The Prehistoric People from Sigatoka:

An Analysis of Skeletal and Dental Traits as Evidence of Adaptation.

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Abstract

The biological relationships of Pacific people has long been the subject of conjecture and research. Yet very few skeletons older than 1000 years have been recovered and studied. The excavation of 63 skeletons from the Sigatoka Dune Site, (VL16/1) Fiji has provided a unique opportunity to examine a discrete skeletal population dated to *circa* 180 AD. The study of the Sigatoka population focuses on four areas. One focus compares sex differences in the Sigatoka population using data provided by analyses of census, health, and pathology. Secondly, the distribution of burials is analysed using biological data. A third focus compares the Sigatoka with skeletal and anthropometric data obtained from Pacific populations. The fourth focus examines selective forces which may have influenced the Sigatoka body form.

The people from Sigatoka appear to have experienced few episodes of growth disruption, nor is there bony evidence of infectious diseases. In the absence of deleterious health factors, the Sigatoka people were able to obtain comparatively tall statures and heavy body mass. Mean age at death is around 30 years of age. However, evidence of good health suggests that the average length of life of the entire population may have been around 40 years of age.

Some of the bony pathologies present are argued to be effected by cultural activities determined by sex and social status. The consequences of these pathologies compromised health and may have contributed to an earlier age of death in some individuals. Social hierarchy is also implied by the location and distribution of burials. Heavier, taller, and older males were buried at the highest point of the burial ground. These differences indicate a society which was stratified and complex.

The ability to draw firm conclusions of affinity from comparisons between Sigatoka and Pacific populations are limited by the vagaries genetics, environment, and limited sample sizes. However, there are indications that the Sigatoka people have close skeletal affinity with Lapita associated skeletons. Strong similarities in body form and skeletal traits also seem to exist with most Polynesians groups but not with non-Polynesian populations. Furthermore, significant skeletal differences occur between Sigatoka and recent Fijians. The extent of these differences and the time frame in which change took place are argued to be a consequence of frequent and perhaps widespread contact from the west, probably Vanuatu.

The skeletal characteristics and body form of the Sigatoka people are suggested to reflect an adaptation to a cooler environment than contemporary tropical Fiji. Their body form fits in with models which suggest an adaptation to a cool marine environment. However, cultural mechanisms may have also contributed to the evolution of the Sigatoka body form.

Preface

The archaeological excavation of the Sigatoka skeletal material began in 1987 as a salvage excavation to recover human skeletal material which was rapidly eroded from the dune site. The success of the initial excavation and the discovery of a burial ground more extensive than first thought meant that a second season of excavation was required to recover all the skeletons. In total 63 individuals were recovered. Some of individuals were represented by bone fragments and have been stored at the Fiji Museum since 1988. The fragile state of the bones meant that much information was lost in the excavation stages. However, information loss was minimised by examining the skeletons *in situ* . For this reason it is important that a biological anthropologist to be present at excavations.

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Chapter One

Research objectives

1.0 Introduction

Human settlement in Fiji spans more than 3500 years. Although archaeological research has not yet been able to document human activity in Fiji for most of this period, there is an increasing wealth of data on the cultural aspects of the inhabitants. This data is providing a picture of periodic changes in the archaeological record. In particular temporal variations in pottery manufacture and decoration have been identified. In some cases these changes occur at about the same time in Fiji and Samoa, Tonga and Vanuatu. The synchrony of pottery changes has provided evidence for contact between these islands. However, very little is known about the human biology of prehistoric Fijians. Certainly the difference in physical appearance of the Fijian people compared to Tongans or Samoans has proved to be enigmatic since European exploration of the area (Flower, 1881; Howells, 1973). The excavation and analysis of a collection of human skeletal material from Sigatoka dune site on the south coast of Viti Levu, Fiji, has provided a unique opportunity to redress this lack of knowledge and to contribute to the understanding of the human biology of prehistoric Fijians and inhabitants of the Pacific Islands.

In 1986 the director of the Fiji Museum, Fergus Clunie, noted that coral mounds and human skeletal material were eroding from the Sigatoka dune site. A request was made to investigate the site more fully and recover any burials because they were under threat of erosion and destruction. The timely excavation of the burial ground in 1987 and 1988 recovered 63 extremely fragile skeletons. In 1993 the cemetery was destroyed by a hurricane. The skeletal material excavated from the site has proved to be the largest single collection of a discrete population from the southern Pacific dated before 1000 AD. These skeletons are invaluable in assessing the prehistoric human biology of the Pacific, more specifically the human biology of central and eastern Pacific and that of Fiji in particular.

1.1 Fiji in the context of the Pacific

The human inhabitants of small isolated Pacific islands provide a rare opportunity to study human micro-evolution. The Pacific basin is dominated by a marine environment, but the islands within that area have a variety of ecological niches. The range of island ecosystems and their geographic isolation have not only provided an environment that stimulated cultural and technological adaptive innovations (Kirch and Green, 1987), but also invoked a biological response in the human inhabitants of the Oceanic islands (Houghton, 1990, 1991^{a}, 1991^{b}). Given the length of human settlement in Fiji and it's geographic location, skeletal material from this island group provides an opportunity to study biological characteristics in relation to other Oceanic populations and to assess the influences that variables, such as the environment, isolation and migration, may have on human populations.

1.2 Research objectives

The focus of this thesis is adaptation. One aspect that will be examined is the biological success the Sigatoka people had in adapting to their environment. The second aspect to be assessed is to consider the Sigatoka skeletal characteristics and the selective forces that may have influenced them.

With the focus on adaptation in mind, the first major objective is to describe the Sigatoka skeletal material and develop a picture of how they appeared physically; what health problems they experienced; what cultural activities; and what traits are evident on the bone and dentition.

The second major objective is to evaluate and discuss the success the Sigatoka people had in adapting to their environment. One measure of adaptive success is the analysis of census data, health and pathology evident from the skeletons.

The third major objective is to compare the Sigatoka people with other Fijian skeletal series and Oceanic populations and to examine factors that may have influenced their body form. Comparative Oceanic populations that are to be compared to Sigatoka are divided into subsets based on geographic provenance. These populations provide examples of adaptations to a range of Oceanic environments.

To achieve the objectives listed above, a range of skeletal dental traits are used for which some understanding of their expression exists. The use of a range of variables will tend to identify a trait that deviates from the norm (Relethford and Lees, 1982). Furthermore, a range of traits will assist in making inferences on the various factors, such as environmental, genetic, and developmental, and how they influence the observed phenotype.

To gain an impression of body form, Sigatoka skeletons will be compared to other Oceanic populations. This will provide a means to test the model that the Remote Oceanic populations, Lapita associated people, and Sigatoka people conform to a large body size, in contrast to other Near Oceanic populations who tend to have smaller body sizes. Comparisons will be undertaken to examine the rule that variations in body form suggests an adaptation to a particular environment. This rule is based on the application of thermo-regulation principles which hold that a large or small body surface area and body mass reflects an adaptation to hot or cold climates (Bergmann, 1847; Allen, 1877; Newman, 1953; Eveleth, 1966; Houghton, 1990, 1991[a], 1991[b]; Ruff, 1994). For example, in this study a long limb-to-stature ratio should indicate a warm climate adaptation and short limb-to-stature ratios should indicate a cold climate adaptation.

