahui [footnote 1] over widespread resources" (Leach 1969:49). The question of food exchange must also be considered. Preserved seal flesh may have been transported some distance and exchanged with other groups before it was consumed. Accurate

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Footnote 1: Rahui - a 'conservation' concept, used to regulate exploitation of certain food resources, thus ensuring supplies throughout the year (Leach 1969:44). Best (1942:132) defines rahui as "a prohibitory enactment or pronouncement concerning food supplies".

reconstructions of the proportions of meat from seals and other sea mammals in the diet of the Waihora people could thus be complicated by such factors, and would be impossible through midden analysis alone.

Recovery methods

Thorough recovery of as much faunal and floral material as possible is fundamental to accurate reconstruction of diet. All excavated material should be sieved, using as fine a mesh as practicable for the particular matrix. While the more commonly used 0.25 inch (6.4mm) sieve will recover a significant amount of biological material, many smaller items such as small bones, fish otoliths and plant seeds will be lost. Studies on the impact of sieve-size choice on the nature of recovered fauna have shown that the recovery rate of smaller faunal remains increases dramatically as sieve mesh size decreases (Grayson 1984:168-171). In a recent discussion, based on her study of sieve size effects on faunal fish recovery, Butler (1988) demonstrated that up to 77% of identifiable specimens (NISP) could be lost through a 6.4mm sieve (ibid.:104). Furthermore, a comparison of the NISP-derived relative taxonomic frequencies between the fractions of the assemblage obtained from nested sieves of 6.4mm and 3.2mm mesh size, indicated that Salmonidae comprised 45% of the assemblage in the 6.4mm sample and 24.3% of the assemblage in the 3.2mm sample (ibid.). Thus, an interpretation based on the 6.4mm fraction alone would result in higher frequencies of Salmonids than actually occurred in the site, and may be used for the basis

of an erroneous argument for a more specialised fishery focused on Salmonids (ibid.). In her consideration of the effects of sieve size on Lapita fish faunal studies, Butler concludes that the predominant use of relatively large mesh sieves in Lapita excavations may have resulted in the loss of up to 77% of identifiable fish remains, and inaccurate relative taxonomic abundance estimates (ibid.). However, MNI-derived estimates of taxonomic abundance may not necessarily be significantly changed by the use of smaller sieve sizes.

Nagaoka (1988) has stressed the importance of accurately recording any changes in sieve size which may occur in the course of an excavation. In his excavation of two rock shelters on Lakeba, Best (1984) first employed dry-sieving through a 5mm mesh, which "removed the greater proportion of the charcoal-rich matrix without losing cultural material, the matrix sticking to the smaller artefacts and retaining them in the sieve" (ibid.:60). This was followed by wet-sieving through a 1.5mm mesh, a procedure necessary as the water supply was limited (ibid.). Wet-sieving, as used by Best on Lakeba, is particularly useful for the recovery of botanical remains and other items which may be overlooked during dry-sieving, often because the surrounding matrix may be adhering to them. Nagaoka (1988) has claimed that the decrease over time in relative abundance of pigeon and dove bones at Qaranipuqa rock-shelter (Site 101/7/197), interpreted by Best as occurring as a result of human overexploitation, may have been a consequence of the sieve size(s) used within lower layers and that this cannot be

confirmed or discounted because sieve size changes were not adequately recorded (ibid.:119). However, if Best's (1984:60) explanation of sieving procedures for the two rock-shelters is taken to be a description of standard procedures used for all layers of these excavations, as I believe it is meant to be, then Nagaoka's criticism in this instance is unfounded. However, her point about the necessity for accurate recording of sieve size changes is a valid one.

Small and microscopic biological remains may be recovered by putting all material which passes through the sieves through a flotation machine. This method is based on the simple principle that organic material has a lower specific gravity than inorganic material and will thus float on the surface of the water (Wing and Brown 1979:149). The floating material, such as carbonised seeds and other botanical remains, landsnails and bone, may be scooped from the surface of the water and retained for subsequent analysis.

In addition to the above recovery methods, thorough dietary analysis requires bulk soil samples to be taken, to be analysed in the laboratory for macroscopic botanical remains such as pollen, spores, phytoliths, stellate (star-shaped) hairs and other epidermal fragments (ibid.).

Quantification

The need for accurate quantification of archaeologically

recovered faunal material has been recognised for several decades. Since White's (1953) initial description of a basic procedure for estimating the minimum number of individuals (MNI) in an assemblage, modification and refinement of the method has resulted in a variety of approaches to the quantification of faunal material. The quantification process usually involves two or three stages: determining the minimum number of individuals represented; calculating their relative importance in terms of meat yield; and the conversion of meat weights into energy yields (Smith 1985:106). For the purposes of recovering dietary information, the first two stages are more relevant as the aim is to determine which species were consumed in what quantities.

Minimum Number of Individuals (MNI)

White's (1953) method involved separating the most abundant element of the species found into right and left components and using the greater number as the unit of calculation (Grayson 1984:27). While White recognised this approach as being conservative, because "we cannot be sure all of the lefts match all of the rights" (White 1953, cited in Grayson 1984:27), he considered that more accuracy would only be possible with the expenditure of a great deal of effort for a small return. Recent modifications of White's method (for example, Nichol 1978; Smith 1985) have identified ways in which more information can be considered in the calculation of MNIs, although not without significantly increasing the time and effort required.

One basic improvement, suggested by Flannery in 1967 (cited in Nichol 1978:157), involves examining left and right bones for differences, due to such variables as age or size, which could not be explained by bilateral asymmetry within a species. This procedure could increase the MNI, as each bone without a corresponding opposite bone would be counted as representing an additional individual. Nichol (ibid.:159) suggests that computer programming could be used to match paired bones, from bone measurements, thus identifying any 'extras'. Another approach predicts body lengths or weights from bone dimensions, and on the basis of these predicted measurements unpaired bones can be compared for significant similarities and differences (Smith 1985:110). Smith (ibid.) used measurements of skeletal elements of sea mammals to place individuals into size-related age-sex groups where possible. In those cases where age and sex could be determined, MNI was often greater than the initial 'raw' MNI obtained using more conventional methods which did not take age and sex into account(ibid.:114). Leach (1979) employed MNI calculations in a study of bird butchering techniques. The method involves dividing each represented limb bone into a number of identifiable fragment types. After recording numbers for bones of both left and right sides, certain combinations of fragments are summed to obtain several minimum numbers, the largest of which becomes the maximum minimum number (ibid.:104). However, this method is quite specific to the analysis of bird bone for which it was developed and cannot necessarily be employed legitimately in the analysis of other kinds of faunal remains. For example, in a discussion of the problems associated with the calculation

of MNIs of tropical Pacific fishes, Leach (1986) warns against adjusting MNIs for such fishes by matching fragments of one anatomical component (ibid.:155). This is because of the difficulty of identifying tropical Pacific fish bones to species level, let alone to individual, so that "neither a matched pair nor an unmatched pair can be assumed to belong even to the same genus" (ibid.:154). This same identification problem is the principle reason why Leach (1986) also argues against adjusting MNIs of tropical fishes upwards for anatomical size matching and mismatching (ibid.:154), and this would similarly apply to the above methods suggested by Nichol (1978) and Smith (1985).

Several other potential problems which could affect the calculation of MNIs can be identified. The differential preservation of midden remains affects the number of specimens which can be identified and included in analysis of minimum numbers. Some bones and shells, although present, may be so fragmented as to be unidentifiable. Grayson (1985:2) points out that the complexities of taphonomic pathways should also be taken into account during quantification analysis. The numerical structure of faunas produced by taphonomic processes in some cases may be unrelated to that of the original faunal deposits, and "because we know so little about taphonomic processes ... it is not clear that the detailed numerical structures of faunas that have been produced by those processes are to be trusted" (ibid.).

The limitations of this method of obtaining dietary

information should be recognised, and where the problems discussed above cannot be solved, other alternative methods must be considered. In those cases where minimum numbers can be determined reliably, the value of the method for dietary analysis can be increased by converting MNI to useable meat weights.

Calculation of meat weights

The quantity of useable meat provided by each species in a given assemblge is more relevant to determining their relative contribution to diet than the number of individuals of each species represented. White (1953) originally proposed that the useable meat weight be calculated by multiplying the average weight of meat obtained from an adult of a given species by the calculated minimum number of individuals of that species. For the purpose of comparison of meat weights between sites this method would normally be adequate, but for the purpose of identifying the amount of meat from each species eaten by a particular group its accuracy may be reduced because average adult body weights can vary with age, sex, location, season, and other factors such as availability of food and population density (Smith 1985:115). These kinds of factors would also affect the accuracy of meat weights calculated from equations which relate a particular measure of bone size to the body size and weight of a species (for an example of this procedure refer to Fleming 1986). Nevertheless, when attempting to answer questions about the relative proportions eaten of particular species, calculation of meat weights will be more useful than calculation of MNIs alone.

The reliable calculation of body weight is not, however, the only limiting factor in arriving at accurate estimates of meat yield. A distinction can be made between the amount of available meat in an animal and the amount of meat which is actually consumed (Lyman 1979). The weight of meat available is generally the weight of the animal, excluding the weight of the skin, the skeleton and the viscera (Wing and Brown 1979:132). As the percentage of useable meat varies for different animals, individual calculations must be made for each species. Once a reliable value for the amount of meat available has been determined, there follows the difficult task of estimating the amount of meat actually consumed. As an example, there has been considerable discussion about the ratio of blubber to meat likely to have been consumed by sea mammal hunters (Anderson 1981; Smith 1985; Noli and Avery 1988). While a diet incorporating large quantities of blubber may lead to an imbalance between fats and carbohydrates, and the development of potentially fatal ketonuria (Smith 1985:117), a high protein diet may lead to protein poisoning (Noli and Avery 1988). Any determination of the amount of sea mammal meat consumed would thus involve some speculation about the amount of blubber included in the diet.

A more reliable means of determining the amount of meat actually consumed was proposed by Lyman (1979), who suggested that the weight of useable meat yielded from identified butchering units may be a more realistic basis from which to make such estimates. Following Lyman's lead, Smith (1985) developed a method for detecting butchering patterns which could identify

more accurately the partial carcass consumption of sea mammals. This allowed for the calculation of more reliable estimates of consumed meat weights for several species of New Zealand sea mammals, and subsequently some assessment of their proportional contribution to diet was possible.

Many of the problems discussed in relation to estimating meat weights from bone are also encountered when estimating meat yields from shellfish. The weight of meat produced by a shellfish is subject to seasonal variation, while the meat weight/shell weight ratio is dependent on shell size (Nichol 1978:145). In addition, if shell weights are used to estimate meat yield, a correction factor must be applied as the weight of a shell may be reduced by up to 23% due to the loss of calcium carbonate through leaching (ibid.).

The calculation of meat weights from archaeologically recovered faunal material is nevertheless a method which is potentially useful for providing information on dietary proportions. A classic application of this method is demonstrated by Shawcross (1972) in his analysis of the faunal material from Houhora in Northland, New Zealand. However, as can be recognised from the problems inherent in analysing such material, the best that can be achieved from this method is a reliable estimate of the contribution of a particular component to a diet. Estimates of meat yield are useful for the insights they provide and for their enhancement of midden analysis, but they are still estimates. Ultimately, other more direct methods

must be employed if accurate quantitative analysis of diet is to be achieved. Before discussing those methods which have this potential, namely trace element and stable isotope analysis, some further traditional methods of obtaining dietary information will be reviewed.

OTHER METHODS OF OBTAINING DIETARY INFORMATION

Environmental Studies

Consideration of the prehistoric environment surrounding a site is recognised as being fundamental to any study concerned with reconstruction of prehistoric diet. Because the dietary information which can be gained from midden analysis alone is characteristically limited by factors such as differential preservation of remains and taphonomic processes, additional information is required if a complete dietary reconstruction is to be made. Foods which were potentially available to prehistoric people can be identified through environmental analysis and this is particularly important in the case of plant foods which normally do not survive in middens. However, it should be recognised that the availablity of foods is not the only criteria which determines the composition of the diet. Cultural factors may operate to exclude certain foods which may have been readily available and nutritionally adequate.

Higgs and Vita-Finzi (1972) proposed that people will choose to settle in locations which have easy access to staple foods which can be economically exploited. They also assumed that a human group will make use of all available resources within a territory, provided they possess the necessary technology with which to do so (ibid.:2). As noted above, cultural preferences may influence the exploitation of resources and where quantitative analysis of diet is concerned, such assumptions cannot be justified. Rather, environmental analysis of a prehistoric site can be used most effectively to determine the patterns of resource availability in the vicinity, and to give a useful indication of the probable composition of the diet of the prehistoric population. More direct methods of dietary analysis could then be employed to confirm or disprove these initial dietary reconstructions.

As an example, the environmental context of Lapita settlement locations has recently been examined by Lepofsky (1988) in an attempt to resolve two main issues. The first is related to the size of islands on which Lapita people settled, while the second, which is more relevant to the present study, concerns the type of subsistence base that supported the Lapita populations on these islands (ibid.:33). Lepofsky undertook site catchment analyses of several Lapita sites, to determine whether Lapita colonisers regularly selected certain environments for settlement over others (ibid.:34). Results showed that Lapita people favoured coastal areas which were accessible by watercraft, which were close to a fresh water source and which

were in the vicinity of potentially cultivatable land (ibid.:46). In addition, more than half the sites studied were within 2km distance from a fringing reef or lagoon (ibid.:36). These results confirm the maritime orientation of the Lapita people, and the location of sites in areas of arable land indicates that Lapita people could have practised horticulture. However, the availability of arable land does not necessarily mean that horticultural use was made of it. Lepofsky (ibid.:46) suggests that the association of Lapita sites with a wide variety of environments implies that the Lapita people were generalists, but the location of Lapita sites may simply be a function of geography, with many locations on habitable islands in the Pacific providing just such a range of resources within a 2km radius. Whether the Lapita people were horticulturists, strandloopers or generalists cannot be determined from this sort of environmental study. Instead, such a study is valuable for the important background information it can provide to support more direct methods of dietary analysis. Using stable isotopes and trace elements, which do have the potential to determine the proportions of marine and terrestrial foods in the diet, it may be possible to find some direct evidence for the first time on what until now has been merely in the realm of guesswork.

Micro-organic remains

The relevance of environmental studies to dietary analysis can be increased by the analysis of micro-organic remains, such as pollen, spores and phytoliths. The recovery of these remains

can give insights into the ecology of an area and the land use strategies of prehistoric populations. The more commonly employed method is pollen analysis, developed initially as an aid to dating archaeological sites, but also useful for providing information about vegetation types.

Pollen can survive over long periods because the outer wall of the pollen grain, the exine, is extremely resistant to decay, although the action of aerobic bacteria may destroy the pollen walls. Preservation is therefore most complete where conditions are less favourable for aerobic bacteria, in water-logged deposits, arid soils and semi-desert areas, in arctic or alpine deposits and in acid soils (Dimbleby 1967:119). Pollen grains are morphologically diverse and the genus can usually be identified relatively easily, although identification to species level is often not possible. Identification is made by comparison with prepared slides of pollen grains of living taxa whose identity is known. This can present a problem in Pacific archaeology where the prehistoric plant inventory may not be known, or species may have undergone genetic changes. A further complication may be caused by the fact that many Pacific plant foods have been reproduced vegetatively for several millennia and may have lost the ability to flower and set seed, although Leach (1976:145) cautions that this may be an erroneous belief. Yen's (1974) study of New Zealand kumara revealed that flowering was not totally inhibited and seed formation was possible, leading to the conclusion that sexual reproduction may have played a role in producing local variations of the species

(ibid.:cited in Leach 1976:146). Leach suggests that "kumara pollen and seeds might be present in a few New Zealand contexts but ...they are most unlikely to be found in quantity" (1976:146). A similar uncertainty about pollen and seed production exists for taro and yam which have been known to produce flowers, but this is not common (ibid.). Therefore, although pollen production may have occurred in the past in these cultigens, significant amounts of such pollen are unlikely to be recovered from most New Zealand and Pacific sites.

Other problems associated with pollen analysis are related to the pollen dispersal characteristics of different species, with those that are wind pollinated being over-represented in most assemblages. Some knowledge of the dispersal characteristics of particular species is therefore necessary for accurate interpretation of results. It is also important to recognise that the presence of pollen in a soil sample does not necessarily mean that the plant was eaten, but merely indicates that it grew at or near the site. The dietary evidence which can be provided from pollen analysis is therefore largely indirect and must be used in combination with direct methods of dietary reconstruction, such as stable isotope and trace element analysis, if accurate reconstruction of dietary proportions is to be achieved. However, direct dietary evidence can be obtained from analysis of pollen in coprolites, with the qualification that this method can only identify what was eaten over a period of hours or a few days. This method will be discussed more fully later in this chapter.

Spores are microscopic bodies released by most non-flowering plants as a means of dispersing the species, but identification can be difficult (Dimbleby 1967:127). Their presence may have some significance to dietary analysis, for instance in the detection of changes in land use. In New Zealand, forest was regularly cleared to encourage bracken fern re-growth (Davidson 1984:39), a practice which could be identified if significant increases in fern spores could be detected. This could be relevant to dietary reconstruction, as in some parts of New Zealand fern root was an important component of the diet (ibid.:115).

Phytoliths are deposited in soils as a result of the decomposition of vegetation. The most recognisable phytoliths are bodies of opaline silica ($SiO_2.nH_20$) which are deposited in the cells of plants, particularly grasses, and which are most useful in distinguishing major groups of grasses, rather than identifying specific taxa (Wing and Brown 1979:157).

The identification of spores and phytoliths are, like pollen analysis, indirect methods of obtaining dietary information, and at their most useful they can confirm the presence of certain plants at a site. The presence of those plants cannot, however, be taken as confirmation that they were used as a food source. Such confirmation must be sought from more direct methods of dietary analysis.

Land snail analysis

The presence of anthropophilic land snails in a site has become recognised by some archaeologists as a reliable method of identifying early horticulture (Hunt 1980, 1981; Kirch and Yen 1982). Adventive species, or those which have been introduced by human agency, can be distinguished from a set of criteria proposed by Harry (1964, cited in Hunt 1981:262). These species typically have no close relatives in the area where they have been introduced and tend to remain restricted to human modified environments, where they breed more rapidly than indigenous species (ibid.). Hunt (1981) has identified at least two species "of probable adventive status" from the Yanuca site in Fiji (ibid.:262), Lamellaxis gracilis and Gastrocopta pediculus, which have been characterised as 'tropical tramps' by Solem (1959, cited in Hunt 1980:262). Although recognising that more research is needed on pre-human land snail faunas in Oceania, Hunt claims that

> "the transport and successful colonisation of at least L. gracilis and G. pediculus indicate these anthropophilic 'hitch-hikers' must have arrived as invisible associates of economic plants or other items of commerce" (ibid.:263).

Hunt uses the presence of these anthropophilic land snails, in combination with other evidence for early forest clearance, to argue for "horticulture as a strategy present in the economy of Fiji's earliest colonists" (ibid.) The identification of L.

gracilis in prehistoric deposits on Tikopia is similarly seen by Kirch and Yen (1982) as an affirmation of other evidence for "the transport of plant materials to Tikopia beginning with initial colonisation" (ibid.:309).

Best (1984) has questioned some of the assumptions made in land snail analyses, pointing out that there is often no attempt made to determine whether so-called 'adventive' species occur in deposits which are dated prior to human habitation (ibid.:527). He also sees the need for more research into the dispersal of these species, as agents other than man may be involved (ibid.). Furthermore, even if the probability that snails and man arrived together is accepted, Best points out this does not necessarily mean that there is any correlation between these animals and any economic activity of the settlers (ibid.). Snails may have been transported by mediums other than plants or roots, for example among the fibres of baskets, in mats, on/in storage vessels, while vegetation around a site may often be disturbed for reasons other than those of horticulure or agriculture (ibid.). Best concludes that "'adventive' snails probably tell us more about theoretical trends in archaeology than the economy practised by their carriers" (ibid.).

More research is thus needed in the area of land snail analysis before this method may be used as a reliable means of obtaining dietary information, and even then such information is likely to be indirect and in need of confirmation from other sources.

Field evidence

Direct evidence of early agriculture can be provided from the analysis of prehistoric field systems. The presence of agricultural terraces, field drains, irrigation systems, garden bondaries, storage pits, man-modified or 'plaggen' soils, and other modifications to the landscape are all indications of agricultural or horticultural activities (Leach 1976; Earle 1980). While the analysis of these field features can lead to invaluable insights into social organisation and culture history (Earle 1980; Green 1980), the dietary information which can be gained is usually too general to be of use in reconstructing the proportions of plant foods in the diet. In some cases, for example where population and area of land under cultivation is known, it may be possible to calculate the probable proportion of cultivated foods in the diet, using methods similar to those employed in calculating faunal energy values. However, such details are rarely available in New Zealand and the Pacific, and even if they were, the possibility of other non-cultivated plant foods contributing to the diet could not be ruled out.

Analysis of field systems can thus identify a horticulural orientation, but it cannot tell us whether other resources, such as those from the marine environment, were exploited, and in what quantities.

Artefacts

Some broad indications of dietary components may be gained by an examination of the artefacts recovered from a site, and the consideration of their role in food procurement and preparation. However, some caution should be exercised when attributing function, as this is not always immediately apparent from casual examination of an artefact. Leach, Intoh and Smith (1984) report the recovery of whalebone and wooden clubs from the Fa'ahia site on Huahine, but whether they were used as fighting weapons, or for clubbing dolphins which is equally plausible, is a matter for speculation (ibid.:189). The ceremonial, ornamental or symbolic significance of some artefacts, such as fish hooks, has been recognised (Anderson 1983:23; Davidson 1984:64) and the possibility that a given artefact had such a function cannot be discounted. In addition, Leach and Davidson (n.d.) suggest that there is a variable relationship between fishing technology and fish catches, with the range of fish hook types represented in a site not necessarily reflecting those species which may have been taken for food (ibid.:3,27). Fish may have been caught by other methods such as poisoning, trapping, spearing and netting, while all those fish that were caught with hooks may not necessarily have been eaten. Any analysis based on the presence or absence of particular artefacts, or on incorrect identification of artefact function, will obviously lead to erroneous assumptions about the diet and economy, which can have far reaching implications.

Best (1984:495) discusses the problem of distinguishing

shell vegetable scrapers from shell midden debris, and the consequent lack of proven vegetable scrapers in the early layers of Site 196 on Lakeba. He points out that Kirch (1978) claims that this and other indirect evidence, such as the identification of pig bones from at least one site on Niuatoputapu "reinforce[s] the interpretation of Lapitoid economy as having been broad spectrum, integrating both developed cultivation systems and marine exploitation technology" (ibid.:12). Best feels that as these shell scrapers represent one of the main pieces of evidence that Kirch sees as rebutting the strandlooper theory, it is unfortunate that he does not provide the criteria by which these 'scrapers' have been identified as such (1984:495). Best suggests that the provision of micro-photographs of these tools may have been helpful in distinguishing between them and food remains (ibid.:652).

A problem common to many of these methods of identifying early horticulture is that interpretations of function, form or significance are often made at a subjective level. Best (ibid.) points out that although Oceanic horticulturists use such artefacts as pottery, adzes, ovens and stone flakes, "it does not follow that all who use them are necessarily horticulturists". This has important implications for the Lapita subsistence debate, where adherence to the strandlooper hypothesis or the early horticulture hypothesis often depends upon individual interpretations of the available indirect evidence. Kirch (1988) has recently emphasised the inadequacy of existing Lapita faunal and floral assemblages to resolve the subsistence issue, and

welcomes a move toward more rigorous attention to the recovery of direct archaeological evidence, such as plant macrofossils where possible (ibid.:160). However, as Kirch suggests, this is not always possible and other archaeological techniques such as flotation, palynology, opal phytolith analysis and environmental investigations must be applied to Lapita sites (ibid.). To Kirch's "panoply of potential archaeological techniques" (ibid.) we can now add those methods which can provide direct evidence of the nature of prehistoric diets, trace element and stable isotope analysis of human bone.

Historical Records

The examination of historical records may sometimes be the only means of obtaining information pertaining to diet, food preferences, food procurement strategies and resource availability, particularly in New Zealand and the Pacific where many areas have not been investigated archaeologically. However, as with most methods of dietary reconstruction discussed in this chapter, there are some inherent problems in the nature of historical records themselves which affect their reliability. The main limitation of this method is that we cannot be sure that what was recorded was actually correct, due mainly to bias on the part of the observer or the informant. Leach, Intoh and Smith (1984) suggest that many observations about economic activities tend to emphasise spectacular activities at the expense of the more mundane (ibid.:194). Similarly, such records often describe what foods people believed to be economically important, rather

than what they actually ate most of the time (ibid.). Consequently, any reconstruction of diet based on historical records alone would rarely be reliable. Nevertheless, historical records can provide a useful framework which can be 'fleshed out' with the details gained from archaeological research.

In New Zealand, where many areas are largely unknown archaeologically, the work of early ethno-historians (for example Colenso 1868; Best 1902, 1942; Te Rangi Hiroa 1921) has proved invaluable in reconstructing the lifeways of proto-historic populations. Leach's (1969) study of the Poutini Ngai Tahu of the West Coast of the South Island was enriched by the inclusion of the observations of early European travellers such as Mackay, Brunner and Heaphy. After careful examination of the journals of the latter two men, and an evaluation of post-European economic changes, Leach concluded that "the pattern of food gathering activities observed by Brunner and Heaphy could not have been markedly different from that of the late prehistoric period" (ibid.:66). The two journals were thus considered to be reliable accounts and provided the basis for a reconstruction of the late prehistoric economy of the Poutini Ngai Tahu. This revealed that these people concentrated on hunting, gathering and fishing, with horticulture playing a minor role, if any (ibid.:74). Seasonal fluctuation in resource availability was also identified, a problem which was resolved to some extent by preservation of the summer food surplus (ibid.:75). Having made her detailed reconstruction of the late prehistoric economy, Leach emphasised the necessity of fieldwork to correct and check the information

retrieved from the records (ibid.:78). This is necessary if we are to gain more than general dietary information, and essential if we are to identify the proportions of various foods in the diet.

Palaeopathology of bones and dental analysis

The examination of human teeth and skeletal remains can be most useful, with respect to dietary analysis, for providing general information about the level of nutrition and, in the case of teeth, the texture of foodstuffs consumed. Most dietary interpretations based on such analyses need to be substantiated by other methods of dietary reconstruction.

Palaeopathology of bones

The examination of skeletal remains for pathological conditions can provide some useful indications of the quality and quantity of diet. Several indicators of bone loss, or osteoporosis, when considered with indicators of bone maintenance, can provide valuable information on the nutritional status of individuals and populations. Protein deficiencies can be identified by retarded formation of new bone matrix, while disturbances in calcium metabolism are manifest in altered rates of mineralization of the new matrix (Martin, Goodman and Armelagos 1985:248). The overall skeletal response to nutritional stress is an increase in bone resorption and a decrease in bone formation, resulting in a net loss of bone (ibid.:234).

Harris lines, or lines and bands of increased bone density, reflect short periods during which bone growth has ceased. While Harris lines may be caused by the body's response to nutritional deprivation, they may also be due to deprivation during illness or may simply be a function of age-related resistance to growth disruption (ibid.:257). Therefore, the incidence of Harris lines is not particularly useful for dietary reconstructions.

Porotic hyperostosis, an expansion of the marrow or diploe area of the bone, occurs in the thin bones of the skeleton, such as the crania, the ribs and the sternum. It is a skeletal manifestation of anaemia, the cause of which may be due to factors other than nutritional quality (ibid.:266). As Martin et al. have stressed,

> "Interpretation...requires an archaeological reconstruction of diet in order to determine the potential, and actual, uses of resources" (ibid.:267).

This method is thus of little use in dietary reconstructions as it requires prior knowledge of the diet in question. Clearly, the dietary information which can be gained from the analysis of skeletal remains is limited to general interpretations about dietary quality.

Dental analysis

The nature of the diet of a given individual can be determined to some extent by an examination of the teeth for developmental disturbances, pathological conditions and patterns of wear. Nutritional inadequacies may be reflected in developmental disturbances such as enamel hypoplasia, which is a deficiency in enamel thickness due to premature degeneration of the ameloblasts, the enamel-producing cells (Rose, Condon and Goodman 1985:284). In general, increases in enamel defect rates represent a decline in nutritional adequacy, especially proteins, but the exact nature of the nutritional deficiency cannot be determined by this method. Defective enamel may also be the result of other metabolic disturbances (Sognnaes 1956, cited in Rose et al. 1985), and thus the identification of developmental disturbances can only indicate likely nutritional deficiencies. Any conclusions about dietary inadequacies made from the observation of developmental disturbances of the dentition should be treated as tentative and requiring confirmation from other methods of dietary reconstruction.

Patterns of dental wear as a result of attrition - direct tooth-on-tooth contact - and abrasion - contact between the enamel and foreign substances, such as grit - have been used to identify the texture of dietary components. While the fibrous nature of some foods may result in severe tooth wear, as has been identified in some prehistoric New Zealanders who consumed significant quantities of fern root and other abrasive foods

(Houghton 1980:128), a correlation between some food preparation techniques and tooth wear has been noted (Powell 1985:309). The use of stone grinders for the preparation of flour has been found to increase the incidence of tooth wear in the populations concerned, as minute particles of stone are retained in the food and act as abrasive agents (ibid.). In the Pacific, where stone food pounders were used in the preparation of foods such as taro and breadfruit, high incidence of tooth wear may indicate the use of such grinders, and may possibly give some indication of the nature of the diet. Non-alimentary uses of the teeth, for instance as tools, may be revealed by inspection of the direction as well as the degree of tooth wear (ibid.:312), thus eliminating wear caused by factors other than diet.

The pathological condition of the teeth, particularly the incidence of dental caries, can often provide accurate indications of the nature of the diet. Caries is a microbial disease affecting the calcified tissues of the teeth, first dissolving the inorganic structures of the tooth surface by acids of bacterial origin, and eventually leading to a disintegration of the organic matrix (Menaker 1980, cited in Powell 1985:313). A link has been established between the consumption of sticky textured carbohydrate foods, particularly those which are consumed frequently during the day, and high incidences of caries. Dietary cariogenicity may also be affected by the texture of foods consumed, as abrasive foods tend to wear down potential caries loci from high-risk tooth surfaces, as well as stimulating natural oral cleansing (Powell 1985:314). Therefore,

the incidence of caries in populations with a high degree of tooth wear is often less than in populations with a less abrasive diet. This pattern was identified by Evans (1987) for several prehistoric oceanic groups, and in some cases low incidences of caries may have been due to an "hypothesised neutralising effect of a high fish protein diet on the incidence of caries" (ibid.:108). Walker and Erlandson (1986) note that marine resources in general, and fish bones in particular, are rich in fluoride (ibid.:380), a chemical which is known for its cariostatic (having the quality of preventing or inhibiting caries) properties (Powell 1985:315). They also report that low caries rates have been found among modern populations with a dietary emphasis on small fish (Walker and Erlandson 1986:380). This relationship between high levels of marine food consumption and low levels of dental caries is particularly relevant to dietary studies of Pacific populations, where marine resources were widely exploited. Where questions about the proportions of marine and terrestrial foods in the diet are to be asked, the incidence of dental caries in a given population may be a valuable indication of marine consumption levels.

High calcium phosphate levels in diet are also known to retard carious invasion, and because such levels also promote the calcification of dental plaque into dental calculus, a high prevalence of dental calculus is often associated with a low prevalance of dental caries (Powell 1985:315). Some behavioural practices, for instance the use of lime, may serve to enhance calcium phosphate levels to the extent that the effects of high

carbohydrate diets are counteracted (ibid.). In the Pacific the practice of betel nut chewing is widespread, and in prehistory was probably chewed in combination with lime, as it is today. A recent study of beetle nut chewing in Papua New Guinea (ibid.) suggested that while factors such as the regular chewing and the resultant abrasion of occlusal surfaces, and the alkalinity of the betel nut-lime combination may have all contributed to a low rate of caries, high incidences of betel nut chewing may also be associated with low incidences of caries. Evans (1987) observed that a group of individuals from Namu, identified as horticulturists, exhibited a lower than expected result for the incidence of caries (ibid.:109). This was attributed to the presence and influence of severe calculus deposits, the incidence of which Evans felt was best explained by the chewing of betel nut in combination with lime (ibid.).

This kind of analysis is invaluable for the direct information which can be obtained about the texture and the nutritional value of diets. However, the limitations of dental analysis in general lie in the inability of the method to detect individual dietary components and the proportions in which they were eaten. For the purposes of dietary reconstruction, dental analysis is best used as a source of information which can complement the information which may be gained from other methods of investigation.

Coprolite analysis

The analysis of human coprolites is one of the most direct methods of obtaining information about prehistoric diets. Items recovered from coprolites would normally have been ingested over a short period of time, from between one and three days, and may be derived from a single, or several, meals. However, there are some limitations with this method which should be recognised. Fry (1985) has pointed out that while the components recovered from a coprolite represent undigested dietary fragments, they do not necessarily demonstrate absolute diet composition (ibid.:142). This may be due to differential digestion of dietary components. For instance, certain soft food items, such as meat, may leave little or no record, having been almost completely digested. In contrast, some undigestable items, such as grit, hair or coarse vegetable fibres, may be represented in excess of their actual importance. Other items, such as single feathers, fibres or insect parts, may not represent meals at all, having been ingested accidentally or being the residual remains of earlier meals (ibid.). Therefore, any reconstruction of dietary proportions based solely on material recovered from coprolites may be inaccurate.

The examination of coprolites by pollen analysis may provide some evidence for dietary reconstructions, although the presence of pollen in coprolites is not necessarily indicative of diet. Some wind-borne pollens found in coprolites may have been ingested unintentionally with other foodstuffs, but the presence

of insect-borne pollens may indicate direct human consumption of flowers (Fry 1985:144).

Some other problems may arise in the initial identification of the species of defecator. While human feces may be easily distinguished by size and shape from those of large herbivores, it is more difficult to distinguish between those from humans and carnivores (Wing and Brown 1979:154). Methods of identification of defecators have involved extraction with trisodium phosphate, which has been used to distinguish between human and dog coprolites by colour differences, and the distinction of human coprolites by an assumed uniquely omnivorous human diet (ibid.). Distinctions have also been made on the basis of smell, the location from which the coprolite was recovered and the presence of host-specific parasites (McGill 1989). However, these methods of distinction have rarely been found to provide conclusive identification of species of the defecator, and several methods must be employed in combination before an identification can be made. McGill (1989:20) has suggested that current methods of identification are singularly unreliable because in most cases the identifications made are subjective, based on interpretations made by the researcher. Furthermore, most of these methods identify characteristics which result from differences in diet, and results are therefore likely to be affected by dietary changes (McGill 1989:32ff.). McGill (ibid.) has highlighted the need for development of an area of study which will be species specific rather than subject to changes in diet. Her research has resulted in some significant advances being made in this

direction, with the discovery that protein has the ability to survive in coprolites and should be able to be attributed to species (McGill 1989:117). It is to be hoped that future advances in the field of coprolite analysis, following McGill's lead, will result in improvements in coprolite identification and will lead to more accurate reconstructions of human diet.

The potential of this method has been recognised, but one inherent limitation, which cannot be overcome by improvements in technique, is that a coprolite can only reveal what was eaten over a few days. In order for dietary reconstructions to be of use in answering questions about subsistence strategies, the role of horticulture, and the proportions of marine versus terrestrial foods in diets, methods which can identify the nature of the long-term diet must be employed. Two such methods involving the direct analysis of human bone have recently been introduced to the range of available archaeological techniques for dietary reconstruction. These recent developments of trace element and stable isotope analysis, the latter of which is the subject of this thesis, will now be discussed.

B. RECENT DEVELOPMENTS IN DIETARY ANALYSIS

TRACE ELEMENTS

Trace elements occur in the body in amounts of less than 0.01% of the human body mass (Schroeder 1973, cited in Gilbert

1985:345), and certain trace elements are known to accumulate in bone in amounts which, for some elements, reflect the quantity of the element ingested from various foodstuffs and/or water sources (Gilbert 1985:346). For the purposes of archaeological reconstruction of diet, the differential concentrations of some trace elements in plants and others in animal tissues means that it is possible to estimate the proportions of animal and vegetable foods in the diet (ibid.:347). While zinc, copper, molybdenum and selenium are associated with animal protein, the levels of strontium, magnesium, manganese, cobalt and nickel are generally higher in vegetable matter (ibid.). However, not all of these elements accumulate in bone in detectable amounts, which reduces the range of trace elements which may be used as dietary indicators.

Studies employing trace element analysis for dietary reconstructions were first undertaken in the early 1970's, with Brown's (1973) pioneer study being concerned with measuring strontium levels in human bone as a means of discriminating between high- and low-status individuals (ibid., cited in Gilbert 1985:349). Strontium has been most commonly used as a dietary indicator because its movement through the food chain is reasonably well understood (Horwood 1988:39). Plants absorb strontium and calcium directly from the soil, although different types of plants in the same environment will accumulate different amounts of strontium. For example, succulent herbaceous plants, such as shrubs, accumulate higher strontium concentrations than grasses, because more strontium is concentrated in leaves and

storage than in stems (Wing and Brown 1979:79). Strontium is accumulated in the skeletons of terrestrial vertebrates in direct proportion to the amount of strontium in their diet, but the amount of strontium present will be less than the amount which was ingested. This is because strontium is discriminated against in favour of calcium during absorption and bone deposition (ibid.). The bone strontium values of vertebrates from a given area will vary according to their diet, the bones of herbivores containing less strontium than the plants which formed their diet, and browsers having higher concentrations than grazers (ibid.). Carnivores will have less strontium than the herbivores on which they fed, because the levels of strontium decrease at each trophic level of the food chain. Similarly, the levels of omnivores will fall somewhere between those of herbivores and carnivores (ibid.).

Strontium is particularly useful in determining the percentage of meat relative to vegetable foods in human diet, although care must be exercised in the interpretation of results. A major problem in this respect relates to environmental variations in strontium levels, which means that differences between populations from different areas may be a function of their location rather than their diet, and thus comparisons between those populations would be invalid (Horwood 1988:43). However, Horwood (ibid.) has recently developed a method which can circumvent this problem, involving the use of a faunal standard as a baseline for inter-site comparison. A further complication in interpretation can arise if filter feeding

molluscs have been included in the diet, as some of these species have concentrated levels of strontium and other trace elements in their flesh, due to the continual uptake of these elements from water during filter feeding (ibid.:48). Where reconstructions of diet are concerned, the inclusion of such species in the diet can make it difficult to distinguish between a high intake of vegetable foods and a diet rich in filter feeding shellfish, from strontium levels alone. A similar ambiguity in interpretation can arise if nuts and berries were included in the diet, because these foods also contain high elemental levels. To overcome this problem, Schoeninger and Pebbles (1981:396) suggest that some prior knowledge of the range of foods consumed is necessary before interpretations can be made.