Body proportions alone are not a good indicator of biological affinity but tend to reflect biological adaptability. This is because these features are able to adapt to new and extreme environmental conditions in a relatively short time (Newman, 1953; Damon, 1977; Lister, 1989; Ruff, 1994). Although, it has been pointed out that environmental differences complicate information on the derivation and affinities of a group as a biological population, it is equally clear that modifications of environment do not completely erase distinctions of body proportions among ethnic groups (Roberts 1953).

An additional consideration is the role of genetic bottle necks and the founder effect. The founder effect operates when a small number of individuals leave a parent population and settle in isolation elsewhere. This new population will have less genetic variation than the parent population. Genetic bottle necks operate within the limits of the founder effect. Each subsequent division from a founding population and continued isolation reduces genetic variation. A limited gene pool will influence the genotype and phenotype of that population.

The provenance of Oceanic populations discussed in this thesis are described in Chapter Two. It is sufficient to state here that populations from Tepoto and extreme Polynesia are used as examples in which genetic bottle necks and the founder effect seem likely to have occurred. These populations are geographically isolated, and were probably biologically isolated through much of their prehistory. The small atoll of Tepoto has a limited population carrying capacity. It is possible that periodic climatic events, such as tropical storms, killed off portions of the population and by doing so further influenced the size of the gene pool and ultimately changed the phenotype of the descendant population.

In contrast, Near Oceanic populations are considered to be biologically heterogeneous, having experienced different selective forces over a longer period than Polynesians. Some of these groups are compared to the Sigatoka males. Comparisons are also made with the Lapita associated skeletons.

1.3 Definition of terms

To understand the factors that may have influenced body form of the Sigatoka people and other Oceanic populations used in this study, a clear understanding of the terms associated with adaptation are required. In this thesis the term adaptation refers to the response of a population to the natural and cultural environment affecting the possession of existing genes or the acquisition of genetic systems. The genetic system provides the information that acts to maintain or improve survival and reproduction (Baker, 1988; Pilbeam, 1988). Individuals within a population may not possess all the required phenotypes to live optimally in a particular environment, but a population is adapted to an environment if it is able to survive in competition with other competitors of the same ecological niche, and if it is able to survive the environmental pressures of that niche (Hulse, 1960; Waterlow, 1985).

Selection refers to the opportunity that some individuals in a population contribute more offspring than do others. The characteristics of these individuals will increase in frequency through time within a population. Selective forces may be from the natural environment, such as climate or altitude. Other selective forces may be enforced by culture, such as socially determining which individuals may reproduce.

Genotype refers to the genetic constitution of an individual. The genotype is made up of the complete set of alleles inherited from the parents. Some of this information will be expressed biologically and much of it will not be, but the information may be passed on to following generations.

Phenotype refers to the observable (physical) characteristics of an individual that result collectively from both it's heredity (genotype) and environment.

In the context of these definitions, adaptation to a particular set of circumstances is the end result of selection. Populations and/or gene frequencies within a population may alter, adapting to new circumstances as they arise. The purpose of these changes is to seek and maintain a particular state or function (Waterlow, 1985). For example morphological adaptations in the teeth and mandible in primate species occurred in response to preferentially exploiting different foods (Anapol and Lee, 1994). The ability to alter and adapt to different dietary niches was the result of selective forces acting on different primate species.

Responses to different environments are evident in *Homo sapiens*. Many of these responses reflect variations or flexibility in phenotype in reply to environmental pressures (Baker, 1992). These changes are termed adaptability and reflect the ability of the genetic system to produce a range of different phenotypes, (and/or physiological adjustments), in response to different environmental pressures (Molnar, 1992; Ruff, 1994). The main attribute of adaptability is that it is reversible (Waterlow, 1985). Examples of adaptability are a reduction of body mass in warm climates compared to cold climates, or an increase in chest circumference in a population as a response to high altitudes (Baker, 1988; Frisancho, 1969).

Some forms of environmental pressures are sufficient to effect selection for different genotypes. An example of this type of selection is the relationship between malaria and red-cell variants (HbS, thalassemia, HbE). Individuals with these genes are less likely do die of malaria than those individuals who do not possess these variants (Harrison, 1992; Molnar, 1992).

Not all the traits expressed in a population are necessarily the result of an adaptation. Gould and Lewontin (1979) have pointed out that some expressions in a species seem to relate to purely random factors, and these expressions can be manifest in spite of natural selection. In this sense morphological characteristics of a skeletal population need not be the result of an adaptive response. It is therefore important not to restrict the analysis of skeletal material to a selection of diverse individual traits but to select traits that will be able to provide an expression of the body form and function of a population.

1.4 Thesis structure

The thesis structure is as follows:

Chapter Two provides background information to the study. A brief summary of the main theoretical models examining initial prehistoric settlement and of the eastern Pacific is given. A more detailed examination of the current concepts of human biology of the initial settlers is undertaken. A review of Fijian prehistory and studies of Fijian human biology is then presented. This is followed by a short discussion of the archaeological investigation of the Sigatoka burial ground and habitation site. An outline of the comparative populations used in this study is presented. Finally the statistical methods used in this thesis are discussed.

Chapter Three discusses the theory and methods of collecting census data, such as sex, age and the calculation of life expectancy from skeletal populations. The census data of the Sigatoka population are analysed and the results are presented to provide an assessment of the sex ratios, age distribution and growth, and also an indication of the cultural and biological success of the population.

Chapter Four outlines the theory and recording methods of the variables that are used to analyse aspects of health of the Sigatoka population. Some of the variables, such as stature and body mass, are non-specific and are either reflections of skeletal response during growth or provide an indication of body weight at the time of death. Other variables such as cortical bone thickness may be influenced by biomechanical strain and illness. By collectively analysing these variables, patterns of skeletal response to an individual's environment are assessed.

The results of the analysis of variables associated with health of the Sigatoka population are given. These results are interpreted to reflect the general health status of the population as a measure of adaptive success.

Chapter Five investigates skeletal pathology found in the Sigatoka population. A literature review that discusses the variables used to assess pathology is presented. The pathologies examined are specific and identifiable skeletal or dental responses. However, they may not accurately reflect pathologies within a living population, because bony evidence most frequently reflects the chronic phase of a disease rather than those phases and diseases that affect the soft tissue.

Pathology provides an indication of the factors that may affect the biological success of a population by limiting the reproductive potential of that population. Alternatively, pathology may be a selective response, whereby individuals who had less resistance to a pathology display chronic stages of infection and may have ultimately succumbed to infection(s) or disease(s). Conversely individuals with greater resistance may not display the chronic phases of an infection or disease. Furthermore, pathology may be a reflection of a particular cultural activity, in which case a particular behaviour may limit the success of individuals within a population. The results of the analysis of pathologies evident in the Sigatoka population are presented and comparisons are made with other Oceanic populations.

Chapter Six discusses skeletal and dental traits from the Sigatoka population. These traits reflect differing levels of genetic influence and the response of a variable to environmental factors, such as diet, and the activities an individual may have performed during life. The analysis of dental and skeletal variables indicate how the population appeared in life. Males and females are compared. Only metric and morphological traits for which there is some genetic understanding are used in the analysis.

Chapter Seven discusses the internal social differentiation in the Sigatoka burial ground on the basis of skeletal biological differences. Because bone responds to the effects of biomechanical strain, diet and pathology, skeletal variables can be used to infer differing behavioural tasks and access to food between groups of individuals buried in different locations. Furthermore, non-specific traits such as age, stature and body mass estimates can be used to assess relative social differences within a population. This information can provide information on the social structure of a skeletal population. In this Chapter males and females are analysed separately.