A more accurate reconstruction of diet can be achieved if levels of more than one trace element are determined. Horwood (1988) used zinc and magnesium in addition to strontium in her study of six human groups from New Zealand and the Pacific. Zinc was included because of its potential to identify red meat consumption, although high zinc levels are also found in some seafoods and in nuts and legumes (ibid.:59). A higher zinc concentration in fresh water than marine filter-feeding shellfish allowed for the confirmation of the consumption of fresh water mussels by a group of people from Lake Rotoiti, New Zealand, which had been suggested by high strontium values (ibid.:132). Magnesium, while not a trace element but rather one of the four 'bulk' metals in the human body, is useful for detecting consumption of green plants, some fruits and berries, because

magnesium is found in high levels in these foods (ibid.:62). In contrast, fats have low magnesium levels and Horwood (ibid.) explored the further possibility of using magnesium to detect the consumption of sea mammal blubber for a Moriori population from the Chatham Islands, off the east coast of New Zealand. Her results revealed high magnesium values for the Chatham Islanders, which was interpreted as possibly reflecting the consumption of karaka berries coupled with a low fat intake (ibid.:143).

Some additional factors which have been found to complicate interpretation of trace element results are related to anatomical variation in trace element levels, which can be overcome by selecting the same anatomical element for analysis; variations with age and possibly sex, the former being overcome by studying only adults; and problems associated with diagenesis, which necessitates testing for any diagenetic alteration of bone before trace element examination is begun (Horwood 1988:43-51). Provided these factors are taken into account, the technique of trace element analysis is a reliable method of determining the relative contribution to diet of meat and plant foods. The identification of the marine component of the diet is more problematic, because trace element values for marine and terrestrial foods are often similar. Horwood (ibid.:64) suggests that this problem may be overcome by either comparing trace element results from an inland and a coastal population, utilizing faunal bone as a baseline, or by identifying marine food consumption by other means. The latter solution may be more practical, as in many cases it would not be possible to compare an inland and coastal population. A clear

distinction can be made between marine and terrestrial diets using stable isotope analysis of human bone, and this method will now be discussed.

STABLE ISOTOPE ANALYSIS

Stable isotope analysis of human bone can provide direct information about the proportions of various foods in the diet, and, when used in conjunction with other methods of dietary reconstruction, has the potential to overcome many of the inherent difficulties of more traditional methods. Initial work in this field involved the determination of carbon isotope ratios and the detection of early maize cultivation in the Americas (Vogel and van der Merwe 1977; Burleigh and Brothwell 1978), followed by investigations to distinguish between marine and terrestrial diets (Tauber 1981; Chisholm, Nelson and Scwarcz 1982), and examination of seasonal mobility patterns (Hobson and Collier 1984; Sealy and van der Merwe 1985). More recently, the use of nitrogen isotope ratios in conjunction with carbon has increased the reliability and the scope of the method. In this present study, sulphur isotope ratios will also be introduced, in order to reduce certain ambiguities which can arise with the use of both carbon and nitrogen alone.

The background

The earth's carbon exists in three isotopic forms: 12C, 13C and 14C. While 14C disintegrates radioactively over time, 13C

and 12C are stable and the worldwide average ratio between them, approximately 1.1:100, has remained more or less unchanged over time (van der Merwe 1982:596). However, this 13C/12C ratio differs from one carbon bearing material to another, and it has been found that certain types of plants possess distinctive δ13C values. Research has revealed that these differences are related to the photosynthetic pathways utilised by these plants, and differences in the fractionation of carbon isotopes during carbon dioxide metabolism (ibid.:597). Three photosynthetic pathways - C3, C4 and CAM - have been distinguished. C3 plants include all trees and most shrubs, and grasses from temperate regions and tropical forests. North America and Europe almost exclusively contain C3 plants, with the exception of maize and sugar cane. C4 plants include most grasses and a few shrubs in sub-tropical savannah and arid regions. Grasses growing in salt marshes and along the ocean are often C4 species as well, even though the climate may be temperate (ibid.:598). C4 photosynthesis appears to be an adaptation to environments where plants are subject to strong solar radiation during the growing season, particularly where there is a shortage of water (ibid.). They are common in Australia and South Africa, where most grasses of the interior are of C4 type, and in some areas of the Pacific, such as Papua New Guinea (this present research) and upland Hawaii (Rundel 1980; Clark 1983). The identification of maize as a C4 plant has enabled its introduction to be documented in the Americas, and the presence of at least one C4 food plant, sugar cane, in the Pacific is relevant to this study. CAM plants are succulents, such as cactuses.

The recognition of these three photosynthetic pathways, and the associated development of stable isotope analysis as a method for determining dietary components, arose from research associated with fractionation effects on radiocarbon ages (ibid.). Because the correction factors used by radiocarbon laboratories were based on the 13C/12C ratio of the sample, reference δ13C values were recorded for a wide range of plants throughout the world (ibid.). This was followed by the rapid development of a methodology for the utilisation of stable isotope analysis for answering questions about prehistoric diet. Following the initial interest in the introduction of maize agriculture, the research emphasis shifted to the possibility of using the method to distinguish between marine and terrestrial diets.

There is generally a clear distinction between the carbon values of marine and terrestrial foods, and a number of researchers (Tauber 1981; Chisholm, Nelson and Schwarcz 1982; Hobson and Collier 1984) successfully used stable carbon isotope analysis to determine the proportions of marine versus terrestrial foods in diets. However, it soon became apparent that there could be problems in interpretation of the δ13C values, if both marine foods and C4 plants were included in the diet. The presence of these foods could not be distinguished on the basis of δ13C values because the 13C/12C ratios of many marine organisms are very similar to those of C4 plants, and the one may be mistaken for the other (Sealy and van der Merwe 1986:35). The need to overcome this problem led to the consideration of other

stable isotope ratios as dietary indicators, and the subsequent identification of the potential of the nitrogen 15N/14N ratio in this respect.

The combination of stable carbon and nitrogen ratios in dietary studies increased the accuracy with which dietary reconstructions could be made. After extensive preliminary investigation (DeNiro and Schoeninger 1983; Schoeninger, DeNiro and Tauber 1983), Schoeninger and DeNiro (1984) obtained stable nitrogen and carbon isotope ratios of bone collagen from more than 100 marine and terrestrial animals. It was found that while δ13C values from marine and terrestrial feeders overlapped to a great extent, the δ15N values for those animals served to clearly distinguish marine from terrestrial feeders, with the ranges for the two groups overlapping by less than 1 per mil (ibid.:631). In addition, only bone collagen δ15N levels reflected the trophic levels at which the animals fed (ibid.:632). The use of δ15N values of bone collagen to distinguish between exclusively marine and exclusively terrestrial diets was advocated, particularly when there was a possibility of δ13C values being complicated by C4 plants in the diet. However, a further complication, first identified by Schoeninger, DeNiro and Tauber in 1983 and confirmed by Schoeninger and DeNiro in 1984, can arise if marine foods from a coral reef environment were included in the diet. Because of increased nitrogen fixation by blue-green algae in the vicinity of coral reefs, relative to that occurring in other parts of the ocean, δ15N values of foods from reef environments are lower than those from the open ocean, and in fact resemble

terrestrial δ15N values (Schoeninger, DeNiro and Tauber 1983:1382). This can present problems in analysis of results and δ13C values must be used to detect the marine origins of the diet. An exceptional combination of bone collagen δ13C values (greater than -9 per mil) and δ15N values (less than +7 per mil) for vertebrates in tropical reef areas has been highlighted as a "signature of total dependence on marine foods" (Schoeninger and DeNiro 1984:637). While this distinct signature for tropical reef environments could be invaluable for stable isotope studies in the Pacific, its usefulness would largely depend on establishing whether or not C4 plants were included in the diet.

In the Pacific, there is a real likelihood that both C4 plants and marine foods from a reef environment were included in prehistoric diets, and it is therefore necessary to consider the use of a third isotope to identify dietary components. For the present study, the potential of the sulphur isotope 34S in this respect will be explored. Stable sulphur isotope ratios have been shown to distinguish between marine algae, inland plants and marsh grasses (Peterson, Howarth and Garritt 1985:1361), and appear to make clear distinctions between terrestrial and marine sources, with the reservation that there may be some ambiguities in sulphur values from coastal areas (Mizutani and Rafter 1969).

Potential problems

Effects of age, sex and differences between anatomical elements

The value of stable isotope analysis for dietary reconstructions is dependent on establishing that variations in stable isotope values between individuals could not be due to anything other than variations in diet. The possibility that other factors may be involved was considered by DeNiro and Schoeninger (1983) who used stable carbon and nitrogen isotope ratios of bone collagen to examine variations within individuals, between sexes and within populations raised on monotonous diets. Results showed only small variations in the carbon and nitrogen isotopic composition of bone collagen between different individuals who ate the same diet, and between different bones from the same individual, while there was no significant difference between sexes (ibid.:202). Variations observed were of the order of 1 per mil or less and this was considered negligible when compared with the variations which result from dietary differences. While these results suggest that the use of different anatomical elements from different individuals would not affect isotope values, as a precaution it would be preferable to use the same bone where possible. Rib bones would be particularly suitable as they are of little use to the physical anthropologist for diagnostic purposes and their destruction for isotope analysis could thus be justified. However, these bones are also more likely to be contaminated with soil particles and great care must be exercised during sample preparation to ensure

the thorough removal of such material. Two more recent studies (Hobson and Schwarcz 1986; Lovell, Nelson and Schwarcz 1986) have confirmed a lack of age or sex effects on δ13C values for wild herbivores and a population of humans.

Diagenesis

Of greater significance for isotopic analysis of diet is the likelihood that isotope ratios may be modified by diagenetic processes. It has been established that postmortem alteration of bone collagen isotope ratios can occur, but this is not necessarily a function of the age of the sample, and not all bones from a particular environment may be affected (DeNiro 1985:808). However, it is possible to identify those samples which have been subject to diagenetic changes. DeNiro (1985) found that prehistoric bone collagen samples with atomic carbon-to-nitrogen (C/N) ratios outside the range observed for fresh collagen samples, which fall between 2.9 and 3.6, had been affected by diagenesis, and suggested that such samples should be eliminated from studies (ibid.:808).

In a subsequent study (1986) Nelson, DeNiro, Schoeninger, De Paolo and Hare examined the effects of diagenesis on strontium, carbon, nitrogen and oxygen concentration and isotopic composition of bone, using modern and prehistoric bones of animals with marine and terrestrial diets. Strontium concentrations and isotopic composition of the prehistoric samples did not discriminate between the two types of diet,

probably due to groundwater leaching, and oxygen isotope ratios in fossil apatite carbonate failed to reflect the differences between marine and terrestrial feeders observed for modern samples (Nelson et al.:1944). In contrast, collagen δ13C and δ15N values from prehistoric samples in most cases distinguished between species feeding in the marine and terrestrial environments (ibid.), being generally unaffected by diagenesis. Thus, values obtained from bone collagen may be considered reliable for reconstruction of prehistoric diets, provided their C/N ratios are within the range observed for fresh samples. Ideally then, C/N ratios should be obtained for all samples, but for the present study C/N ratios will be available only for those samples which will be processed for carbon isotope analysis. In the interpretation of results the assumption will have to be made that, for each site, those samples for which C/N ratios are available are representative of all samples from that particular site. Possible intra site variations in sample contamination may not always be detected with this approach, but provided C/N ratios are obtained for more than one sample from each site it is hoped that some indication of any such contamination will be found.

Effect of heating

Some errors in analysis may arise if the bone samples used have been heated, either during cooking or by burning. DeNiro, Schoeninger and Hastorf (1985) compared nitrogen and carbon isotope ratios of bone collagen from heated and unheated bones.

The δ13C and δ15N values of boiled and roasted samples were within about 1 per mil of the unheated samples and their C/N ratios remained unchanged (ibid.:3). However, more extreme heating, to temperatures exceeding 295° Celsius, shifted δ13C and δ15N values by as much as 5 and 4 per mil respectively, and these large shifts were accompanied by changes in the C/N ratios of these samples (ibid.:4). The magnitude of the shift was found to reflect the duration of the heating, with some samples heated to high temperatures retaining δ13C and δ15N values that were within 1.2 per mil of the unheated samples, while their C/N ratios remained unchanged (ibid.). DeNiro et al. concluded that shifts in bone collagen δ13C and δ15N values caused by burning would be likely to cause large errors in dietary reconstructions, while shifts caused by cooking would be unlikely to do so. They recommend that for dietary analysis, the use of collagen from bones which have undergone severe burning should be avoided, and that such bones may be identified by anomolous C/N ratios (ibid.:6).

Climatic influence

Recent research has suggested that in some climatic situations nitrogen isotope ratios may show variations which cannot be ascribed to diet (Heaton, Vogel, von la Chevallerie and Collett 1986). Analysis of human and animal bones from southern Africa revealed that in areas receiving less than 400mm of rain per year, δ15N values for animals and humans fell into the 'marine diet' range, with δ15N values generally increasing with increased

aridity (ibid.:823). It was suggested that this phenomenon was linked to nitrogen metabolism in the body of animals, rather than increased nitrogen fractionation in the plants they ate (ibid.). These findings have important implications for dietary reconstructions based on isotopic analysis, and suggest that the influence of climate on nitrogen ratios should be taken into account during interpretation of results. However, other researchers have not agreed completely with Heaton et al., pointing out that the observed nitrogen values may not have reflected climatic influences alone (Ambrose and DeNiro 1987). As an example, Ambrose and DeNiro (ibid.) compare the nitrogen ratios of bone collagen from some early historic pastoralists of Orange Free State and some late prehistoric farmers of the Northern Transvaal. The nitrogen ratios of the pastoralists were higher than the farmers, which Ambrose and DeNiro ascribe to trophic level effects, rather than to the relationship between higher nitrogen values and lower rainfall which can be demonstrated for these two groups (ibid.). However, Ambrose and DeNiro confirm that some water-conserving herbivorous mammals would be expected to have higher 15N/14N ratios than those that do not conserve water, concluding that

> "until the contributions of ecological and physiological processes to variation in animal tissue nitrogen isotope ratios are more clearly understood, paleodietary analysis based on 15N/14N ratios of bone collagen must be regarded as uncertain in all but the simplest of ecological contexts." (ibid.)

This issue is therefore unresolved and clearly some caution should be exercised in interpretation of nitrogen isotope ratios. However, for the purposes of this study, these problems of interpretation may not arise because generally the populations studied did not live in low rainfall areas, and in most cases herbivorous water-conserving mammals were not available and therefore could not be included in the diet.

Conclusions

Provided these possible complicating factors are considered during interpretation of results, stable isotope analysis has great potential for answering the questions posed in Chapter one. Many of the limitations of traditional archaeological methods of reconstructing prehistoric diet may be avoided by the application of this more direct method. For this study, the following research strategy was employed.

RESEARCH STRATEGY

The selection of samples to be included in the present study will be determined by several factors. The main criterion for selection is to answer the questions posed in Chapter one.

The first question, concerning the subsistence focus of the early Lapita colonists in the Pacific, can best be answered by the inclusion of an early population from an island environment.

Because of the dearth of early Lapita skeletal material, the sample size in this instance will be unavoidably small. Skeletal material from several early Lapita individuals has been recovered from recent excavations on Lakeba (Best 1984), in Fiji's Lau Islands, and this could provide some indication of the early Lapita diet.

The second question, concerning the significance of sugar cane in the diets of early Pacific populations, can be considered by the inclusion of a population known to have consumed sugar cane in significant quantities. The ethnographic documentation of sugar cane consumption by proto-historic Easter Islanders suggests that samples from this location could answer this question.

The third question, concerning the proportions of reef versus open ocean components in the diet, could be answered by including populations from a number of Pacific locations, the main criterion for selection being the presence of a coral reef in close proximity to a site and some prior evidence to suggest a significant marine focus in the food procurement strategy of the population(s) selected.

The fourth question, of a more general nature, concerns identifying the proportions of marine and terrestrial foods in prehistoric diets in New Zealand and the Pacific. This question could be answered by the inclusion of most available Pacific and New Zealand populations in this study. The only criterion for

selection, apart from availability of skeletal material, would be some evidence that both marine and terrestrial foods were included in the diet.

The fifth question, concerning the identification of both exclusively terrestrial and exclusively marine diets, can be answered by the inclusion of at least one inland population, and at least one population thought to have exclusively exploited a marine environment. In reality, the likelihood of a prehistoric New Zealand or Pacific population focussing exclusively on one environment is small, but the possiblity remains and will be explored in this thesis.

The second criterion for selection of samples is more straightforward - the availability of suitable skeletal material. Within these criteria, some other selection procedures should be followed. Where practicable, in order to control for possibile differences in isotope ratios between different anatomical elements, the same bone, for example rib, should be selected for analysis. In all cases, samples selected should be free from chemical contamination by bone preservatives, sometimes used during excavations to prevent bone disintegration, which may affect results.

The successful application of the above research strategy to the selection of samples for multiple stable isotope analysis has the potential to answer a number of questions in Pacific archaeology which are as yet unanswered. The importance of

obtaining quantitative information about the dietary components of prehistoric New Zealand and Pacific populations cannot be stressed enough, in order to provide some direct evidence about early horticulture in the Pacific, to demonstrate the adaptation of the basic Polynesian economy to a wide range of environments, and to reveal the extent to which Pacific populations relied on marine resources for their survival. The application of this research strategy to the selection of samples for this study will be discussed in Chapter three, followed by the analytical methods employed to obtain the isotope ratios.

CHAPTER THREE

MATERIALS AND METHODS

SAMPLE SELECTION

One hundred and nineteen samples of human bone from 13 sites throughout the Pacific and New Zealand were selected for analysis, with the aim of answering the questions posed in Chapter one, following the research strategy described in Chapter two. Four early skeletons from Lakeba in the Lau Islands were selected to answer question one, concerning the subsistence focus of early Lapita colonists in the Pacific. Twelve skeletons from Easter Island were selected to answer question two, concerning the significance of sugar cane in the diets of Pacific populations. A number of populations from a range of sites were available to answer questions three and four, concerning the proportions of reef foods, and marine and terrestrial foods, in prehistoric Pacific and New Zealand populations. A total of 113 skeletons was selected, from Saipan and Tinian in The Marianas, Watom in New Britain, The Chatham Islands and Lake Rotoiti in New Zealand, Motupore and Nebira in Papua New Guinea, Namu in The Solomon Islands, and 'Atele and Pea from Tongatapu, Tonga. Of these populations, those from Lake Rotoiti and The Chatham Islands were considered most likely to provide an answer to question five, concerning the identification of exclusively terrestrial and exclusively marine diets. In addition, five

samples of animal bone from modern and archaeological contexts and one plant sample were processed to act as a baseline for comparison. Site locations are shown in Figure 3.1 and the full list of samples appears in Appendix 1.

SAMPLE PREPARATION

All bones were cleaned of excess dirt by brushing with a soft brush, immersed in deionized water in an ultrasonic bath for approximately two minutes, and rinsed thoroughly in deionized water. After drying at 35° Celsius the samples were reduced to a powder in a tungsten carbide tema mortar. The grain size of the powder ranged between 10 and 100μ (see Appendix 2). XRF analysis was carried out (see Appendix 2) to see if tungsten was present in the bone powder, to determine whether the tungsten carbide from the tema mortar had contaminated the sample with carbon. If so, results from 13C analysis might be suspect. The analysis revealed that tungsten was present at concentrations less than 100ppm (0.01%). As contamination rates as high as 1% can be expected to alter the δ13C value by less than the measurement precision on the mass spectrometer (Leach pers. comm. 1989), it was concluded that the use of a tema mortar is perfectly satisfactory for preparation of bone samples for 13C analysis.

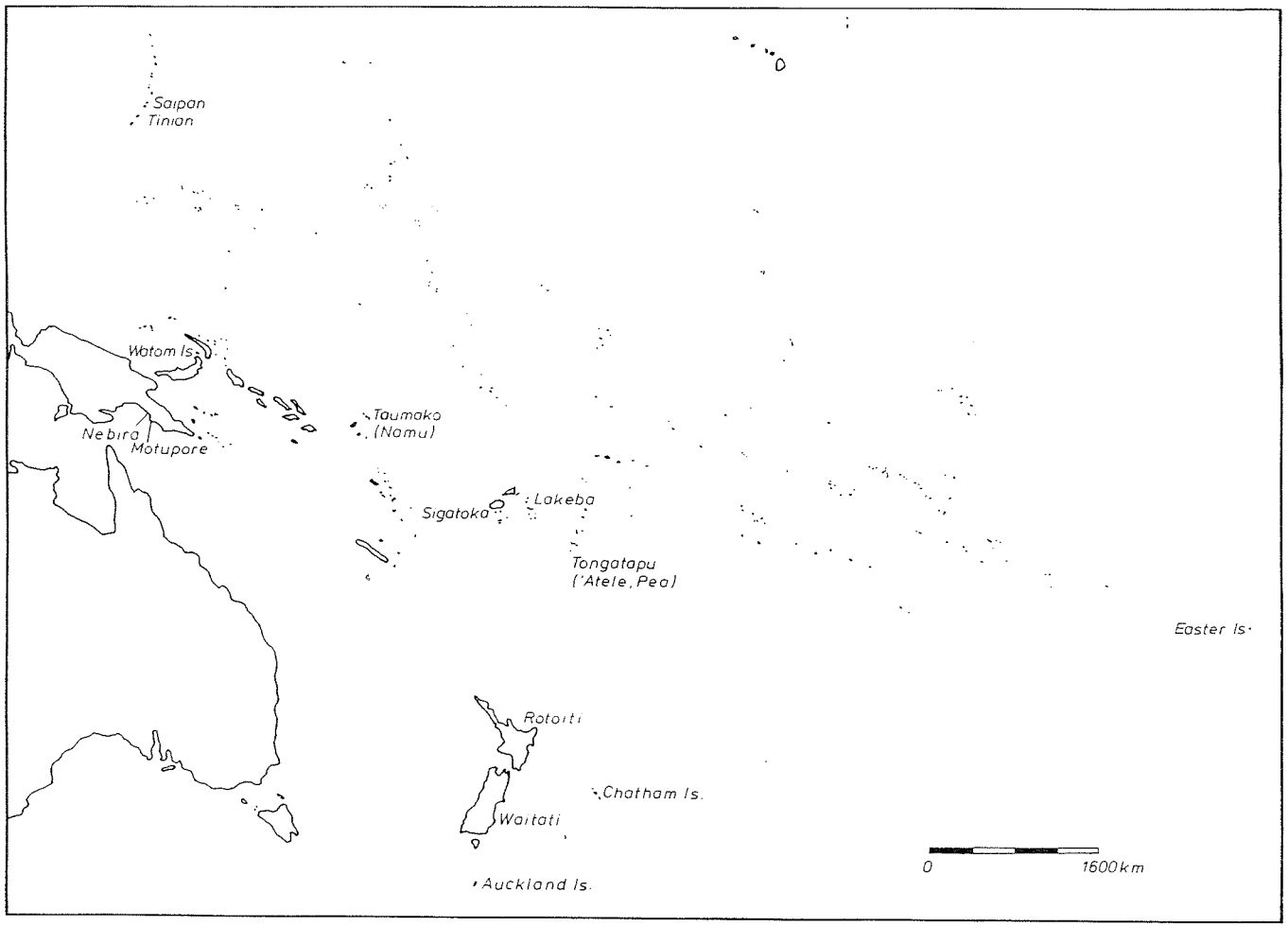

Figure 3.1: Map of the Pacific showing the site locations of samples analysed for stable isotope ratios.

Stable carbon isotope analysis is normally carried out on collagen prepared from whole bone samples. The demineralisation of the bone during collagen production eliminates those sources of carbon which may have come from the surrounding soil. Bone apatite carbon is also known to exchange with atmospheric carbon under some circumstances, and this could affect the 12C/13C ratio. In other studies where both carbon and nitrogen ratios have been used, both sets of results have been obtained from the same collagen samples which would obviously eliminate some sources of error. However it is not entirely clear that there is any advantage in using demineralised samples for nitrogen determinations, although some contamination might be suspected from water-soluble nitrates. For this study the possibility of using whole bone powder was investigated because this greatly simplifies sample preparation.

Five samples were sent for analysis to the Waikato Stable Isotope Unit at Ruakura. For each sample, whole bone powder, and collagen produced from the whole bone powder, was processed. The results (Table 3.1) were not entirely conclusive, but this may have been due to differences in the collagen extraction process.

Table 3.1: Results of preliminary δ15N tests on collagen and bone powder.

Acc.No.	Site	Burial number	δ15N (collagen)	δ15N (bone powder)	Difference
AX848	Namu	160	9.39	10.66	+1.27
AY 65	Namu	35	11.12	12.97	+1.85
AY 66	Namu	37	6.31	11.65	+5.34
AY 68	Namu	57	8.68	10.26	+1.58
AY 73	Namu	87	11.14	12.83	+1.69
				mean	+2.35 +-0.75

The sample AX848 was prepared according to the method described below and is considered to give the most reliable results. A small but consistent difference between the results from bone powder and collagen was revealed. However, while the absolute values from bone powder were slightly higher than those from collagen, the relative integrity of the results was still maintained. This suggested that accurate nitrogen ratio determinations, for comparative purposes, could be obtained from bone powder just as easily as from collagen extracts, and it was decided to proceed with nitrogen determinations from bone powder for all samples. As a final check, collagen was produced from one sample from each site and nitrogen determinations were obtained from that collagen for comparison with the bone powder results.

COLLAGEN ISOLATION

Bone powder was digested in 5% aqueous phosphoric acid. This removed most of the mineral content of the bone and left an organic 'soup' which hereafter will be referred to as 'collagen'. 'Collagen' was produced for 43 samples plus the bone standard (for a description of the bone standard see Appendix 2) and the yields of 'collagen' are shown in Appendix 3. An additional sample, AX848, was processed to 'collagen' before the present study was commenced and is not included in Appendix 3. The δ15N, δ13C and δ34S determinations for AX848 are included in the results of this thesis.

METHOD OF COLLAGEN EXTRACTION

Before any stable isotope analysis was carried out the following procedure was developed for the extraction of 'collagen'. This extraction procedure can be modified to advantage (shorter time, better yield) depending on the coarseness and nature of the bone powder. A very fine powder will be 'demineralised' in less than one day, whereas a coarse or compact powder may take 3-5 days. The test for completeness of extraction should be used at the earliest indication that no more carbonate remains. However, caution is required as bubble formation can be quite slow. Extensive treatment with phosphoric acid or heating in the presence of acid (pH<4) will decrease the yield of protein (Myers pers. comm. 1988).

Procedure:

Reserve 1gm of bone powder from the sample for hydroxyproline analysis.

Prepare the dilute phosphoric acid by adding concentrated phosphoric acid to distilled water in proportions of 85ml of acid per litre of water. Add a known amount of bone powder to 1 litre of dilute phosphoric acid (the acid should be cooled to at least room temperature before adding the bone powder). Ensure that the phosphoric acid is in excess relative to the total amount of calcium carbonate. Approximately 1 litre 5% v/v of orthophosphoric acid per 30gm of dry bone should be sufficient.

Seal with laboratory parafilm or foil.

Stir manually, removing as much material from the sides of the beaker as possible.

Place on a magnetic stirrer and adjust the speed to maintain constant movement of the material. A large stirring bar is required.

Leave for one day, or until all foaming has ceased. Note any presence of magnetic particles (sand, iron, steel fragments, etc.) on the stirring bar. Remove these from the sediment.

Allow the material to settle for about half an hour, decant

off the acid and replace with fresh acid, topping up to 1 litre.

Repeat for three to five days, if necessary, until activity has ceased.

To check if the process is complete, add some distilled water to the sediment and then introduce a small amount of dilute phosphoric acid onto the material by pipette. If no bubbles appear during a period of 20-30 minutes the process is complete. Gentle warming (to approximately 35° Celsius) for a few minutes may help in deciding whether bubbles are forming (minute CO_2 bubbles cling to bone particles indefinitely and may not be visible near the end of the extraction - centrifugation at 300rpm also helps remove bubbles).

Wash the sediment with distilled water repeatedly until the pH is as close to 6 as possible. Either centrifuge or allow to settle each time before decanting off the water. The supernatent can be checked for pH using a pH metre or litmus paper. A pH of 5 - 5.5 is acceptable; a pH of 6 is better but is difficult to achieve. In fact it may not go much above 3 until the residue has been thoroughly washed. The main advantage to washing off as much acid as possible is that the higher the pH, the easier it becomes to separate the 'collagen' residue from the liquid.
Centrifugation is the most efficient way of washing as it allows the removal of 90%+ of the wash water without loss of sediment.

Dry the 'collagen', preferably by freeze drying. Air drying

tends to make the material clump together in a hard mass.

DEVELOPMENT OF THE METHOD OF 'COLLAGEN' EXTRACTION

The above method was developed from the preliminary tests described below. 10 litres of dilute phosphoric acid was mixed, by adding 85 ml of phosphoric acid to every litre of distilled water. This produced an aqueous solution of approximately 5%.

Test 1

30gms of bone powder from the Otago University bone standard (see Appendix 2) was added to 1 litre of 5% phosphoric acid in a conical flask and sealed with parafilm. Frothing occurred immediately and the flask was swirled to remove as much material as possible from the sides of the flask. A stirring bar was added and the flask was then placed on a magnetic stirrer for 24 hours.

The following day the flask was removed from the stirrer. No sediment was visible and the liquid was cloudy, making it impossible to decant the liquid off. It was suspected that the reaction between the acid and the bone powder had occurred within hours as opposed to the expected several days, probably due to the fineness of the powder. Because the collagen tended to be held in suspension, it was decided that the process of separating the acid from the suspended material might be more successful if

the liquid was spun in a centrifuge.

The acid solution was centrifuged at 3500 revs at 15° Celsius for five minutes. There was still material suspended in solution and after some experimentation a spin time of 12 minutes at 4000 revs was found to be satisfactory.

The sediment was washed out of the centrifuge tubes with distilled water, poured into a conical flask , hand swirled and left to settle. A few drops of dilute phosphoric acid were introduced onto the sediment by pipette, to test for further reaction. No bubbles were observed, signifying that the reaction was complete. The flask was topped up to 1 litre with distilled water, hand swirled and allowed to settle.

The sample was washed several times with distilled water by decanting off as much water as possible and replacing it with fresh distilled water until the pH rose above 3. The water was then decanted off until about 80ml of liquid remained. As much material as possible was skimmed from the surface of the water which had been decanted off, and scraped from the sides of beakers with a spatula, to maximise the yield. The beaker containing the extract was sealed with 'glad-wrap' to prevent contamination.

Test 2

It was decided to repeat the test because of the length of

time the sample had remained in the acid, and the difficulties encountered with the centrifuge spin times.

1 litre of 5% dilute phosphoric acid was placed in a conical flask and 30gm of bone powder from the Otago University bone standard was added. Frothing occurred immediately and the flask was manually stirred in order to remove as much residue from the sides of the flask as possible. After the addition of a stirring bar the flask was sealed with parafilm and placed on a magnetic stirrer.

After one hour most of the frothing had subsided. A thick deposit was scraped from around the sides of the flask which was swirled and placed back on the magnetic stirrer for another hour.

The flask was removed from the stirrer and the liquid allowed to settle. After the liquid had settled no bubbles or frothing were observed and the process was assumed to be complete. Again, the insoluble material remained suspended or was slow to settle and it was decided to use centrifugation to recover the solids.

The solution was spun in the centrifuge for 12 minutes at 4000rpm as for test 1.

The sediment was washed out of the centrifuge tubes with distilled water, poured into a 2 litre conical flask, hand swirled and left to settle. When the material had settled a few

drops of dilute acid were introduced onto the sediment by pipette. No bubbles were observed and the reaction was assumed to be complete. More distilled water was added to top the level up to 850ml. The sample was washed as for test 1 until the pH had risen above 3. Although a pH >5 is ideal it became apparent that this would be very difficult to achieve and it was decided to settle on a pH >3. This would be unlikely to affect the isotope analysis.

Yields

Both samples were spun in a centrifuge to remove excess liquid and then transferred to flasks and placed on a freeze dryer. The dried material was two toned in colour, chocolate brown and a lighter shade similar to brown sugar. The material was hard and crumbly with test 1 appearing more compacted and chunky, and smaller in volume. The extracts weighed as follows:

Test 1	1.314gm
Test 2	1.590gm

These weights represented yields of 4.3% and 5.3% respectively. These results indicate that an average of 0.48gm of 'collagen' extract would be produced from every 10gm of bone powder. However, this could be expected to differ between sites, and possibly between individuals, because the degradation of collagen in archaeological bone (Hedges and Wallace 1978) may occur at different rates between sites, reflecting differences in

soil chemistry.

The 'collagen' extracts were then tested to determine their purity. It was necessary to establish whether the above procedure had successfully produced collagen, and if so what percentage of collagen was present in the extracts. If the extracts were not 100% collagen, the possibility that carbonates were present would have to be investigated, as carbonates could affect the carbon isotope determinations.

TESTS CARRIED OUT TO DETERMINE THE PURITY OF THE 'COLLAGEN' EXTRACTS

To determine the yield of 'collagen'

The extracts were tested to determine the amount of hydroxyproline present, and this was compared with the amount of hydroxyproline in the original bone powder, and the yield of collagen was obtained. The procedure followed was adapted from a method developed by Gordeladze, Halse, Djoseland and Haugen (1978).

The procedure was carried out as follows. In order to calculate the amount of bone powder required it was assumed that:

Bone powder on average has 10% collagen

The extract has 50% collagen

Collagen has 10% hydroxyproline

In order to test for hydroxyproline, a minimum amount of 10 µgm of hydroxyproline is needed in the assay tube. This is in solution, 10 µgm/100 µl of 6NHCl and 2ml (2000 µl) of liquid is a convenient volume for hydrolysis. Therefore a minimum amount of 200 µgm of hydroxyproline is required, which is equivalent to 2000 µgm of collagen, or 4000 µgm of the extract (according to above assumptions), or 20000 µgm of bone powder. The minimum amounts of bone powder and extract required are:

20 mg of bone powder in 2ml 6NHCl

4 mg of extract in 2ml 6NHCl

Six ampoules were prepared as follows:

1	Bone powder(1)	23.2mg +- 0.1mg in 2.0 +- 0.05ml 6NHCl
2	Bone powder(2)	48.3mg +- 0.1mg in 2.0 +- 0.05ml 6NHCl
3	Extract (1)	65.9mg +- 0.1mg in 2.0 +- 0.05ml 6NHCl
4	Extract (2)	48.1mg +- 0.1mg in 2.0 +- 0.05ml 6NHCl
5	Standard solution	hydroxyproline in 2.0 +- 0.05ml 6NHCl
6	Blank	2.0 +- 0.05ml 6NHCl

The ampoules were sealed over a flame. After cooling the ampoules were checked for leaks and all solid material was seen to be immersed in HCl. The ampoules were placed in an oven overnight at 105° Celsius in order to hydrolyse the samples.

The following day, the ampoules were cooled, broken open, and the hydrolysates were filtered through Whatman #1 filter paper and assayed as follows:

Aliquots of hydrolysates or diluted stock hydroxyproline standard were placed in assay tubes (plastic-stoppered ground glass necked pyrex test tubes, 1.5cm x 120cm) and 6NHCl added to a total volume of 100µl. Blank tubes (BK1, BK2) contained only 6NHCl. Labels and aliquots were:

Bone 1 (B1-30µl, B2-60µl, B3-90µl)

Bone 2 (BP1-30µl, BP2-60µl, BP3-90µl)

Extract 1 (1A-5µl, 1B-10µl, 1C-30µl)

Extract 2 (2A-7µl, 2B-14µl, 2C-30µl)

Dilute Standard * (S1-20µl, S2-30µl, S3-40µl, S4-60µl, S5-80µl)

* The stock standard was 45.6mg analar sigma (analar) L-hydroxyproline per 50ml water, with a drop of concentrated HCl added. This was diluted to a 1:10 solution in 6NHCl.

The liquid in the assay tubes was treated as follows:

0.5 cc Na_2CO_3 (5%) was added to neutralise the acid

0.5 cc Buffer A (0.1m Na Citrate) was added

1.0 cc isopropanol was added after vortexing

0.5 cc Buffer B Chloramine T - 0.4gm of Chloramine T in 50 ml of water, with 20ml of acetate (Boocock 1986:4)- was added. At this

stage the oxidation of hydroxyproline to pyrole took place (Rawle 1980:18).

The tubes were again vortexed and left for 5-7 minutes, at room temperature, then cooled on ice.

1.0 cc pDMAB (para-dimethylaminobenzaldehyde) was added (Gordeladze et al. 1978). Addition of pDMAB and heating leads to chromophore development, essential for the evaluation of spectrometric interference (Rawle 1980:18).

The tubes were vortexed and placed in a bath of water heated to 70° Celsius for 15 minutes and then cooled on ice.

After vortexing and allowing the tubes to come to room temperature the liquid in the assay tubes was coloured, with colour ranging from yellow through orange to red. A small amount of liquid from each tube was poured into individual 1cm plastic spectrometer cells and placed into an LKB Netrospec spectrometer. The wavelength was set at 552 nanometres, and all optical densities were read against water in cell 1.

The results are tabulated in Table 3.2.

Table 3.2: Optical densities of samples tested for hydroxyproline content.

Sample No.	Optical density +-.002	Optical density - mean blank +-.004
BK 1	0.024	
BK 2	0.033	
Mean blank	0.029	
S 1	0.279	0.250
B 1	0.364	0.335
S 2	0.390	0.361
S 3	0.519	0.490
B 2	0.690	0.661
BP 1	0.698	0.669
S 4	0.715	0.686
S 5	0.934	0.905
B 3	0.996	0.967
BP 2	1.274	1.245
1 A	1.649	1.620
2 A	1.667	1.638
BP 3	1.783	1.754
2 B	>2.500	
1 B	>2.500	
1 C	>2.500	
2 C	>2.500	

The amount of hydroxyproline in the standards was calculated and multiple regression analysis was carried out to produce a hydroxyproline standard curve (Figure 3.2).