Chapter Eight discusses the comparisons between the Sigatoka population and other Fijian skeletal material. The skeletal material is compared to obtain an impression of body form. Body form may be influenced by various factors such as nutrition and muscularity, but is ultimately influenced by adaptation to selective forces. Comparisons between populations therefore need to consider the effects of differential selective forces acting upon them that produce responses that are manifest in bone. The comparison of the Sigatoka skeletal material with other Fijian populations is discussed within the concept of environmental adaptation and contact with other populations.

Chapter Nine compares the Sigatoka population with selected Pacific populations. Traits that are known to have a strong genetic basis are used. In particular some dental traits are used which appear to be less variable within a given population. Stature and body mass estimates are also compared, using the assumption that comparative populations were subjected to a similar range of factors that influenced final stature and body mass.

Chapter Ten discusses and compares the body forms of Pacific populations in relation to the Sigatoka people, and in particular the relationship of the Sigatoka population to Polynesian populations and to Lapita associated skeletons. An adaptive model is used to explain the body form of the Sigatoka population

Chapter Eleven synthesizes and summarises the thesis.

Chapter Two

A review of archaeological and biological models of the Pacific and Fiji, and an outline of the sample populations and statistics.

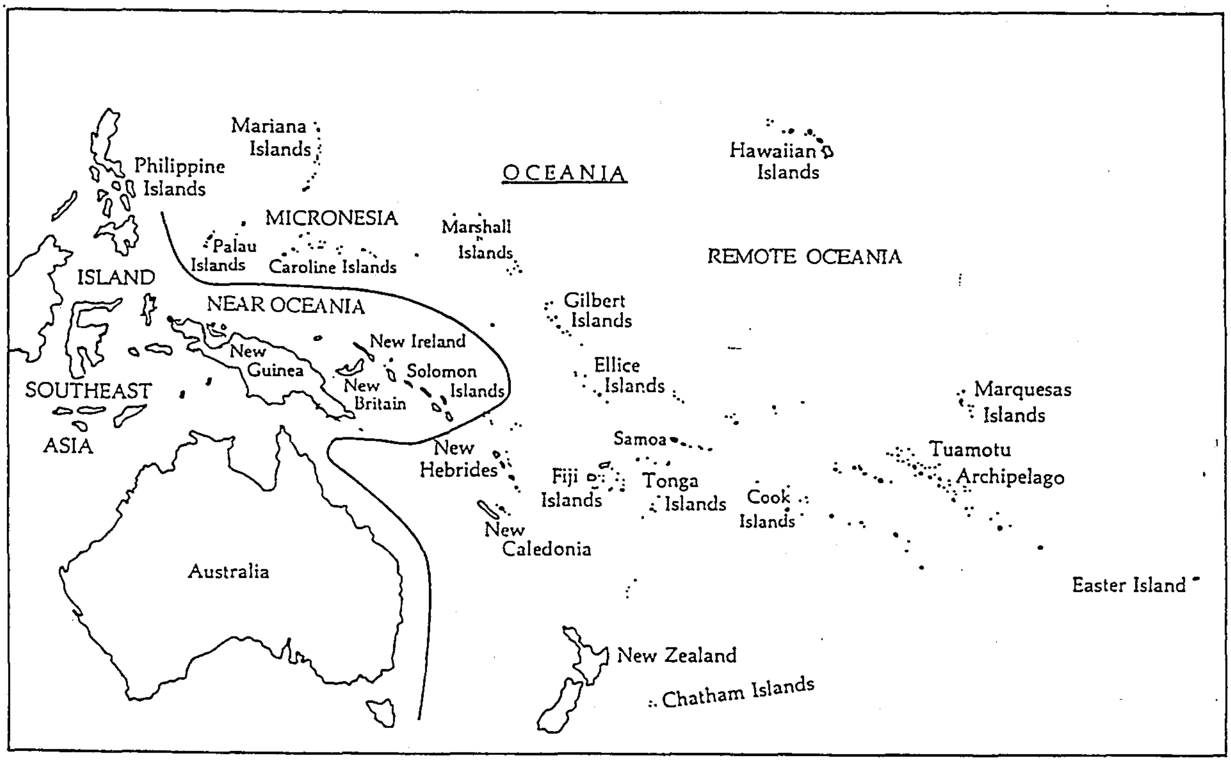
1.0 Introduction

This Chapter presents a brief summary of current concepts of the prehistory and human biology of Oceania with reference to Fiji and the skeletal material recovered from Sigatoka. However, it is not intended to provide an extensive review of the wider Pacific prehistory. A more detailed review of Fijian prehistory will then be given. This will be followed by summaries of the excavations at the Sigatoka Dune site (VL16/1). The methods of excavation and preservation of the Sigatoka skeletal material will be presented. This will be followed by a brief presentation of the comparative populations used in this study. Finally, the statistical methods used in this study will be outlined.

1.1 Review of Pacific settlement and human biological background

The Pacific Ocean covers nearly one third of the earth's surface. There are island chains scattered within this area. The size of these islands tends to decrease from west to east, while the distance between them increases. The area of interest in this study extends from New Guinea in the west, to Easter Island in the east, Hawaii in the north, and New Zealand in the south (Figure 2.1). At the time of European exploration of the Pacific Ocean most of the islands were or had been settled by cultural groups that came to be broadly categorised as Melanesians, Micronesians, and Polynesians. The prehistoric settlement of these islands raised questions of the biological origin, adaptations and cultural relations of the inhabitants, and how these peoples were able to settle widely scattered islands in the eastern Pacific Ocean. Moreover, European explorers noted the biological diversity of types of people living in Melanesia, which includes the area from New Guinea - Solomon Islands to Vanuatu, New Caledonia and Fiji, while commenting on the culturally and phenotypically homogeneous populations in the islands to the east of Fiji, Polynesia (Figure 2.1). The Fijian population was considered intermediate between these two large groupings (Hale, 1846; Williams, 1858).

Figure 2.1
Map of the Pacific islands and the divisions of Near Oceania and Remote Oceania.



There is a need to dispose of the distinctions that divided a large portion of the Pacific into; Polynesia, Melanesia and Micronesia (Green, 1994). While these models once served their purpose as simplified formulations based on a minimal amount of biological and archaeological data, they are no longer adequate. Sufficient data has now been gathered to demonstrate that a clear dichotomy does not exist between the areas that these models project (Green, 1994). Within current formulations, there is a need to realise the biological human diversity, not only in Near Oceania, but also in Remote Oceania. Therefore, recent models based on the prehistory of Oceania have found a useful distinction can be made between Near Oceania, (long settled, very diverse populations in physical appearance, language and culture), and Remote Oceania, (settled within the last 3000 years, less diversity in physical appearance, language and culture). This division is made between New Guinea and the Solomon Islands proper, constituting Near Oceania, and the Reef/Santa Cruz Islands, Vanuatu, New Caledonia, Polynesia, and Micronesia, constituting Remote Oceania (Figure 2.1).

1.2 Theories on the origins of Lapita culture and Lapita people

1.21 Archaeological evidence

Lapita refers to a distinctive, highly decorated pottery style first recovered from Watom Island (Figure 2.2) in the Bismarck Archipelago (Green, 1979). Archaeologists have found Lapita pottery in widely scattered sites, from the Bismarck Archipelago (Near Oceania) to Samoa and Tonga (Remote Oceania). In Samoa and Tonga, Lapita pottery is associated with the earliest cultural dates. Research has discovered additional cultural and linguistic evidence that is associated with the pottery, so that it is now possible to refer to a Lapita cultural complex (Green, 1979; Allen, 1984; Ambrose, 1988).