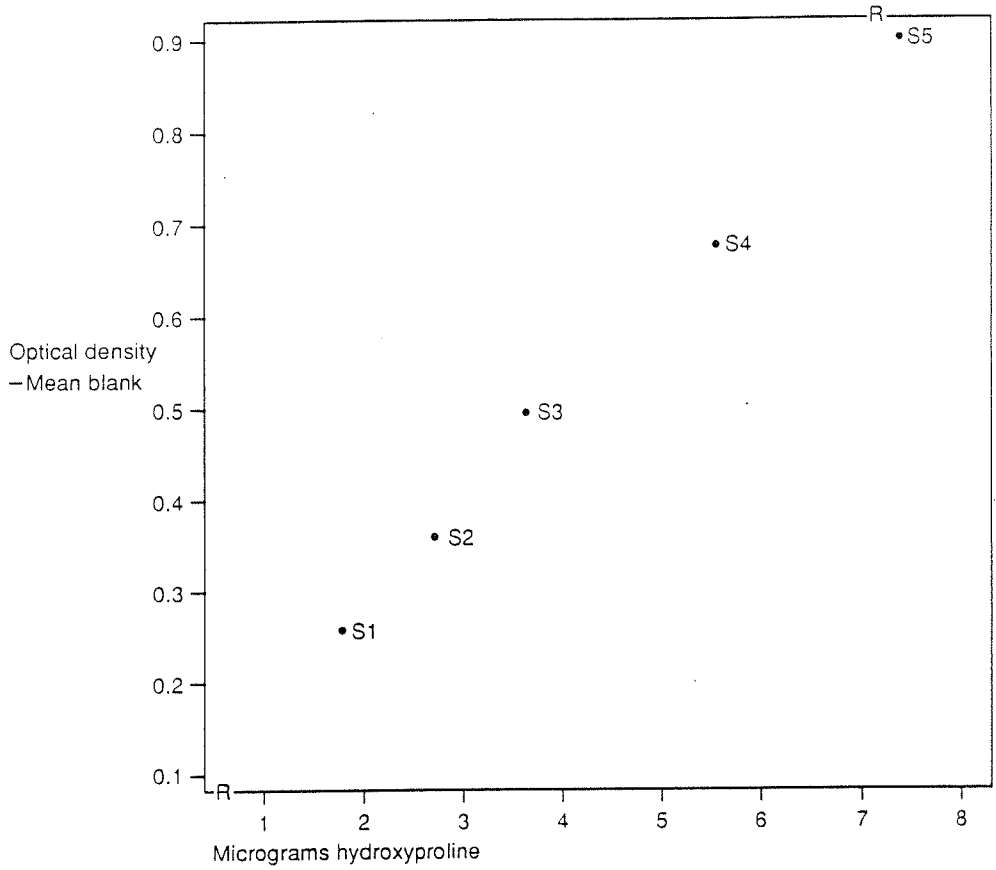

Figure 3.2: Hydroxyproline standard curve, used to calculate the amounts of hydroxyproline and collagen in the samples of bone powder and 'collagen' extract, as presented in Table 3.3.

The following regression equation (r=0.999, t test highly significant) was then used to calculate the amount of hydroxyproline per assay tube.

µgm of hydroxyproline

= (8.399 x optical density-mean blank of sample) - 0.327

The total amounts of hydroxyproline and collagen were then calculated, assuming that there is 12.8% hydroxyproline in mammalian collagen, and that this would hold true for all the collagen samples in this study. This figure was obtained from the formula:

µgm hydroxyproline x 7.8125 = µgm collagen (Rawle 1980:19).

Thus, 100/7.8125 = percentage of hydroxyproline in mammalian collagen

= 12.8%

The amounts of hydroxyproline and collagen in the samples of bone powder and 'collagen' extract are shown in Table 3.3. The working used to construct the table is shown below for sample B1.

Column 1 - calculated from the regression equation

Column 2 - volume of hydroxyproline in the assay tube

Column 3 - 2.49/30 x 2000 = total hydroxyproline in the ampoule = 166. This was calculated for B1, B2 and B3 and the mean value was 171.03. This was used in subsequent calculations

Column 4 - the weighed amount of the sample in the assay tube (gms)

Column 5 - .1710/.0232 x 100 = µgm hypro/100gm sample = 737.06 = .737 gm hypro/100gm sample

Column 6 - .737/12.8 x 100 = collagen/100gm sample = 5.76%

Table 3.3: Amounts of hydroxyproline (hypro) and collagen in the samples of bone powder and 'collagen' extract.

	Micrograms hypro	Vol hypro	total hypro in ampoule (µgm)	wgt. in ampoule (gm)	gm hypro/ 100gm sample	collagen/ 100gm sample
B1	2.49	30	166.00			
B2	5.22	60	174.00			
B3	7.79	90	173.10			
			------			
		mean=	171.03	0.0232	0.737%w/w	5.76% +-0.07
BP1	5.29	30	352.66			
BP2	10.13	60	337.66			
BP3	14.40	90	320.00			
			------			
		mean=	336.77	0.0483	0.697%w/w	5.45% +-0.04
1A	13.28	5	5312.0	0.0659	8.06%w/w	62.97% +-1.40
2A	13.43	7	3837.1	0.0481	7.98%w/w	62.34% +-1.06

As can be seen from Table 3.3, the percentage of collagen in the extract was 62.66% (mean value). The enrichment factor from the bone to the 'collagen' was calculated as follows:

mean percentage of collagen in bone powder = 5.61%

mean percentage of collagen in extract = 62.66%

Enrichment factor = 62.66/5.61

= 11.17

At this stage it was not possible to conclude that the extraction process had been successful. The 'collagen' extract consisted of approximately 63% collagen, but it was necessary to determine that what remained was not likely to affect the results of the stable isotope analysis. Any contamination of results would be likely to come from crystalline structures which may be present in the extract, and the possibility of such structures being present was explored using XRF and XRD analysis.

XRF AND XRD ANALYSIS

XRF and XRD analysis was carried out on the bone powder and the 'collagen' which had been extracted from the bone powder, to obtain some comparisons between the two. The main concern was to confirm whether the extraction process had removed calcium carbonate and hydroxyapatite from the bone powder. If carbon was found to be present, in the form of calcium carbonate, the

extraction process would have to be modified as the presence of carbon would adversely affect the carbon isotope results. Due to limitations on time and resources it was not possible from the XRD and XRF analysis to obtain quantitaive results on the percentages of calcium carbonate, hydroxyapatite or silicon (quartz). But for the purposes of this study, it was sufficient to obtain qualitative rather than quantitative results, in other words to determine the presence or absence of the structures in question.

Sample preparation

1. Standard preparation method

Samples were mixed with a mowiol organic binder, placed into a press with mylar film above and below the sample and pressed into discs under five tons pressure for one to two minutes. The first disc was weighed and subsequent discs were made to the same weight, which was necessary if they were to be compared.

2. Preparation of bone and 'collagen' samples for XRF and XRD

The discs produced from the two 'collagen' extracts were not entirely satisfactory, being very thin and tending to curve. Preliminary runs were made through the XRF machine and both samples gave similar results, so the best disc, which was 'collagen' sample 2, was selected for comparison with the original bone powder. Disc 2 weighed 1.2gm.

The bone sample was prepared by mixing 1.2gm of bone powder with 0.3ml mowiol organic binder. After drying the sample was pressed, but the disc was very crumbly when removed. The process was repeated with the amount of binder increased to 0.45ml. The second disc was more solid and held together well although a small piece broke off the edge. It was decided to use the second disc because although it was very thin, it was comparable by weight to the disc from 'collagen' extract 2.

XRF

The samples were analysed on a Philips PW 1410 x-ray fluorescence spectrometer, in order to check for the presence of calcium which may be present as calcium carbonate. A check was also made for the presence of silicon (quartz).

Machine settings

Step scans were made over the Ca Kα and Si Kα peaks using the x-ray spectrometer fitted with a molybdenum tube and run at 70 kilovolts and 30 milliamps. A 10 second count was made at each of the 0.01° 2θ steps.

Calcium

The Ca Kα peak was scanned using a fine collimator, the flow-proportional counter and a LiF200 crystal.

Silicon

The Si Kα peak was scanned using a coarse collimator, the flow-proportional counter and a PE(pentaerythritol) crystal.

Results

The results, as shown in Figures 3.3 and 3.4, showed both calcium and silicon present in both the bone and the 'collagen'.

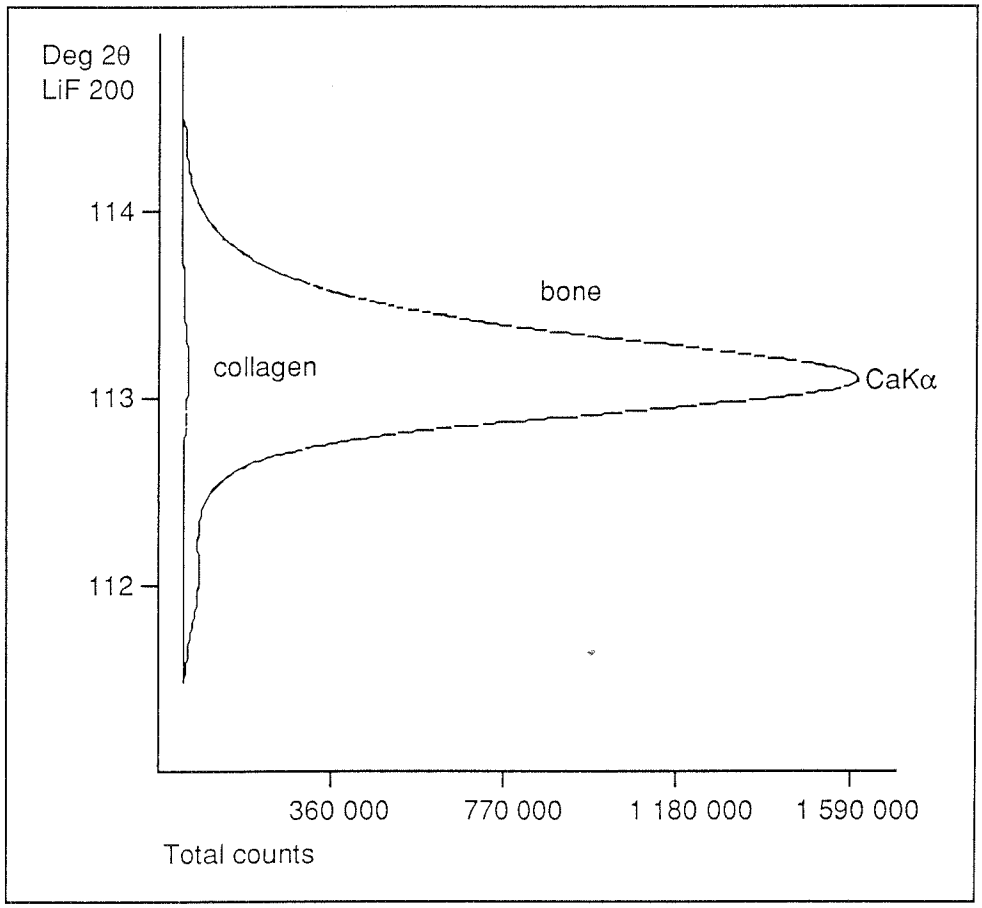

Figure 3.3: The results of XRF analysis to detect the presence of calcium in bone powder and in 'collagen' extracted from the bone powder. The CaKα peak was measured with a LiF200 analysing crystal with 10 second count times, using a fine collimator. The results do not reflect the absolute amounts of calcium in the bone powder and 'collagen' extract, but rather the amount of calcium proportionate to the total volume of material. The proportion of calcium in the 'collagen' extract is considerably less than in the bone, reflecting the removal of calcium carbonate from the bone powder during the extraction of collagen.

The relative amount of calcium present in the 'collagen' was considerably less than in the bone (see Figure 3.3), while the relative amount of silicon increased from the bone to the 'collagen' (see Figure 3.4). This may have been due to an enrichment of silicon during the production of 'collagen' as the silicon would not be affected by the acid treatment.

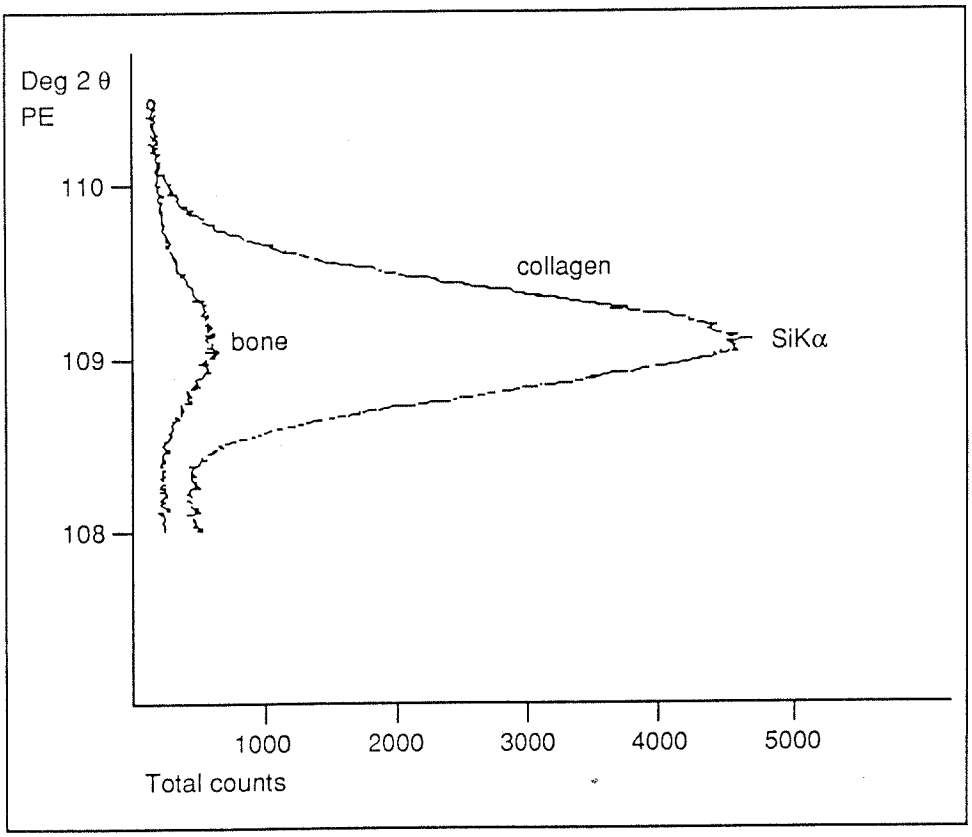

Figure 3.4: The results of XRF analysis to detect the presence of silicon in bone powder and in 'collagen' extracted from the bone powder. The SiKα peak was measured with a PE analysing crystal with 10 second count times, using a coarse collimator. The results do not reflect the absolute amounts of silicon in the bone powder and 'collagen' extract, but rather the amount of silicon proportionate to the total volume of material. There is an enrichment in silicon from the bone to the 'collagen' due to the loss of carbonate and other materials from the bone.

XRD analysis was then carried out to identify whether the calcium identified in the 'collagen' was in the form of calcium carbonate.

XRD

The samples were run through a Philips 2kW x-ray diffractometer fitted with a PW1050 goniometer, a PW1752 curved graphite monochromator, and a copper X-ray tube. The aim was to determine whether any crystalline structures were present, in particular checking for hydroxyapatite and calcium carbonate.

The bone sample was run at an output range of 400 counts per second (cps), between 20 and 50° 2θ (see Figure 3.5).

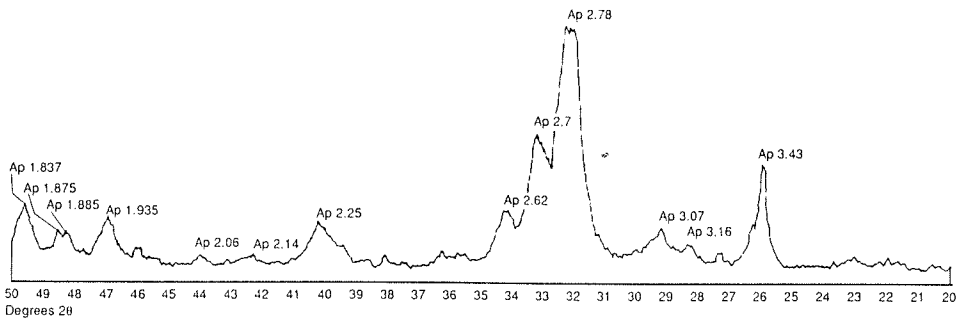

Figure 3.5: The results of XRD analysis of the bone standard, using a copper X-ray tube to scan between 20 and 50 degrees 2θ at 400 counts per second, to detect the presence of crystalline structures, in particular hydroxyapatite and calcium carbonate. Hydroxyapatite was detected.

Hydroxyapatite was present (cf. ASTM card 25-166) and twin peaks at 22.5 and 26.25° 2θ were possibly quartz. No calcite was detected, but the most intense peak of aragonite at 3.39 Angstroms appears from behind one of the more intense hydroxyapatite peaks. The weaker aragonite peaks were not identified. These results do not preclude the fact that calcite may be present in the bone, but simply shows that it is not present in sufficient quantity to be detected here.

'Collagen' sample 2 was run first at an output range of 1000 cps, a range of much greater intensity than used for the bone sample, because of the high background for sample 2 (see Figure 3.6). While this setting is not very good for comparisons, it will detect structures if present, which is sufficient for this analysis. The sample was run between 20 and 30° 2θ and two quartz peaks, corresponding to 4.26 Angstroms and 3.343 Angstroms were detected.

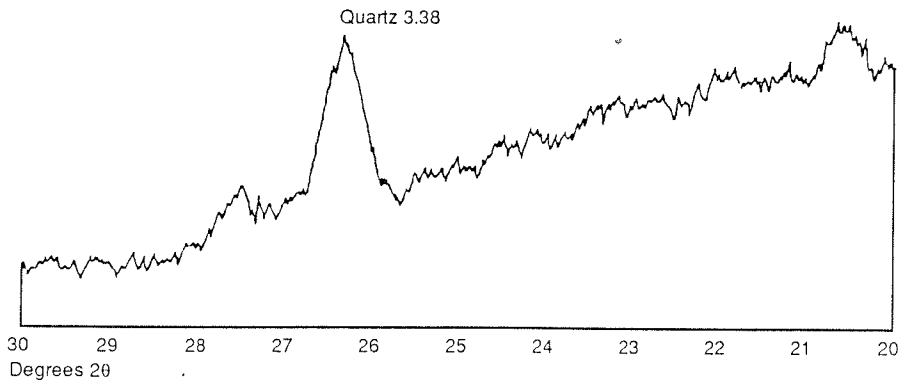

Figure 3.6: The results of XRD analysis of the 'collagen' extract, using a copper X-ray tube to scan between 20 and 30 degrees 2θ at 1000 counts per second, to detect the presence of crystalline structures, in particular hydroxyapatite and calcium carbonate. These were not identified, although quartz (from soil) is clearly seen.

A second run (see Figure 3.7) at an output range of 1000 cps from 30 to 41° 2θ detected no hydroxyapatite, calcite or aragonite peaks.

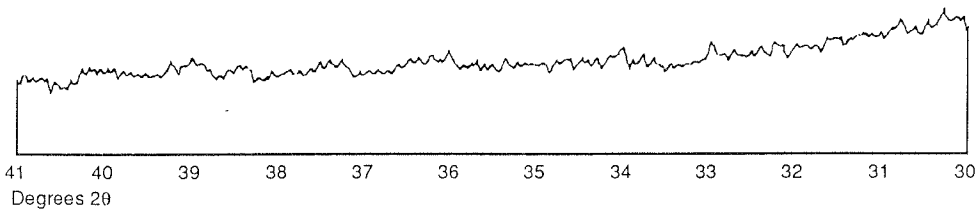

Figure 3.7: The results of XRD analysis of the 'collagen' extract, using a copper X-ray tube to scan between 30 and 41 degrees 2θ at 1000 counts per second, to detect the presence of crystalline structures, in particular hydroxyapatite and calcium carbonate. No hydroxyapatite, calcite or aragonite peaks were detected.

The sample was re-run (see Figure 3.8) at greater intensity (4000 cps) scanning between 15 and 32° 2θ, to check the peaks detected on the first run, and to recheck for any calcium carbonate or hydroxyapatite which have main peaks at about 29.43 and 31.65° 2θ respectively. The results confirmed that quartz was present, but minimal calcium carbonate, aragonite or hydroxyapatite.

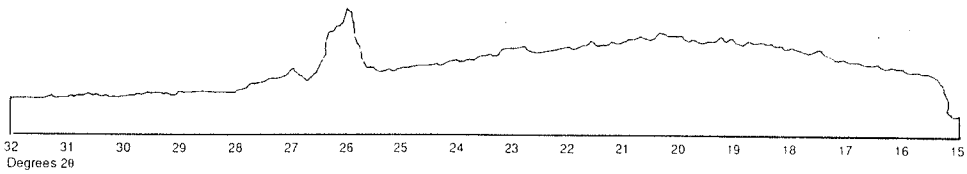

Figure 3.8: The results of XRD analysis of the 'collagen' extract, using a copper X-ray tube to scan between 15 and 32 degrees 2θ at 4000 counts per second, to check the analyses presented in Figures 3.6 and 3.7. The presence of quartz and the absence of calcium carbonate, aragonite and hydroxyapatite was confirmed.

Discussion

It was concluded from the XRF and XRD analysis that if any calcium carbonate or hydroxyapatite was present in the 'collagen', the amounts were so small that they were undetectable, and therefore the stable isotope analysis would not be affected. Similarly the identified silicon component would have no effect on the stable isotope determinations. The unidentified portion of the extract probably consisted of non-collagenous proteins and bone proteoglycans (Myers pers. comm. 1988), which would not be removed by the extraction process. The proportions of these compounds would be expected to vary from sample to sample, as they are less stable than collagen and tend to be broken down and lost more readily (Hedges and Wallace 1978:384). The rate at which these organic components of

bone are broken down may be a function of several factors, including environment, length of deposition and the species from which the bone originates (Hare 1980:217). Bone proteoglycans contain a high percentage of sulphate groups, and for a given sample are presumed to have the same isotopic ratios of sulphur as would be found in the collagen (Myers pers. comm. 1988), although this needs to be confirmed.

From the tests carried out to determine the purity of the 'collagen' extract it was concluded that the extract consisted of approximately 63% collagen, a smaller percentage of other organic components, and some silicon containing material. No crystalline structures were detected. The method developed for the extraction of 'collagen' from bone powder was thus concluded to be a reliable method for processing all subsequent samples for this study.

The decision as to which samples should be processed to collagen for carbon and sulphur determinations was made in the following way. At least two samples from all sites (where at least two were available) should be processed to collagen, and this number would be increased as time and resources permitted. For those sites with special significance, for example Rotoiti as an inland site and the Chathams as a marine oriented location, as many samples as possible should be processed. The next criterion was the amount of bone powder available. For some samples, particularly those from Easter Island, only small amounts of bone powder were available. Of the Easter Island samples, four,

weighing less than 5.9gms, were successfully processed to 'collagen' as these samples gave particularly high yields of 'collagen' from bone powder (see Appendix 3). This was probably because there was very little mineral content in the bone. Where a choice had to be made as to which samples to process, in most cases this was made on the basis of the amount of bone powder available. The yields of 'collagen' then determined which samples would be processed for sulphur analysis. Ideally, 1gm, and certainly not less than 0.75gm, of 'collagen' was found to be needed for combustion, in order to obtain enough sulphur for a $\delta^{34}S$ determination to be made.

PARR BOMB EXTRACTIONS FOR SULPHUR ISOTOPE DETERMINATIONS

Before sulphur isotope evaluation could be made of the samples, the 'collagen' was combusted in a Parr bomb to produce sulphur dioxide which was absorbed into distilled water in the bomb, forming sulphuric acid. The liquid was then treated with $BaCl_2$ to precipitate $BaSO_4$. This solution was then processed for sulphur isotope determinations.

Sample combustion

Each sample of approximately 1gm of dry 'collagen' was compressed into a pellet in a press. After weighing the pellet was placed into the metal cup which is suspended from the lid of the Parr bomb. A platinum wire was fastened between the

terminals, a piece of cotton was tied to the wire and placed so that the cotton was in contact with the pellet. 1ml of distilled water was poured into the bomb cylinder. This was to absorb any sulphur dioxide given off during combustion. The lid was placed on, with the sample suspended from it, and screwed down by hand, making sure the rubber seal was secure. The bomb was connected to the oxygen supply and filled to 25 atmospheres pressure. The oxygen supply was then disconnected and the valve on the bomb was covered with the sealing cap. The firing circuit was tested to ensure that the platinum wire had not broken and the terminals on the bomb were then connected to an electric current and the sample ignited. The combustion process generated some degree of heat and the bomb was therefore immersed in cold water for at least 15 minutes before opening. This allowed for the full absorption of all the sulphuric acid produced during the combustion process. After 15 minutes the pressure was released from the valve and the top of the bomb was carefully removed. The bomb and all fittings were thoroughly washed out with distilled water into a container, following the principles of quantitative chemistry, to ensure maximum retention of the sample. To the sample 0.6ml 6NHCl was added for every 200ml of bomb washings and the container was securely sealed. After a short period of time, between one and four days, the bomb digests were processed to produce $BaSO_4$.

THE METHOD DEVELOPED FOR THE PRECIPITATION OF $BASO_4$

Each bomb digest was transferred to a 400ml beaker and warmed to approximately 70° Celsius. A solution of 5% $BaCl_2$ was prepared by dissolving 4.2gm $BaCl_2$ in 80ml distilled water, and warmed. The warmed $BaCl_2$ was added dropwise from a pipette to the sample, stirring with a glass rod, until the liquid became cloudy. The precipitate was allowed to settle and then a further 3-4ml of warmed $BaCl_2$ was added dropwise, first reheating the sample if the temperature had dropped below 70°. The beaker was covered with 'gladwrap' and allowed to settle overnight.

The following day as much liquid as possible was decanted off without disturbing the precipitate which was then washed thoroughly into a 100ml beaker. This was covered with 'gladwrap' and again allowed to settle overnight. The next day around 60ml of liquid was decanted off without disturbing the precipitate and the beaker was then placed on a hot plate to evaporate as much liquid as possible. The sides of the beaker were washed down with distilled water to make sure all the precipiate had been collected. During the evaporation process the temperature was regulated to prevent the liquid from reaching boiling point. When the amount of liquid had been reduced to between 5 and 10ml the sample was washed into a plastic screw-top bottle with distilled water and was securely sealed. Samples were then sent to the DSIR in Wellington for sulphur isotope evaluation.

THE DEVELOPMENT OF THE METHOD FOR THE PRECIPITATION OF $BaSO_4$

The above method was adopted after preliminary tests showed that the percentage recovery of $BaSO_4$ could be maximised if the sample was sent to the processing laboratory in solution. For these preliminary tests five samples of 'collagen' produced from the bone standard were combusted in a Parr bomb, and $BaSO_4$ was produced after $BaCl_2$ was added to the washings from the bomb, as described above. Instead of reducing the volume of liquid after the precipitation of $BaCl_2$, the samples were processed as follows.

A millipore filtration apparatus was assembled. A 0.22μ cellulose millipore filter was washed with warm distilled water, dried and weighed. The filter was placed in the filtration apparatus and approximately 3ml of warm distilled water was washed through it to make sure it was functioning correctly. As much liquid as possible was decanted off from the 400ml beaker without disturbing the precipitate. The sample was then warmed and passed through the millipore filter. When all the sample had been filtered the beaker was rinsed with warm distilled water and the rinse water was passed through the filter. Finally the sample was washed several times with warm distilled water passed through the filter to ensure that all traces of $BaCl_2$ were removed. The filter was carefully removed from its holder using laboratory tweezers and dried overnight at 75° Celsius. The filter plus the $BaSO_4$ precipitate was then weighed and the yield of $BaSO_4$ was calculated. The results are presented in Table 3.4.

Table 3.4: $BaSo_4$ yields (by weight).

Acc. No. of sample	Wgt. filter, + dish (gm)	Wgt. filter, + precipitate + dish (gm)	Wgt. precipitate (mg)
S3	7.5836	7.5938	10.20
S4	7.5238	7.5368	13.00
AX 994	7.5143	7.5240	9.70
AY 51	7.4520	7.4634	11.40
AY 25	7.4271	7.4340	6.90

The yields of sulphur were then calculated. The results are presented in Table 3.5.

Table 3.5: Sulphur yields (percentage by weight).

Acc. No. of sample	Wgt. of Collagen combusted (gm)	Wgt. of $BaSO_4$ (mg)	Wgt. of* Sulphur (mg)	% Yield Sulphur** (by wgt.)
S3	0.8451	10.20	1.40	0.12
S4	1.1131	13.00	1.79	0.20
AX 994	1.4077	9.70	1.33	0.19
AY 51	0.7453	11.40	1.57	0.12
AY 25	0.8938	6.90	0.95	0.08

* In 1 mg of $BaSO_4$, there is 0.1374 mg sulphur

** Expected yield of sulphur is between 0.14% and 0.22% (see text)

The yields of sulphur ranged from 0.08 to 0.2% by weight. This can be compared with expected yields, which range from 0.14 to 0.23%, and which were calculated as follows.

In a preliminary test, 0.8gm of organic extract ('collagen') from AX848 (burial 160 from Namu) was processed and 12.7mg of $BaSO_4$ was obtained.

% yield of $BaSO_4$ (by weight) = (.0127/0.8) x 100

= 1.6%

The percentage of sulphur in $BaSO_4$ was then calculated:

(Gmw $BaSO_4$ = 233.4)

$$\% \text{ sulphur} = (32.06/233.4) \times 100$$

$$= 13.7\%$$

Therefore in 1mg $BaSO_4$, there should be 0.137mg sulphur. In the preliminary test the amount of sulphur obtained from 0.8gm of 'collagen' was 0.137 x 12.7 = 1.8mg sulphur, which represents a yield of 0.23% by weight ((.0018/0.8) x100). Based on the preliminary test, 1gm of collagen would be expected to yield 2.3mg of sulphur.

Based on the composition of collagen, the expected yields of sulphur were then calculated. Only three amino acids - cysteine, cystine and methionine - contain sulphur (Oser 1965), but cysteine is not present in the collagen of higher vertebrates (Brown 1979:365). The percentages of sulphur in cystine and methionine were calculated to be 26.7% and 21.5% respectively.

Gmw cystine ($C_6 H_{12} O_4 N_2 S_2$) = 240.2

$$\% \text{ Sulphur} = (64.1/240.2) \times 100$$

$$= 26.7\%$$

Gmw methionine ($C_5 H_{11} O_2 N S$) = 149.2

$$\% \text{ Sulphur} = (32.1/149.2) \times 100$$

$$= 21.5\%$$

Figures for the percentages of cystine and methionine in

bone collagen could not be found, but collagen from cattle hide has 0.1% cystine and 0.9% methionine (Oser 1965:132). Thus in 1gm of collagen from cattle hide, there should be 1mg of cystine and 9mg of methionine, containing 0.267mg and 1.935mg of sulphur respectively. Therefore 1gm of collagen from cattle hide would be expected to yield 2.202mg sulphur, which represents a 0.22% yield by weight. The yield of sulphur from bone collagen may be different from the yield from cattle hide, but this figure is useful as a guide.

Finally the expected yield of sulphur from the 'collagen' extract was calculated, based on the finding that there is approximately 63% collagen in the extracts.

Maximum expected yield from 1gm pure collagen = 2.2mg
(assuming that the yield from cattle hide is similar to the yield from bone collagen)
Maximum expected yield from 1gm 'collagen' extract
= 2.2 x 0.63
= 1.4mg
= .14% yield
(= 1.4/32.1 x 233.4
= 10.2mg $BaSO_4$)

These results show that the yields from the five test samples (see Table 3.5) lie within the expected range. However, because the range of values was quite wide and the number of samples was small, it was decided to make sure that the filter

method used to recover the $BaSO_4$ was in fact recovering the maximum possible amount of the precipitate.

The percentage recovery of $BaSO_4$ for this method was tested by dissolving 0.1233gm $(NH_4)2\ SO_4$ in 200ml of distilled water, and adding 0.6ml 6NHCl. This sample was put through the same process as the above five samples. A total of 9ml $BaCl_2$ was added to produce the precipitate. A total of 167mg of $BaSO_4$ was recovered. The percentage recovery was then calculated:

$$\text{mw } BaSO_4 = 233.43$$

$$167\text{mg } BaSO_4 = 167/233.4 \text{ mmoles } BaSO_4$$

$$= 0.715 \text{ mmoles}$$

$$0.1233\text{gm } (NH_4)2\ SO_4 = 0.933 \text{ mmoles}$$

$$\text{Theoretical yield} = 0.933 \text{ mmoles}$$

$$\text{Actual yield} = 0.715 \text{ mmoles}$$

$$\% \text{ recovery} = 0.715/0.933 \times 100$$

$$= 76.6\%$$

This method was thus found to recover 76.6% of the total $BaSO_4$ present in the sample. In order to improve the percentage recovery of $BaSO_4$, it was decided to send all further samples to the testing laboratory in solution, thus eliminating the filtration process and by-passing one possible source of sample loss. This was possible because the sample does not need to be put through the washing process, which was designed to remove all traces of $BaCl_2$, in order to obtain a sulphur isotope reading (Lyon pers. comm. 1987).

STABLE ISOTOPE DETERMINATIONS

CARBON AND SULPHUR

13C and 34S analysis was carried out at The Institute of Nuclear Sciences in Lower Hutt. The procedure followed is outlined in Appendix 4.

NITROGEN

An initial batch of 107 samples of bone powder and 12 samples of collagen from the following sites was taken to the Stable Isotope Unit, Ruakura, for processing: Rotoiti, Watom, Chathams, Nebira, Namu, Tonga ('Atele and Pea), Motupore, Easter Island, and Fiji (Lakeba). In addition, samples of bone powder from the Otago University bone standard and 'collagen' prepared from the standard were processed.

Before the samples were prepared for nitrogen determinations, tests were carried out on one sample from each site to determine the exact percentage of water soluble nitrates present. This was to determine whether soluble nitrates from the surrounding soil matrix might have contaminated the samples, thus affecting the nitrogen ratios.

Tests carried out to detect water soluble nitrates

Approximately 1gm of bone powder from each sample was

placed into a 100ml conical flask. To this, 100ml of distilled water was added and the flask was placed on a tumble shaker for one hour to ensure thorough mixing. The samples were then centrifuged for 10 minutes at 5000rpm (G=3500) at 5° Celsius. The liquid was decanted off and run through a micro-Kjeldahl distillation line.

Nitrogen compounds, if present, are likely to exist in the samples predominantly in the form of ammonium or nitrates and the distillation process will trap separately any ammonium or nitrates which may be present in the sample. The distillation procedure was as follows:

1 Before the samples were run through the distillation line a flask containing water was distilled on each side of the distillation line to establish blanks.
2 An aliquot of 50 ml of the sample was placed in a distillation flask, and to this 0.5gms of magnesium oxide was added.
3 The sample was placed on the distillation line and the distillate was collected in a 100 ml beaker containing 5 ml 20gm/litre boric acid. This process traps nitrogen in the form of ammonium, NH_4.
4 After five minutes the beaker was removed and titrated with an autoburette against sulphuric acid until the pH was reduced to approximately 4.9-5.0.
5 The sample was removed from the distillation line, 0.2gms of Devarda's alloy was added, and the flask was placed

back on the distillation line and distilled into a second beaker of boric acid. This process traps nitrogen in the form of nitrates, NO_3.

6 After a further five minutes the second beaker was titrated against sulphuric acid until the pH reached approximately 4.9-5.0.

The results are presented in Table 3.6.

Table 3.6: Results of tests to detect water-soluble nitrates.

Acc.No.	Site	Mls H_2SO_4 (beaker 1) NH_4	Mls H_2SO_4 (beaker 2) NO_3	Total N (µgm)	%N (whole bone)	%Soluble N
AY 48	Rotoiti	0.029	0.054	58.93	4.18	0.14
AY 56	Watom	0.025	0.015	28.40	0.68	0.42
AY 39	Chathams	0.019	0.021	28.40	4.24	0.07
AY 62	Namu	0.040	0.028	48.28	1.54	0.31
AY 9	Tonga	0.017	0.022	27.69	1.02	0.27
AY488	Motupore	0.021	0.013	24.14	1.30	0.19
AY 82	Lakeba	0.019	0.023	29.82	0.49	0.61
AY774	To-1 (Pea)	0.020	0.014	24.14	0.81	0.30
AY 36	Nebira	0.020	0.014	24.14	0.76	0.32
AY859	Easter Is.	0.064	0.548	434.52	2.43	1.81
AY860	Easter Is.	0.062	0.525	417.00	3.70	1.10
Standard (Namu)		0.017	0.053	49.70	1.24	0.40

The percentage of soluble nitrogen was less than 0.61 for all samples except Easter Island. The figures for percent N in the whole bone were obtained later during the distillation of the bone powders in preparation for δ15N determinations. The figures for the percentage of soluble nitrogen were first estimated using a figure of 10mg of nitrogen per 1gm of bone powder, based on average results for nitrogen yield from whole bone. The results obtained were of sufficient accuracy to indicate that the percentage of soluble nitrogen present in most samples was small. For Easter Island, two samples were processed because the first gave a substantially higher result than samples from other sites, and it was decided that a repeat test would rule out any error. The figures for the percentage of soluble nitrates shown in Table 3.6 were calculated, for each sample, from the percent nitrogen values for whole bone obtained during the subsequent distillation of the samples.

Sample working to obtain the percentage of soluble nitrogen, for Rotoiti AY48:

A standard solution was titrated against the sulphuric acid stock and it was found that 1ml acid was required for 0.71mg N (710 µgm)

mls H_2SO_4 added to beaker 1 = 0.029 (NH_4)

mls H_2SO_4 added to beaker 2 = 0.054 (NO_3)

Total N = (0.029x710) + (0.054x710)

= 58.93 µgm

The percentage of nitrogen in the sample was 4.18%, therefore 1gm of bone powder will contain 41.8mg of nitrogen.

In this sample there is 58.93 µgm of soluble nitrogen compared with a total of 41.8 mg of nitrogen available.

Percent of soluble nitrogen in Rotoiti AY48

$= (58.93 \times 10^{-6} / 41.8 \times 10^{-3}) \times 100$

$= 0.14\%$

All bone and 'collagen' samples in the initial batch were then processed for δ15N determinations. It was decided to attempt to obtain δ15N determinations for the samples containing the water-soluble nitrogen from Easter Island in order to determine whether the water-soluble nitrates had derived from the surrounding soil matrix or from the organic nitrogen in the bone.