Archaeological excavations in the Bismarck Archipelago have recovered artefacts and pottery of Southeast Asian origin. While, obsidian sourced to Talasea, New Britain has been recovered from archaeological sites in south eastern Sabah, Borneo (Allen, 1984; Ambrose, 1988; Allen and White, 1989; Bellwood and Koon, 1989; Gosden *et al.*, 1989; Green, 1989). These findings demonstrate that the Lapita culture was involved in two-way contact with Southeast Asian cultures. The extent and means by which this contact occurred are unclear. However, it does illustrate that cultural contacts existed not only between Southeast Asia and the Lapita cultural complex, but also between other cultural traditions in western Near Oceania and Southeast Asia. Shell and bone tools, exotic obsidian, evidence of domesticated plants and animals, and two-way sailing technology demonstrates that these people had the ability to take and implement an economic system into a new environment without being completely dependent on local resources (Allen and White, 1989).

1.22 Archaeological models

An Orthodox view

An association of some cultural material between the Lapita cultural complex and some prehistoric Southeast Asian cultures has led a number of archaeologists to consider the idea that the Lapita cultural complex originated in Southeast Asia (Bellwood, 1989). This view postulates that the Lapita culture originated in Island Southeast Asia sometime around 2000 to 3000 BC, perhaps earlier (Bellwood, 1989). By 2000 BC a Southeast Asian people entered the Bismarck Archipelago and remained there in relative isolation. The cultural tradition and the people living on the Bismarck Archipelago at 2000 BC can be traced back to Southeast Asia on the basis of cultural traits, such as pottery decoration and manufacture, canoe technology, linguistics; plant foods; and biological characteristics such as biochemical and skeletal markers. By *circa* 1500 BC groups associated with the Lapita cultural complex quickly moved through Island Near Oceania. It is suggested that during their transition through Near Oceania they had minimal genetic or cultural contact with the resident populations. At around the same date, evidence of Lapita culture first appears in Fiji and west Polynesia.

Indigenous development model

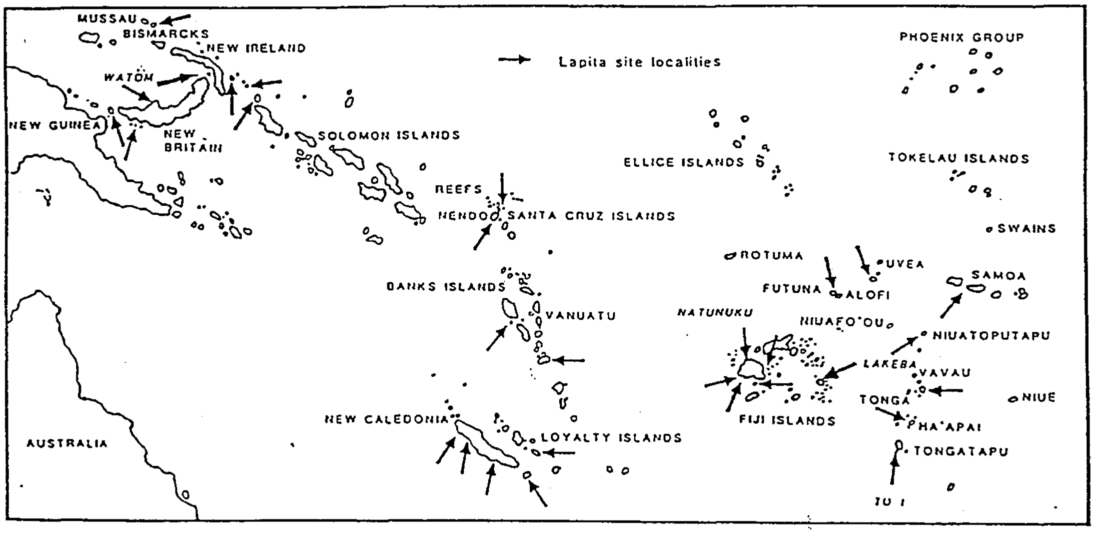
The Indigenous Development Model is based on the premise that the Lapita cultural complex and the Lapita biological types are largely indigenous developments, descendant from earlier cultures and people from around the Bismarck Archipelago, with some minor Southeast Asian influence (Terrell, 1986; White *et al.*, 1988; Allen and White, 1989; Green, 1989). This model states that Lapita pottery decorative techniques are a local phenomenon and they have not been identified in Southeast Asia. Furthermore, the model recognises that the Lapita complex co-existed in an environment where other local cultural traditions were present and some of which pre-dated Lapita (Kennedy, 1981). These pre-Lapita traditions had actively distributed obsidian in the western islands of Near Oceania before 1500 BC (Gosden *et al.*, 1989). The Indigenous development model holds that the body form of the Lapita people, their competent sailing methods, effective trading network, and rapid population growth were developed in the Bismarck Archipelago, and were of primary necessity to enable the successful and rapid colonisation of Remote Oceania.

The archaeological findings seem to indicate that the Lapita complex was part of a large, but not necessarily direct, trading network with Southeast Asia. This network allowed the introduction of ideas and material and probably genes into the islands of Near Oceania. However, the major focus of this cultural complex seems to have been within its immediate locality in the Bismarck Archipelago. This situation probably existed until the people associated with the Lapita cultural complex were confidently able to use their maritime experience to extend their cultural and probably biological spheres of influence. Their expansion from the Bismarck Archipelago seemed to have occurred at roughly the same time that Lapita ceramics appear there. Whether Lapita pottery was a local development or if it represents an imported development, is not too important in regard to human biology. This is because the new ceramic style was introduced or developed at a time when all other elements of the culture were present and the particular body form of the Lapita people had evolved.

1.23 Lapita cultural expansion

At around 1500 BC the Lapita culture rapidly moved through previously settled coastal locations and on to small off-shore islands in Near Oceania as evidenced by the presence of Lapita pottery (Allen and White, 1989). Lapita pots of similar antiquity have been recovered from the earliest archaeological sites in Remote Oceania (Figure 2.2). The types of pottery decoration are essentially the same in each of these sites, indicating a homogeneous culture, despite a distance of around 4500 kilometres separating the most distant sites (Irwin, 1992). It seems likely that two-way contact continued for some time between the dispersed Lapita settlements as indicated by the presence of cultural artefacts such as obsidian from Talasea, New Britain in Fiji (Best, 1984) and Vanuatu (Bird *et al.*, 1981).

Figure 2.2
The location of Lapita sites



In Near Oceania, Lapita archaeological sites have only been located on small islands and in coastal locations. This settlement pattern is extremely important. First, it may indicate that Lapita movement through eastern Near Oceania avoided areas that were heavily populated by people with other cultural traditions. The possibility that some Lapita settlements may have been situated in areas of greater population concentrations cannot be discounted. After the beginning of the first millennium these sites may have been rapidly assimilated into the local tradition or were perhaps overwhelmed by subsequent non-Lapita developments and are therefore not archaeologically visible.

1.24 Linguistics

The reconstruction of palaeo-Pacific languages has allowed the relationship of contemporary language groups to be traced back to a common language. This is based on the assumption that cultural groups are static in their use of a particular linguistic family. Linguistic reconstruction points to the languages of Fiji and Polynesia originating from the same Proto-Central Pacific language with which the Eastern Lapita cultural complex can be equated. Proto-Central Pacific is related to Proto-Eastern Oceanic and Proto-Oceanic, but here the equation to Lapita becomes increasingly tenuous (Green, 1981). Linguists maintain that between *circa* 1600 to 1200 BC the first colonists in Fiji were pre-Polynesians who spoke a Proto-Central Pacific language (Pawley and Green, 1985). The following thousand or so years was a period of consolidation during which population numbers increased, and the initial phases of new cultural traits probably emerged.

The period of consolidation ended in divergence, during which time (Central Pacific) Proto-Polynesian developed. Proto-Polynesian represents the parent language of contemporary Polynesian languages. Just why this divergence occurred is largely open to speculation, but it may relate to the decline in ocean-going sailing. The Fijian language diverged from the Polynesian languages to form its own distinctive traits (Geraghty, 1983).

1.25 Biological Models

The Lapita cultural complex and the people associated with it in Remote Oceania are considered to be ancestral to Polynesian populations (Allen and White, 1989; Bellwood, 1989; Serjeantson, 1989). Because of this ancestral relationship, it is important to understand the biological models that argue for the origin of the people associated with the Lapita cultural complex, although this question is peripheral to the main objective of this study. There are two main competing models which theorise the origins of the Lapita people. One model, the Intrusive model, argues that Lapita people migrated from Asia or Southeast Asia (Brace and Hinton, 1981; Turner, 1989; Serjeantson, 1989; Pietrusewsky, 1989[b], 1991; Katayama, 1992). An alternative model, the Indigenous model, proposes that the Lapita people evolved from some population in Island Near Oceania (Terrell, 1986; Houghton, 1990, 1991[a], 1991[b]).

Intrusive model

Molecular biologists have identified a number of genetic markers in Polynesian populations that do not occur at statistically significant frequencies in Micronesians (O'Shaughnessy *et al.*, 1990) or Near Oceanic populations, but can be linked with Island Southeast Asian populations (Serjeantson and Hill, 1989; Hagelberg and Clegg, 1993). Perhaps the genetic marker with the greatest potential for identifying genetic lineage is the Asian-specific nine base pair mitochondrial deoxyribonucleic acid deletion (mtDNA 9 bp). Human mtDNA is haploid and is strictly maternally inherited (Stoneking and Wilson, 1989). The mtDNA 9 bp deletion is found at high frequencies in east Polynesians. It is less frequent among Tongans and among Fijians (Hertzberg *et al.*, 1989).

Stoneking and Wilson (1989) found that the mtDNA 9 bp deletion occurred at a low frequency among coastal Near Oceanic populations, while among East Asians it occurs at a frequency of nearly 20% (Wrischnik *et al.*, 1987). Similarities in gene arrangements between Polynesians and Southeast Asians on one hand, and differences with Micronesians and Near Oceanic populations on the other, has lead some molecular biologists to conclude that Polynesians could not have evolved from a Near Oceanic population within the past 30,000 years. Their position is one that favours a migrating population from Southeast Asia. Serjeantson and Hill state this emphatically;

> "The genetic data have not located a precise "homeland" for the pre-Polynesians, but the evidence clearly indicates that the they are mainly derived from a Southeast Asian population prior to Mongoloid expansion" (1989:286).

Serjeantson (1989) and O'Shaughnessy *et al.* (1990) suggest that Fijians, "Melanesians" and Southeast Asians contributed to the Polynesian gene pool. This seems to be a reasonable assumption, but the problem with it is that each of these populations is viewed as a distinct biological grouping. The Polynesian similarities to these populations can be explained by founder effects, genetic drift, admixture and serial migration, or a small founding Polynesian population with low mtDNA variability.

Caution is sounded here because the identification of seemingly population-specific gene arrangements is one thing, but their interpretation is another and may leave us with more questions than answers. The problem with interpreting the mtDNA 9 bp deletion is that mtDNA may have a variable mutation rate through time and the rate may differ more between populations than first thought (Goldman and Barton, 1992). For example, relatively high frequencies of mtDNA 9 bp deletions are not unique to Polynesians, they have also been identified in some Amerindian populations (Hertzberg *et al.*, 1989; Sheilds *et al.*, 1992). However, other genome data tends to support Serjeantson and Hill (van de Water *et al.*, 1991).

Several biological anthropologists share similar views to the molecular biologists. Howells (1973, 1979) has long argued on the basis of anthropometric studies and on blood group frequencies that a Near Oceanic population could not be ancestral to the Polynesians. Howells asserts that the Lapita people retained the biological, cultural and economic traits that were peculiar to them through segregation from other communities in Island Near Oceania (Howells, 1987).

Pietrusewsky's (1987, 1990, 1991) analyses of Polynesian and Near Oceanic crania using multivariate techniques concedes that there is limited relationship between the two groupings. However, the possibility of a population of pre-Polynesians originating from Southeast Asia, is in his view much more likely.

> "There is no evidence in these results that would suggest a Melanesian origin of Polynesians. Because of their close biological ties between Polynesians and populations farther east, a homeland in Southeast Asia is a distinct possibility" Pietrusewsky (1991:12).

The analysis and interpretation of dental traits have lent support to Howells. Brace and Hinton (1981) argue that a cline in tooth size exists from west to east Oceania. Populations in Near Oceania tend to have large teeth compared to the small teeth in populations from Remote Oceania. Brace and Hinton (1981) conclude that differences in tooth size indicate, first, that there could have been very little biological mixing between the pre-Polynesian people and Island "Melanesians". This interpretation suggests that pre-Polynesians must have moved rapidly through Island Melanesia before their colonisation of Remote Oceania. Second, because of the small tooth size of Polynesians, they must be more closely related to the Southeast Asians than "Melanesians". These views have been supported by a number of dental studies that maintain that tooth morphology varies too greatly between Polynesians and Near Oceanic populations to support a contention that pre-Polynesians originated from a Near Oceanic island population (Turner and Swindler, 1978; Kirch *et al.*, 1989; Turner, 1989). These interpretations support the Intrusive view.

The essence of the Intrusive view and the interpretations of most molecular biologists is that the Lapita people represent an intrusive Southeast Asia population in the Bismarck Archipelago. They lived there for several centuries, were very mobile, but had minimal intermixing with surrounding Near Oceanic populations. However, it would seem unlikely that intermixing did not take place because of the Lapita complex's demonstrated seafaring technology and trade networks.

Consideration must be given to the view that a Near Oceanic population(s) had some influence on the pre-Polynesian genotype in the Bismarck Archipelago. Friedlaender (1987^{a}) and associates have demonstrated the diversity of genetic groupings on Bougainville. Another authority has noted that Near Oceania contains not just one population group but hundreds of linguistically and genetically diverse groups (Terrell, 1986). If a group from one of these populations was to leave to settle a new area it would be difficult to trace their precise origin, particularly several thousand years later and with the incomplete understanding of the genetic diversity of Near Oceanic populations. Currently few of these populations have had their genotype identified, but even the gene mapping completed to date in New Guinea has revealed large differences between Highland and Lowland populations. The results of the work of the Solomon Island Project (Friedlaender, 1987^{a}) are just as intriguing. The conclusion that this study arrived at after working on identifying various biological traits among Bougainville Islanders is;

> "Our findings reinforce the accepted theme of extraordinary Melanesian biological heterogeneity over short distances, along with emerging natural groupings over large areas" (Friedlaender, 1987^{a}:351).

Given that biological diversity exists so markedly in a small area, is it not possible that some groups in Near Oceania could have Polynesian characteristics, particularly in prehistory?