PREPARATION OF SAMPLES FOR δ15N DETERMINATIONS

All samples were processed as follows:

1 Approximately 0.40gms of bone powder was weighed into pyrex test tubes.
2 5ml of 'Stew's brew' was added to each sample. 'Stew's brew' was developed as a modification of the method described by Bergersen (1980), and consisted of 1 litre H_2SO_4 (N free), 100gm K_2SO_4, 1.0gm selenium and 25gm salicylic acid. The

salicylic acid was added to ensure conversion of free NO_3 to NH_4.

3 A couple of boiling chips (anti-bumping granules) were added to each tube to stop loss of fluid through bumping.

4 The tubes were placed into a digestion block in a fume cupboard and heated slowly to 340° Celsius. The samples were left for approximately one and a half to two hours, until all the powder had been digested and the liquid was clear. They were then removed from the block and placed in a rack to cool.

5 Each sample was placed into a distillation flask and 25-30ml 10N NaOH was added. The sample was distilled for eight to nine minutes on a micro-Kjeldahl distillation line into 5ml 20g/litre boric acid.

6 The liquid trapped in the beaker of boric acid was titrated with an autoburette against sulphuric acid until the pH reached 4.9-5.00. The amount of acid used was noted and used to calculate the percent N in the sample. The pH was then further reduced to just below 4.0 by manual addition of sulphuric acid.

7 The sample was placed on a hot-plate to begin to evaporate the liquid, but before the liquid evaporated completely was placed in an oven overnight at 90° Celsius.

8 When all the liquid had evaporated the sample was washed out of the beaker with distilled water into a small test tube. The test tube was placed back into the oven to evaporate the liquid.

9 The ammonium sulphate samples were placed on a vacuum line to produce pure N_2 gas. Lithium hypobromite (LiOBr) was added to the ammonium sulphate to produce N_2 gas, which was passed

through liquid nitrogen cold traps to remove impurities before being collected in glass tubes and sealed.

10 The sealed tubes were opened and read on a VG micro-mass 602E mass spectrometer.

The results are presented in Table 3.7.

Table 3.7: Results of processing initial batch of samples for δ15N determinations. Those samples which have no δ15N value were processed again in the second run.

RUN A

Acc. No.	Gms powder	Mls acid	%N	δ15N	S.D.
AY 9	0.4023	5.61	1.02	12.640	0.180
AY 10	0.4080	8.79	1.58	9.960	0.090
AY 11	0.4078	6.13	1.10	10.307	0.090
AY 12	0.4026	17.63	3.21	10.776	0.050
AY 13	0.4018	7.95	1.45	11.926	0.090
AY 14	0.4076	7.57	1.36	10.186	0.067
AY 15	0.4018	4.66	0.85	9.880	0.047
AY 16	0.4023	6.13	1.12	10.569	0.032
AY 17	0.4009	8.53	1.56	10.606	0.077
AY 18	0.4060	7.51	1.36	9.257	0.088
AY 19	0.4027	4.64	0.84	10.462	0.016
AY 20	0.4085	7.60	1.36	10.234	0.023

RUN A - continued

Acc. No.	Gms powder	Mls acid	%N	δ15N	S.D.
AY 21	0.4012	7.79	1.42	9.431	0.086
AY 22	0.4033	9.31	1.69	10.887	0.068
AY 23	0.4064	21.72	3.92	9.250	0.040
AY 24	0.4019	8.20	1.50	9.988	0.025
AY 25	0.4058	5.06	0.91	8.294	0.111
AY 26	0.4012	8.10	1.48	9.293	0.056
AY 27	0.4044	6.92	1.25	9.409	0.012
AY 28	0.4076	10.15	1.83	10.285	0.110
AY 774	0.4015	4.46	0.81	10.327	0.031
AY 82	0.4071	2.72	0.49	10.317	0.098
B.S.	0.4093	6.82	1.22	10.550	0.040
H.S.	0.1026	4.19	2.99	1.044	0.148

Acid standard = 735

AY 9 - AY 28	Atele (Tonga)
AY 774	Pea (Tonga,To-1)
AY 82	Lakeba (Fiji)
B.S.	Bone Standard
H.S.	Herbage Standard

RUN B

Acc. No.	Gms powder	Mls acid	%N	δ15N	S.D.
AY 62	0.4084	8.55	1.54	11.650	0.100
AY 63	0.4090	7.22	1.30	12.460	0.020
AY 64	0.4057	8.78	1.59	10.765	0.035
AY 67	0.4062	6.06	1.10	11.394	0.039
AY 69	0.4009	7.78	1.43	11.214	0.110
AY 70	0.4076	7.19	1.30	5.182	0.061
AY 71	0.4030	5.86	1.07	12.887	0.021
AY 72	0.4032	6.31	1.15	8.367	0.034
AY 74	0.4031	6.04	1.10	12.217	0.017
AY 75	0.4053	6.86	1.24	10.663	0.103
AY 76	0.4073	7.91	1.43	12.130	0.040
AY 77	0.4038	6.16	1.12	12.684	0.051
AY 78	0.4064	6.24	1.13	12.377	0.038
AY 79	0.4027	6.98	1.27	11.274	0.040
AY 80	0.4044	7.39	1.34	10.936	0.039
AY 81	0.4048	6.38	1.16	10.064	0.129
AY 56	0.4014	3.73	0.68	11.656	0.055
AY 57	0.4038	3.22	0.59		
AY 58	0.4044	2.79	0.51	5.766	0.051
AY 59	0.4049	3.17	0.58	10.853	0.014
AY 60	0.4069	1.54	0.28		
AY 61	0.4058	2.98	0.54	9.686	0.009
H.S.	0.1056	4.17	2.90	0.640	0.038

Acid standard = 735

AY 62 - AY 81 Namu (Solomons)

AY 56 - AY 61 Watom (New Britain)

H.S. Herbage Standard

(No Bone Standard for Run B)

RUN C

Acc. No.	Gms powder	Mls acid	%N	δ15N	S.D.
AY 39	0.4025	23.22	4.24	17.145	0.032
AY 40	0.4055	24.58	4.45	20.260	0.010
AY 41	0.4057	25.02	4.53	19.243	0.071
AY 42	0.4024	23.77	4.34	17.962	0.056
AY 43	0.4045	23.77	4.32	17.662	0.030
AY 44	0.4023	22.97	4.19	17.137	0.009
AY 45	0.4059	16.65	3.01	16.988	0.018
AY 46	0.4039	23.48	4.27	17.422	0.015
AY 47	0.4055	22.16	4.17	17.649	0.051
AY 488	0.4060	6.93	1.30	12.934	0.018
AY 489	0.4067	6.92	1.30	12.852	0.044
AY 490	0.4042	4.56	0.86	12.168	0.043
AY 491	0.4085	5.93	1.11	11.255	0.083
AY 492	0.4035	4.39	0.83	10.163	0.016
AY 493	0.4048	6.63	1.25	10.457	0.026
AY 494	0.4033	5.66	1.07	12.287	0.038
AY 495	0.4056	7.71	1.45	12.070	0.050
AY 496	0.4026	5.60	1.06	12.303	0.058
AY 497	0.4078	5.51	1.03		

RUN C - continued

Acc. No.	Gms powder	Mls acid	%N	δ15N	S.D.
AY 498	0.4021	5.51	1.04	12.524	0.028
AY 499	0.4059	5.52	1.04	9.508	0.013
AY 500	0.4046	5.09	0.96	9.790	0.010
AY 501	0.4040	3.73	0.70	6.640	0.024
B.S.	0.4026	6.61	1.25	10.600	0.032
H.S.	0.1037	4.20	3.08	0.967	0.028

Acid standard = 735 (AY39 - AY46)

Acid standard = 763 (AY47 to end)

AY 39 - AY 47 Chathams

AY 488 - AY 501 Motupore (Papua New Guinea)

B.S. Bone Standard

H.S. Herbage Standard

RUN D

Acc. No.	Gms powder	Mls acid	%N	δ15N	S.D.
AX 859	0.4049	12.93	2.43	13.441	0.019
AX 860	0.4069	19.79	3.70	13.498	0.067
AX 861	0.4062	16.29	3.06	13.825	0.021
AX 862	0.4018	23.56	4.47	11.942	0.054
AX 863	0.4039	25.83	4.88	13.107	0.045

RUN D - continued

Acc. No.	Gms powder	Mls acid	%N	δ15N	S.D.
AX 864	0.4033	21.83	4.13	14.052	0.029
AX 865	0.4075	7.84	1.47	13.062	0.026
AX 866	0.4037	21.57	4.08	13.670	0.054
AX 867	0.4044	22.83	4.31	12.734	0.022
AX 868	0.4040	17.74	3.35	13.932	0.096
AX 869	0.4060	17.83	3.35	13.740	0.025
AX 870	0.4037	5.88	1.11	15.094	0.025
AY 48	0.4036	22.13	4.18	11.428	0.021
AY 49	0.4058	19.70	3.70	12.111	0.023
AY 50	0.4019	22.10	4.19	10.769	0.191
AY 51	0.4055	21.10	3.97	12.299	0.084
AY 52	0.4016	18.03	3.42	12.503	0.042
AY 53	0.4055	23.15	4.35	9.693	0.031
AY 54	0.4067	20.97	3.93	12.367	0.029
AY 55	0.4022	20.49	3.89	12.570	0.020
AY 12	0.4048	17.34	3.27	11.590	0.020
AY 23	0.4034	20.93	3.96	9.774	0.014
B.S.	0.4027	6.45	1.22	11.700	0.020
H.S.	0.1041	4.18	3.06	3.036	0.019

Acid standard = 763

AX 859 - AX 870 Easter Island.

AY 48 - AY 55 Rotoiti

AY 12 + AY 23 Atele repeats (first results were not reliable due to problems encountered during processing)

B.S. = Bone standard

H.S. = Herbage standard

RUN E

Acc. No.	Gms powder	Mls acid	%N	δ15N	S.D.
AY 35	0.4025	4.39	0.83	10.839	0.028
AY 36	0.4028	4.05	0.76	10.667	0.015
AY 37	0.4072	6.13	1.14	10.109	0.011
AY 38	0.4041	5.03	0.95	10.912	0.022
AX 989	0.4033	7.45	1.41		
AX 990	0.4049	5.63	1.06		
AX 991	0.4039	6.50	1.22	10.805	0.173
AX 992	0.4038	5.45	1.03	11.794	0.052
AX 993	0.4059	7.33	1.37		
AX 994	0.4062	5.23	0.98	11.053	0.252
AX 995	0.4079	5.14	0.96	11.164	0.079
AX 996	0.4024	6.32	1.19	10.154	0.064
AX 997	0.4027	5.02	0.95	10.243	0.116
AX 998	0.4052	5.83	1.09	10.632	0.049
AX 999	0.4036	6.24	1.18	10.617	0.041
AX 1000	0.4049	8.96	1.68	9.398	0.030
AY 64	0.4021	8.57	1.62	10.248	0.035
AY 70	0.4017	6.95	1.32	7.934	0.054

RUN E - continued

Acc. No.	Gms powder	Mls acid	%N	δ15N	S.D.
B.S.	0.4028	6.65	1.26		
H.S.	0.1051	4.15	2.998	0.956	0.074

Acid standard = 763

AY 35 - AY 38 plus AX 998 - AX 1000 Nebira

AY 64 + AY 70 Namu (Repeats. First results were unreliable due to problems encountered during processing)

B.S. = Bone Standard

H.S. = Herbage standard

RUN F (collagen)

Acc. No.	Gms powder	Mls acid	%N	δ15N	S.D.
AX 990	0.0507	5.07	7.60	10.762	0.036
AX 994	0.0503	4.62	6.98	11.241	0.028
AY 67	0.0516	10.83	15.98	12.118	0.032
AY 69	0.0553	9.96	13.71	12.011	0.028
AY 9	0.0508	8.94	13.40	10.879	0.027
AY 25	0.0509	9.49	14.20	9.393	0.012
AY 39	0.0515	11.88	17.57	16.455	0.208
AY 41	0.0525	12.38	17.96	18.704	0.027
AY 498	0.0506	7.63	11.48	11.364	0.041
AY 499	0.0509	5.47	8.17	10.981	

RUN F - continued

Acc. No.	Gms powder	Mls acid	%N	δ15N	S.D.
AY 51	0.0516	10.92	16.12	12.102	
AY 57	0.0512	7.20	10.70	11.904	0.034
C.S.	0.0514	9.33	13.82	11.747	0.039
H.S.	0.1026	4.03	2.98	1.316	0.043

Acid standard = 763

C.S. = Collagen Standard (produced from bone standard)

H.S. = Herbage Standard

STANDARDS

Acid standard:

The value for the acid standard is included in all runs. The acid standard was used to calculate the percent N in each sample processed. The value for the standard was obtained in the following way (the working shown is for the second standard, begun during Run C):

10ml of ammonium sulphate (50µgm N/ml was mixed with 0.5gm of MgO and distilled. 0.68 & 0.67ml of H_2SO_4 was needed to neutralise the blanks. Blanks were 0.0 µgm N/ml. The value for the H_2SO_4 standard was calculated by the formula:

µgm N(std.) / mls acid(std.-blank)

= 500 / 0.675-0.02

= 763.36 µgm N/ml H_2SO_4

The acid standard was then used to calculate percent N in the samples by the formula:

Acid Standard x mls acid(sample) / weight (sample) x 10^4

Bone Standard:

This was from the Otago University bone standard and was processed in each run, except Run F (Table 3.7) as a control.

Collagen Standard:

This was produced from the Otago University bone standard and was processed in Run F (Table 3.7) as a control.

Herbage Standard:

This was the herbage standard used as a control for all δ15N determinations at the Stable Isotope Unit. Percent N for the herbage standard should be around 3.00, and the δ15N value should be around 1.00.

EASTER ISLAND SAMPLES

1 50ml of the liquid was placed in the distillation flask.

2 0.5gm of magnesium oxide and 0.2gm of Devarda's alloy were added.

3 The samples were placed on the distillation line for 10 minutes and distilled into 5ml 20gm/litre boric acid.

4 The distilled liquid was titrated with an autoburette against sulphuric acid until the pH reached 4.9-5.00.

5 The pH was then reduced to 4 by manual addition of sulphuric acid.

6 The samples were then dried by the method used for the other samples and processed for δ15N determinations.

7 Because the amount of nitrogen was so small, the gas was trapped on molecular sieve pellets cooled in liquid nitrogen. At a low temperature the molecular sieve absorbs N_2 strongly and then releases it at room temperature.

8 The samples were read on the mass spectrometer.

The results, as shown in Table 3.8, were very similar to the δ15N determinations obtained from bone powder for the same samples.

Table 3.8: Easter Island tests to determine δ15N for soluble nitrates.

Acc.No.	δ15N	S.D.
AX 859	13.048	.049
AX 860	12.794	.018

For AX859, the determinations from the soluble nitrates and from bone powder were 13.048 and 13.441 respectively. For AX860, the determinations were 12.794 and 13.498 respectively. The similarity of these values suggests that the soluble nitrogen in the bone is isolated from the environment, and

> "it is a reasonable proposition to suggest that the soluble nitrogen in the bone powder is derived from the organic nitrogen in the bone" (Haystead pers. comm. 1988).

It was therefore concluded that δ15N determinations obtained from bone powder would accurately reflect the diets of the individuals concerned, and would not be affected by the site environment.

A second batch of samples from the Marianas, Lakeba and Sigatoka (Fiji) plus some animal samples were processed in subsequent runs. The results are presented in Table 3.9. Some

samples included in Run 2A are repeats of those processed in the first run (Table 3.7), either because of problems encountered with the mass spectrometer, or during processing.

Table 3.9: Second batch of samples processed for δ15N determinations.

RUN 2A			
Acc.No.	%N	δ15N	S.D.
AY 11	1.13	10.580	0.400
AY 57	0.59	12.852	0.210
AY 58	0.51	10.275	0.067
AY 60	0.28	14.909	0.093
AY 39	4.41	16.080	0.005
AY 494	1.05	13.185	0.045
AY 495	1.44	12.702	0.045
AY 496	1.04	12.223	0.040
AY 497	1.02	12.190	0.040
AX 868	3.31	14.420	0.050
AY 50	4.21	12.320	0.015
AX 989	1.35	11.282	0.015
AX 990	1.09	12.836	0.054
AX 993	1.35	11.906	0.027
AX 994	0.96	11.018	0.013
AX 997	0.96	11.628	0.023
AY 39(Coll)	16.80	16.108	0.009
AY 499 "	7.33	10.981	0.063

RUN 2A - continued

Acc.No.	%N	δ15N	S.D.
AY 51(Coll)	15.65	12.102	0.018
AY 57 "	10.35	12.436	0.034
Coll. Std.	13.71	11.568	0.093
Bone Std.	1.25	12.752	0.033
Herb. Std.	2.97	2.300	0.018

RUN 2B

Acc. No.	%N	δ15N	S.D.
AX 002/3	1.88	7.983	0.031
AX 004/5	1.01	21.688	0.040
AX 006/7	2.02	5.588	0.027
AX 008/9	4.42	18.130	0.026
AX 852	3.95	8.704	0.015
AY 778	2.09	12.391	0.021
AY 779	1.77	11.852	0.013
AY 780	1.44	9.967	0.034
AY 781	0.91	11.529	0.031
AY 782	1.11	13.244	0.025
Bone Std.	1.21	11.646	0.011
Herb. Std.	3.13	4.268	0.059

AX 002/003 - AX 852 = Animal samples

AY 778 - AY 782 = Marianas

RUN 2C

Acc. No.	%N	δ15N	S.D.
AY 784	0.32	11.718	0.009
AY 785	1.76	11.269	0.012
AY 785b	0.55	12.741	0.260
AY 786	2.85	10.111	0.051
AY 787	0.46	9.755	0.110
Bone Std.	1.22	11.046	0.017
Herb.Std.	2.41	1.098	0.011

AY 784 - AY 786 = Lakeba

AY 787 = Sigatoka

The full results of the nitrogen, carbon and sulphur isotope analysis will be presented in Chapter five. Prior to that, the diets of the study groups as suggested by existing archaeological evidence will be considered in Chapter four, in order to form some expectations of those results, and to provide a basis from which to evaluate the findings of the present study.

CHAPTER FOUR

THE DIETS OF THE STUDY GROUPS AS SUGGESTED BY EXISTING ARCHAEOLOGICAL EVIDENCE

INTRODUCTION

Before presenting the results of the multiple isotope analysis, some consideration will be given to the dietary reconstructions, for the various populations studied, which can be developed from archaeological investigations. Where appropriate, ethnographic information will also be referred to. This approach will serve to highlight the aspects of the diets which could be expected to be identified by the isotope analysis.

EASTER ISLAND

The individuals from Easter Island are twelve of 298 recovered by the 1981 Easter Island Anthropological Expedition (Owsley, Miles and Gill 1986:416) and were obtained from the collection established by that expedition for the Easter Island Museum. Several types of sites are represented in the sample, including caves, ahu and burial cysts (avanga), and what has been commonly called a wedge shaped ahu (Ahu poe poe) which is mainly a place of interment (Seelenfreund 1986). Radiocarbon dates for the 1981 series yielded post AD 1680 dates, and this was

confirmed by 66 obsidian hydration dates from the caves and structures containing the burials (Owsley, Miles and Gill 1986:416). The individuals used in the present study are all from the late protohistoric (AD 1722-1868) and early historic (AD 1870-1880) periods (Seelenfreund 1986).

Little archaeological evidence pertaining to the diet of this population is available, but some impressions of the protohistoric diet of Easter Islanders can be gained from ethnographic descriptions. Metraux (1971:151ff.) emphasises the importance of horticulture to the contact population of Easter Island. Many of the first visitors reported numerous well-ordered plantations where crops were grown year-round. Some of the more important staple foods were kumara (Ipomoea batatas), several varieties of yam, bananas (Musa sapientum) and sugar cane (Saccharum officinarum). Several wild plant foods were gathered and were particularly important during times of famine (Metraux 1971:160). The importance of sugar cane was noted by Forster in 1777 when he remarked that sugar cane "...contained a very sweet juice which the inhabitants presented to us very frequently, and particularly whenever we asked for something to drink" (cited in Metraux 1971:156). Sugar cane was also used to quench the thirst during journeys and consumed in great quantities during feasts. Owsley, Miles and Gill (1986) studied dental caries in the entire skeletal sample excavated in 1981, and found a high incidence of caries which they interpreted as being partly due to the cultural practice of sucking sugar cane to relieve thirst (ibid.:420). If consumption of sugar cane was high in the portion of the skeletal

sample analysed in the present study, the carbon stable isotope results should identify this C4 plant as an important dietary component.

A variety of marine foods was included in the diet of the protohistoric Easter Islanders. Four edible varieties of seaweed were gathered and eaten on the shore (Metraux 1971:161); shellfish, crabs, sea-urchins and other molluscs were traditionally gathered by women from the rocky shore, reef environment (ibid.:191); octopuses were caught with bare hands and crayfish and marine eels were trapped in nets and snares (ibid.:190). According to island folklore turtles were valued in ancient times and this is supported by the occurrence of turtle watchtowers, or tupa, along the shore near ancient settlements (ibid.:189). Judging from the abundance of fish hooks in caves, the common representation of fish in petroglyphs and the numerous fishing episodes in folklore, fishing was important to these people. However, in an 1866 account, Eyraud stated that fish had an insignificant place in the diet and was considered a great delicacy, and Geisler noted in 1883 that next to weapons, fishing implements were the most valued artefacts (ibid.:172). Metraux (ibid.) notes that since the time of Captain Cook the Easter Islanders have complained of the scarcity of fish, and this is particularly apparent near the island where fishing is not good, probably because Easter Island has no protecting barrier reef. Deep sea fishing would have been largely precluded in prehistory by the scarcity of wood for boat building. The scarcity of fish in prehistory is further suggested by the fact that sanctions

operated to limit fishing at certain times, forbidding it completely during winter (July-September). Ayers' (1979) analysis of Easter Island fishing confirmed that while marine-related technology has tended to reflect off-shore, deep water angling for prestige fish, inshore angling and other capturing methods such as netting, spearing, snaring and hand collecting had more subsistence impact (ibid.:88). This evidence suggests that, while the prehistoric and protohistoric Easter Islanders held fishing in high regard, in practice the amount of seafood consumed would not have been as great as might be suggested from an analysis of prehistoric fishing technology. Therefore it is expected that the stable isotope results will reflect a mixed diet, possibly with a heavier emphasis on terrestrial foods.

FIJI - LAKEBA

Lakeba is the largest of the Lau Islands which lie to the north east of Viti Levu in Fiji and occupy an intermediary position between Fiji and Tonga. The four individuals from Lakeba were excavated by Best between 1976 and 1978 from two adjacent sites on the north-west coast of the island. Both sites, although now at least 180m inland, appear to have been on the coast when first occupied around 3,000 years ago (Best 1984:41). Lakeba is skirted by a reef lagoon, which is up to 1100m wide in the north, and these sites were well situated to take advantage of the lagoonal-reef resources.

The Wakea site (101/7/196) is a large early open site on the coastal sand flats, today part of a rough plantation planted in breadfruit, coconut and voivoi (pandanus caricosus) (ibid.:89). Two burials from this site were used in the present study, both from the lower levels of layer B which was relatively unaffected by recent agricultural practices, the depth of most cultivation activities extending only to the A/B boundary (ibid.:92). Both of these individuals were excavated from Trench 28, the first (AY82) being an almost complete burial. The second (AY784) was recovered from layer B8, a few centimetres below AY82. This individual had been buried in articulation but had apparently been disturbed, to the extent that some bones from this individual were present in layer B7 (Houghton 1984:A82). C14 dates showed that the site was first occupied between 760 and 1020 BC (Best 1984:102). The earlier burial, AY784, has been estimated to date between 600 and 900 BC (Best 1987a), and AY82 is slightly more recent.

The Qaranipuqa site (101/7/197) is a large rock shelter eroded out of the base of the limestone cliffs, lying immediately to the south of the Wakea site and reflecting a similar length of occupation. The bone material from this site was extremely fragmented and it was not possible to get an accurate determination of the number of individuals present (Houghton 1984:A84). Two samples of bone were used for the present study, one (AY785) from layer M, dating to around 2-300 BC, and the other (AY786) from the top of the rock shelter, dating somewhere within the last 500 years (Best 1987a). One bone from individual

AY785 had been burnt, as had several bones from this site, and this was processed separately as AY785b, to eliminate any possible effect on the isotope ratios from burning. As no cultural deposits were encountered from between c 1700 and 900 BP (Best 1984:78), there is no possibility of disturbance in the site over this time period, and despite the fragmented nature of the material, it can be assumed that the two individuals from this site are temporally separated. Therefore it should be possible to detect with stable isotope analysis any changes in diet which may have occurred between c 2000 and 500 years ago in this area.

Evidence pertaining to early diet from both sites indicated a heavy reliance on sea foods, particularly fish from the reef/lagoon environment, with almost complete exclusion of pelagic species (ibid.:507). The sole cultural evidence for fishing technique was the presence of pearl shell fishooks in the layers for the first 1000 years of settlement. Best (ibid.:506) suggests the use of nets and poisons as alternative fishing methods, as the reef/lagoon species represented in these sites are often caught by such methods in the Pacific today. Shellfish was also important to the early inhabitants, with later layers showing evidence of heavy and continued exploitation, while turtles were important food items at all times (ibid.:539).

The nearby forest environment was also exploited and forest birds, dominated by megapodes, pigeons and doves are abundant in early assemblages (ibid.:528). Best finds little evidence for

horticulture in the early Lapita period which ends c 500 BC, although two pearl shell blades identified as "probably hoes" belonged to this period, and possibly a cowrie shell scraper (ibid.:642). The domestic fowl, Gallus gallus, was present in both sites by c 660-840 BC, but Best feels it is not possible to state with certainty whether it was introduced with first occupation, and if it was its contribution to the economy was small (ibid.:532).

Environmental analyses showed that beginning around 2000 BC large-scale burning occurred on Lakeba and this is attributed to slash and burn gardening practices (ibid.:563). A move inland between c 2500 BP and 2100 BP is also interpreted as being indicative of the beginnings of horticulture, as more land was utilised for gardening. The dog and the pig, the latter generally taken to be a correlate of agriculture, do not appear in these Lakeba sites until c 1000 AD (ibid.:544), but this does not necessarily mean that horticulture was not being practised. Isotope results could be expected to reflect a change in diet, towards a greater emphasis on terrestrial foods, from around 2000 BP, possibly earlier. Before this, according to Best

> "it is perfectly possible for marine resources to have formed the base of the colonisers' diet for the first 500 years of occupation" (ibid.:653).

Houghton's analysis of the early burial (AY82) identified advanced dental caries which caused the loss of several teeth,

but there was little evidence of salivary calculus or periodontal disease. His reconstruction of the Lakeba diet, from all teeth studied, suggested that quantities of fish, soft fruits and vegetables were eaten, but little fibrous material was included in the diet (Best 1984:538). The high incidence of caries in AY82 is unusual for someone who supposedly ate large quantities of sea foods and smaller amounts of carbohydrates. The stable isotope analysis should show whether Houghton's reconstruction of the diet is correct, and if it is the caries may have been caused by factors other than diet.

FIJI - SIGATOKA

The individual (AY787) from Sigatoka was excavated by Best in 1987 from the Sigatoka dune site (VL16/1) situated on the west side of the Sigatoka River mouth, on the south coast of Viti Levu. Eight burials were excavated from three coral mounds, and another five fragmented burials from just outside the mounds. Four burials to the west of the main excavation area were in various stages of erosion and two were thought to be quite recent 'casual' interments (Best 1987b:4). Preliminary determinations of nitrogen and hydroxyproline content were obtained for three burials, F.C.1 (excavated by Clunie and Parry), West 1 and West 4 (one of the apparently recent burials) in an attempt to find their relative ages. Results suggested that West 1, the highest of the isolated individuals, was older than F.C.1, one of the coral mound burials, and that F.C.1 was younger than West 4

(ibid.:5). Although this was contrary to expectations, Best suggests that this "could indicate that the coral mound burials are relatively recent events, and do not belong to the layer on which they were found" (ibid.). Alternatively, he suggests that differences in the burial environments could have affected the results. This seems a more likely explanation. A C14 date of 1870 +-70 BP (WK 996B) was obtained for F.C.1, which gives a time range of 5 BC to AD 240 (ibid.). A δ13C value of -15.9 per mil was also given for F.C.1, which indicates that this individual ate a significant amount of sea foods. The West 1 burial, identified as being older than F.C.1, was made available for stable isotope analysis. The results of this analysis could be expected to show a stronger emphasis on sea foods if this individual is older. A high terrestrial diet would tend to suggest that West 1 is more recent than F.C.1, as it would be difficult to argue for a shift away from terrestrial foods in Fiji c 2000 BP.

MARIANAS - SAIPAN AND TINIAN

The individuals from the Mariana Islands of Saipan and Tinian will be discussed together here because of the close proximity of the two islands, and their overall cultural similarity. Five individuals, two from Saipan and three from Tinian, were selected for stable isotope analysis from a number of skeletons being studied at the University of Otago.

The first Saipan skeleton (AY781) was recovered from the Grotto site, SLH (Saipan Latte House), on the northern end of Saipan, in a salvage excavation after construction work destroyed a Latte House and partially exposed a burial in which at least two individuals were represented (Pietrusewsky and Batista 1980:18). A radiocarbon determination carried out on longbone remains from individual SLH-1 (AY781) gave a date of 720+-100 BP (UCR-1232D) (Russell 1988). The second Saipan skeleton (AY782) was recovered from site MHS (Mariana High School), and is one of at least five individuals recovered during a salvage excavation after the site had been disturbed during tree-planting (Pietrusewsky and Batista 1980:14).

The three individuals from Tinian were all excavated from shallow pits cut into the bedrock at site TLH (Tinian Latte House) (Pietrusewsky and Batista 1980:4). A radiocarbon determination from two femora from burial TLH-3 (AY779) gave a date of 313+-70 BP (UCR-1231) (Russell,1988).

There was no direct information available from the excavations which could be related to the diet of these five individuals, but the skeletal analysis gives some indication of the types of foods eaten. The Saipan individuals had moderate degrees of caries and slight tooth wear. The teeth of AY782 were stained from chewing Betel nuts and alveolar resorption was quite marked on the lower teeth (Pietrusewsky and Batista 1980:16). Betel nut chewing may cause alveolar resorption, while a fairly rough diet may help prevent it because it exercises the gums (Roy

pers.comm. 1988). This material has recently been studied by Roy (1989) and her analysis of AY781, a male aged between 18 and 25 years, revealed that "both clavicles had costo-clavicular sulci", (ibid.:Appendix 3:347) suggesting that this individual had made strong downward usage of the arm and shoulder. This particular condition has been associated with paddling canoes (Houghton 1980:116). Two of the Tinian people, AY778 and AY780, had higher rates of caries, tooth wear and other dental conditions (Pietrusewsky and Batista 1980:6,13), but this may have been related more to the ages of these women (late 30s to 40s, or possibly older) than to their diet. The third individual, AY779, identified as possibly female, aged 12 to 15 years, had very little caries or tooth wear (Roy 1989:Appendix 3:350). Again, this is probably a function of her age rather than her diet.

Judging from the condition of the teeth, the diet of these people was not particularly abrasive, but contained significant amounts of carbohydrates which can lead to caries. Ethnographic descriptions of the Mariana Islands give some indication of the range of foods which may have been eaten by these people. On the island of Guam, approximately 200km south west of Tinian, the traditional foods which were being cultivated in the 1500s were taro, breadfruit, yams and to a minor extent rice, while fadang (Cycad nuts), arrowroot and bananas were important stand-by foods in times of scarcity or famine (Pollock 1986:122). While rice was probably not grown on Saipan and Tinian, the range of plants gathered and cultivated was probably similar. According to Pollock (ibid.:127), sugar cane may also have been present on

Guam at contact in the early 1500s, so the possibility that it was eaten on Tinian and Saipan should be considered. An indication of C4 plant consumption from the results of the stable isotope analysis could confirm this. Interpretation of the results could be complicated however, by the presence of a fringing reef along the length of the western coast of Saipan, and some small stretches of reef around Tinian.

Hanson (1989) recently (after the present research was completed) studied nine individuals from the Duty Free Site, Garapan Village, Saipan, obtaining carbon and nitrogen isotope values from four of these people. The carbon values for these people ranged from -18.9 to -18.5 per mil, revealing a high dependence on terrestrial sources for all individuals, which was unexpected considering the presumed availability of marine resources (ibid.:39). The nitrogen values ranged from 6.1 per mil for an old male adult to 9.2 per mil for a young male aged around 22 years, which was interpreted as indicating that reef foods were important in the diets of the three older individuals (one male and two females), but less important for the younger male. It was suggested that these results could be interpreted as reflecting "a greater dietary emphasis on a pelagic/reef-fish mix in the young male compared to a reef-fish/mollusc mix in the older adults" (ibid.:42). This identification of possible age- and sex-specific differences in the marine component of the diet is significant, and the possibility of a similar pattern being reflected in the results of the present study will be considered during the interpretation of results.

NEW BRITAIN - WATOM

The Watom individuals were recovered from the Kainapirina deposits, or Site 8, in the Rakival village on Watom Island, which lies about 4 miles to the northeast of the Gazelle Peninsula in New Britain. AY56, AY57 and AY58 were recovered by Specht during excavations in 1966, while AY59 to AY61 were recovered by Green, Anson and Specht in 1985. Lapita occupation of the Rakival area has been well documented (Green and Anson 1987) and C14 determinations suggest that the Kainapirina occupation layers span the age range between c 400 BC and AD 100 (ibid.:124), with the interments taking place soon after a short initial domestic occupation.

Evans (1987) studied the teeth from two of these individuals, AY57 and AY60. Some fibrous or gritty input into the diet was suggested by the degree of tooth wear, and a low incidence of caries was thought to have been due either to high protein intake from marine food or to low sample size (ibid.:98). While these conclusions may be of some help in interpretation of stable isotope results, more direct dietary evidence is needed.

Evidence pertaining to diet is not extensive but what is available is sufficient to predict what the isotope analysis should show. Specht (1968:125) reported that marine shells from the beach and reef environment were the commonest objects excavated, followed by the bones of pig, marine fish, and birds, including the domestic fowl Gallus gallus. This was recovered

from the adjacent Site 6, or Maravot. Some botanical material described as nutshells and root and stem wood was excavated, with the majority of nutshells being from Canarium, with some identified as Terminalia sp. and coconut shell fragments. Green and Anson (1987:125) recovered both bone and shell from layer C2, the lowest occupation layer at Kainapirina. Identifications of the fishbone revealed a characteristic Lapita emphasis on inshore fishing, indicated by the presence of the families Scaridae, Sparidae, Labridae, Lutjanidae and Serranidae, all common in a reef/lagoonal environment (ibid.). Shellfish were predominantly intertidal bivalves and browsing molluscs such as Turbo, Trochus and Tridacna species, with the remainder being intertidal predatory and scavenging molluscs, suggesting that "clearly a beach and reef zone much like that in front of Rakival today was the source for the shellfish" (ibid.:126). This suggested heavy reliance on fish and shellfish from the reef environment would be expected to show up in the nitrogen isotope results, but the determinations from carbon and sulphur should clarify any ambiguities. Specht's identification of pig in early layers was confirmed by Green and Anson who point out that the pig and chicken are both well known from Lapita sites (ibid.:125). In addition bird, turtle, reptile, possibly lizard and crab bones were identified. While the presence of the pig and the chicken has been claimed to be an indicator of horticulture (Kirch 1979b) this may not necessarily be the case. However, whether or not horticulture was significant for these Watom Islanders, the evidence available suggests that there was a significant terrestrial component in their diet. The isotope analysis should

be able to confirm this interpretation.

NEW ZEALAND - CHATHAMS

The individuals from the Chathams consist of two groups and have all been identified as Moriori according to burial custom (Horwood 1988:86). Four individuals, AY44 to AY47, were excavated in 1975 by Sutton from the Waihora site (NZAA site number C240/283) in the Point Durham area on the south west coast of Chatham Island. The remaining five individuals are from unknown locations on the Chatham Islands, having been recovered between 1892 and 1894 and deposited in the Otago Medical School (ibid.). There is no information available for these five individuals which could lead to the reconstruction of their diets. Therefore any discussion of the diet of the prehistoric Moriori of the Chatham Islands must be based on the information recovered by Sutton from Waihora and on subsequent analyses of his results.

The Chatham Islands lie 970km east of Banks Peninsula on New Zealand's South Island, at a latitude of 44° S. Both atmospheric and oceanic convergences occur in the Chathams area, resulting in a temperate climate which is characteristically overcast, windy, low in rainfall and sunshine hours and high in humidity (Sutton and Marshall 1980). These climatic conditions, which may have been more severe in the prehistoric period (Sutton 1979), precluded the cultivation of kumara and other traditional

Polynesian staples. According to Sutton (1979:44), "in the absence of horticulture, terrestrial food resources were limited to small medium-sized birds, the Polynesian rat, a few freshwater fishes and a group of natural plant foods, most of which were small and fibrous".

The Waihora site (NZAA site number C240/283) has been identified by Sutton as a village in association with a range of contemporary specialised middens, which have been radiocarbon dated to the period between AD 1550 and 1650 (ibid.). The excavation of the inland middens revealed seasonal exploitation of broadleaf forest birds, including the 'mutton-birding' of the Taiko (Pterodroma magentae). Coastal middens reflected two specialised activities - shell-fishing and sealing - and the excavation of an extensive seal butchering site (NZAA site number C240/689) on a low river terrace 300m north of Waihora revealed that fur seals were hunted continuously throughout the year. From a quarter of the site 112 fur seals, 12 elephant seals, eight leopard seals and two New Zealand sea lions were recovered (Sutton and Marshall 1980:42).

The Durham area today is rich in marine resources with a high density of fish in the inshore zone and abundant littoral resources around the intertidal platform. Sutton (1979) considers that the prehistoric inhabitants of the area had access to a similarly rich range of resources and were primarily coastal hunters, exploiting in descending order of importance seals, fish, marine birds and shellfish (ibid.:236). Beyond claiming that

terrestrial food sources were of minor importance, Sutton feels that further detailed reconstruction of diet is precluded by very considerable sampling problems and the loss of organic materials in the archaeological sites (ibid.:228). Archaeological evidence of two terrestrial plant foods - the karaka nut (Corynocarpus laevigatus) and fernroot (Pteridium esculentum) - was found in Durham sites but none of the technological evidence found could be directly related to their collection (ibid.:259).