Indigenous model

An alternative hypothesis favours an *in situ* indigenous development of the Lapita/pre-Polynesian body form. One proponent of this view has stated the following.

> "To settle Polynesia with a group evolved from one of the varied populations of Island Melanesia makes the simplest plausible thesis, requiring at least voyaging [technology] (though the distances are formidable enough) and no long transits (purportedly) through genetically alien territory" (Houghton, 1989:229).

Houghton based this opinion on metric and nonmetric traits found on skeletal material associated with Lapita cultural material on Watom Island.

In a series of recent papers Houghton has proposed that the robust and muscular Polynesian body form was selected for and evolved in response to a cool marine oceanic environment encountered during several thousand years of inter-island voyaging, trading and fishing within Island Near Oceania.

A major selective force in ocean sailing is the effect of wind chill, particularly on a damp or wet body. Body heat loss is strongly affected by wind velocity in that for a given temperature a strong wind will result in greater cold stress than for a slower wind (Frisancho, 1979). One way to minimise heat loss is to decrease body surface area and increase muscle mass. Numerous studies have shown that in a given exposure episode a person with a larger body mass will be able to produce more heat than a comparatively smaller body (Pugh, 1967; Spealman, 1968, Houghton, 1991). Additionally, the effects of physical activity will increase body heat production. Therefore, during the marginal sailing conditions that would have been encountered by prehistoric colonisers of Remote Oceania, survival favoured individuals with larger body mass (Houghton, 1989, 1991^{a}, 1991^{b}).

This idea is worth reflecting upon because it is the first model dealing with the mechanisms of how a particular population may have adapted to new environmental circumstances beyond founder effects and population drift. Furthermore, it expresses a model in favour of *in situ* evolution. Certainly the time involved, 30,000 to 35,000 years was sufficient to adapt culturally to the marine environment (Irwin, 1992). There are a number of problems with Houghton's idea. First, there is the problem of how quickly a population responds to environmental selection pressures to change genotype and phenotype. Phenotype and genotype change may be slow when selective pressures are relaxed (Harrison, 1988). Conversely changes can be rapid when selective pressures are extreme (Susanne, 1977). The problem is to determine if the selective forces were relaxed or extreme.

A second problem is that Houghton's hypothesis presents an argument for only natural selection, while ignoring the possibility of cultural selection. A mechanism for cultural selection may have operated whereby large individuals were chosen for voyaging expeditions and colonisation episodes, perhaps because it was known that larger bodied individuals had better survival chances than smaller individuals. In short, the cultural selection of specific phenotypes operated as genetic selection for tall stature and large body mass.

Another problem with natural selection having operated in Near Oceania is that the inter-island distances are not great, perhaps 200 to 300 kilometres at the most, which translates into a generous three to five days sailing (Irwin, 1992). Thus, it would be unlikely that on a well equipped voyage that the coolness of a tropical ocean would be sufficient to select against individuals with a slighter build, particularly given the likelihood that these were people who were familiar with the marine environment and had culturally adapted to it (Green, 1985; Irwin, 1992).

Nevertheless, given the diversity of peoples in Island Near Oceania and the inter-island trade networks that seemed to have been present early in prehistory, it is possible to envisage how a population may have adapted to seafaring through both natural selection and cultural selection. On balance the natural selection mechanism by which the Polynesians body form is suggested to have evolved (Houghton, 1990, 1991[a], 1991[b]), has support from studies that have observed temporal changes in human (Molnar, 1992) and animal body form (Newman, 1953).

The high level of non-insulin dependent diabetes (NIDDM) seems to be an additional cool climate adaptive feature expressed by Polynesians. Contemporary Polynesians have relatively higher incidences of NIDDM compared to other populations (Simmons, 1994). Polynesians tend to have higher birth weights, and increase fat levels and muscle mass more rapidly than other populations (Baker, 1994). The selective and adaptive value of rapidly accumulating muscle mass has advantages as a metabolic heat source in a cool environment as Houghton (1990, 1991[a], 1991[b]) has pointed out. Similarly, the ability to rapidly accumulate body fat that acts as a food store, has a clear evolutionary advantage over individuals or populations who have comparatively low levels of NIDDM. For example, an ability to rapidly build up body fat would be a selective advantage in small island environments as a buffer against short term food shortages. Additionally, fat storage would have a selective advantage on even relatively brief voyages in the advent of low food store onboard canoes.

Hypermorphic Asiatic model

A third hypothesis contains aspects of the two previous models. It is argued that Polynesians are hypermorphic Asiatics (Katayama, 1992). This idea basically means that the Polynesians attained the adolescent growth spurt earlier than many other populations. Pituitary growth hormones continued to be released until a similar age range as that found in other populations. Katayama maintains that this capacity evolved as a consequence of some adaptive changes that occurred during the process of colonising uninhabited Pacific islands. It is claimed that a number of Polynesian characteristics are similar to Asiatic Mongoloid, such as genetic markers and osteological characteristics. This model proposes a physiological mechanism that may have contributed to the development of the large Polynesian phenotype. However, it does not explain the biological basis of hypermorphism nor is a comprehensive model proposed suggesting how this physiological mechanism was selected for.

Dietary model

One further theory deals with the expression of the large body form found in Polynesians and perhaps pre-Polynesians. The model proposes that the development of large body form was the result of good diet and hence the ability to attain the genetically set stature and body mass. Individuals expressing this phenotype were selected by cultural means to colonise the Eastern Pacific (van Dijk, 1991).

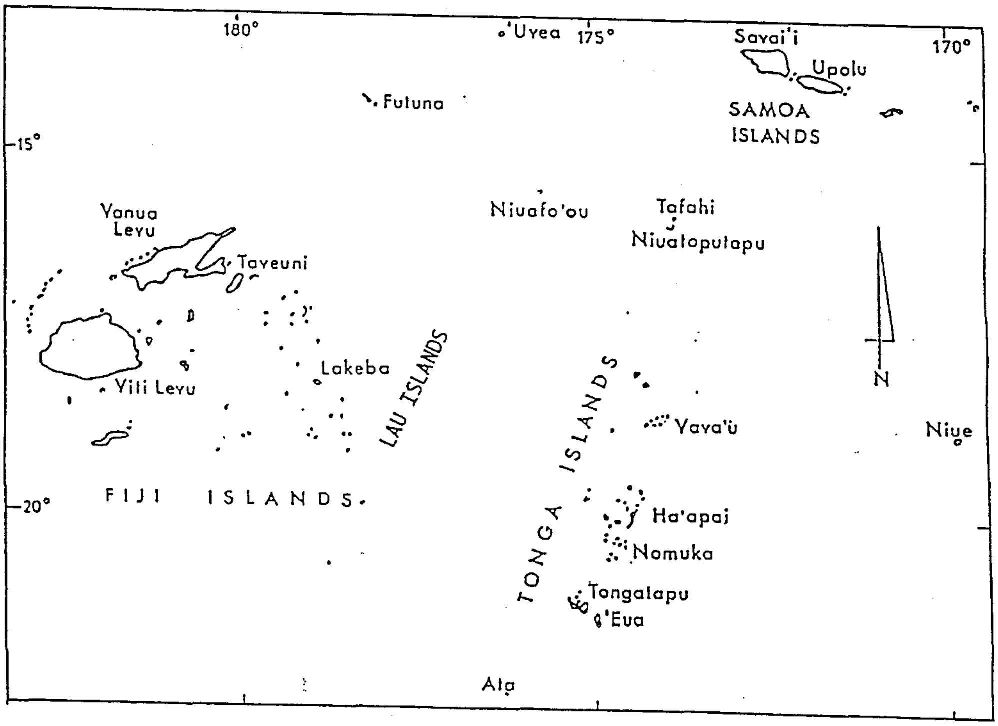
The problems with this idea are that it does not explain where the genotype for large body form was obtained from or how the genes came to be present. Nor does it consider natural selection as a mechanism involved in shaping the Polynesian phenotype and genotype.

1.3 The Fijian question: biological relationships

Historically Fiji has been seen as an indistinct dividing line between Melanesia and Polynesia (Hale, 1846; Flower, 1880; Frost, 1979; Kirk, 1988). In terms of prehistory this lack of distinction does not seem to have always been the case. Fiji, Tonga, and Samoa were probably first settled by the Lapita people, at *circa* 1100 to 1300 BC (Green, 1979; Hunt, 1980; Best, 1984). As previously discussed, Lapita people are considered to be ancestral to Polynesians, therefore it seems reasonable to suggest that pre-Polynesian culture and biological characteristics developed in the Fiji-Tonga-Samoa triangle (Figure 2.3).

Biological and cultural variation in Fiji seem to have developed after the Lapita contact network collapsed, which probably occurred before 200 AD. (Gabel, 1958; Ward, 1967; Howells, 1973; Frost, 1979; Hunt, 1987; Serjeantson and Hill, 1989). Two hypotheses have been proposed to account for the degree of cultural and biological diversity in Fiji compared with Tonga and Samoa. These hypotheses are the conventional model and the internal divergence model.

Figure 2.3
Fiji and the main western Polynesian island groups, Samoa and Tonga.



1.31 Archaeological models

The conventional model.

The conventional model proposes that Fiji experienced a series of migrations from the west, particularly from Vanuatu. Joseph Waterhouse (1866) first described local accounts of intrusive migrations from the west. The concept of migrations as an explanation of change still retains support. Frost (1979) used the concept of intrusive migrations to account for changes in ceramic style sequences. He noted two main episodes of ceramic style discontinuity. The first episode occurred sometime between 0 AD and 200 AD when Lapita pottery was replaced by impressed pottery ware. The second episode of discontinuity was around 1100 AD when impressed pottery was replaced by incised ceramic reliefs. The new incised ceramic reliefs are seen to have close similarities to pottery styles of eastern Vanuatu (Frost, 1979).

Changes in pottery traditions are important because they may represent contact from outside Fiji, probably from Vanuatu. The effect of these episodes of contact was to inextricably alter the cultural and biological tradition in Fiji. It can be used to explain the apparent "Melanesianized Polynesians" of contemporary Fijian physical type (Howells, 1973; Serjeantson and Hill, 1989).

The internal divergence model.

The internal divergence model has been proposed to account for the importance of local innovation identified by recent archaeological analyses and linguistic evidence (Hunt, 1987). The model suggests that in the centuries immediately after initial settlement (*circa* 1300 to 1200 BC), wide scale interaction among communities across Fiji occurred. For some reason this interaction was reduced and a period of community isolation followed, during which only sporadic contacts were maintained. Isolation allowed local dialects to develop, simultaneously with changes in pottery manufacture and style. The period of isolation was followed by an era of large scale and frequent interaction between Fijian communities, Tonga and Samoa, and to a lesser extent with Vanuatu (Hunt, 1987).

The concept of contact with populations beyond Fiji is retained as an important point in both these models. However, the difference is one of degree. The question which remains to be answered is; could isolated groups in inland Fiji, (Vanua Levu and Viti Levu), have not only developed regional cultural and linguistic differences, but also biological differences. Friedlaender (1987[a]) noted biological diversity over short distances in populations on the island of

Bougainville. He suggested that natural selection was not a dominant factor contributing to biological diversity, but migration and isolation are seen to be more persuasive pressures. The question concerning Fiji is whether isolation lasted long enough to allow biological diversity to evolve?

Archaeological evidence indicates that the Lapita people settled Fiji at around 1300 - 1200 BC. Samoa and Tonga were settled by the same cultural complex, probably carried by the same people at the same time (Davidson, 1979; Spriggs, 1984). Archaeological and linguistic evidence indicates parallel development between the three island groups for about 1000 to 1500 years (Green, 1963; Kirch, 1987; Davidson, 1990). Similarities have not only been noted in ceramic styles, but also in other aspects of material culture. Parallel cultural developments suggest regular contact between Tonga, Samoa, and Fiji. Yet, they retained some insularity and developed a distinctive cultural identity which differed from other populations to the west (Green, 1963; Davidson, 1977; Hunt, 1987; Kirch, 1987).

Changes in pottery decoration and method of decoration from Lapita dentate stamped decorated wear to paddle impressed ceramics, occurred sometime between 0 and 200 AD. The new pottery style had similarities to Northern Vanuatu pottery. During the same period obsidian and domesticated kava was probably imported from Central Vanuatu (Best, 1987; Lebot and Cabalion, 1988; Lebot and Levesque, 1989). Proponents of the conventional model have argued that pottery changes reflect cultural changes and possibly an infusion of new people from Vanuatu (Serjeantson and Hill, 1989). However, archaeological data reveals no change in other aspects of the material culture (Best, 1984), nor is there any linguistic evidence of language changes (Pawley and Green, 1973; Geraghty, 1983). It is suggested that some stylistic pottery changes were introduced into Fiji as imported innovations from Northern and Central Vanuatu. While there appears to have been some introduced cultural and linguistic characteristics from Northern and Central Vanuatu, these did not replace Fijian cultural or linguistic traditions. Consequently it is unlikely that large scale contact took place at this time. Nevertheless, the actual level of contact is debatable (Best, 1984).

A stronger argument can be made for greater contact from the west. Archaeologists have pointed to a change in the cultural assemblage at around 0 and 200 AD (Green, 1963). Pottery styles changed from impressed ceramics to incised ceramics. The new incised ceramic reliefs have close similarities to those from Vanuatu (Green, 1963). Concurrent with this change was the development and widespread construction of fortifications. Frost (1979) has hinted that these developments could be associated with Near Oceanic movements into Fiji. In the absence of any real data this idea remains speculative.

Biological anthropologists have focused on the ceramic change to help explain the divergence of human biological traits between Fiji and its close Polynesian neighbours, Tonga, and Samoa (Trent *et al.*, 1986; Kirk, 1988), despite the archaeological evidence of continuing contact with these areas (Best, 1984). In essence, some biological anthropologists view this difference as the "Melanesianized Polynesians" of Fiji (Howells, 1973). To clarify this concept, some biological anthropologists have, to some degree, accepted the assumptions postulated by the conventional model that the dominant Fijian genotype changed from pre-Polynesian to one which reflects Near Oceanic or Vanuatu genotypes. This change can only be explained by intrusive migrations from at least 1100 AD. Let us consider their evidence.

Molecular biologists have demonstrated that Fijians do display some unique Polynesian genetic characteristics. They have calculated that Polynesian traits in human leucocyte antigens (HLA) and alpha globin haplotypes contribute 20% to the Fijian gene pool, (thus 80% is acquired from some other source) (Serjeantson, *et al.*, 1982; Trent *et al.*, 1988). Perhaps the most demonstrative biochemical trait illustrating the ancestral link between the Fijian population and Polynesians has been the discovery that the maternally inherited Asian specific mtDNA 9 bp deletion. This mtDNA 9 bp deletion is found in 82% of Fijians compared with a close to 100% frequency in east Polynesians. Among Tongans the frequency is similar to Fijians (77%). This implies a very close genetic relationship between Fijians and Tongans (Serjeantson, *et al.*, 1982; Trent *et al.*, 1988).