Ethnographic records suggest that these terrestrial plants were of considerable importance, particularly the karaka which was traded for sealskin capes and consequently ownership of karaka stands was a noteable form of wealth (Anderson 1981:148). The pith of the mamaku tree fern (Cyathea medullaris) was regarded as a prestige food (ibid.), and while important socially it was probably somewhat rare and therefore not consumed in large enough quantities to be reflected by isotope analysis. However, the role of fernroot in the diet can be explored. Ethnographic observations of fernroot being semi-cultivated (ibid.) seem to be supported by pollen analysis which suggests burning of vegetation on swamps and exposed slopes of the Durham area around AD 1685 and AD 1755 (Sutton 1979:21). The burning of the highly inflammable tarahinau forest (D. arboreum) may have been undertaken by the prehistoric inhabitants of the area to encourage the growth of bracken fern (ibid.:22). Anderson (1981) feels that the importance of plant foods in the Moriori diet has been underestimated and has criticised Sutton and Marshall (1980) for ascribing food choices primarily to food quality. He

considers other aspects, especially food availability, to have been important (Anderson 1981:154). The relative importance of fern root and other terrestrial plants can be explored in the present study.

Analysis of the burials from Waihora has produced evidence of extreme wear on some teeth, and loss of others, with evidence of the 'fern-root plane' in Burial 1 (AY44). This suggests "a rough diet containing plenty of gritty shellfish and tough fibre such as fern-root, and possibly a quite marked seasonal variation, with food being quite scarce at certain times" (Houghton 1976:7). Horwood (1988:114) has found little evidence for consumption of significant quantities of vegetable foods or filter feeding shellfish by the Waihora people, and tends to support Sutton's view that these people were primarily hunter gatherers exploiting mainly seals and marine birds.

Multiple stable isotope analysis can determine the quantitative role of marine and terrestrial foods in the diet of the Point Durham Moriori, and has the potential to confirm or reject the interpretations of Sutton, Anderson and Horwood.

NEW ZEALAND - ROTOITI

Little is known about the eight individuals from Lake Rotoiti in the central North Island of New Zealand. Thought to have been buried prior to 1860, they were recovered from a pit on

a pa site on the northern shores of the lake. Although archaeological evidence related to diet is sparse for this area, several ethnographic reports contain useful information on the traditional foods eaten by the Rotorua-Rotoiti people (Best 1902; Colenso 1868,1880; Te Rangi Hiroa 1921).

Colenso (1880:10) recounted visiting the Rotorua lakes, an area renowned for its fine and prolific kumara crops, attributed to the extra warmth of its heated volcanic soils. Other staple cultivated vegetable foods included the taro and gourd, while a wide variety of uncultivated fruits and vegetables were gathered and used in season. Among these were the fern root, the sow thistle (puwha), ti (Cordyline sp.), karaka kernel, the heart of nikau palm, and the pollen of raupo flowers which was mixed with water and baked. Some commodities from the inland forests may have been exchanged with coastal tribes for marine fish and seaweeds. Colenso (1880:29) writes "I have known baskets of it [seaweed] dried, to be taken inland to Taupo and elsewhere....as a suitable present, in exchange for the delicacies of the interior forests, like the karaka kernels", and this may well have applied to the Rotoiti area which lies approximately 50km from the Bay of Plenty. Some indication of marine foods in the diets of these Lake Rotoiti individuals could therefore be expected in the stable isotope results.

The Tuhoe people of the Urewera area, to the south of the Rotorua lakes, exploited numerous species of forest birds, including kiwi, weka, kaka, koko (tui), kakapo, kereru and

several smaller birds. The kiore, or rat, was one of their principle animal foods and was trapped in large numbers, with both rats and birds being preserved for use in times of scarcity (Best 1902). Most of these species would have been available in the Rotoiti area and could have been important components in the diet there.

In his description of Maori food supplies of Lake Rotorua, Te Rangi Hiroa (1921) includes three freshwater fish, the inanga (Retropinna richardsoni), the toitoi (Gobiomorphus gobioides) and the kokopu (Galaxias fasciatus), which were caught in season using nets (kupenga). The koura, or freshwater crayfish (Paranephrops) was found in nearly all the freshwater streams of the region, but "could nowhere be found in such quantities as at Rotorua" (ibid.:435). Koura were caught either by dragging a paepae, or dredge-net, across the lake bottom; or in Tau Koura, bundles of fern lowered into the lake which attracted the shelter-seeking crayfish, and sometimes the toitoi. These fern bundles were called taruke by the Lake Rotoiti people and Te Rangi Hiroa (ibid.:440) suggests that this name was probably adopted from their coastal relatives. The kakahi, or freshwater mussel (Hyridella menziesi) was one of the most prized food items of the Rotorua people, being available all year round although of better quality in winter. It was obtained by dredging from canoes with a Mangakino, or dredge rake, which consisted of a framed net attached to a long handle. Although not all of these freshwater animals are specifically mentioned as being available from Lake Rotoiti, the close proximity of the two lakes suggests

that they probably were. In any case, the people buried at Rotoiti could be expected to have had access to these foods and to have included them in their diet to some extent. The freshwater mussel component of the diet has been revealed by trace element analysis of the Rotoiti individuals (Horwood 1988:). High zinc and strontium levels were obtained together, and this is a pattern likely to reflect the consumption of a significant quantity of nuts and/or shellfish.

The Rotoiti individuals had access to a wide range of vegetable foods, both cultivated and uncultivated, forest birds and rats, and freshwater fish, shellfish and crustaceans. Some contact with the coast is suggested and this may have included food exchange. The stable isotope results are expected to indicate a predominantly terrestrial diet, but some marine component may be indicated.

PAPUA NEW GUINEA - MOTUPORE

Motupore is an island approximately 16km to the east of Port Moresby in Bootless Bay, Papua New Guinea. It lies 650m offshore, within the barrier reef which protects Bootless Bay from heavy seas, and is surrounded by a fringing reef (Allen 1977;1978). From 1970 a series of excavations were carried out on Motupore Island as part of a training programme for prehistory students from the University of Papua New Guinea (Allen 1978), and the 14 burials used in the present study were

made available from the 40 excavated between 1972 and the first 1975 season.

Radiocarbon analysis of 22 samples suggested that Motupore was occupied permanently and continuously for a period of 450 years, from the beginning of the 13th century AD until well into the 17th century AD (Allen 1978:51). Allen (ibid.:53) has suggested that these people were the ancestors of the Motu people who inhabited the coastal regions when first European contact was made with the area in the 1870s. Although dates for individual burials were not available for this study, similarities between burial practices in both early and late periods suggested cultural continuity (Allen 1977:443). A similar continuity was apparent in the pattern of exploitation of food resources throughout the occupation period (ibid.:444). This evidence for continuity suggests that the results of the stable isotope analysis can be expected to be similar for all the Motupore individuals. If this proves not to be the case, however, the possiblity of differences being based on sex or status should be considered, although this will not be able to be confirmed without relevant age/sex information.

Faunal remains reflect the exploitation of a relatively narrow range of food animals, with a heavy emphasis on marine animals and fish from inshore shallow and reef environments. This reef component can be identified by isotope analysis. Turtle remains, probably green turtle (Chelonia mydas) and/or hawksbill (Eretmochelys imbricata), were plentiful throughout the deposits,

as were estuarine molluscs, while lower frequencies of dugong (Dugong dugon) and two bones from saltwater crocodile (Crocodylus porosus) were recovered. A separate excavation at the same site by Groube and Pernetta revealed a more continuous, but low level, exploitation of saltwater crocodile at Motupore (Allen 1986:66). Apart from one rodent and one lizard vertebra, the only wild terrestrial animal identified in the assemblage was the agile wallaby (Macropus agilis) with 158 individuals represented. Allen has suggested that this concentration of wallaby provides evidence for food exchange with the inland Koita people, in whose territory this species of wallaby is common. The basis of the argument is that if the Motupore inhabitants were hunting these animals themselves, other common savannah species could be expected to be present in midden remains. As they are not present, Allen suggests that the Motupore people received the wallaby from inland groups in exchange for fish and other marine animals, and pottery which was manufactured in quantity on Motupore (Allen 1977:444). However, if the wallaby remains were laid down throughout the occupation period, over at least 450 years, the number of individuals would hardly be enough to reflect extensive trade. Bulmer (1979:19) suggests that the lack of other animals in midden remains does not prove that they were not hunted, but simply shows that if they were caught they were eaten elsewhere. Whether the wallaby were obtained by trade or not, these animals are present at Motupore in sufficient numbers for their consumption to affect the isotope results from the bones of the people who ate them, particularly if they were consumed within a short period of time. Some indication of

terrestrial foods could be expected if the wallaby were a significant component in the diet.

However, it is quite probable that other terrestrial foods contributed to the Motupore diet. Small amounts of dog and pig were recovered from the site, although ethnographic observations suggest that the Motu did not eat dog (Allen 1977:444). Pig may have made some small contribution to the diet. While Motupore itself lacked garden land and suitable water supplies, some areas on the mainland adjacent to Motupore could have been cultivated in conjunction with the wet season rains (Allen 1978:48). Ethnographic reports of the 1870s describe gardening as being important to the coastal Motu people for about four months of the year, with yams, bananas and coconuts being the main crops (Bulmer 1978:41). In addition, a variety of bush foods were available on the mainland in the immediate vicinity of Motupore (Allen 1978:48) and may have been gathered by the Motupore people.

The Motupore diet, as suggested by the faunal remains from the site, appears to have been predominantly marine based. However, terrestrial foods from several sources may have made a significant contribution to the diet. With stable isotope analysis it should be possible to determine the relative importance of marine and terrestrial foods in the diet of the Motupore people.

PAPUA NEW GUINEA - NEBIRA

Nebira is situated on the inland river plains, to the north-west of Motupore and about 10.5km from the coast. Several archaeological sites have been located at Nebira which is a double-peaked hill overlooking the Laloki River (Bulmer 1978:119). The individuals from Nebira were some of those excavated by Bulmer from site ACJ (formerly Nebira 2, or POM22B) in 1968 and 1969. Although the stratigraphy was difficult to discover and interpret (ibid.:126), two groups of burials have been identified, the earlier one probably dating to between AD 1000 and 1100, and the later group to between AD 1240 and 1500.

Nebira is well sited for the exploitation of a wide range of food resources. The terraces of the Laloki river provided valuable garden land, a commodity which was comparatively scarce in the Port Moresby area (Bulmer 1978:17). Across the river from Nebira the lowland forest harboured a wide variety of animals, in particular wallabys, bandicoots, rats and a variety of birds (ibid.:31). About 2km to the west the Waigani swamp provided opportunities for the hunting and fishing of several species, including crocodile, catfish, freshwater mussels and prawns, ducks and other wild fowl (ibid.:28). Ethnographic reports suggest that the Koiari people in the Nebira region maintained trade relationships with the coastal Motu people (ibid.:41), and this sort of exchange may have occurred in prehistory. As discussed above, Allen has suggested that the Motupore people

supplied marine foods to the inland Koiari people, in exchange for wallabys and garden produce.

Analysis of cultural materials excavated from Nebira revealed marine shells in all periods of occupation, the majority of which were species from coral reef and rocky shore environments. Small proportions of estuarine gastropods and bivalves were present throughout the site, but there was no indication of the use of brackish or freshwater shellfish. The heaviest concentration of shells was in the top two layers, above the burials and likely to have been deposited after the 15th or 16th centuries AD (ibid.:169). This suggests that the coastal connection may in fact be fairly recent and, if this is correct, the stable isotope analysis of the Nebira burials would give little indication of a marine component in the diet. However, several of the shellfish species represented at Nebira were from a coral reef environment. If these shellfish were being eaten in quantity the nitrogen isotope values would suggest a terrestrial diet, and this will have to be taken into account in the interpretaion of results.

Small fragments of animal bones, representing some 50 individuals from at least 13 species, were scattered throughout the excavation. Bulmer (ibid.:170) suggests that the bones may have been fragmented because they were eaten by free range pigs and/or dogs, or alternatively because food refuse was disposed of away from the site. She tends to favour the second explanation as there was no evidence of the burials having been disturbed by

animals. If this is correct, the faunal remains from the site may not represent the complete diet of the people who were buried there. Of the animal remains that were recovered, the most common species were pig, dog and wallaby, followed by rats, birds, bats, goat (thought to have been a prehistoric introduction) and a little fish. Dugong and turtle were possibly present. The dog remains were teeth used as ornaments in burials and were probably not eaten (ibid.:172).

No archaeological evidence for the use of plant foods was recovered but the location of the site and ethnographical evidence suggests that significant quantities of vegetable foods may have been eaten. At least 35 wild plants in the Port Moresby area were edible, including mangrove fruit, breadfruit, cordyline root, pandanus fruit, nuts and a range of wild tubers, including a variety of yam (ibid.:21). A more definite indication of the importance of terrestrial foods can be gained from the stable isotope analysis, but whether the source was from meat or vegetable foods may not be obvious. Horwood (1988) studied the diet of these Nebira people using trace element analysis, concluding that a wide range of resources was exploited from forest, river, grassland and coastal environments (ibid.:152). Relatively high magnesium levels suggested that a significant amount of berries and/or nuts were included in the vegetable component of the diet (ibid.). Although trace element analysis has the potential to distinguish between meat and vegetable foods, Horwood's results for this site did not clearly indicate the relative proportions of these foods in the Nebira diet. She

concluded that the Nebira diet was from mixed terrestrial and marine sources (ibid.:153).

Pietrusewsky's analysis of the Nebira burials revealed that the population as a whole had good dental health, with low incidences of caries and dental absesses and moderate dental wear. This may have been due to the low age at death (25.5 years) of this population, rather than as a result of their diet. 36% of the 26 individuals studied showed evidence of betel-nut chewing (Bulmer 1978:166). Evans (1987) analysed the Nebira teeth and interpreted the degree of caries as minimal and mild, suggesting that "the carious lesions present in this group...may be from eating horticultural foods of a soft and sticky nature" (ibid.:97). Other components of diet implied by the condition of the teeth were either plant foods which were not fibrous or gritty, or a lot of meat which is not very fibrous.

SOLOMONS - NAMU

The site of Namu is situated on the island of Taumako, a Polynesian outlier in the south-east Solomon Islands. Namu is essentially a burial ground around 300 years old, from which over 200 skeletons were recovered by Leach and Davidson in 1977. Twenty one individuals from Namu were selected for the present study, and the bone standard is comprised of Namu bone (see Appendix 2).

Little economic material was present in this site which is probably a reflection of its burial function. At sites throughout the island the general density of faunal remains was light, the main animals represented being shellfish, fish, turtle, pig and some bird. The sites contained no information which could be used to assess the relative importance of the plant component of the Taumako prehistoric diet (Leach and Davidson 1986:1). Leach and Davidson suggest that the general paucity of faunal remains may reflect disposal patterns, rather than the unimportance of these foods. They point out that on Taumako today the practice is to dump garbage into the sea, largely on the reef flats (ibid.:2). If this was the case in prehistory, it would be difficult to say much about the early diet from analysis of food remains in dry land archaeological sites.

Ethnographic information is also limited for Taumako and it is thus difficult to predict what the stable isotope analysis might reveal. However, some insight into the possible components of the prehistoric diet may be gained from analysing the modern diet, and the available resources. A wide variety of foods is grown in Taumako gardens today (some of which are modern introductions), including breadfruit, taro, kumara, yam, sugar cane, papaya, kassava, sago, coconuts, mango and numerous tree fruits and nuts (ibid.). While the breadfruit seasons are sometimes unreliable, and some crops may have failed on occasions, on the whole it is probable that a similar wide range of plants was successfully cultivated 300 years ago.

Foods from the marine environment include fish and shellfish, but Leach and Davidson suggest that in prehistory, as today, the proportion of the diet derived from fish may have been relatively small (ibid.:1). They believe that while fishing and related activities are socially important, filling an important recreational role, fish may not fill stomachs very often. Shellfish gathering on Taumako is traditionally done by women and children and this was probably the case in prehistory, with shellfish being a more regular component of the diet.

From the stable isotope analysis it should be possible to ascertain whether the prehistoric diet was significantly different from the modern Taumako diet. Some indication of the relative importance of the marine and terrestrial components of the prehistoric diet can be expected.

TONGA - 'ATELE

The 'Atele area in the grounds of Tonga College on Tongatapu Island is situated on a narrow strip of land between the raised southern cliffs and the shallow inner lagoon with its extensive shellfish beds (Davidson 1969:253). Twenty adult individuals were selected from those excavated by Davidson in 1964 from two burial mounds, To-At-1 and To-At-2.

To-At-1

Before being used for burial the site was probably used intermittently for cooking, as evidenced by scattered shells and coral oven stones, and the presence of possible post holes penetrating the sub-soil suggested an agricultural use for the site (ibid.:264). The oldest burials were interred prior to construction of the mound, but unfortunately accurate radiocarbon dates could not be obtained for these early burials. After the construction of the mound the site appears to have functioned solely as a burial area. Eight individuals from To-At-1 were analysed in the present study.

To-At-2

This mound was larger than To-At-1 and before excavation was suspected to have been a faitoka, or chief's burial mound. This was ruled out during the excavation when no coral slab vault characteristic of faitoka was uncovered (ibid.:283). Potsherds were found at the bottom levels and their eroded appearance led to the interpretation that they were in a garden area before being sealed under the mound (ibid.:274). In addition, the agricultural rather than residential use of the site was suggested by the virtual absence of midden material, apart from occasional fragments of seed and non-human bone (ibid.). The stratigraphy at To-At-2 was more difficult to interpret than at To-At-1, and some burials had been disturbed by later interments, but it was possible to assign most burials to the major periods

of use of the site (ibid.:271). Two collagen C14 dates were obtained, although these have relatively large errors due to problems in obtaining sufficient collagen from the bones. A left femur and right humerus from Burial 41 (AY22), probably the earliest burial, gave a date of 770+-200 yrs BP (GaK-1204), and a left tibia and fibula from Burial 10 (not used for isotope analysis) gave a date of 390+-110 BP (GaK-1205). Davidson feels that the mound was probably truly prehistoric, being in use between the 10th and 17th centuries AD (ibid.:274), and that the age range of To-At-1 was probably similar. Twelve individuals from To-At-2 were analysed in the present study.

The evidence for the use of the area for gardening activities prior to the construction of both mounds is clear and thus indicates the presence of horticulturists in Tonga by the 14th century AD at the latest and probably before the 10th century AD. In any case, because they were buried after the site had been used for horticulture, these people were probably horticulturists and the results of the stable isotope analysis should reflect this. The differences in size and orientation between the two mounds and the restricted use of black tapa in burials at To-At-2 may indicate differing practices or differences in status between the two groups (ibid.:280). Status differences may be reflected in diet and could be indicated in the results of the present study. In addition, because it was possible to assign most of the individuals to major periods of use of the site, if there were changes in proportions of marine and terrestrial foods in the diet over time this should also be

reflected in the results.

Skeletal analysis of the 'Atele individuals showed a low incidence of caries (8.3%) with tooth wear being described as "not severe but rather of the cusp-blunting type" (Pietrusewsky 1969:312). This would tend to suggest a mixed diet, containing some abrasive components such as shellfish, obtainable from the inland lagoon, and little carbohydrate content, indicated by the low incidence of caries. Walker and Erlandson (1986) have suggested that people who eat significant quantities of fish and other high-protein sea foods have less carious lesions than people who eat a lot of carbohydrates.

Evidence from other excavations on Tongatapu (Poulsen 1968) which may be relevant to prehistoric diet include Arca shell net sinkers and cowrie-shell tops for octopus lures; Tonna and Arca shell scrapers and possible paring knives of Strombus shell which may have been used in preparation of plant foods; and bones of domesticated chicken, pig and dog at both early and late levels of excavated shell midden sites.

Stable isotope analysis of the 'Atele population is thus expected to show a mixed marine and terrestrial diet.

TONGA - PEA

The individual from Pea was excavated in 1963/64 by Poulsen

from the Lapita shell midden, To-1, within the township of Pea, two and a half miles to the north-west of 'Atele on Tongatapu. The stratigraphy of the site was complicated and the burial has been loosely assigned to the middle Lapita horizon of Tonga (Poulsen, cited in Spennemann 1985). While this individual may be earlier than the burials from 'Atele, the problems with the stratigraphy mean that this cannot be confirmed. Therefore, while it would be tempting to try to ascertain whether the diet of this individual supports the strandlooper hypothesis, that is that earlier Lapita populations relied more on marine food resources, it is probably unwise to do so.

Analysis of the skeletal remains showed arthritic changes in the neck and this, combined with evidence on the right clavicle ("paddler's shoulder"), suggested frequent use of the paddle (Spennemann 1985:2). Advanced levels of caries were noted and while this may be directly related to the individual's diet, it is important to note here that the individual has been assessed as being middle-aged and the state of the teeth may be as much a function of age as of diet.

SUMMARY

In this chapter the diets of each group of individuals in the present study have been reconstructed from the available archaeological and ethnographic evidence as much as possible. From these initial reconstructions some expectations of the

stable isotope results have been developed. In Chapter five the results of the stable isotope analysis will be presented. These results will be discussed in Chapter six, with reference to the expectations presented here and the objectives outlined in Chapter one.

CHAPTER FIVE

RESULTS

The results of the stable isotope analysis for all processed samples are shown in Table 5.1. All nitrogen determinations were obtained from bone powder, while all carbon and sulphur determinations were obtained from collagen. All determinations are in parts per mil and values are given to two decimal places. The determinations for the bone standard (bone std.) are mean values. The determinations for the burnt sample from Lakeba (AY785b) have been included in Table 5.1, but will not be included in subsequent results because burning appears to have affected the determinations, particularly carbon. Some nitrogen determinations were repeated, either because problems were encountered with the mass spectrometer or during sample preparation (such as samples evaporating completely on the hot plate). In all such cases, where more than one determination was obtained for a particular sample and the first value was suspected to have been inaccurate, the most recent has been included in the results. The preliminary δ15N determinations for five samples from Namu, AX848, AY65, AY66, AY68 and AY73, are also included.

Table 5.1: δ15N, δ13C and δ34S values (in per mil) for all samples. N = 125 (119 human, 5 animal, 1 plant)
The δ15N values reported in this table refer to those obtained from bone powder, not collagen extract.
A separate study of this revealed a mean difference of +0.20 per mil from collagen to bone powder (see Table 5.4). This was regarded as insignificant (see Page 180) and therefore not subtracted from the values obtained from bone powder.

Easter Island N=12

Acc. No.	δ15N (bone powder)	δ13C (collagen)	δ34S (collagen)
AX 859	13.44	-18.14	
AX 860	13.50	-18.77	14.4
AX 861	13.83	-19.33	
AX 862	11.94		
AX 863	13.11		
AX 864	14.05		
AX 865	13.06	-17.40	
AX 866	13.67		
AX 867	12.73		
AX 868	14.42		
AX 869	13.74		
AX 870	15.09		

Fiji - Lakeba N=4

Acc. No.	δ15N (bone powder)	δ13C (collagen)	δ34S (collagen)
AY 82	10.32	-16.45	
AY 784	11.72	-15.81	15.90
AY 785	11.27	-13.42	
AY 785b	12.74	-16.35	
AY 786	10.11	-15.86	13.40

Fiji - Sigatoka N=1

AY 787	9.76	-19.48	

Marianas - Saipan N=2

AY 781	11.53	-19.37	17.60
AY 782	13.24	-17.86	14.50

Marianas - Tinian N=3

AY 778	12.39	-17.95	14.50
AY 779	11.85	-17.81	16.90
AY 780	09.97	-18.07	15.40

New Britain - Watom N=6

Acc. No.	δ15N (bone powder)	δ13C (collagen)	δ34S (collagen)
AY 56	11.66		
AY 57	12.85	-18.25	11.50
AY 58	10.28	-18.22	08.30
AY 59	10.85	-17.61	
AY 60	14.91		
AY 61	09.69		

New Zealand - Chathams N=9

AY 39	17.15	-14.37	14.10
AY 40	20.26	-13.46	15.50
AY 41	19.24	-16.21	17.50
AY 42	17.96		
AY 43	17.66	-13.33	15.50
AY 44	17.14		
AY 45	16.99	-14.81	16.10
AY 46	17.42		
AY 47	17.65		

New Zealand - Rotoiti N=8

AY 48	11.43		
AY 49	12.11		

New Zealand - Rotoiti - continued

Acc. No.	δ15N (bone powder)	δ13C (collagen)	δ34S (collagen)
AY 50	12.32	-17.90	05.90
AY 51	12.30	-17.57	-2.90
AY 52	12.50	-18.16	4.80
AY 53	09.69	-19.63	4.10
AY 54	12.37		
AY 55	12.57		

Papua New Guinea - Motupore N=14

AY 488	12.93		
AY 489	12.85		
AY 490	12.17		
AY 491	11.26		
AY 492	10.16		
AY 493	10.46		
AY 494	13.19		
AY 495	12.70		
AY 496	12.22		
AY 497	12.19		
AY 498	12.52	-15.70	10.90
AY 499	09.51	-13.31	11.80
AY 500	09.79		
AY 501	06.64		

Papua New Guinea - Nebira N=16

Acc. No.	δ15N (bone powder)	δ13C (collagen)	δ34S (collagen)
AY 35	10.84		
AY 36	10.67		
AY 37	10.11		
AY 38	10.91		
AX 989	11.28		
AX 990	12.84	-14.46	01.80
AX 991	10.81		
AX 992	11.79		
AX 993	11.91		
AX 994	11.02	-17.28	04.30
AX 995	11.16		
AX 996	10.15		
AX 997	10.24		
AX 998	10.63		
AX 999	10.62		
AX 1000	09.40		

Solomons - Namu N=22

Bone Std.	11.70	-17.96	16.00
AX 848	10.66	-15.79	11.10
AY 62	11.65		
AY 63	12.46		

Solomons - Namu - continued

Acc. No.	δ15N (bone powder)	δ13C (collagen)	δ34S (collagen)
AY 64	10.25		
AY 65	12.97		
AY 66	11.65		
AY 67	11.39	-17.90	15.60
AY 68	10.26		
AY 69	11.21	-17.60	16.90
AY 70	07.93		
AY 71	12.89		
AY 72	08.37		
AY 73	12.83		
AY 74	12.22		
AY 75	10.66		
AY 76	12.13		
AY 77	12.68		
AY 78	12.38		
AY 79	11.27		
AY 80	10.94		
AY 81	10.06		
Tonga - 'Atele N=20			
AY 9	12.64	-17.39	11.40
AY 10	09.96		

Tonga - 'Atele - continued

Acc. No.	δ15N (bone powder)	δ13C (collagen)	δ34S (collagen)
AY 11	10.58		
AY 12	11.59		
AY 13	11.93		
AY 14	10.19		
AY 15	09.88		
AY 16	10.57		
AY 17	10.61		
AY 18	09.26		
AY 19	10.46		
AY 20	10.23		
AY 21	09.43		
AY 22	10.89	-17.77	12.20
AY 23	9.77		
AY 24	9.99		
AY 25	8.29	-18.83	14.60
AY 26	9.29		
AY 27	9.41		
AY 28	10.29	-17.69	13.10

Tonga - Pea (To-1) N=1

AY 774	10.33	-15.42	12.50

Animal samples N=5

Acc. No.	δ15N (bone powder)	δ13C (collagen)	δ34S (collagen)
AX 852			
Cow	8.70	-22.53	12.30
AX 002/3			
Dugong	7.98	- 1.92	9.80
AX 008/9			
Sea lion	18.13	-13.23	16.40
AX 004/5			
Turtle	21.69	-10.39	13.00
AX 006/7			
Wallaby	5.59	- 9.25	

Plants N=1

Grass (Papua New Guinea)		-10.89

As can be seen from Table 5.1, 119 human samples and five animal samples were processed for δ15N determinations. δ13C determinations were obtained from 40 of the human samples, the five animal samples and one plant sample, while 32 of the human samples and four of the animal samples were also processed for δ34S determinations. The results of the stable isotope analysis

for these 32 human and four animal samples, for which all three isotope determinations were obtained, have been extracted from Table 5.1 and are presented in Table 5.2 for ease of comparison between samples and between sites.

Table 5.2: δ15N, δ13C and δ34S values (in per mil) for 36 samples. N=36 (32 human, 4 animal)
The δ15N values reported in this table refer to those obtained from bone powder, not collagen extract (see note to Table 5.1).

Acc. No.	δ15N (bone powder)	δ13C (collagen)	δ34S (collagen)
Easter Island N=1			
AX 860	13.50	-18.77	14.4
Fiji - Lakeba N=2			
AY 784	11.72	-15.81	15.90
AY 786	10.11	-15.86	13.40
Marianas - Saipan N=2			
AY 781	11.53	-19.37	17.60
AY 782	13.24	-17.86	14.50

Marianas - Tinian N=3

Acc. No.	δ15N (bone powder)	δ13C (collagen)	δ34S (collagen)
AY 778	12.39	-17.95	14.50
AY 779	11.85	-17.81	16.90
AY 780	09.97	-18.07	15.40

New Britain - Watom N=2

AY 57	12.85	-18.25	11.50
AY 58	10.28	-18.22	08.30

New Zealand - Chathams N=5

AY 39	17.15	-14.37	14.10
AY 40	20.26	-13.46	15.50
AY 41	19.24	-16.21	17.50
AY 43	17.66	-13.33	15.50
AY 45	16.99	-14.81	16.10

New Zealand - Rotoiti N=4

AY 50	12.32	-17.90	05.90
AY 51	12.30	-17.57	-2.90
AY 52	12.50	-18.16	04.80
AY 53	09.69	-19.63	04.10

Papua New Guinea - Motupore N=2

Acc. No.	δ15N (bone powder)	δ13C (collagen)	δ34S (collagen)
AY 498	12.52	-15.70	10.90
AY 499	09.51	-13.31	11.80

Papua New Guinea - Nebira N=2

AX 990	12.84	-14.46	01.80
AX 994	11.02	-17.28	04.30

Solomons - Namu N=4

Bone Std.	11.70	-17.96	16.00
AX 848	10.66	-15.79	11.10
AY 67	11.39	-17.90	15.60
AY 69	11.21	-17.60	16.90

Tonga - Atele N=4

AY 9	12.64	-17.39	11.40
AY 22	10.89	-17.77	12.20
AY 25	08.29	-18.83	14.60
AY 28	10.29	-17.69	13.10

Tonga - Pea (To-1) N=1

Acc. No.	$\delta^{15}N$ (bone powder)	$\delta^{13}C$ (collagen)	$\delta^{34}S$ (collagen)
AY 774	10.33	-15.42	12.50
Animal samples N=4			
AX 852			
Cow	08.70	-22.53	12.30
AX 002/3			
Dugong	07.98	- 1.92	09.80
AX 008/9			
Sea lion	18.13	-13.23	16.40
AX 004/5			
Turtle	21.69	-10.39	13.00

Atomic carbon-to-nitrogen (C/N) ratios were obtained for the 40 human and five animal samples from which 'collagen' was extracted, and which were subsequently processed for carbon determinations at the Institute of Nuclear Sciences (see Appendix 4). The C/N ratios for these samples are presented in Table 5.3. When considering Table 5.3, it should be noted that a sample with a C/N ratio within the range reported for fresh bone, 2.9 - 3.6, is thought to have been unaffected by diagenetic processes

(DeNiro 1985:808). The C/N ratio for AY785b is included in Table 5.3 to illustrate the effect of burning on the C/N ratio, which, if outside the fresh bone range, can be an indication that the ratios of stable isotopes in the sample may be inaccurate. Other samples which may have been contaminated are marked with an asterisk in Table 5.3. Of particular significance in this respect is the C/N value for AY787 which is well outside the acceptable range, indicating contamination of the sample.

Table 5.3: Atomic carbon-to-nitrogen (C/N) ratios of all samples processed at the Institute of Nuclear Sciences. Those marked with an asterisk (*) are likely to have been contaminated.

Accession	Site	C/N
AX859	Easter Island	3.0
AX860	Easter Island	3.0
AX861	Easter Island	3.0
AX865	Easter Island	3.5
AY82	Fiji, Lakeba	3.4
AY784	Fiji, Lakeba	3.6
AY785	Fiji, Lakeba	3.0
AY785b	Fiji, Lakeba	4.7*
AY786	Fiji, Lakeba	2.9
AY787	Fiji, Sigatoka	5.2*

Table 5.3 - continued

Accession	Site	C/N
AY781	Marianas, Saipan	3.4
AY782	Marianas, Saipan	3.3
AY778	Marianas, Tinian	3.3
AY779	Marianas, Tinian	3.2
AY780	Marianas, Tinian	3.3
AY57	New Britain, Watom	3.7*
AY58	New Britain, Watom	3.8*
AY59	New Britain, Watom	3.3
AY39	New Zealand, Chathams	2.9
AY40	New Zealand, Chathams	3.3
AY41	New Zealand, Chathams	2.9
AY43	New Zealand, Chathams	3.2
AY45	New Zealand, Chathams	2.9
AY50	New Zealand, Rotoiti	3.0
AY51	New Zealand, Rotoiti	2.9
AY52	New Zealand, Rotoiti	3.3
AY53	New Zealand, Rotoiti	3.1
AY498	Papua New Guinea, Motupore	3.3
AY499	Papua New Guinea, Motupore	3.3
AX990	Papua New Guinea, Nebira	3.8*
AX994	Papua New Guinea, Nebira	3.5
Bone Standard	Solomons, Namu	3.4
AX848	Solomons, Namu	3.4
AY67	Solomons, Namu	3.3

Table 5.3 - continued

Accession	Site	C/N
AY69	Solomons, Namu	3.1
AY9	Tonga, Atele	3.1
AY22	Tonga, Atele	3.2
AY25	Tonga, Atele	3.2
AY28	Tonga, Atele	2.8
AY774	Tonga, Pea	3.5
AX852 (Cow)	Waitati, New Zealand	2.8*
AX002/3 (Dugong)	Papua New Guinea, Motupore	2.7*
AX004/5 (Turtle)	Papua New Guinea, Motupore	3.6
AX006/7 (Wallaby)	Papua New Guinea, Motupore	3.9*
AX008/9 (Sea lion)	Auckland Island	3.9*

In order to facilitate interpretation of the results of the stable isotope analysis, the results for nitrogen, carbon and sulphur are presented seperately in Figures 5.1, 5.2 and 5.3 respectively.

NITROGEN

The results of the nitrogen analysis for all samples except AY785b are plotted in Figure 5.1.

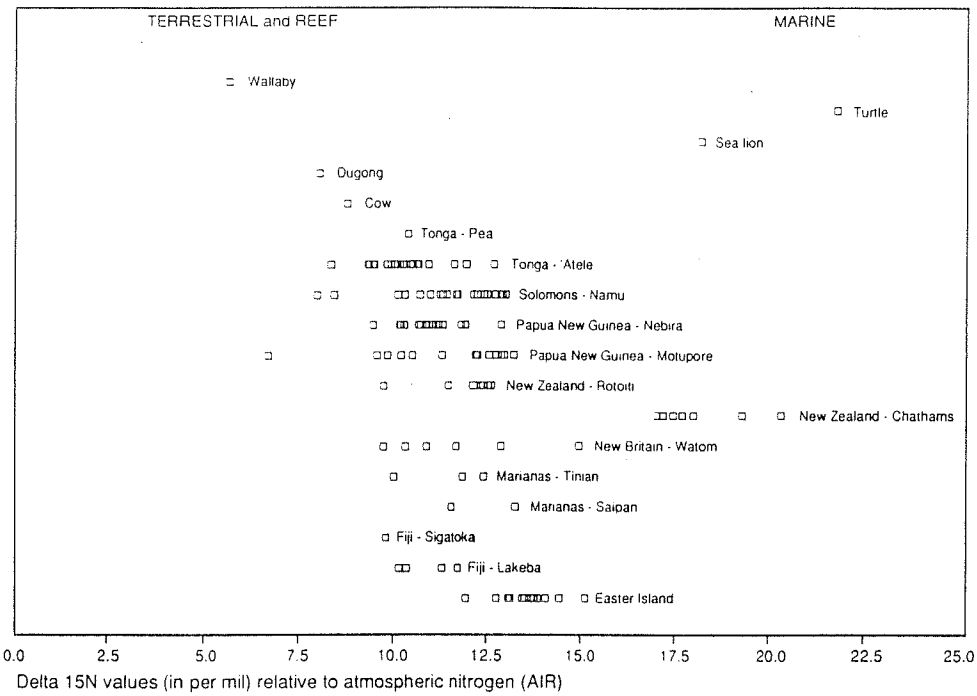

Figure 5.1: δ15N values (in per mil) obtained from bone powder for all human samples, grouped by site, and five animal samples.

The low value for dugong reflects the inshore coral reef environment in which it feeds. In evaluating the nitrogen results it should be noted that there is an enrichment of approximately 3 per mil in δ15N values from bone collagen at each trophic level of a food chain (Schoeninger and DeNiro 1984:625). In the present study δ15N values were obtained from 'collagen' and bone powder for 12 samples, to determine whether values from bone powder were significantly different from those from

'collagen'. Any significant difference would have to be either added to, or subtracted from, the 3 per mil trophic level difference between δ15N diet values and δ15N bone collagen values, in order to predict the δ15N value of the diet. The results (see Table 3.7 and Table 3.9) are compared in Table 5.4.

Table 5.4: Comparison of δ15N values (in per mil) from 'collagen' and bone powder for 12 human samples. Values marked with an asterisk (*) are mean values.

Acc. No.	δ15N ('collagen')	δ15N (bone powder)	Difference
AX 990	10.76	12.84	+2.08
AX 994	11.24	11.03*	-0.21
AY 67	12.12	11.39	-0.73
AY 69	12.01	11.21	-0.80
AY 9	10.88	12.64	+1.76
AY 25	9.39	8.29	-1.10
AY 39	16.29*	16.62*	+0.33
AY 41	18.70	19.24	+0.54
AY 498	11.36	12.52	+1.16
AY 499	10.98*	9.51	-1.47
AY 51	12.10*	12.30	+0.20
AY 57	12.17*	12.85	+0.68
		Mean	+0.20 +- 0.32
		SD	1.12 +- 0.23

The mean difference between the δ15N values obtained from bone powder and those obtained from collagen was +0.20 +- 0.32 per mil. This difference is considered to be insignificant. Thus, for the purposes of the present study, the trophic level enrichment factor of 3 per mil from bone collagen will be assumed equally to apply to values obtained from bone powder. This means that all populations which have δ15N values in the range from approximately 6-13 were eating foods with δ15N values from 3-10. In order to determine whether these foods were from terrestrial or coral reef environments, or both, the results of the carbon and sulphur analysis must be considered.

CARBON

The results of the carbon analysis for all samples processed except AY785b are plotted in Figure 5.2.

The value for wallaby suggests the inclusion of C4 grasses in the wallaby's diet, and the value for the C4 grass from Papua New Guinea lends support to this interpretation. The highly enriched value for dugong reflects its feeding environment, the evaporating ponds and reef areas on the coastal fringe. In such areas, where there is limited water circulation, C13 can become very enriched in the water and hence in the aquatic vegetation (Lyon pers. comm. 1988; Keegan and DeNiro 1988:321). Dugongs are known to feed predominantly on intertidal and subtidal sea grasses, and occasionally on marine algae, probably when sea

grasses are scarce (Heinsohn and Marsh 1977:106). They may sometimes eat invertebrate animals such as crabs, snails, hydroids, sea cucumbers and tunicates, probably taken incidentally with sea grasses (ibid.:108).

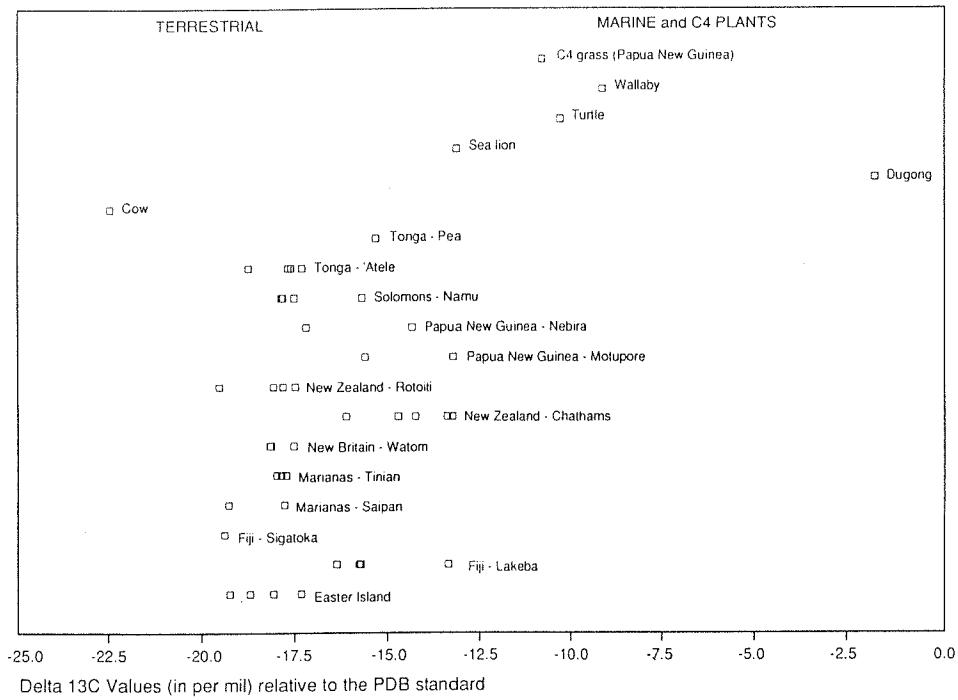

Figure 5.2: δ13C values (in per mil) obtained from collagen for 39 human samples, grouped by site, five animal samples, and one plant sample.

Several factors should be considered in the interpretation of the carbon results. Average values for C3 and C4 plants are around -26.5 per mil and -12.5 per mil respectively (van der Merwe 1982:599), while marine δ13C values average -11 per mil

(Keegan and DeNiro 1988:330). For human bone collagen a fractionation factor, or increase in δ13C values, of +5 +- 1.0 per mil relative to diet has been estimated (ibid.:329). This means that an individual with an exclusively terrestrial diet would have a δ13C value of approximately -21.5 per mil, while one with an exclusively marine diet would have a δ13C value of approximately -6.0 per mil. A value of -14.0 per mil would suggest an equal contribution from both terrestrial and marine sources. This interpretation could be complicated, however, if C4 plants played a significant part in the diet. It is interesting to note that the δ13C value for wallaby is only 1.64 per mil more positive than the value for the C4 grass (Imperata cylindrica). This could be due to a different fractionation value for wallaby, although this is unlikely as van der Merwe (1982:602) reports a fractionation value of +5.3 per mil for small browsing animals in South Africa. It may also reflect differential shifts from C3 and C4 plants, although it has been suggested that the fractionation value for C4 plants may be slightly higher than the +5 per mil for C3 plants (ibid.). A third more likely possibility is that the wallaby diet consisted of both C3 and C4 plants.

SULPHUR

The results of the sulphur analysis for all samples processed are plotted in Figure 5.3.

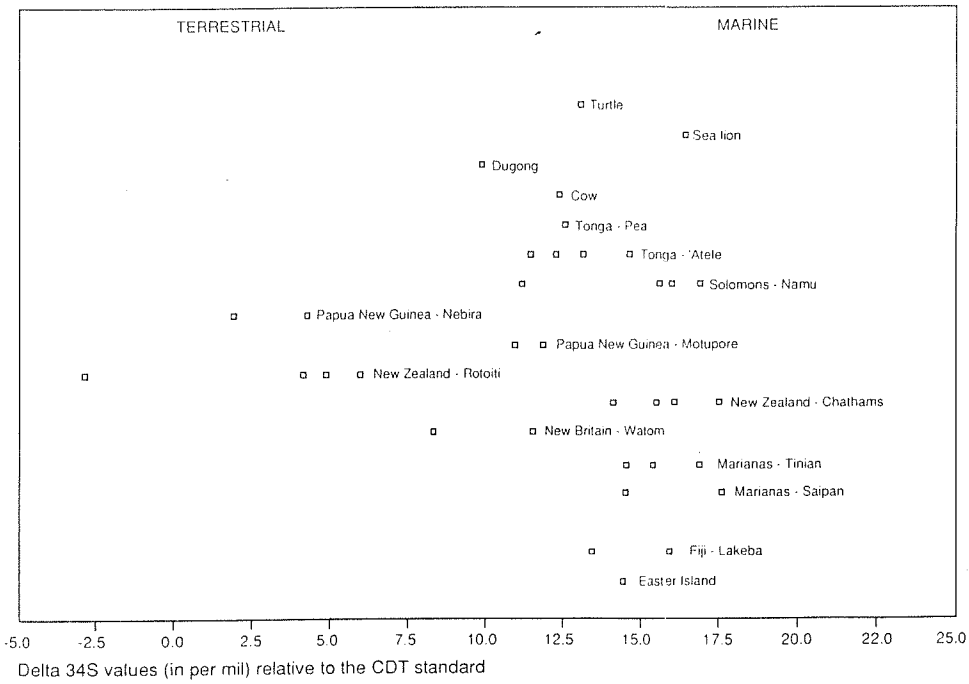

Figure 5.3: δ34S values (in per mil) obtained from collagen for 32 human samples, grouped by site, and four animal samples.

Although there are few published values available for comparison, it has been established that the δ34S value for marine sulphates and plants is around +20 per mil (Krouse and Levinson 1984:191). Krouse and Ueda (1987:117) obtained a δ34S value of +21.4 per mil for a modern marine bivalve shell from New Zealand, while fish teeth specimens had sulphur isotope compositions about 6 to 8 per mil lower than oceanic sulphate.

They suggest (ibid.:118) that this is consistent with their findings of shifts towards lighter δ34S values in going up the marine food chain, although they do not quantify these shifts. While δ34S values may be different in teeth and bone collagen, the possibility of a shift of around -5 per mil in bone collagen δ34S values, relative to diet, should be considered when interpreting the δ34S results. Peterson, Howarth and Garritt (1985:1361) give mean δ34S values for upland plants, spartina (a C4 marsh plant) and plankton as being +4.7 +- 0.9 per mil, -2.4 +- 4.4 per mil and +18.8 +- 0.6 per mil respectively.

The nitrogen, carbon and sulphur results from Table 5.2 are plotted three-dimensionally in Figure 5.4. For some of these people, where reef foods were included in the diet, the nitrogen values will appear more terrestrial than the carbon or sulphur values. Similarly, if C4 plants were eaten, the carbon values for such people will appear more marine than the nitrogen and sulphur results.

The results presented here and the implications of these results will be discussed in detail in Chapter six.

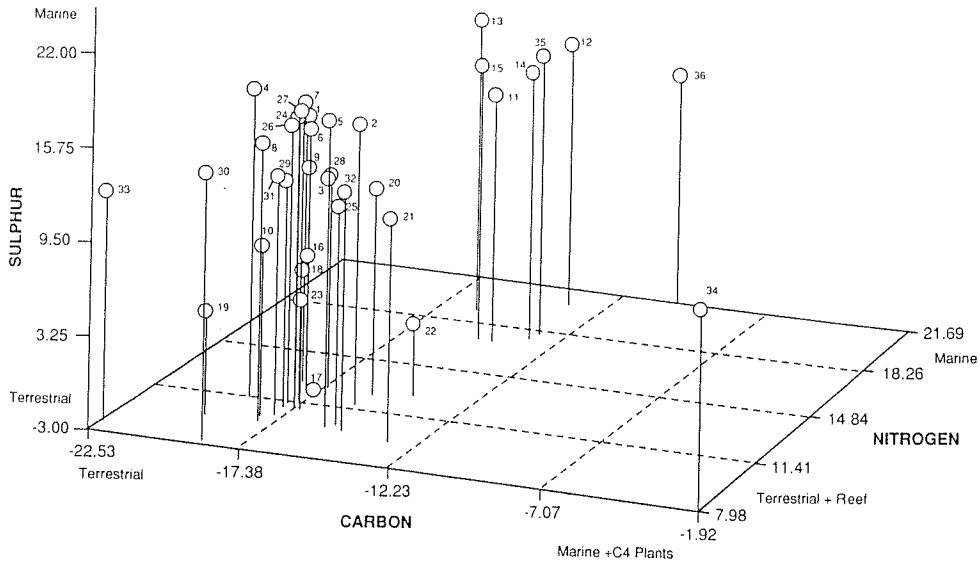

Figure 5.4: Three dimensional plot of δ15N, δ13C and δ34S values (in per mil) of 32 human and four animal samples.

Key to figure 5.4

1	Easter Is	AX860	13	Chathams	AY41	25 Namu	AX848
2	Lakeba	AY784	14	Chathams	AY43	26 Namu	AY67
3	Lakeba	AY786	15	Chathams	AY45	27 Namu	AY69
4	Saipan	AY781	16	Rotoiti	AY50	28'Atele	AY9
5	Saipan	AY782	17	Rotoiti	AY51	29'Atele	AY22
6	Tinian	AY778	18	Rotoiti	AY52	30'Atele	AY25
7	Tinian	AY779	19	Rotoiti	AY53	31'Atele	AY28
8	Tinian	AY780	20	Motupore	AY498	32 Pea	AY774
9	Watom	AY57	21	Motupore	AY499	33 Cow	AX852
10	Watom	AY58	22	Nebira	AX990	34 Dugong	AX002/3
11	Chathams	AY39	23	Nebira	AX994	35 Sea lion	AX004/5
12	Chathams	AY40	24	Namu Bone Std		36 Turtle	AX006/7

CHAPTER SIX

INTERPRETATIONS AND DISCUSSION

The results presented in Chapter five will now be discussed, firstly with reference to some notable features of the results for each site, and secondly with reference to the questions posed in Chapter one. Before beginning the discussion of results it is necessary to recognise that there will be some inherent limitations to interpretation, relating firstly to the current incomplete state of knowledge about the movement of these isotopes, particularly sulphur, through the food chain and secondly to the limited availability of comparable isotope values for potential food sources in the Pacific region.

Three factors are considered relevant in constructing a general framework for the discussion of results, and in deciding the order of priority to be given to the discussion of the three isotope ratios. These are: sample sizes; the availability of published isotope values from marine and terrestrial food sources for comparison; and the availability of general information regarding the movement of the isotopes through the food chain, including the identification of any fractionation or enrichment factors. With these factors in mind, some general statements can be made concerning the potential of the three isotopes for accurate reconstruction of the diets of the study groups.

Nitrogen

All human and animal samples (n=124) were processed for nitrogen determinations, and therefore the nitrogen results can be expected to be more representative of the populations from which they were drawn. In addition, a large number of published values is available for comparative purposes and the movement of nitrogen through the food chain is well understood. An enrichment factor of approximately 3 per mil in δ15N values from bone collagen at each trophic level of the food chain has been identified (Schoeninger and DeNiro 1984:625). Nitrogen is considered to be the most reliable of the three isotopes for the assessment of the land/sea component in the diets of these groups of people, and it is therefore proposed that the results of the nitrogen analysis will form the basis of the discussion for most groups. However, it must also be remembered that the presence of foods from a coral reef environment will complicate interpretation of the nitrogen results, and in such cases a close examination of the carbon and sulphur results will be necessary.

Carbon

While the sample sizes for carbon (n=45: 39 human, 5 animal and 1 plant) are considerably smaller than for nitrogen, these results can be discussed with regard to published values for a wide variety of marine and terrestrial plants and animals. The movement of carbon through the food chain is well understood and a fractionation factor for human bone collagen of +5 +-1.0 per

mil relative to diet has been well established (Keegan and DeNiro 1988:329). The effect of the consumption of C4 plants on carbon isotope ratios has also been identified, and this will be considered while interpreting the results.

Sulphur

Exploration of the potential of the sulphur 34 isotope for dietary reconstruction has been one of the aims of this thesis. Because sample sizes are small (n=36) and little published information is available to aid interpretation, reconstructions based on the results of the sulphur isotope analysis are more tentative. Little is known about the movement of the sulphur isotope through the food chain, although it has been suggested that sulphur values may become progressively lighter at each higher trophic level of the marine food chain (Krouse and Ueda 1987:118). Peterson, Howarth and Garritt (1985) have reported small trophic shifts for gypsy moth caterpillars and trout. Caterpillars raised on a commercial baby food had a δ34S value of +7.6 per mil, compared with +6.3 per mil for the food, while the δ34S values for trout ranged from +9.4 to +9.6 per mil, from a diet with a δ34S value of +8.2 per mil (ibid.:1361). These small trophic shifts towards heavier δ34S values contradict the findings of Krouse and Ueda (1987), but it is not possible to determine which results are the more reliable, on present evidence. Krouse and Ueda's (1987) study compared values for fish teeth with values for oceanic sulphate, while Peterson et al. (1985) compared values for body tissues (the exact nature of

which were not specified) of caterpillars and trout with their known diet values. Whether values from teeth may be compared with values from other body tissues, and whether these values in turn may be compared with the values obtained from bone collagen for the present study, is not known. Further research in this area is required before any definitive statements can be made regarding trophic level fractionation of sulphur.

INTERPRETATION OF RESULTS

The results of the stable isotope analysis will be discussed for each site, with regard to the general expectations expressed in Chapter four which were generated from existing archaeological evidence, and with particular reference to the more notable features of the results. To facilitate the discussion the mean values for $\delta^{15}N$, $\delta^{13}C$ and $\delta^{34}S$ for each site are presented in Table 6.1, and the $\delta^{13}C$, $\delta^{15}N$ and $\delta^{34}S$ values for the animals processed for this study are presented in Table 6.2.

Table 6.1 Mean and standard deviations of δ15N, δ13C and δ34S values (in per mil) for all sites.

Location	δ15N (bone powder)	N	SD	δ13C (collagen)	N	SD	δ34S (collagen)	N	SD
Easter Is.	13.55	12	0.81	-18.41	4	0.83	14.40	1	-
Lakeba	10.86	4	0.77	-15.39	4	1.34	14.65	2	1.77
Sigatoka	9.76	1	-	-19.48	1	-	-	-	-
Saipan	12.39	2	1.21	-18.62	2	1.07	16.05	2	2.19
Tinian	11.40	3	1.27	-17.94	3	0.13	15.60	3	1.21
Watom	11.71	6	1.92	-18.03	3	0.36	9.90	2	2.26
Chathams	17.94	9	1.09	-14.44	5	1.17	15.74	5	1.23
Rotoiti	11.91	8	0.96	-18.32	4	0.91	2.98	4	3.99
Motupore	11.33	14	1.83	-14.51	2	1.69	11.35	2	0.64
Nebira	10.89	16	0.81	-15.87	2	1.99	3.05	2	1.77
Namu	11.30	22	1.36	-17.31	4	1.03	14.90	4	2.59
Atele	10.26	20	0.99	-17.92	4	0.63	12.83	4	1.37
Pea (To-1)	10.33	1	-	-15.42	1	-	12.50	1	-

Table 6.2: δ15N, δ13C and δ34S values (in per mil) of animal samples.

Animal	δ15N (bone powder)	δ13C (collagen)	δ34S (collagen)
Cow	8.70	-22.53	12.30
Dugong	7.98	- 1.92	9.80
Sea lion	18.13	-13.23	16.40
Turtle	21.69	-10.39	13.00
Wallaby	5.59	- 9.25	-

The interpretation of results may be approached in three ways. The first approach involves defining some end-point values, drawn from the human isotope values determined in the present study, which will provide a 'most marine' and a 'most terrestrial' reference value for each isotope. This approach allows for the calculation of the relative proportions of marine and terrestrial foods in the diets of each population.

The second approach involves consideration of the animal values from the present study in the definition of the 'most marine' and the 'most terrestrial' end-point values. The diet of the animals in question would have to be considered for this approach, because in certain circumstances animal values could be difficult to interpret. For example, marine animals feeding in

the littoral environment, such as the turtle and the dugong, may exhibit isotopic values which are intermediate for sulphur and enriched for carbon; animals feeding around coral reefs will produce nitrogen values which are terrestrial-looking; and animals eating C4 plants will produce marine-looking carbon values.

The third approach involves comparing the values obtained in this study with published values of other human populations and of marine and terrestrial plants and animals. The difficulty with this approach is that there are very few published values for New Zealand and the Pacific, and in many cases only values for similar food sources from similar environments are available. These three approaches will now be discussed in relation to the definition of end-point values for each of the three isotopes of nitrogen, carbon and sulphur.

Nitrogen end-point values

With reference to the human values presented in Table 6.1, the 'most marine' nitrogen value is 17.94 per mil for the Moriori of the Chatham Islands, while the 'most terrestrial' value is 9.76 per mil for the individual from Sigatoka in Fiji. The value from the Chatham Islands is in line with archaeological expectations, reflecting a diet with a strong emphasis on marine resources. In this location the likelihood of reef foods affecting the nitrogen results is nill, and this value is therefore considered to be a reliable 'most marine' value for the

human samples. In contrast, the 'most terrestrial' value from Sigatoka is unlikely to be reliable because the Sigatoka sample, AY787, appears to have been contaminated (see Table 5.3) which may have affected the isotope ratios. The next 'most terrestrial' value of 10.26 per mil from 'Atele in Tonga is more reliable with respect to the problem of sample contamination, although the C/N ratio for one 'Atele sample (AY28) is slightly below DeNiro's (1985:808) safe range (see Table 5.3). However, while the probability of diagenetic alteration of the 'Atele samples is low, there is some likelihood that reef foods were included in the diet which could affect the nitrogen results. A reef food component may also be included in the diets of several of the other groups studied here and it is thus impossible to define reliably a 'most terrestrial' end-point value from the human nitrogen isotope results.

This problem of reef foods producing δ15N values which are similar to those from terrestrial sources can be overcome if appropriate animal nitrogen values are employed to define the 'most marine' and the 'most terrestrial' end-point values. Obviously, for the purposes of defining the 'most terrestrial' end-point, the value used should come from an animal known to feed exclusively from terrestrial sources, and in the present study a value of 5.59 per mil was obtained for wallaby. It could be argued that a value of 5.59 per mil would be too low for human consumers of terrestrial foods, as humans are often at least one trophic level higher up the food chain than terrestrial herbivores. However, for prehistoric New Zealand and most

Pacific Island populations, terrestrial herbivores were not a major food source, the bulk of the terrestrial dietary component being derived from vegetable foods. δ15N values from such populations could be expected to be similar to the wallaby value as in most cases humans would occupy the same trophic level in the food chain as terrestrial herbivores. The value of 5.59 per mil can thus be employed as a suitable 'most terrestrial' end-point value for the interpretation of the results.

The use of a marine animal δ15N value to define a 'most marine' end-point value may also be considered, provided that animal did not feed in a coral reef environment. The value for sea lion from the present study, 18.13 per mil, would satisfy this requirement as these animals do not live in areas where there are coral reefs. The values from dugong and turtle are less reliable as these animals live in coastal areas and are known to feed in the vicinity of coral reefs (Heinsohn and Marsh 1977:109). The green turtle (Chelonia mydas), like the dugong, feeds extensively on sea grasses but marine turtles utilize a wider range of habitats than dugongs (ibid.). Turtles are commonly seen along rocky shores, on coral reef flats and around reefs and islands away from the coast, in contrast to dugongs which prefer sheltered inshore areas (ibid.). The nitrogen value for dugong obtained in this study, 7.98 per mil, suggests that food from shallow reef areas was definitely eaten by this animal, while the value for turtle, 21.69 per mil, does not appear to reflect consumption of reef foods. However, given that marine turtles are known to feed in the vicinity of coral reefs, and

considering the availability of a value for sea lion, an animal known conclusively not to feed in reef areas, it is preferable to use the sea lion to define a 'most marine' end-point value for nitrogen. Of particular interest is the fact that the δ15N value for sealion is very close to that for the Chatham Islanders, with a difference of only 0.19 per mil between them, which reflects the similarity of their diets. However, despite this similarity, a nitrogen 'most marine' end-point value defined from the sea lion, known to feed exclusively in the marine environment, may more accurately reflect an exclusively marine based diet than the Chatham Islands value, as it is unlikely that these people totally excluded terrestrial foods from their diet. The inclusion of a small proportion of terrestrial foods in the Chatham Islands diet has been indicated from archaeological investigation (for example see Smith 1985; Horwood 1989), which suggests that the δ15N value of 17.94 per mil obtained from the Chatham Islanders studied here does not represent an exclusively marine diet.

The interpretation of the results may also be enhanced by the comparison of the nitrogen values obtained in the present study with published values from other human populations and from marine and terrestrial plants and animals. A wide range of published nitrogen values is available for comparison with the results of the present study and, where appropriate, these will be discussed.

The nitrogen results will therefore be interpreted using

two main approaches: the results will be considered firstly in relation to nitrogen end-point values defined from the animal results of the present study, and secondly in relation to the published results of other researchers.

Carbon end-point values

The human values for carbon (see Table 6.1) range from a 'most marine' value of -14.44 per mil for the Chatham Islanders to a 'most terrestrial' value of -19.48 per mil for the individual from Sigatoka. As was the case for nitrogen, the carbon value from the Chathams is in line with archaeological expectations, while the Sigatoka value is unlikely to be reliable due to probable sample contamination. Of the other highly terrestrial-looking values, the possibility that C4 plants may have been included in the diets cannot be ruled out, except in the case of the Lake Rotoiti individuals from inland New Zealand. Consequently it is impossible to determine accurately which population consumed the most terrestrial diet, and therefore a 'most terrestrial' end-point value derived from the human results would be unreliable.

The C4 plant problem can be overcome by the use of a carbon value from a terrestrial herbivore known to have eaten C3 plants exclusively. While the wallaby value of -9.25 per mil strongly indicates that C4 plants were eaten by this animal, the cow does not eat C4 plants and therefore the carbon value for cow, -22.53 per mil, will be used as the 'most terrestrial' end-point value

for the interpretation of the carbon results. Although the human value from the Chathams could be used to define an adequate 'most marine' end-point value, again, because the Chathams diet is unlikely to have been derived exclusively from marine sources, the use of the sea lion carbon value, -13.23 per mil, can be expected to produce more accurate assessments of the land/sea component in the diets of the study groups. The carbon values for dugong and turtle must be discounted as these animals feed in the littoral environment where carbon values can become highly enriched. However, the carbon values for the sea lion are more negative than expected for an exclusively marine diet, and may be due to the inclusion in their diet of marine zooplankton. Keegan and DeNiro (1988:330) report that the particulate organic carbon of marine phytoplankton produces more negative carbon values for plankton-feeding fishes, and suggest that zooplankton-feeding fishes may be a potential source of more negative δ13C values. This may also apply to other animals feeding on marine zooplankton, such as the sea lion and marine birds. It is unclear whether this apparently elevated carbon value from the sea lion will weaken the validity of the dietary proportions constructed from the carbon results. For the majority of the populations studied here, it is likely that either marine birds or zooplankton feeding fishes were included in the diet, and therefore the use of the sea lion as a standard would be appropriate. For those populations thought to have had a more terrestrial based diet, Rotoiti and Nebira, use of the sea lion standard could prove misleading. However, Hobson and Collier (1984), following Chisholm, Nelson and Schwartz (1983), have

assumed end-point values of -12 per mil and -21.4 per mil, for purely marine and purely terrestrial C3 protein consumers, for their study of the diet of coastal Queenslanders (Hobson and Collier 1984:238), and the results of the present study tend to compare well with these values. Thus the value of -6 per mil for a purely marine-based diet, as calculated in Chapter five, by subtracting a -5 per mil fractionation factor from Keegan and DeNiro's (1988) average value of -11 per mil for marine δ13C values (ibid.:330), may be an unrealistically low value for human consumers of marine foods. The sea lion carbon value of -13.23 per mil will therefore be used as the 'most marine' end-point value for carbon. It is also relevant to note here that both the carbon and nitrogen results for sea lion are very close to those obtained by Schoeninger and DeNiro (1984:627) for Californian sea lion (see Table 6.3).

As with nitrogen, published results from carbon isotope analyses of a wide variety of plants and animals are available for comparison with the results of the present study. The approach to the interpretation of the carbon results will therefore involve firstly discussing the human results in relation to the carbon end-point values derived from the animal results, and secondly in relation to the published values of other researchers.

Sulphur end-point values

The human sulphur values (see Table 6.1) range from a 'most

marine' value of 16.05 for Saipan to a 'most terrestrial' value of 2.98 for Lake Rotoiti. With the present limited state of knowledge about the movement of the sulphur isotope through the food chain, and with the limited sulphur values available from marine and terrestrial food sources, it is impossible to determine whether the above values accurately reflect the full marine-terrestrial range of diet values for human populations. The possibility should also be considered that, as for carbon and C4 plants, and nitrogen and reef foods, certain foods or foods from certain environments may produce anomalous sulphur readings. Until such possibilities can be explored with further research, the results of the present study must be assumed to be unaffected by such factors in order for meaningful interpretations, however tentative, to be made.

Given that the results are accurate, the question of whether to determine the sulphur end-point values from the human or the animal samples must be considered. As was the case for the nitrogen and carbon sea lion values, the sulphur value from the sea lion is slightly more marine-looking than the 'most marine' human value. Again, the use of the sea lion to determine the 'most marine' end-point value for sulphur is considered to be more appropriate than the use of a human value, because the animal is known to feed exclusively in the marine environment.

The definition of a 'most terrestrial' sulphur end-point value is more difficult. While the most terrestrial-looking human value could be used, in order to maintain some uniformity

in the discussion of the results for the three isotopes it may be preferable to use a non human value to define the 'most terrestrial' end-point value. In the absence of a sulphur value from an animal known to have an exclusively terrestrial diet, a value of 0.0 per mil will be taken as the most terrestrial. This value is not arbitrary, being based on the value of +4.9 +- 0.9 per mil for inland plants reported by Petersen, Howarth and Garritt (1985:1361), the suggestion that there may be a trend towards lighter δ34S values at each trophic level of the marine food chain (Krouse and Ueda 1987:117), and the assumption that a similar shift may occur with terrestrial food sources. For the purposes of this discussion this shift is assumed to be approximately 5.0 per mil.

The discussion of the sulphur results, with reference to these 'most terrestrial' and 'most marine' end-point values of 0.0 and 16.4 per mil respectively, will therefore be more tentative than the discussion of the nitrogen and carbon results. Where appropriate, reference will also be made to the available small number of δ34S values published by other researchers.

The defined end-point values for the three isotopes, for 'most terrestrial' and 'most marine' diets respectively, are 5.9 to 18.13 per mil for nitrogen, -22.53 to -13.23 per mil for carbon and 0.00 to 16.40 per mil for sulphur, as presented in Table 6.3.

Table 6.3: The defined 'most terrestrial' and 'most marine' end-point values (in per mil) for nitrogen, carbon and sulphur.

End-point values	δ15N	δ13C	δ34S
'most terrestrial'	5.90	-22.53	0.00
'most marine'	18.13	-13.23	16.40

Using these end-point values, the dietary proportions of terrestrial and marine foods can be calculated from each isotope for each group of people studied. For the purposes of inter-site comparison the calculated proportions of terrestrial foods in the diets are presented in Table 6.4, expressed as relative percentages. These relative percentages were calculated using the following formula:

% terrestrial foods =

('most marine' end-point value - x/

'most marine' - 'most terrestrial' end-point value) x100

where x = the δ15N, δ13C or δ34S value of an individual or a group. Using the mean δ15N value for Easter Island as an example:

% terrestrial foods = (18.13 -13.55/ 12.23) x 100

= 37%

Table 6.4: Relative percentages of terrestrial foods in the diets of the study groups, calculated from the defined end-point values for nitrogen, carbon and sulphur. NB: Consumption of reef foods may result in higher terrestrial percentages calculated from nitrogen, and consumption of C4 plants may result in lower terrestrial percentages calculated from carbon.

Site	Relative percentages of terrestrial foods		
	N	C	S
Easter Island	37	56	12
Lakeba	59	23	11
Sigatoka	68	67	-
Saipan	47	58	2
Tinian	55	51	5
Watom	52	52	40
Chathams	2	13	4
Rotoiti	51	55	82
Motupore	56	14	31
Nebira	59	28	81
Namu	56	44	9
'Atele	64	50	22
Pea (To-1)	64	24	24

The results of the stable isotope analysis for each site can now be discussed, firstly with reference to the relative percentages of terrestrial foods expressed in Table 6.4, and secondly with reference to the results from other studies. For this purpose δ13C and δ15N values of some marine and terrestrial animals selected from published studies are presented in Table 6.5, and δ13C and δ15N values for tropical cultigens are presented in Table 6.6. These particular plants and animals were selected because of their similarity to species likely to have been consumed by the populations being studied here.

Table 6.5: δ13C and δ15N values (in per mil) of selected marine and terrestrial animals.

a Schoeninger and DeNiro 1984 Table 1

b Sealy, van der Merwe, Thorp and Lanham 1987 Table 1

c Keegan and DeNiro 1988 Table 2

d Katzenberg 1989 Table 3

e Lyon pers. comm. 1988

Group	Scientific and common names	Location	δ13C	δ15N
Marine				
Invertebrates				
	(c) Bittium varium (gastropod)	Turks and Caicos Island	-10.9	+3.7
	(c) Strombus gigas (megagastropod)	Turks and Caicos Islands	-12.6	+2.1

Table 6.5 - continued

Group	Scientific and common names	Location	$\delta^{13}C$	$\delta^{15}N$
Marine mammals				
	(a) Zalophus californianus Sea lion	California	-12.6 (mean values) N=4	+19.3
	(a) Phoca vitulina Harbor seal	California	-12.3 (mean values) N=3	+17.6
	(b) Arctocephalus pusillus	South Africa	(mean value) N=2	+17.6
Marine fish				
	(a) Katsuwonus pelamis Tuna	California	-14.2	+11.4
	(a) Holocentrus suborbitalia Squirrel fish	California	-13.6	+14.4
	(a) Strongylura exilis Needlefish	California	-11.1	+16.0
Reef fish				
	(a) Sparisoma sp. Parrot fish	Bahamas	-7.8	+3.9

Table 6.5 - continued

Group	Scientific and common names	Location	δ13C	δ15N
Marine birds				
	(a) Aptenodytes sp. King penguin	Falkland Islands	-19.0	+13.0
	(a) Eudyptes sp. Macaroni penguin	Falkland Islands	-18.1	+9.4
Freshwater fish				
	(d) Catostomus sp. Sucker	Great Lakes, Ontario	-23.1	+3.6
	(d) Stizostedion sp. Walleye	Great Lakes, Ontario	-17.8	+9.9
Freshwater shellfish				
	(e) Hyridella menziesi Freshwater mussel	Lakes Rotoiti and Rotoma, New Zealand	-18.4	

Table 6.6: δ13C and δ15N values (in per mil) of tubers from modern tropical cultigens. Samples were collected in the Bahamas (Ba), Cuba (Cu) and Belize (Be). (From Keegan and DeNiro 1988:324 Table 1).

Cultigen	Location	δ13C	δ15N
Dioscorea sp. (yam)	Cu	-25.1	+7.6
Dioscorea sp. (red yam)	Be	-26.3	+3.7
Dioscorea sp. (white yam)	Be	-27.0	+5.2
Dioscorea sp. (black yam)	Be	-27.3	+2.8
Ipomaea batatas (sw. potato)	Ba	-25.7	+3.8
		mean = -26.28	mean = +4.6

EASTER ISLAND

As discussed in Chapter four, it is expected that the values obtained for Easter Island will indicate a mixed diet, tending towards a greater emphasis on terrestrial sources. The role of sugar cane in the Easter Island diet is ambiguous, and if there was a significant contribution of that cultigen to the diet, such a contribution could be expected to be revealed in the results of the carbon analysis.

With reference to Table 6.4, the results of the stable

isotope analysis suggest that the proportions of terrestrial foods in the Easter Island diet were between 12% and 56%. The nitrogen estimation is unlikely to be affected by reef foods as there are no coral reefs in the vicinity of Easter Island. The terrestrial proportion of the diet calculated from the carbon end-point values is larger than that calculated from nitrogen or sulphur. Returning to Keegan and DeNiro's (1988:330) suggestion that zooplankton-feeding fishes may be a potential source of more negative δ13C values, and the suggestion proposed here that this may also apply to other animals feeding on marine zooplankton, the proportions of terrestrial foods in the Easter Island diet may have been lower than indicated from the carbon results if marine birds were a significant component of the diet. The values for penguin listed in Table 6.5 are highly negative, and such results may be expected for other marine birds with similar diets. Clearly, this problem cannot be resolved here with what is essentially a 'simplistic' approach, but should be able to be investigated more thoroughly in the future with multi-dimensional computer modelling, as employed by Minagawa and Akazawa (1989) in their study of Japanese Jomon hunter-gatherers. For a succesful resolution of this problem isotope values would also be required for a wide variety of possible food sources available to the proto-historic Easter Islanders. The results of the carbon analysis do however tend to rule out the possibility that sugar cane made a significant contribution to the Easter Island diet, as the ingestion of sugar cane in any quantity would have resulted in more positive, or more marine-looking, carbon values.

The proportion of terrestrial foods estimated from the sulphur result is relatively low, at 12%. Again, an explanation for this result is not possible with the kind of comparative approach being employed here, but there are several possibilities which can be considered. The sulphur value from which the terrestrial dietary proportion was calculated comes from one sample only (AX860), which reduces its reliability to some extent. The high sulphur value may be explained in part by considering the postulated effect of sea spray sulphates causing values of terrestrial foods to appear marine (Mizutani and Rafter 1969). This may be particularly relevant for Pacific island environments, where typically the land mass is small and any given location lies in close proximity to the sea. Alternatively, the higher sulphur value may be a function of the end-point values which have been defined here for sulphur, and which are more tentative than those defined for nitrogen and carbon. If this is the case future revision of these end-point values, which will be possible when more $\delta 34S$ values become available for Pacific plants and animals, may clear up what now appear to be ambiguities related to the sulphur results.

The Easter Island results therefore pose more questions than can be answered in this present study. However, it should be possible to resolve some of these problems in the future if isotope values from a range of potential food sources can be determined.

FIJI - LAKEBA

The proportion of terrestrial foods calculated from nitrogen for Lakeba is considerably higher than those calculated from carbon and sulphur. This may be due to the inclusion of reef foods in the diet and the presence of a large reef lagoon in close proximity to Lakeba adds weight to this suggestion. The proportion of the marine component which was derived from a reef environment cannot be determined here, but should be possible with multi-dimensional modelling.

The interesting aspect of the results for the Lakeba people is that they tend to support Best's (1984) interpretation of the diet, which emphasised a reliance on fish from the reef/lagoon environment. There are also some indications of a shift in orientation towards terrestrial resources over time. In Table 6.7 a comparison is presented between terrestrial dietary proportions calculated from the oldest sample (AY784) and from the most recent (AY786).

Table 6.7: Comparison between the terrestrial dietary proportions calculated from two individuals from Lakeba.

Acc. No.	Age (yrs. BP)	Relative percentage of terrestrial foods		
		N	C	S
AY784	2700	52	28	3
AY786	500	66	28	18

While the apparent increase over time in terrestrial dietary proportions indicated from nitrogen may alternatively reflect an increase in consumption of reef foods, the increased terrestrial proportions indicated from sulphur suggest that consumption of terrestrial resources did increase over time. This may reflect an increased reliance on horticulture by the later inhabitants of Lakeba. However, it is currently not possible, using stable isotope analysis, to distinguish between the consumption of wild vegetable foods and those which were cultivated. It is therefore difficult to determine whether the early colonisers of Lakeba were horticulturists, although the estimated proportions of terrestrial foods consumed by them may reflect horticultural activity. A more definitive statement on the early Lakeba diet may be possible with the use of multi-dimensional computer modelling to distinguish between reef and terrestrial dietary components, and to interpret more clearly the sulphur results.

FIJI - SIGATOKA

The nitrogen and carbon analysis of the individual from Sigatoka, AY787, suggests the terrestrial component of this person's diet was relatively high. Unfortunately, insufficient collagen was produced from AY787 to obtain a sulphur value, thus precluding any further assessment of the proportion of terrestrial foods in this individual's diet.

The significance of these results depends on the age of this individual. If this was a particularly early skeleton the proportion of terrestrial foods in the diet could point to early horticulture in this region. Based on determinations of nitrogen and hydroxyproline content, this individual has been considered relatively older than an individual dated to 1870 +- 70 BP (Best 1987b:5). However, the age of AY787 (West 1) is by no means certain, having not been dated directly. The reliability of the method of relative dating by nitrogen and hydroxyproline content is also thoroughly questionable. The possibilty that the results may have been affected by differences in the burial environment was considered by Best (ibid.), and can be examined here with reference to Table 5.3. The atomic carbon-to-nitrogen (C/N) ratio of 5.2 for AY787 is well outside the range of values for collagen from fresh bone, which lie between 2.9 and 3.6 (DeNiro 1985:808), which suggests that this sample has been subjected to diagenetic alteration. This tends not only to invalidate the dating of this sample, but also to lessen the reliability of the stable isotope results as the isotopic composition may have been affected by diagenesis. It is therefore not possible to make any conclusive statements about the Sigatoka diet from the analysis of this individual.

MARIANAS - SAIPAN and TINIAN

The nitrogen and carbon results from both Saipan and Tinian suggest that the proportion of terrestrial foods in the diets of

these people was approximately 50%. The proportion of terrestrial foods estimated from the sulphur results is considerably lower for both groups, being 2% for Saipan and 5% for Tinian. The reason for this is unclear, but may be related to incorrect definition of end-point values for sulphur or to some as yet unidentified anomalies in the sulphur values of certain foods, which may affect the sulphur isotope values of their consumers. Interpretation of the sulphur results may be possible with future research to determine $\delta^{34}S$ values for a range of Pacific plants and animals.

With reference to the archaeological expectations of the diet of these five individuals discussed in Chapter four, the dental analysis revealed degrees of caries and tooth wear which suggested that the diet was not particularly abrasive, but contained significant amounts of carbohydrates which can lead to caries. It therefore seems unlikely that as little as 2% to 5% of the diet was derived from terrestrial sources, as suggested by the sulphur values. Instead it seems highly likely that the diet consisted of almost equal proportions of marine and terrestrial foods, as predicted from the nitrogen and carbon values.

While the Tinian diet is unlikely to have contained reef foods there are coral reefs in the vicinity of Saipan and the possibility of some fish being from a reef/lagoon environment should be considered. If reef foods were included in the diet in significant proportions, the nitrogen values would suggest that the diet included a higher proportion of terrestrial foods than

was actually eaten. If this were the case, the percentages calculated from the nitrogen results should indicate a significantly higher terrestrial component in the diet than the carbon percentages. For Saipan, the percentages of terrestrial foods calculated from nitrogen are lower than those calculated from carbon. From these results it is not possible to detect any consumption of reef foods by these people. The validity of this interpretation should be able to be examined in the future with multi-dimensional computer modelling.

A consideration of the nitrogen and carbon results was undertaken to determine whether there is any indication of age- and sex-specific differences in the marine proportion of the diet, similar to the differences proposed by Hanson for the people from the Duty Free Site on Saipan (1989:42). For reference, the δ15N and δ13C values of the two Saipan and three Tinian individuals studied here are included in Table 6.8, together with age and sex details provided by Roy (1989).

Of the Saipan individuals, both identified as male, the older man appears to have included more marine foods in his diet than the younger one, which may simply be a factor of his age. This is to be expected as stable isotope ratios are known to reflect the diet for long periods, perhaps up to ten years before death (Tauber 1981:332). Unfortunately, it is not possible to determine whether there were any sex-related differences in the proportions of marine foods in the Saipan diet as no females were available for study from the SLH and MHS Sites on Saipan.

Table 6.8: δ15N and δ13C values (in per mil) of five individuals from Saipan and Tinian, Mariana Islands.

Acc. No.	Location	Sex	Age	δ15N (bone powder)	δ13C (collagen)
AY781	Saipan	M	18-25	11.53	-19.37
AY782	Saipan	M	20-40	13.24	-17.86
AY778	Tinian	F	30+	12.39	-17.95
AY779	Tinian	F	12-15	11.85	-17.81
AY780	Tinian	F	40+	09.97	-18.07

The three individuals from Tinian, all identified as female, have similar nitrogen values to the Saipan individuals. AY780, aged over 40 years, appears to have the most terrestrial diet. These differences in the marine component of the diet may be age-related, with older women eating more terrestrial foods. In the absence of any results for Tinian males, nothing can be said about possible sex-related differences in dietary proportions of marine and terrestrial foods.

Some consideration should be given to the possible inclusion of C4 plants in the Tinian and Saipan diets, as sugar cane is thought to have been present on Guam in the early 1500s (Pollock 1986:127). If C4 plants were included in the diet of these people, the carbon values would suggest a more marine-oriented diet than was actually the case. Thus, the

percentages calculated from the carbon values would appear less terrestrial than those calculated from nitrogen. As has been demonstrated above, this is not apparent from the results of this study, and it is concluded that if C4 plants were included in the Saipan and Tinian diets, they were in insufficient quantities to be detected here. Again, multi-dimensional computer modelling should be able to produce more conclusive evidence of the absence or presence of C4 plants in the Tinian and Saipan diets.

The results of the analysis of these five individuals from the Marianas therefore suggest that their diet consisted of approximately equal proportions of foods from the marine and terrestrial environments. The presence of reef foods in their diet has not been identified, while the postulated presence of C4 plants in the terrestrial portion of the diet has not been confirmed. The apparent anomaly in the results of the sulphur analysis needs to be investigated and will be returned to later in this discussion.

NEW BRITAIN - WATOM

The proportion of terrestrial foods in the Watom diet, as calculated from the nitrogen, carbon and sulphur values, is between 40% and 52% (see Table 6.4). Before further discussion, it should be noted that two of these individuals have produced C/N ratios which lie just outside the range considered to be reliable (see Table 5.3). AY57 has produced a C/N ratio of 3.7

and AY58 a C/N ratio of 3.8, compared with the proposed reliable range of 2.9 to 3.6 (DeNiro 1985:808). There is therefore a possibility that diagenetic processes may have altered the isotopic composition of these skeletons. Difficulties were encountered during the excavation of the skeletal remains because "burial features often extended down into the underlying sand beach to within the tidal zone and on a daily basis filled with water" (Green, Anson and Specht 1989:217), rendering all the human bone "wet, soft and difficult to remove intact" (ibid.). Such water-logging is likely to have caused some diagenetic alteration of the bones and this appears to be reflected in the C/N values.

Archaeological expectations of the Watom diet indicate that a large proportion of the marine component of the diet was derived from a littoral reef environment. This cannot be confirmed using the simplistic comparative approach employed here, but may be possible with multi-dimensional computer modelling.

The Watom results indicate a mixed diet, with approximately equal proportions of marine and terrestrial foods. This confirms the archaeological expectations expressed in Chapter four, which suggest that a significant proportion of the diet was derived from terrestrial sources. The relatively high proportion of terrestrial foods in the diet suggests that these Watom Islanders could have been horticulturists, but this cannot be confirmed using stable isotope analysis.

The analysis of nine Chatham Island Moriori has revealed an adaptation to the marine environment which is unique in this study. The proportions of terrestrial foods in the diet of these individuals can be calculated to be 2% from the nitrogen values, 13% from the carbon and 4% from the sulphur. It is probable that the percentage of terrestrial foods calculated from carbon is too high as the consumption of marine birds, known to comprise a significant proportion of the diet (Sutton 1979:236), may result in more negative, or more terrestrial-looking, carbon values as proposed above. The proportion of terrestrial foods is thus more likely to be less than 13% for these Chatham Islanders.

This is an extremely interesting result and reflects a remarkable adjustment to an environment which was low in terrestrial resources, but richly endowed with a wide variety of marine resources, and tends to confirm the interpretations of Sutton (1979) and Horwood (1988), and refute those of Anderson (1981). However, the consumption of large quantities of marine birds and mammals may have detrimental effects on the human body, either through excessive fat consumption leading to ketonuria (Denniston 1972, cited in Anderson 1981:152), or excessive protein consumption leading to protein poisoning (Noli and Avery 1988). Anderson (1981:153) has argued that ketonuria, the result of the accumulation of acidic ketone bodies in the bloodstream from the metabolism of fat and which can lead to serious illness and death, can only be averted if carbohydrates comprise at least

15% of the daily diet. He also suggests that ketogenic effects may have been reduced in prehistoric Tasmanian diets by the high consumption of shellfish which generally contain more carbohydrates than fats (ibid.), although the levels of both of these are relatively low in shellfish. Alternatively, low or reduced consumption of fats may prevent the onset the ketonuria. Horwood's (1988) trace element analysis of the Chatham Islanders examined in the present study produced high levels of magnesium, which was interpreted as reflecting a low fat intake and consequently Horwood suggested that the consumption of vegetable foods to compensate need not have been high (ibid.:143). If this was the case, the consumption of vegetable foods could have been lower than Anderson's proposed safe level of 15%, particularly if shellfish were consumed, without the effects of ketonuria being manifest.

Noli and Avery (1988) have recently questioned the concept of a largely protein marine diet as an economic strategy over more than a few days. They argue that people cannot survive long on protein alone, and that only between 20% and 50% of daily energy needs can safely be derived from protein sources over extended periods (ibid.:397). Consumption in excess of these levels can, according to Noli and Avery, cause azotaemia (excess nitrogen) and ammonia intoxication which can be lethal (ibid.). They conclude that

> "it would have been particularly dangerous on the coast to live on the flesh of shellfish, fish and

marine mammals for longer than a few days at a time without the inclusion of a carbohydrate- or fat-rich source of energy" (ibid.:399)

suggesting that coastal populations could have prevented protein poisoning by the inclusion of carbohydrates or fats in their diets. Noli and Avery acknowledge that the phenomenon of protein poisoning needs to be investigated further (ibid.), and it is suggested here that there could be differences in metabolism between human groups which may differentially affect their ability to assimilate proteins.

Further research in these areas may throw some light on the results of the present isotope analysis of these Chatham Islanders. Such an exclusively marine diet may have been physiologically viable if a balance was able to be struck between protein, fat and carbohydrate consumption. The inclusion of seaweeds in the diet as well as terrestrial plants may also have helped to counteract the effects of protein poisoning and ketonuria, while the isotope values would still indicate marine foods.

Leaving aside the problems of protein poisoning and ketonuria, the results from the Chatham Islands are quite unique in the present study, revealing as they do an extremely high reliance on marine food sources. There are several interesting features of the Chathams results. Firstly, the three isotope values for these people are remarkably close to the values

obtained in this study for the sea lion (see Tables 6.1 and 6.2), which has an unambiguously marine diet. Furthermore, there is a striking similarity between the nitrogen and carbon results for the Chatham Islanders, 17.94 per mil and -14.44 per mil respectively, and nitrogen and carbon values of 18 per mil and -13 per mil obtained from a recent study (Minagawa and Akazawa 1989) of a group of prehistoric and historic fisher-hunter-gatherers from Hokkaido in Northern Japan (ibid.:6). A similarity was noted between the Japanese values and values reported by DeNiro (1987) for historic Northwest coast Indians (Haida and Tlingit) and Eskimos (ibid.:11). These North American people have been identified archaeologically and ethnographically as having a high dependence on marine foods, particularly marine mammals (DeNiro 1987:188), and the results for the Chathams are remarkably similar to these Indian and Eskimo values.

The concurrence of the results for the Chatham Islanders from this present study and those for the Japanese Jomon and the American Northwest coast Indians is extremely encouraging. It is also very relevant to the above discussion on the physiological viability of a predominantly marine-based diet. The fact that three groups from different ethnic and geographic backgrounds developed and maintained a very similar dietary adaptation, heavily focused on the marine environment, suggests that such a diet is indeed physiologically viable. It also attests to the remarkable adaptability of human populations, and in particular the Polynesian adaptation to the harsh conditions of the Chatham Islands environment.

The results from the analysis of the Lake Rotoiti people provide an interesting contrast to those of the Chatham Islanders. The sulphur value of +2.98 per mil, which suggests a diet consisting of approximately 82% terrestrial foods, is the lowest, or most terrestrial-looking, sulphur value obtained for this study. This proportion of terrestrial foods is in line with expected results based on ethnographic evidence, but some caution should be exercised here. Lake Rotoiti is located near Rotorua in an active volcanic zone and there is a possibility that volcanic fumarole sulphur may influence δ34S values of foods from such an environment. Further research may reveal whether such an environmental effect exists. However, the δ34S value for Rotoiti is close to the δ34S value of +4.7 per mil reported by Peterson, Howarth and Garritt (1985:1361) for inland C3 plants from New England, and this suggests that the Rotoiti sulphur value may be reliable.

The nitrogen and carbon values both suggest lower proportions of terrestrial foods than the sulphur values, in the region of 51% and 55% terrestrial foods respectively. However, if the Rotoiti diet reported ethnographically is considered, the possibility arises that these proportions are too low. The Rotoiti population, as mentioned above, are unlikely to have included marine birds or animals in their diet in any significant quantity, and it may therefore be more appropriate to estimate proportions of marine and terrestrial foods using end-point

values from published studies. Taking a δ13C value of -21.5 per mil as the 'most terrestrial' and -6.0 per mil as the 'most marine', the value of -18.32 per mil for Rotoiti indicates an approximately 80% terrestrial diet. However, an alternative explanation can be put forward which considers the inclusion of freshwater resources in the diet.

These people may have made extensive use of the resources available from the waters of Lake Rotoiti, including several species of freshwater fish, crayfish (Paranephrops) and the freshwater mussel (Hyridella menziesi). While there are few published values available for freshwater animals, Schoeninger and DeNiro (1984) list δ13C values for freshwater fish ranging from -12.7 to -23.7 per mil, and δ15N values ranging from +6.6 to +9.5 per mil (ibid.:629). Katzenberg (1989) has recently reported δ15N values for freshwater fish from Southern Ontario ranging from 3.6 per mil for suckers (Catsostomus spp.) to 9.9 per mil for walleye (Stizostedion spp.) (ibid.:326). The species with higher nitrogen values tended to be those which occupied higher trophic levels in the food chain (ibid.:327). Carbon values for the same freshwater fish ranged from -23.1 per mil for sucker to -17.8 per mil for walleye, which again seems to reflect trophic level fractionation (ibid.:326). More relevant to the present study, a mean δ13C value of -18.38 +-0.48 per mil was obtained from the analysis of 12 samples of Hyridella menziesi from Lakes Rotoiti and Rotoma in the North Island of New Zealand (Lyon pers. comm. 1988). These results suggest that the inclusion of freshwater animals in the diet may produce more

positive carbon values than would be expected for a largely terrestrial diet. Consumption of large amounts of freshwater mussels for instance would result in δ13C values in the region of -13 per mil, allowing for a fractionation factor of 5 per mil. A diet including foods from freshwater sources and terrestrial plants such as kumara and taro, known to have been important in this inland location for historic Maori, would produce carbon values somewhere between -13.0 and -21.0 per mil, depending on the proportions involved. It therefore seems that the proportion of terrestrial foods in the Rotoiti diet, as calculated above from the carbon value, could be too low. Unfortunately, because of the similarities in carbon values from terrestrial and freshwater sources, it is not possible to distinguish between or to determine the proportions of foods from those sources, using carbon.

A similar explanation may be proposed for the proportion of terrestrial foods calculated from the nitrogen value, based on a consideration of Schoeninger and DeNiro's (1984) and Katzenberg's (1989) nitrogen values for freshwater animals. Allowing for trophic level effects, a diet including a large amount of freshwater fish would produce nitrogen values between 7 and 13 per mil, again erroneously indicating some marine component in the diet. Schoeninger, DeNiro and Tauber (1983) have suggested, based on analysis of phytoplankton and zooplankton, that organisms in freshwater systems have δ15N values intermediate between those of terrestrial and marine organisms, and furthermore "distinguishing between freshwater and terrestrial

food sources by nitrogen isotope analysis may be impossible" (ibid.:1382). Unfortunately a δ15N value was not available for the freshwater mussel, but it is likely that it would fall within the range for freshwater fish. In the absence of more definitive data, it can only be concluded that the proportion of terrestrial foods in the Rotoiti diet was probably higher than the 51% calculated from the nitrogen value.

The Rotoiti people appear to have subsisted on a diet which included between 50% and 80% terrestrial foods, and, based on the above discussion of freshwater δ13C and δ15N values, it can be tentatively suggested that the proportion of terrestrial foods was closer to the higher estimation of 80%. The balance of the diet was derived from marine sources and this tends to add weight to the suggestion that some food exchange did take place between the inland lakes region and the coast, a practice observed by Colenso (1880) in the Taupo region (ibid.:29). The diet of these people, with its focus on terrestrial food sources, stands in marked contrast to that of the Chatham Island Moriori, and both attest to the remarkable adaptability of the Polynesian subsistence strategy.

PAPUA NEW GUINEA - MOTUPORE

The analysis of the 14 individuals from Motupore has produced some interesting results. The mean nitrogen value suggests that the diet consisted of approximately 56% terrestrial

foods, which would seem reasonable if wallaby and other terrestrial animals contributed significantly to the diet. But on consideration of the range of nitrogen values, from 6.64 to 13.19 per mil, this explanation seems unlikely. These nitrogen values indicate diets consisting of 94% and 40% terrestrial foods respectively, or more plausibly diets with differing proportions of reef based foods. The location of Motupore Island, together with the analysis of faunal remains from the area, suggests that the Motupore diet was predominantly marine based. The nitrogen isotope results can therefore be interpreted as indicating a marine component with a strong emphasis on reef foods. However, because terrestrial and reef foods cannot be distinguished using nitrogen isotope ratios it is not possible from the nitrogen results to determine the proportions of these foods in the Motupore diet.

However, the wide range of nitrogen values may be due in part to some post-mortem contamination of samples. It is difficult to determine whether this is in fact the case as C/N ratios are available for only two individuals, and although these results indicate no diagenetic alteration of these particular samples there is no guarantee that other individuals from the same site have not been affected by diagenetic processes. The question of dietary continuity should also be considered here, as the range of nitrogen values could be a function of dietary differentiation over time rather than between contemporary individuals.

A consideration of the carbon and sulphur values for the two individuals AY498 and AY499 tends to give support to the initial interpretation of the lower nitrogen values as reflecting an increased coral reef component in the diet. Both the carbon and the sulphur values for AY499 indicate that that particular individual ate more marine foods than AY498, whereas the nitrogen value for AY499 could reflect either a higher proportion of terrestrial foods or more foods from a reef environment. When the carbon and sulphur results are taken into account, the inclusion of more marine foods, particularly reef foods, in the diet of AY499 seems the more likely explanation.

The mean carbon value for AY498 and AY499 suggests an overall marine dietary component of 86%, significantly higher than the proportion of marine foods suggested from the nitrogen values, but of course conceivable if reef foods were eaten. However, for this particular site there are further complications to the interpretation of the carbon results, because of the apparent inclusion of wallaby (Macropus agilis) in the Motupore diet. Carbon isotope analysis carried out in the present study for wallaby from the Motupore site revealed that the wallaby diet included a large proportion of C4 plants, and the inclusion of these animals in the Motupore diet is suggested by the concentration of wallaby bone in the terrestrial component of the Motupore assemblage. Carbon values could therefore be expected to be affected by the consumption of wallaby, provided that wallaby was consumed in sufficient quantity, resulting in highly marine- looking carbon values.

Sulphur isotope analysis was included in this thesis with the expectation that such difficulties in interpretation of nitrogen and carbon results might be resolved by consideration of sulphur values. As mentioned above, there are some apparent anomalies with the sulphur results which as yet are unable to be explained adequately, but this problem may be resolved with further research. The Motupore sulphur values indicate a diet with approximately 69% marine foods, and if these sulphur values are accurate, consideration of the results from all three isotopes suggests that the Motupore diet was focused on the sea, with approximately 70% of the diet coming from that source. The inclusion of reef foods in the diet has resulted in more terrestrial-looking nitrogen values, while the inclusion of a terrestrial C4 plant consumer in the diet has resulted in more marine-looking carbon values.

PAPUA NEW GUINEA - NEBIRA

The people from the inland site of Nebira, in contrast to those from Motupore Island, appear to have focused on the exploitation of terrestrial resources, although not exclusively. As can be seen from Table 6.4, the proportion of terrestrial foods in the diet, as indicated from the nitrogen, carbon and sulphur results are 59%, 28% and 81% respectively. It should be noted here, however, that the C/N ratio of AX990, 3.8, is outside the 'safe' range and may have been affected by diagenesis. If the results for AX994 are considered alone, the proportions of

terrestrial foods in the diet are 58%, 44% and 74%, from nitrogen, carbon and sulphur respectively.

The nitrogen values are more uniform than those from Motupore and fall within a similar range to those from the inland site of Rotoiti in New Zealand. As was the case for Rotoiti, the nitrogen value, which is more marine-looking than expected for this site, may be explained by the inclusion of freshwater species in the diet. A number of freshwater species, including crocodiles, fish, freshwater mussels and prawns, were readily available from the nearby Waigani swamp (Bulmer 1978:28), and the nitrogen results suggest that foods from this environment were important in the Nebira economy. The expectations of the Nebira diet which were developed from archaeological evidence, suggesting that shellfish species from a coral reef environment may have been a significant component, have not been substantiated by the nitrogen isotope results. This appears to confirm the suggestion, based on the fact that the concentration of marine shells occurs in the layers above the burials, that the coastal connection may have been more important to the later inhabitants of Nebira, rather than those individuals studied here.

The very marine-looking carbon value can be explained by the inclusion in the diet of both freshwater species and terrestrial animals, in particular wallaby, which feed on C4 plants. The direct inclusion in the diet of the C4 plant sugar cane is also a distinct possibility for these people, although it

is not possible to distinguish direct ingestion of such plants from secondary ingestion through the consumption of C4 plant-eating animals.

The Nebira results are very similar to those from Rotoiti, reflecting a heavy emphasis on the exploitation of terrestrial resources with some marine input, presumably through exchange of resources with coastal groups. For Papua New Guinea, such exchange networks have been well documented ethnographically, and Allen (1977:444) has suggested that the Motupore people exchanged fish and other marine animals for terrestrial resources such as the wallaby. The Nebira people appear to represent the inland participants in such exchange networks.

SOLOMONS - NAMU

The analysis of the Namu burials has produced results which are very similar to those from Saipan and Tinian in the Marianas. The nitrogen and carbon values indicate diets with 56% and 44% terrestrial foods respectively, while the sulphur values suggest that approximately 9% of the diet was derived from terrestrial sources (see Table 6.4).

While the carbon results suggest that the diet consisted of 56% marine foods, the nitrogen results show that a significant proportion of the marine component of the diet was derived from a reef environment. The archaeological expectations expressed in

Chapter four suggested that shellfish may have been a more regular component of the diet than fish. If reef shellfish could be distinguished from reef fish, which is currently beyond the scope of stable isotope analysis but may be possible in the future with further refinements of the technique, the relative importance of shellfish in the Namu diet could be determined. Without such a distinction it is not possible to determine here whether the isotope results reflect a general preference for reef foods over open ocean, or more specifically for reef shellfish over both reef and open ocean fish. The consumption of filter-feeding shellfish can be identified from trace element analysis of human bone, specifically by the co-occurrence of high zinc and strontium concentrations (Horwood 1988:132). High levels of strontium without high zinc levels tends to indicate a high consumption of vegetable foods. Horwood's (1988) trace element study of 100 individuals from the Namu site showed that these people had fairly high strontium and low zinc concentrations, which was interpreted as "...reflecting a high vegetable food intake with comparatively little importance being placed upon marine food resources, or terrestrial meat foods" (ibid.:139). The isotope results of the present study, when considered in combination with Horwood's results, tend to suggest that the reef component of the Namu diet did not include large amounts of filter feeding shellfish, but may have included a mixture of molluscs and reef fish.

The people from the Namu burial ground have been studied by Houghton (see Horwood 1988, Appendix 1) and age and sex details

are available for all the individuals used for the present study. It is thus possible to examine the results of the stable isotope analysis for any indications of sex- or age-related differences in diet. The stable isotope determinations for the Namu individuals are presented in Table 6.9, arranged in two groups by sex, and within the groups by age. The age and sex of the individuals was assigned by Houghton (Appendix 1, Horwood 1988).

With reference to Table 6.9, it can be seen that the nitrogen results will be most useful in determining any age- or sex-related differences in diet, because nitrogen values have been obtained for all individuals. Within both groups there is a wide range of δ15N values, between 7.93 and 12.68 (range = 4.75) for females, and between 8.37 and 12.89 (range = 4.52) for males, which does not appear to be related to the age of the individuals. These variations in δ15N values can be interpreted as reflecting different proportions in individual diets of marine and/or reef foods compared with foods from terrestrial sources.

Table 6.9: δ15N, δ13C and δ34S values (in per mil) of 21 individuals, grouped by sex and age, from Namu, Taumako, Solomon Islands.

Accession Number	Excavation Number	Sex	Age	δ15N (bone powder)	δ13C (collagen)	δ34S
AY 64	N 32	F	15	10.25		
AY 75	N 89	F	18	10.66		
AY 77	N 91	F	20-25	12.68		
AY 69	N 63	F	23-28	11.21	-17.60	16.9
AX848	N160	F	25-30	10.66	-15.79	11.1
AY 80	N103	F	25-30	10.94		
AY 76	N 90	?F	25-30	12.13		
AY 68	N 57	F	30-35	10.26		
AY 74	N 88	F	35-40	12.22		
AY 70	N 64	F	40+	7.93		
AY 79	N 95	F	40+	11.27		
			Means:	10.93	-16.70	14.0
				+-0.39	+-0.92	+-2.9

Table 6.9 - continued

Accession Number	Excavation Number	Sex	Age	δ15N (bone powder)	δ13C (collagen)	δ34S
Males						
AY 62	N 1	M	20	11.65		
AY 72	N 85	M	21-25	8.37		
AY 71	N 73	M	25-28	12.89		
AY 81	N104	M	25-30	10.06		
AY 67	N 48	M	30-35	11.39	-17.90	15.6
AY 73	N 87	M	30-35	12.83		
AY 65	N 35	M	40	12.97		
AY 66	N 37	M	40	11.65		
AY 63	N 23	M	40+	12.46		
AY 78	N 94	M	40+	12.38		
			Means:	11.67	-17.90	15.6
				+-0.46	-	-

Between the groups there is some indication, from the nitrogen values, that the male diet contained either more marine foods or less foods from the reef/lagoon environment than the female diet. To determine whether there were any significant sex-related differences in the Namu diet, a comparison between the mean male and female nitrogen values was made using a

Student's t test. The results (t=1.18 with 19 degrees of freedom) showed that there was no significant difference between the two groups (p=0.05). A comparison of the carbon and sulphur results for females and males does not contradict this result. The mean carbon value for the female group is more marine-looking than that for the male group, while the male sulphur value is more marine-looking than the female value. Because the carbon and sulphur results are ambiguous, which is likely to be related to the very small sample sizes, it is not possible to make any conclusions about sex-related differences in the Namu diet from the results of these two isotopes.

Some of these Namu people have also been examined by Whitehead, Devine and Leach (1986), using electron spin resonance, to determine their relative ages. If the Namu results were able to be arranged chronologically, it may be possible to look for any changes in dietary proportions of marine and terrestrial foods over time, although such changes are probably unlikely considering that the age spread of the burials has been determined as spanning only 168 years (ibid.:361). Unfortunately, it is not possible to examine the results for any changes over time as only two of the individuals examined by Whitehead et al. (ibid.) were used in the present study. These two females, AY69 (N63) and AY74 (N88) were assigned calendrical dates of AD 1633 and AD 1696 respectively (ibid.:360). The more recently buried woman, AY74, has a more marine-looking nitrogen value than the earlier woman, but this may simply reflect differences in dietary proportions between individuals and cannot be used to argue for

any changes over time.

Stable isotope analysis of the Namu individuals has thus revealed that just over 50% of the diet was derived from the marine environment, and that the marine component was composed of both reef and open ocean resources. A combination of fish and shellfish was recovered from the reef environment, but it is not possible, using current methods of interpretation, to quantify the proportions of these foods in the diet. There is a possibility that the male diet included either more marine foods or more food from the open ocean, compared with the female diet.

TONGA - 'ATELE

The individuals from 'Atele appear to have had a mixed marine and terrestrial diet, with a proportion of the marine component being derived from a reef environment. With reference to Table 6.4, the terrestrial component of the 'Atele diet can be calculated to be 64% from nitrogen and 50% from carbon. This can be interpreted as reflecting a significant contribution to the diet from reef foods. The proportion of terrestrial foods as calculated from the sulphur value is considerably lower, at 22%, than the terrestrial proportions suggested by the carbon and nitrogen values. Again, this may be due to several factors, such as incorrectly defined end-point values for sulphur, as yet unidentified anomalous values from certain foods, or environmental factors such as the postulated effect of sea spray

sulphates on the sulphur values of terrestrial foods.

These results have confirmed the archaeological expectations of the 'Atele diet, which suggested that these people were horticulturists who ate similar proportions of marine and terrestrial foods. The possibility that the proportions of marine and terrestrial foods in the diet may have changed over time can now be investigated, and the isotope determinations examined for any indications of status differences between the two groups. Davidson's (1969) analysis of these burials showed that the individuals within each mound could be assigned to groups which could be arranged in order from oldest to youngest, although those from To-At-2 could not be placed in sequence as satisfactorily as those from To-At-1 (ibid.:271). The results of the stable isotope analysis of the 'Atele individuals are presented in Table 6.10, arranged in chronological order for each mound from oldest to most recent, following Davidson (1969). The age and sex of the individuals was assigned by Pietrusewsky (1969).

Table 6.10: δ15N, δ13C and δ34S values (in per mil) of 20 individuals from two burial mounds at'Atele, Tongatapu.

Accession Number	Excavation Number	Sex	Age	δ15N (bone powder)	δ13C (collagen)	δ34S
Mound To-At-1						
AY9	TOAT 1/34	M	young adult	12.64	-17.39	11.4
AY19	TOAT 1/29A	M	adult	10.46		
AY15	TOAT 1/19	?	adult	9.88		
AY10	TOAT 1/10	M	adult	9.96		
AY25	TOAT 1/11	F	adult	8.29	-18.83	14.6
AY11	TOAT 1/14	?	adolescent	10.58		
AY21	TOAT 1/7	M	aged	9.43		
AY12	TOAT 1/6	M	mid-aged	11.59		
			Means:	10.35	-18.11	13.0
				+-0.46	+-0.71	+-1.63
Mound To-At-2						
Period 2:						
AY26	TOAT 2/26	F	adult	9.29		
AY24	TOAT 2/27	F	adult	9.99		
AY20	TOAT 2/40A	F	old adult	10.23		
AY22	TOAT 2/41	M	old adult	10.89	-17.77	12.2

Table 6.10 - continued

Accession Number	Excavation Number	Sex	Age	δ15N (bone powder)	δ13C (collagen)	δ34S
Mound To-At-2						
Period 3:						
AY18	TOAT 2/6	M	young	9.26		
AY13	TOAT 2/25	F	adult	11.93		
Period 4:						
AY23	TOAT 2/4	F	mid-aged	9.77		
AY27	TOAT 2/11	F	adult	9.41		
AY28	TOAT 2/16	F	young adult	10.29	-17.69	13.1
AY17	TOAT 2/18	M	old adult	10.61		
AY14	TOAT 2/30	F	adult	10.19		
Period 5:						
AY16	TOAT 2/42	M	adult	10.57		
			Means:	10.20	-17.73	12.7
				+-0.23	+-0.07	+-0.43

With reference to Table 6.10, there appears to be little or

no difference in the values between the two groups of people, with the mean values for nitrogen, carbon and sulphur being very similar. This suggests that if there were status differences between the two groups, these differences may not have been extended to include significant differences in access to marine and terrestrial food resources. Within the groups there does not appear to be any difference in the proportions of marine and terrestrial foods in the diets of the earlier, compared with the more recent, individuals.

The possibility that there were age- and/or sex-related differences in dietary proportions can also be examined here. In Table 6.11 the individuals included in Table 6.10, excluding AY15 and AY11 who could not be assigned a sex, have been regrouped according to sex and arranged within the groups by age from youngest to oldest.

With reference to Table 6.11, the comparison of isotope values from 'Atele by sex and age has revealed a possible small difference between the sexes in the proportions of marine, or reef foods, similar to that found for Namu. As was the case for Namu this difference is not significant and is only apparent from the nitrogen results. There does not appear to be any difference in dietary proportions between age groups.

Table 6.11: δ15N, δ13C and δ34S values (in per mil) of 18 individuals, grouped by sex and age, from two burial mounds at 'Atele, Tongatapu.

NB: Two individuals who could not be assigned a sex, and who were included in Table 6.10, have been excluded here.

Accession Number	Excavation Number	Sex	Age	δ15N (bone powder)	δ13C (collagen)	δ34S
Females						
AY28	TOAT 2/16	F	young adult	10.29	-17.69	13.1
AY25	TOAT 1/11	F	adult	8.29	-18.83	14.6
AY26	TOAT 2/26	F	adult	9.29		
AY24	TOAT 2/27	F	adult	9.99		
AY13	TOAT 2/25	F	adult	11.93		
AY27	TOAT 2/11	F	adult	9.41		
AY14	TOAT 2/30	F	adult	10.19		
AY23	TOAT 2/4	F	mid-aged	9.77		
AY20	TOAT 2/40A	F	old adult	10.23		
			Means:	9.93	-18.26	13.9
				+-0.33	+-0.57	+-0.78

Table 6.11 - continued

Accession Number	Excavation Number	Sex	Age	δ15N (bone powder)	δ13C (collagen)	δ34S
Males						
AY18	TOAT 2/6	M	young	9.26		
AY9	TOAT 1/34	M	young adult	12.64	-17.39	11.4
AY19	TOAT 1/29A	M	adult	10.46		
AY10	TOAT 1/10	M	adult	9.96		
AY16	TOAT 2/42	M	adult	10.57		
AY12	TOAT 1/6	M	mid-aged	11.59		
AY22	TOAT 2/41	M	old adult	10.89	-17.77	12.2
AY17	TOAT 2/18	M	old adult	10.61		
AY21	TOAT 1/7	M	aged	9.43		
			Means:	10.60	-17.58	11.8
				+-0.37	+-0.21	+-0.43

The largely uniform results for these individuals from 'Atele tend to confirm the proposed early horticultural focus of these people, suggested by the apparent construction of the two burial mounds over gardening areas.

TONGA - PEA

The individual, known as To-1, from Pea to the north-west of 'Atele, appears to have relied less on terrestrial resources than the 'Atele people. As presented in Table 6.4, the terrestrial component of the diet, calculated from nitrogen and carbon respectively, is between 64% and 24%. However, the more terrestrial-looking nitrogen value could alternatively be interpreted as reflecting a large reef component in the diet. A strong reef/marine focus is strengthened for this individual by the sulphur value, 12.5 per mil, which suggests that approximately 76% of the diet was derived from marine sources. These results may reflect an earlier, pre-horticultural emphasis on marine resources in Tonga, and if this particular individual is representative of the middle Lapita horizon, as claimed by Poulsen (cited in Spennemann 1985), these results would be significant to the strandlooper debate. In the absence of a reliable date for this individual, however, any further discussion on the significance of these results to a reconstruction of Lapita diet would be purely speculative.

DISCUSSION

With the above interpretations of the results of this study in mind, the potential of multiple stable isotope analysis to answer the questions posed in Chapter one can now be considered.

1 Were the early colonists of the Pacific predominantly strandloopers or were they horticulturists?

The economic focus, and hence the nature of the diet, of the early Lapita colonisers of the Pacific has been the subject of much debate over the last two decades. Since Groube's (1971) 'strandlooper' proposal, evidence has been produced to both support and refute his suggestion that the early Lapita people depended more on maritime/lagoonal resources than later Lapita people. One aim of this study has been to produce some direct evidence of the diet of the Lapita colonisers, from multiple stable isotope analysis of some early skeletons.

The results of the analysis of four Lapita skeletons from Lakeba, in the Lau Islands of Fiji, have indicated that these people, who colonised Lakeba nearly 3000 years ago, procured approximately 75% of their food from the sea. A significant proportion of the marine component of their diet was derived from the nearby reef environment, which tends to confirm Best's (1984) interpretations of the early Lakeba diet. While the terrestrial proportion of the diet could have included cultivated foods, this is not able to be confirmed with existing methods of interpretation of stable isotope results. It can be said, however, that the early Lapita colonisers of Lakeba ate sufficient terrestrial food for at least some of the terrestrial proportion of the diet to have been grown by these people.

While a small increase, over a period of 2000 years, has

been detected in the proportions of terrestrial foods consumed at Lakeba, it is not possible to state conclusively that this represents increased horticultural activity, just as it is also not possible to conclude that, from first settlement, the Lakeba people were horticulturists. Nevertheless, it is clear that stable isotope analysis is a reliable means of identifying the economic focus of the early colonists of the Pacific. It is to be hoped that in the future the question of whether the early colonists of the Pacific were horticulturists or were predominantly 'strandloopers' will be answered conclusively, provided more early Lapita skeletal material becomes available for isotope analysis.

2 How significant was sugar cane in the diets of early Pacific peoples?

Sugar cane is thought to have been an early domesticate in Melanesia (Warner 1962:407) and is presumed to have been dispersed throughout the Pacific by early Polynesian colonists (Yen 1982). As sugar cane is a C4 plant, its significant inclusion in a diet should be revealed by a comparison of the δ13C values with the δ15N and δ34S values obtained from a given group. The results of the present analysis of 119 Pacific skeletons were examined for indications of C4 plant consumption.

Easter Islanders are reputed to have used sugar cane juice as a substitute for water, a practice which has been associated

with the high incidence of caries among these people (Owsley, Miles and Gill 1986:189). However, the results of this study show that if sugar cane was eaten on Easter Island, it was not consumed in enough quantity to be detected by stable isotope analysis. This result may be due in part to the method of analysis of the results, which is essentially a comparative one. Multi-dimensional computer modelling, which is beyond the scope of this thesis, may in the future be able to detect the presence of sugar cane in the Easter Island diet.

Among the other people studied, using the comparative approach employed here the consumption of C4 plants only can be suggested for the two study groups from Papua New Guinea, but it is unclear whether this indicates direct consumption of C4 plants, such as sugar cane, or indirect consumption through the inclusion in the diet of terrestrial herbivores, such as wallaby, which browsed on C4 plants in Papua New Guinea. The presence of large numbers of wallaby in the coastal Motupore site tends to suggest that the C4 component of the Motupore diet was derived indirectly from the consumption of wallaby, rather than from the direct consumption of sugar cane in any significant quantity. The people from the inland site of Nebira, however, do appear to have included a significant proportion of C4 plant foods in their diet. While wallaby were eaten by the Nebira people large numbers of these animals were not recovered from the site, a fact which in combination with the highly positive carbon isotope results suggests that C4 plants, presumably sugar cane, were consumed directly in sufficient proportions to be detected by

stable isotope analysis.

It can be concluded that sugar cane was significant in the diets of early populations from Papua New Guinea, where the plant is indigenous and believed to have been domesticated (Warner 1962:407). In contrast, sugar cane does not figure significantly in the diets of the other Pacific populations studied here. While the plant may have been available to some or all of the people studied here, it may have been given a low priority as a potential food source.

Using an essentially simplistic comparative approach to the interpretation of the stable isotope results, the significance of sugar cane in the diets of some of these early Pacific people has been determined. The future application of multi-dimensional computer modelling may result in the detection of sugar cane in the diets of some of the other groups studied here.

3 Is it possible to identify the proportions of reef versus open ocean components in diets?

Analysis of the results of this study has revealed, as was expected, that reef foods were important in the diets of many Pacific populations. However, it is not possible to quantify the proportions of reef and open ocean components in diets, at least for the present. More research is needed in several areas, in particular multiple stable isotope analysis of plant and animal

species which could have been included in diets, and specific research on sulphur isotope ratios in plants, animals and humans. Continued investigation in these directions should result in the elimination of some of the uncertainties which thus far have prevented the identification of all the important variables which would have to be considered in order to quantify the proportions of reef versus open ocean foods in diets. In the future such quantification should be possible, especially by computer modelling and dietary simulation studies (for example see Minagawa et al. 1986).

4 Is it possible to identify correctly the proportions of marine and terrestrial foods in prehistoric diets in New Zealand and the Pacific?

In the above discussion, the proportions of marine and terrestrial foods in the diets of the study groups have been calculated from the δ15N, δ13C and δ34S values, and for some groups it is possible to integrate the three values to provide an overall proportion of foods from each source. The anticipated complications to interpretation from the inclusion of C4 plants and reef foods in the diet did arise, but in most instances further unanticipated factors have prevented accurate calculations of dietary proportions from being made. These factors include the apparent anomalies with some of the sulphur results, the lack of isotopic values for plants and animals which are likely to have been included in diets, the possibility that

the consumption of marine animals which consumed zooplankton could result in more terrestrial-looking carbon values, and the likelihood of carbon and nitrogen values from freshwater sources being intermediate between those from marine and terrestrial sources. Until further research has been carried out in these areas it will not be possible to produce accurate determinations of the proportions of marine and terrestrial foods in the diets of the people studied here.

For the present it is possible, using multiple stable isotope analysis, to calculate the percentage of marine or terrestrial foods in a given diet to within a likely range. In the future, with the increased identification of those factors which could complicate analysis, and with the aid of computer modelling, it should be possible to increase the accuracy of such calculations.

5 Is it possible to identify diets which were exclusively terrestrial or exclusively marine?

The results of the multiple isotope analysis of two groups in the present study have shown that the method can be used to identify exclusively terrestrial and exclusively marine diets. While the diets of these two groups, the people from the inland Lake Rotoiti area in New Zealand's North Island and the Moriori from Chatham Island, were not exclusively derived from one or other of these resource zones, it is possible from the

results to suggest a combination of values from the three isotopes which could indicate an exclusive dietary focus on either marine or terrestrial foods.

The identification of a terrestrial 'signature' has been complicated in this study by the fact that both groups which potentially might have focused exclusively on terrestrial resources, those from Rotoiti and Nebira, appear to have included foods from freshwater sources in their diets. Thus, it is only possible to suggest a range of values which could be expected from isotope analysis of people who ate exclusively terrestrial foods, including some from freshwater sources. Such a diet could be expected to produce δ13C values more negative than -19.00 per mil, δ15N values lower than 11.00 per mil and δ34S values lower than 2.00 per mil.

The determination of values which would reflect an exclusively marine diet has been complicated here by the apparently more negative carbon values for diets including large amounts of zooplankton-feeding marine animals. An exclusively marine diet which did not include reef foods, but did include zooplankton-feeding marine animals, could be expected to produce δ13C values more positive than -14.00 per mil, δ15N values higher than 18 per mil and δ34S values higher than 16.00 per mil.

Obviously, such exclusively terrestrial or exclusively marine signatures may only be valid for the particular geographical areas from which they were derived. Because such a

large number of variables may complicate results, such as the consumption of C4 plants, reef foods and foods from freshwater sources, applying the above combinations of values to results from other areas would be inadvisable. Rather, the best approach would be to analyse results from individual groups of people, taking into account possible consumption of reef foods, C4 plants etc. and the environmental setting. If the diet was focused exclusively on either terrestrial or marine resources, the results of this study have shown that such a diet can be identified using stable isotope analysis, provided the environmental context is considered.

FUTURE DIRECTIONS

In the course of this thesis, several important areas which require further investigation have been identified, and will now be discussed.

SULPHUR ISOTOPE VALUES

The sulphur isotope results from several sites have suggested a higher marine diet than has been indicated by the carbon and nitrogen results. Throughout this discussion several possible explanations for this have been mentioned briefly and these will now be summarised.

One explanation for this phenomenon, following Mizutani and

Rafter's (1969) finding that sea water spray was one of the main sources of sulphate in rain water at Gracefield, New Zealand (ibid.:73), is that some δ34S values may be affected by sea spray. Thus, consideration should be given to the possibility that isotope values from coastal sites may be elevated by sea spray sulphates. However, this does not explain the apparently accurate results from some coastal sites, especially Waihora on Chatham Island, which is in an area where sea spray is common. The likelihood of sea spray sulphates affecting some coastal sulphur values could be assessed by comparing sulphur isotope determinations from several samples of one species, taken from both inland and coastal locations.

A second possibility is that the sulphur end-point values which were defined for the purposes of interpreting the results of this study are incorrect. Further research on sulphur isotopes to determine whether there is any fractionation effect or trophic level enrichment for sulphur, and to obtain δ34S values for a wide range of potential food sources, will allow this suggestion to be explored and, if necessary, the end-point values to be revised.

A third explanation is that the sulphur isotope values of some plants or animals may be more marine-looking or terrestrial-looking than would be expected, given the environment from which they are derived. The C4 plant factor for carbon and the reef food factor for nitrogen have already been recognised and the possibilty that some similar factor exists for sulphur should be

considered. Peterson et al. (1985) have identified a mean δ34S value of -2.4 for Spartina alterniflora, a C4 salt marsh plant (ibid.:1361), which is a highly terrestrial-looking value. The consumption of fish which ate such plants, or which lived in a salt marsh environment, may result in ambiguous δ34S values. This possibility, and the possibility that other foods may produce ambiguous sulphur values, should be able to be explored fully when sulphur values become available from a range of food plants and animals.

Plants and animals from certain environments, such as areas where volcanic activity occurs or has occurred in the past, where there are high levels of sulphates in soils, may have unusual sulphur isotope values. The existence of this and other sorts of environmental effects should be able to be confirmed or ruled out with future research.

A further possibility which should be considered is that the unidentified 37% of the 'collagen' extract may contain sulphates which have different isotopic ratios than collagen. This need to determine the composition of the unidentified portion of the 'collagen' extract is discussed more fully below.

Finally, it should be recognised that the elevated sulphur values may be more apparent than real, reflecting the simplistic approach used here for the interpretation of the results of this study. The use of multi-dimensional computer modelling, which is beyond the scope of this thesis, but which has been applied

successfully to other studies (for example see Minagawa and Akazawa 1989), may allow for a more thorough analysis of these results.

Despite the problems associated with the interpretation of the sulphur results, the present research has shown that the sulphur isotope has great potential for inclusion in studies concerned with the reconstruction of prehistoric diets in New Zealand and the Pacific. With continued research into solving the problems of interpretation, it is to be hoped that more researchers will consider the use of 34S, in combination with 15N and 13C, in studies of this kind. The need for extensive testing of plants and animals from marine and terrestrial sources which may have been included in Pacific diets, to obtain a wide range of sulphur values, is particularly important and cannot be stressed enough.

MARINE CARBON VALUES

The carbon values obtained from some Pacific sites have been more negative, and therefore more terrestrial-looking, than would be expected if the proportions of marine and terrestrial foods indicated from the nitrogen and sulphur results are considered. It was suggested earlier that these highly negative carbon values could be related to the consumption of animals which fed on marine zooplankton. Keegan and DeNiro (1988) have reported more negative carbon values for marine plankton-feeding fishes, caused by the particulate organic carbon of marine

phytoplankton (ibid.:330). They call for more research into zooplankton-feeding fishes as a potential dietary source of more negative δ13C values (ibid.), and it has been suggested in this discussion that this research should extend to other marine animals which include marine zooplankton in their diets. Some published carbon values for marine birds (see Table 6.4) are highly negative, and it is hoped that continued analysis of such species will confirm the expectations presented here. This is particularly significant in the Pacific, where terrestrial animals were generally in short supply and marine birds and animals became important sources of meat for some populations.

COMPARATIVE DATA

The basic focus of this thesis has been to attempt to identify the proportions of marine and terrestrial foods in the diets of people from a number of locations within New Zealand and the Pacific. While this has been achieved up to a point, it has become apparent in the course of the interpretation and discussion of results that more detailed information about the isotopic ratios of potential food sources would greatly enhance the value of these results. It is suggested here that future research in the field of stable isotope analysis for the Pacific region be primarily concerned with developing an extensive data base of comparative isotope ratios from a wide range of food plants and animals. Such a focus would be of greater value at this point than the examination of additional human populations.

C/N RATIOS OF ANIMAL SAMPLES

Atomic carbon-to-nitrogen ratios were obtained for the five animal samples processed for this thesis. Four of these samples (see Table 5.3) produced C/N ratios which were outside the range of values, from 2.9 to 3.6, which are characteristic of collagen from fresh bone (DeNiro 1985:808). Samples with C/N ratios outside this range may have been subject to diagenetic alteration. While the variations from the fresh range are not great, this is a problem which should be investigated during future preparation and analysis of animal bone collagen.

COLLAGEN

During the development of the method of 'collagen' extraction to be used in this thesis, some areas were identified which require further investigation. The 'collagen' extract was found to consist of approximately 63% collagen, with the balance probably being composed of other organic components, such as non-collagenous proteins and bone proteoglycans (Myers pers. comm. 1988), and some silicon containing material, probably residual soil particles. It is hoped that future research may be undertaken to determine the exact nature of the unidentified portion of the 'collagen' extract, in order to rule out the possibility that the isotopic ratios being measured might reflect sources other than those relating to the diet.

Some additional research should also be undertaken to

determine the relationship between the sulphur isotopic ratios of bone proteoglycans and of collagen from a given bone sample. Bone proteoglycans, presumed to comprise a portion of the unidentified 37% of the 'collagen' extract, contain a high percentage of sulphate groups. It is therefore important to establish whether the sulphur isotopic ratios of bone proteoglycans are the same as would be found in the collagen. Confirmation that these ratios are the same is required before the absolute reliabilty of sulphur isotopic ratios obtained from the 'collagen' extract can be assured.

SUMMARY

The above interpretation and discussion of results has confirmed the great potential of multiple stable isotope analysis for the reconstruction of prehistoric diets in New Zealand and the Pacific. Some of the special problems associated with such analysis in the Pacific region have been identified, including the presence of coral reefs, the potential consumption of C4 plants and the effect of zooplankton consumption on carbon values. Some apparent problems with the interpretation of the sulphur results have been discussed and some possible explanations have been suggested. Several of these areas require further research, but it is generally concluded that the method will prove to be invaluable for the reconstruction of prehistoric diets in New Zealand and the Pacific.

CHAPTER SEVEN

CONCLUSIONS

The focus of this thesis has been to obtain quantitative evidence for the importance of marine versus terrestrial foods in prehistoric Pacific and New Zealand diets, using multiple stable isotope analysis. In addition, it was hoped that the analysis of the ratios in human bone of the stable isotopes of carbon, nitrogen and sulphur would identify the extent to which the prehistoric Polynesian diet became adapted to new environments. While the use of isotope ratios of carbon and nitrogen in dietary analyses is now widespread, the inclusion of sulphur isotope ratios in this thesis has been an attempt to break new ground and hopefully to overcome some of the ambiguities associated with stable isotope analysis in the Pacific.

Isotope analysis in this region can be complicated on the one hand by the fact that coral reefs are located in close proximity to many Pacific islands, and on the other by the fact that C4 food plants such as sugar cane may have been eaten by early populations. It has been established that δ15N values from coral reef areas are more terrestrial-looking than would normally be expected, and similarly δ13C values from C4 plants are more marine-looking than would normally be expected. Thus, in the Pacific, the results of dietary analyses using only carbon and nitrogen isotope ratios may be impossible to interpret to a

satisfactory degree. It was with the expectation that a third isotope could reduce such ambiguities in interpretation that the stable sulphur isotope 34S was introduced in this thesis, and its potential for clearly distinguishing between marine and terrestrial diets was explored.

The extent to which the above research focus has been successful can now be evaluated. In Chapter one the following five questions were posed which potentially could be answered using multiple stable isotope analysis.

1 Were the early colonists of the Pacific predominantly strandloopers or were they horticulturists?

2 How significant was sugar cane in the diets of early Pacific peoples?

3 Is it possible to identify the proportions of reef versus open ocean components in diets?

4 Is it possible to identify correctly the proportions of marine and terrestrial foods in prehistoric diets in New Zealand and the Pacific?

5 Is it possible to identify diets which were exclusively terrestrial or exclusively marine?

As discussed in Chapter six, the results of the stable isotope

analysis allowed these questions to be answered to some extent using a simplistic comparative approach. However, none of these questions was able to be answered conclusively and this was attributed to several unanticipated factors. In particular, some sulphur results were difficult to interpret, essentially because of a lack of comparative data and an incomplete understanding of the movement of sulphur through the food chain, and several areas of future research were suggested in this respect. Some carbon values appeared more terrestrial- looking than expected and this was interpreted as reflecting the consumption of marine birds and/or marine animals which had eaten marine zooplankton, thought to have more negative, or more terrestrial-looking, carbon values than other marine animals (Keegan and DeNiro 1988). The results of the analysis of two inland populations, from Nebira in Papua New Guinea and Lake Rotoiti in New Zealand, appeared to be complicated by the inclusion of freshwater fish and/or animals in their diets. The δ15N and δ13C values of some freshwater fish and animals have been found to be intermediate between marine and terrestrial values (Schoeninger and DeNiro 1984; Katzenberg 1989).

The future resolution of a further problem in the interpretation of results, namely the lack of comparative isotope values from a wide variety of possible food sources, is expected to alleviate most of the problems of interpretation mentioned above. The development of a comprehensive data base of nitrogen, carbon and sulphur ratios, from New Zealand and Pacific plants and animals, from both marine and terrestrial environments, is

considered to be an essential extension of the work begun in this thesis. The establishment of such a data base will allow for the above interpretations, relating firstly to δ13C values and marine zooplankton, and secondly to freshwater δ15N and δ13C values, to be either confirmed or discounted. With the added knowledge which the resolution of these special problems will bring to the study of prehistoric diets, more precise assessments of the importance of marine versus terrestrial foods will be possible. Of particular significance to the interpretation of the results of this thesis is the determination of a wide range of comparative sulphur values which will greatly extend existing knowledge about the movement of this isotope through the food chain. Such research is also expected to confirm the great potential of the sulphur isotope δ34S for eliminating ambiguities in the results of dietary studies in New Zealand and the Pacific.

It has become increasingly clear during the course of this research that the factors which combine to produce a given isotope ratio are too numerous to allow for accurate dietary reconstructions to be made using a simple comparative approach. However, recent applications of advanced computer modelling techniques to dietary studies (Minagawa et al. 1986; Minagawa and Akazawa 1989) have demonstrated that this problem is not insurmountable. Using multi-dimensional computer modelling, detailed analyses can be carried out based on large numbers of variables to produce reliable assessments of the composition of prehistoric diets. An analysis of the results of this thesis using multi-dimensional computer modelling can be expected to

provide more reliable and detailed answers to the questions posed in Chapter one. It is also expected that such a computer analysis may change some of the interpretations presented here, a possibility which should be kept in mind when reading this thesis.

Clearly, the potential of multiple stable isotope analysis for the reconstruction of prehistoric diets in New Zealand and the Pacific has been well proven here and the implications for archaeology are considerable. With the refinement of analytical techniques and the development of a representative data base of potential food plants and animals, more precise assessments of the relative importance of marine and terrestrial foods in early diets will be forthcoming. The routine inclusion of stable isotope analysis of human bone in future studies of prehistoric populations will greatly increase our understanding not only of early diets but also of human adaptive capabilities. Our understanding of the people of prehistory can only be enriched by such developments.

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APPENDIX 1

DETAILS OF ALL SAMPLES USED FOR ISOTOPE ANALYSIS

A HUMAN SAMPLES

LOCATION: Easter Island

COLLECTION HELD: Easter Island Museum

EXCAVATED BY: Easter Island Museum expedition, 1981 (Gill 1981)

Laboratory Acc. number	Excavation/ Cat. number	Anatomical element	Site number	Place
AX859	-	rib	8-324	Ahu kihi kihi rau mea
AX860	-	rib	8-324	Ahu kihi kihi rau mea
AX861	-	rib	12-471a	Oroi Cave
AX862	RH0286	rib	12-469	Oroi Cave
AX863	RH0285	rib	12-469	Oroi Cave
AX864	RH0219	rib	31-1	Ahu Mahatua
AX865	-	rib	14-21a	Ahu one makihi
AX866	-	rib	7-584	Ahu akahanga
AX867	RH0270	rib	7-598	Akahanga Cave
AX868	RH0092	rib	7-584	Ahu akahanga
AX869	RH0235	rib	31-4	Mahatua poe poe
AX870	RH0234	rib	31-4	Mahatua poe poe

LOCATION: Lakeba, Lau Islands, Fiji

COLLECTION HELD: Otago Medical School and Auckland University

EXCAVATED BY: Best, 1976-78 (Best 1984)

Laboratory Acc. number	Excavation/ Cat. number	Anatomical element	Site number	Place
AY82	196-28	radius/fibia fragments	101/7/196	Wakea
AY784	196-28-B8	unidentified	101/7/196	Wakea
AY785	197-1-M-9	unidentified	101/7/197	Qaranipuqa
AY786	197-3-C	unidentified	101/7/197	Qaranipuqa

LOCATION: Sigatoka, Viti Levu, Fiji

COLLECTION HELD: Auckland University

EXCAVATED BY: Best, 1987 (Best 1987b)

Laboratory Acc. number	Excavation/ Cat. number	Anatomical element	Site number	Place
AY787	West 1	unidentified	VL 16/1	Sigatoka Dune

LOCATION: Saipan, Mariana Islands

COLLECTION HELD: Historic Preservation Office, Saipan

EXCAVATED BY: Historic Preservation Office (Pietrusewsky and Batista 1980)

Laboratory Acc. number	Excavation/ Cat. number	Anatomical element	Site number	Place
AY781	SLH-1	rib	SLH	Saipan Latte House
AY782	MHS-2	rib	MHS	Mariana High School

LOCATION: Tinian, Mariana Islands

COLLECTION HELD: Historic Preservation Office, Saipan

EXCAVATED BY: Historic Preservation Office (Pietrusewsky and Batista 1980)

Laboratory Acc. number	Excavation/ Cat. number	Anatomical element	Site number	Place
AY778	TLH-1	rib	TLH	Tinian Latte House
AY779	TLH-3	rib	TLH	Tinian Latte House
AY780	TLH-4	rib	TLH	Tinian Latte House

LOCATION: Watom Island, New Britain

COLLECTION HELD: Otago Medical School

EXCAVATED BY: Specht, 1966; Green, Anson and Specht, 1985 (Specht 1968; Green and Anson 1987; Green, Anson and Specht 1989)

Laboratory Acc. number	Excavation/ Cat. number	Anatomical element	Site number	Place
AY56	Watom 01	rib	8	Rakival
AY57	Watom 03	rib	8	Rakival
AY58	Watom 04	rib	8	Rakival
AY59	Watom 05	rib	8	Rakival
AY60	Watom 06	rib	8	Rakival
AY61	Watom 07	rib	8	Rakival

LOCATION: Chatham Island, New Zealand

COLLECTION HELD: Otago Medical School

EXCAVATED BY: Sutton, 1975 and unknown (Sutton 1979)

Laboratory Acc. number	Excavation/ Cat. number	Anatomical element	Site number	Place
AY39	E25	rib	-	unknown
AY40	E26	rib	-	unknown
AY41	E27	rib	-	unknown

Chatham Island - continued

Laboratory Acc. number	Excavation/ Cat. number	Anatomical element	Site number	Place
AY42	E32	rib	-	unknown
AY43	E34	rib	-	unknown
AY44	E171	rib	C240/283	Waihora
AY45	E172	rib	C240/283	Waihora
AY46	E173	rib	C240/283	Waihora
AY47	E174	rib	C240/283	Waihora

LOCATION: Lake Rotoiti, North Island, New Zealand

COLLECTION HELD: Otago Medical School

EXCAVATED BY: Unknown. Presented to Otago Medical School, 1983

Laboratory Acc. number	Excavation/ Cat. number	Anatomical element	Site number	Place
AY48	E83,1	rib	-	Lake Rotoiti
AY49	E83,2	rib	-	Lake Rotoiti
AY50	E83,3	rib	-	Lake Rotoiti
AY51	E83,4	rib	-	Lake Rotoiti
AY52	E83,5	rib	-	Lake Rotoiti
AY53	E83,6	rib	-	Lake Rotoiti
AY54	E83,7	rib	-	Lake Rotoiti
AY55	E83,8	rib	-	Lake Rotoiti

LOCATION: Motupore Island, Papua New Guinea

COLLECTION HELD: Australian National University

EXCAVATED BY: Allen, 1972-75 (Allen to Leach pers. comm. 1987)

Laboratory Acc. number	Excavation/ Cat. number	Anatomical element	Site number	Place
AY488	M3 H16-11 SK1	unidentified	AAK	Motupore
AY489	K21-3-IV	unidentified	AAK	Motupore
AY490	M8 I17-111 SK2	unidentified	AAK	Motupore
AY491	M27 H16/11-IV/2 SK1	unidentified	AAK	Motupore
AY492	M6 I17-111 SK1	unidentified	AAK	Motupore
AY493	K20-III-5	unidentified	AAK	Motupore
AY494	K21-III-2, pit A	unidentified	AAK	Motupore
AY495	M4 H17-111	unidentified	AAK	Motupore
AY496	M2 I16-4 WP SK 1	unidentified	AAK	Motupore
AY497	K20/IVSB/2	unidentified	AAK	Motupore
AY498	M47 I/17/11/4	unidentified	AAK	Motupore
AY499	M1 H16-5B SK-1	unidentified	AAK	Motupore
AY500	K20/III/3	unidentified	AAK	Motupore
AY501	G16/IV/6	unidentified	AAK	Motupore

LOCATION: Nebira, Papua New Guinea

COLLECTION HELD: Otago Medical School

EXCAVATED BY: Bulmer, 1968-69 (Bulmer 1978)

Laboratory Acc. number	Excavation/ Cat. number	Anatomical element	Site number	Place
AY35	ACJ43	rib	ACJ	Nebira
AY36	ACJ04	rib	ACJ	Nebira
AY37	ACJ17	rib	ACJ	Nebira
AY38	ACJ20	rib	ACJ	Nebira
AX989	ACJ25	rib	ACJ	Nebira
AX990	ACJ30	rib	ACJ	Nebira
AX991	POM01	rib	ACJ	Nebira
AX992	ACJ10	rib	ACJ	Nebira
AX993	ACJ31	rib	ACJ	Nebira
AX994	POM22B	rib	ACJ	Nebira
AX995	ACJ11	rib	ACJ	Nebira
AX996	AAK3/15	rib	ACJ	Nebira
AX997	POM06	rib	ACJ	Nebira
AX998	POM09	rib	ACJ	Nebira
AX999	ACJ03	rib	ACJ	Nebira
AX1000	ACJ02	rib	ACJ	Nebira

LOCATION: Namu, Taumako, Solomon Islands

COLLECTION HELD: Otago Medical School

EXCAVATED BY: Leach and Davidson, 1977-78 (Houghton n.d.)

Laboratory Acc. number	Excavation/ Cat. number	Anatomical element	Site number	Place
AX848	N160	rib	SE-DF-14	Namu
AY62	N01	rib	SE-DF-14	Namu
AY63	N23	rib	SE-DF-14	Namu
AY64	N32	rib	SE-DF-14	Namu
AY65	N35	rib	SE-DF-14	Namu
AY66	N37	rib	SE-DF-14	Namu
AY67	N48	rib	SE-DF-14	Namu
AY68	N57	rib	SE-DF-14	Namu
AY69	N63	rib	SE-DF-14	Namu
AY70	N64	rib	SE-DF-14	Namu
AY71	N73	rib	SE-DF-14	Namu
AY72	N85	rib	SE-DF-14	Namu
AY73	N87	rib	SE-DF-14	Namu
AY74	N88	rib	SE-DF-14	Namu
AY75	N89	rib	SE-DF-14	Namu
AY76	N90	rib	SE-DF-14	Namu
AY77	N91	rib	SE-DF-14	Namu
AY78	N94	rib	SE-DF-14	Namu
AY79	N95	rib	SE-DF-14	Namu
AY80	N103	rib	SE-DF-14	Namu
AY81	N104	rib	SE-DF-14	Namu

LOCATION: 'Atele, Tongatapu

COLLECTION HELD: Auckland Institute and Museum

EXCAVATED BY: Davidson, 1964 (Davidson 1969)

Laboratory Acc. number	Excavation/ Cat. number	Anatomical element	Site number	Place
AY9	TOAT 1/34	rib	To-At-1	Atele
AY10	TOAT 1/10	rib	To-At-1	Atele
AY11	TOAT 1/14	rib	To-At-1	Atele
AY12	TOAT 1/6	rib	To-At-1	Atele
AY13	TOAT 2/25	rib	To-At-2	Atele
AY14	TOAT 2/30	rib	To-At-2	Atele
AY15	TOAT 1/19	rib	To-At-1	Atele
AY16	TOAT 2/42	rib	To-At-2	Atele
AY17	TOAT 2/18	rib	To-At-2	Atele
AY18	TOAT 2/6	rib	To-At-2	Atele
AY19	TOAT 1/29A	rib	To-At-1	Atele
AY20	TOAT 2/40A	rib	To-At-2	Atele
AY21	TOAT 1/7	rib	To-At-1	Atele
AY22	TOAT 2/41	rib	To-At-2	Atele
AY23	TOAT 2/4	rib	To-At-2	Atele
AY24	TOAT 2/27	rib	To-At-2	Atele
AY25	TOAT 1/11	rib	To-At-1	Atele
AY26	TOAT 2/26	rib	To-At-2	Atele
AY27	TOAT 2/11	rib	To-At-2	Atele
AY28	TOAT 2/16	rib	To-At-2	Atele

LOCATION: Pea, Tongatapu

COLLECTION HELD: Otago Medical School

EXCAVATED BY: Poulsen, 1963-64 (Poulsen 1967)

Laboratory Acc. number	Excavation/ Cat. number	Anatomical element	Site number	Place
AY774	AK (To-1)	unidentified	To-Pe-1	Pea

B ANIMAL SAMPLES

Laboratory Acc. number	Common name	Scientific name	Anatomical element	Location
AX852	Cow	Bos taurus	tibia	Waitati, NZ
AX002/3	Dugong	Dugong dugon	rib	Motupore, PNG
AX004/5	Turtle	unidentified	carapace	Motupore, PNG
AX006/7	Wallaby	Macropus agilis	mandible	Motupore, PNG
AX008/9	Sea lion	unidentified	mandible	Auckland Is.

C PLANT SAMPLE (provided by Pamela Swadling 1987).

Common name	Scientific Name	Location
kunai	Imperata cylindrica	Port Moresby, PNG

APPENDIX 2

THE OTAGO UNIVERSITY BONE STANDARD

The Otago University bone standard was prepared for use in the present study. In order to perfect the method of collagen isolation and to test the purity of the 'collagen' extract, large quantities of bone powder were required. To allow valid comparisons to be made between tests, the bone powder used for each test had to be from the same source, which presented some problems as the bone samples available were generally small (<50gms). This was overcome by using quantities of bone from the Namu excavation, in the Solomon Islands, which could not be provenanced and which therefore was of little benefit in the burial analysis. Approximately 1.4 Kg of bone from square H6 was cleaned in deionized water, dried at 35° Celsius, and ground in a tungsten carbide temma mortar to produce an homogeneous powder. The possibility of contamination of the bone powder with tungsten carbide from the temma mortar was recognised and investigated using XRF analysis (see below). Dr B Vincent of the Otago University Anthroplogy Department prepared a slide of the bone powder and, using an oil immersion lens, examined it under a polarizing microscope in polarized light, at 100 times magnification. The size range of the grains was found to be between 10 and 100μ, with individual grains ranging in shape from subangular to subrounded (Vincent pers. comm. 1989). This was confirmed by passing 1gm of the bone powder through nested sieves with mesh sizes of 100, 75 and 66μ. 60% of the sample was

between 75 and 100μ, 20% was between 66 and 75μ, and the remaining 20% was <66μ.

XRF ANALYSIS OF THE BONE STANDARD AND 'COLLAGEN' FROM THE BONE STANDARD TO DETECT CARBON CONTAMINATION FROM USE OF A TUNGSTEN CARBIDE TEMMA MORTAR

The presence in the bone collagen of carbon from sources unrelated to diet could threaten the reliability of the results from 13C analysis. The tungsten carbide temma mortar, which was used to powder the bone samples, was recognised as a possible source of such carbon contamination. Samples of the bone powder and the 'collagen' prepared from the bone powder were analysed using XRF to see if tungsten was present.

Materials

Discs were prepared as follows:

1 Bone powder. 5gm of bone powder was mixed with 0.3ml mowiol organic binder and pressed under 5 tons pressure for 1-2 minutes. The sample was dried overnight in an oven.

2 'Collagen'. 1gm collagen was pressed under 12 tons pressure for 2-3 minutes. It was not necessary to add any binder. The sample was left overnight.

Methods

The XRF machine was fitted with a molybdenum tube. It was ascertained that this tube would not excite the Kα rays, but would detect the tungsten Lα rays. The tungsten Lα peak at 43.02° 2θ was examined, using a Lithium fluoride (Lif200) crystal, for the following samples:

1 GXR-3 (international standard) which is known to have 1.07% W The sample was scanned between 40 and 44° 2θ. The W Lα peak was detected at 43.02°, which established that the molybdenum tube was exciting the tungsten.

2 JB-1 (international standard - a Japanese basalt) which is known to have 20ppm (0.002%) tungsten. The sample was scanned between 40 and 45° 2θ. The W Lα peak was not detected because of compton scattered radiation from the molybdenum tube.

The JB-1 sample was run again, this time looking for the W Lβ peak, but again this was not detected because of interference.

3 AN-G (international standard) which is known to have 90ppm (0.009%) tungsten. The sample was scanned between 42 and 44° 2θ. The W Lα peak was barely detected. It was concluded that any tungsten present in a sample in a concentration of less than 100ppm (0.01%) would be difficult to detect using the molybdenum tube.

4 Bone. The bone pellet was scanned between 42 and 44° 2θ. The W Lα peak was not detected. A repeat run between 42 and 44° 2θ confirmed that the W Lα peak could not be detected, because of the scattered compton radiation from the molybdenum tube. It was concluded that any tungsten present in the bone powder was in a concentration of less than 100ppm (0.01%).

5 'Collagen'. The collagen pellet was scanned between 42 and 44° 2θ. The W Lα peak could not be detected. The peak caused by the scattered radiation from the molybdenum was detected, and if tungsten had been present in significant amounts this would have shown up as a sharp peak at the top of the molybdenum peak.

Conclusions

If the bone powder does contain tungsten (contamination from the tungsten carbide tema mortar) the tungsten is present in a concentration of less than 100ppm (0.01%).

APPENDIX 3

'COLLAGEN' YIELDS

Yield of 'collagen' from bone powder

Site	Acc. No.	Bone wgt. (gms)	'collagen' wgt(gms)	%yield
Human samples				
Nebira	AX 990	51.07	5.74	11.24
Nebira	AX 994	41.28	5.51	13.35
Rotoiti	AY 50	38.90	7.36	18.92
Rotoiti	AY 51	42.44	8.81	20.76
Rotoiti	AY 52	41.20	12.61	30.61
Rotoiti	AY 53	41.30	8.72	21.11
Watom	AY 57	37.00	1.34	3.62
Watom	AY 58	34.47	1.53	4.43
Watom	AY 59	34.42	0.49	1.41
Namu	AY 67	42.09	1.58	3.74
Namu	AY 69	41.98	2.79	6.65
Atele	AY 9	45.87	2.80	6.10
Atele	AY 22	44.56	3.51	7.88
Atele	AY 25	45.25	2.13	4.71
Atele	AY 28	43.97	3.62	8.24
Pea (To-1)	AY 774	32.50	1.80	5.54
Chathams	AY 39	47.00	9.95	21.17

Appendix 3 - continued

Site	Acc. No.	Bone wgt. (gms)	'collagen' wgt(gms)	%yield
Chathams	AY 40	35.11	7.81	22.24
Chathams	AY 41	50.03	11.51	23.01
Chathams	AY 43	44.29	10.24	23.12
Chathams	AY 45	32.00	6.27	19.59
Motupore	AY 498	49.90	3.34	6.69
Motupore	AY 499	35.13	3.47	9.88
Lakeba	AY 82	11.27	0.13	1.17
Lakeba	AY 784	37.13	0.99	2.67
Lakeba	AY 785	13.90	0.43	3.09
Lakeba	AY 785b	14.50	0.48	3.31
Lakeba	AY 786	31.85	3.05	9.58
Sigatoka	AY 787	32.15	0.37	1.15
Easter Is.	AX 859	5.03	0.36	7.16
Easter Is.	AX 860	5.85	0.76	12.99
Easter Is.	AX 861	1.92	0.41	21.33
Easter Is.	AX 865	1.37	0.22	16.06
Marianas	AY 778	24.84	3.27	13.16
Marianas	AY 779	14.46	1.04	7.19
Marianas	AY 780	32.40	2.37	7.31
Marianas	AY 781	31.30	2.75	8.79
Marianas	AY 782	32.36	1.18	3.65

Appendix 3 - continued

Animal samples:

Site	Acc. No.	Bone wgt. (gms)	'collagen' wgt (gms)	%yield
Motupore (Dugong)	AX 002/003	30.15	1.41	4.68
Motupore (Turtle)	AX 004/005	35.18	1.06	3.00
Motupore (Wallaby)	AX 006/007	25.04	0.16	0.65
Auck Is. (Sea lion)	AX 008/009	31.72	7.46	23.51
Waitati (Modern cow)	AX 852	30.20	3.95	13.09

APPENDIX 4

13C AND 34S ANALYSIS

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1. Carbon-13

Stable carbon isotope analysis involves three steps: (i) conversion to carbon dioxide by oxidation of the sample, (ii) purification of the CO_2, and (iii) analysis of the isotopic composition of the CO_2 by mass spectrometry.

(i) Combustion.

A sealed tube method is used, based on that of Buchanan and Corcoran (1959) and similar to that used by other recent workers such as Boutton et al. (1983).

3-5 mg of the freeze-dried collagen is added to about 800 mg of cupric oxide powder in a length of 6mm o.d. quartz tube. The CuO was previously purified by heating for one hour at 900° Celsius in flowing oxygen. A 50-70mm length of silver wire (previously heated in a stream of hydrogen at 700° Celsius) was added to the tube, and the tube evacuated to less than 100 Pa, and then sealed.

Sets of sealed tubes are then heated to 900° Celsius in a furnace for one hour, and allowed to cool slowly, usually overnight. The CuO supplies adequate oxygen for complete combustion of organic matter to CO_2.

(ii) Purification.

The presence of silver and copper oxides in a slowly cooled tube allows removal of possible contaminants such as oxides of nitrogen, sulphur and halogens, and the gas in the tube is CO_2, H_2O and nitrogen (Boutton et al. 1983).

Tubes are cracked open into a vacuum using a tube-cracker (DesMarais and Hayes 1976), and the condensible gases CO_2 and water are frozen in a liquid nitrogen cooled trap. Nitrogen may be removed by the vacuum pump, or is transferred to a small amount of liquid nitrogen cooled Type 5A molecular sieve, which can be subsequently warmed to room temperature in a calibrated volume and N_2 yield determined.

After removal of nitrogen gas, the liquid nitrogen bath around the trap is replaced by a bath of dry ice/ethanol slush which keeps water frozen but allows CO_2 to distill to another liquid nitrogen cooled trap in a calibrated volume where, upon warming, the CO_2 pressure gives a measure of yield.

In this way C/N ratio is also determined, but due to the errors in weighing the collagen sample used, absolute carbon and nitrogen contents are less precise.

From the calibrated volume the CO_2 is distilled to a sample bottle for mass spectrometry.

(iii) Mass spectrometry.

The purified CO_2 is analysed in a Nuclide 6-60 double inlet, ratio mass spectrometer by comparison with the CO_2 of TKL (Te Kuiti Limestone) standard. Appropriate corrections (Craig 1957) are made for 17 O and instrumental factors and the result expressed relative to the international PDB (Pee Dee Belemnite, a fossil shell carbonate) as follows:

$$\delta 13C \text{ PDB (per mil)} = (((\text{sample } 13C/12C)/(\text{PDB } 13C/12C)) - 1) \times 1000$$

Analytical precision is estimated on the basis of 11 replicates of NBS-21 graphite standard (Rounick et al. 1982), where a mean value of $\delta 13C = -27.99$ per mil was obtained ($n=11$, 1 SD = 0.12 per mil, range = 0.3 per mil).

2. Sulphur-34.

Barium sulphate is filtered from the solution obtained by Parr bomb combustion, by cellulose Millipore (0.1μm) filter. Gentle heating of the filter paper in a platinum crucible allows complete removal of the cellulose by burning.

The $BaSO_4$ is mixed with graphite powder, and heated (Rafter 1967) in a vacuum. The resulting BaS is leached from the graphite mixture into a silver nitrate solution where it forms Ag_2S.

The silver sulphide is filtered and dried, then mixed with cuprous oxide and reacted at 800° Celsius to prepare sulphur dioxide for mass spectrometry (Robinson and Kusakabe 1975).

The sulphur dioxide is analysed for 34S/32S ratio by comparison with a reference gas using a Micromass 1202 mass spectrometer. Results are expressed relative to the CDT (Canyon Diablo meteoritic troilite) international standard as follows:

$$\delta 34S \text{ CDT (per mil)} = (((\text{sample } 34S/32S)/(\text{CDT } 34S/32S)) - 1) \times 1000$$

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