Other genetic markers, such as HLA A2, and gamma-immunoglobulin (Gm) polymorphisms have been argued to indicate the intermediate status of the contemporary Fijian population with Near Oceanic populations on one hand and Polynesians on the other (Kirk, 1988; Trent *et al.*, 1988; Kelly, 1990; O'Shaughnessy *et al.*, 1990; Gao and Serjeantson, 1991).

Interpretation of genetic data has lead some molecular biologists to state that

> "...80% of the women in recently colonised Fiji were Lapita women, even though Lapita people as a whole comprised only 20% of the population" (Serjeantson and Hill, 1989:289).

Serjeantson and Hill (1989) suggest that later immigrants were mainly males, probably because women were under-represented on the sailing voyages. Implicit in their argument is that later contributions were made from populations to the west of Fiji. This interpretation cannot be dismissed, because the archaeological evidence suggests that Fiji experienced at least one major post Lapita episode of contact (Best, 1984). Although the extent of this contact is unclear, it is prudent to consider other aspects which may have contributed to the intermediate status of Fijians. The assumption is that Polynesians are genetically very similar to the Lapita people who lived in Fiji. Therefore, high frequencies of the mtDNA 9 bp deletion, but not at 100% frequency, were always present in the Lapita population. Likewise, in Tonga and probably Samoa, the mtDNA 9 bp deletion was probably never present at frequencies of 100% in the founding Lapita group(s). Nevertheless, Polynesians are held to probably be descendant from populations of Samoa and Tonga (Davidson, 1979; Kirch and Green, 1987). The assertion can be made that the populations of eastern Polynesia were founded by very small groups among which it seems that the mtDNA 9 bp deletion happened to be present in very high frequencies.

Recent analysis of mtDNA extracted from cortical bone of some individuals from Sigatoka has not produced any evidence of the mtDNA 9 bp deletion (Appendix 1), nor were any mtDNA 9 bp deletions found in any Lapita associated skeletons (Clegg and Hagelberg, 1993). However, more recent Polynesian bone samples do have the deletion present (Clegg and Hagelberg, 1993). This difference has been interpreted as evidence of a direct Southeast Asian-Polynesian connection. However, the lack of mtDNA markers in the earlier populations may be due to deterioration of the bone and the organic content. Furthermore, fragmented mtDNA base pair strands were recovered from the older material, suggesting that it is possible that the mtDNA 9 bp deletion sites may have degraded.

Analyses of skeletal material have often dealt with material of unknown provenance and age, although most of the material probably dates from the late prehistoric era. In a series of multivariate studies of prehistoric Fijian crania and a Lapita associated skeleton, Pietrusewsky (1983, 1989^{a}, 1990, 1991) has concluded that Fijians cluster more closely with "Melanesians". He suggests that it is unlikely that Fijians derive from a Polynesian source. Consequently, he feels that there is only a small Polynesian genetic element in contemporary Fijians. In effect Pietrusewsky argues that the Lapita people were

"Melanesians" with a few "Polynesian" traits. This view should be considered as unlikely, particularly in light of the genetic data presented above which shows Fijian-Polynesian biochemical similarities. Furthermore, small sample sizes compromise the validity of multivariate statistical results.

Howells, perhaps the most supportive proponent of the conventional model, argues for population replacement in Fiji, from Polynesian to a mainly "Melanesian" body form (Howells 1973:236). This "impurity", he suggests, explains genetic similarities between contemporary Polynesians and Fijians. His ideas are based on the analyses of anthropometric studies and blood groupings of living subjects and also relies on the interpretation of archaeologists who argue for intrusive "Melanesian" population movements into Fiji. The problem with this model is the validity of the assumption that biological observations of contemporary populations can be projected back to represent a past homogeneous, possibly pre-Polynesian, population in Fiji.

Houghton's (1989^{b}) examination of morphological traits of a skeleton from Lakeba Island dated to the Lapita period, concluded that the skeletal morphology of the individual was;

> "...fully compatible with the known Polynesian skeletal phenotype" (Houghton, 1989^{b}:327).

Therefore, Houghton proposes that Fiji was settled by a people with a similar phenotype to contemporary Polynesians, and that the contemporary Fijians seem to retain some of this phenotype.

There is some reason to suggest that differences between Fijians may have evolved through isolation rather than through intrusive contact. One anthropometric study noted differences between population groups in different locations around Fiji (Gabel, 1958). While it is now possible to discount Gabel's proposition that these differences were caused by intrusive Polynesian migrations pushing the indigenous "Melanesian" people into inland refuges (Ward, 1967), some differences between Fijian populations remain. Gabel's finding supports the idea of internal Fijian variability observed by Flower (1881) who found that cranial characteristics of the Lau Islanders and Viti Levuans differed.

Studies of blood groupings and genetic makers have found variations between different groups in Fiji. One study of blood groupings found as much variation among Fijians as in the rest of the Pacific. It was concluded that Fijians evolved in isolation for some time, mainly under the influence of genetic drift. Migration and natural selection may also have played some part (Ward, 1967). More recent gene studies have also found evidence of Fijian variation. Kirk's (1988) genetic distance analysis based on blood gene markers of contemporary Pacific populations found that the three Fijian populations differentiated from each other. Further support for internal Fijian genetic variation is provided by globin gene data (Trent *et al.*, 1988), although that study did not elaborate on this important point. The problem is to define whether these differences are due to internal divergence or intrusive contact.

On the basis of the different hypotheses reviewed above, two models may have contributed to Fijian genetic variation, either individually or collectively. One model is that small intrusive groups from Vanuatu, Samoa and Tonga intermixed with coastal dwellers but not with inland groups. The second, and probably less likely model, is that small groups became culturally and biologically isolated during human occupation of Fiji. While Fiji does not have the time depth of human settlement that the Near Oceanic Islands have, it is possible that observed biological differences are the initial stages of the development of variation in Fiji, through the mechanisms of migration, isolation and founder effect. The Sigatoka population provides an opportunity to examine these mechanisms.

Both the conventional model and internal divergence model have a number of deficiencies. The conventional model considers that the only mechanism of change in Fiji was intrusive Near Oceanic and/or Vanuatu migrations. Migrations altered the gene pool composition and consequently the phenotype of Fijians towards the body types living in those locations, and influenced the material culture. The problem with this model is the assumption that the first Fijians were genetically Polynesians. It is not known if this assumption is accurate. If the gene pool is not known, then the hypothesised levels of intrusive contact into Fiji remains speculative. It is possible that the gene pool of the first Fijians was more varied than the current Polynesian gene pool. This can partially explain observed variation in mitochondrial DNA and nucleic DNA population markers and variations in blood groupings.

The internal divergence model presents an interesting case favouring local innovative change within a pattern of isolated settlement, with only sporadic contact between population groups within Fiji. Perhaps the most questionable aspects of this model are how ideas and perhaps material culture were rapidly disseminated in an era of minimal contact, as indicated in some cases by archaeological evidence (Best, 1984). Another problem is that the model considers that biological characteristics changed rapidly through isolation. For this to occur, either a limited gene pool, rapid selection (by natural or cultural factors), or isolation, is required.

Both the conventional model and internal divergence model hold that the cultural and human biological history of Fiji is complex. Both models maintain that changes, whether intrusive or indigenous, have long been part of Fijian prehistory.

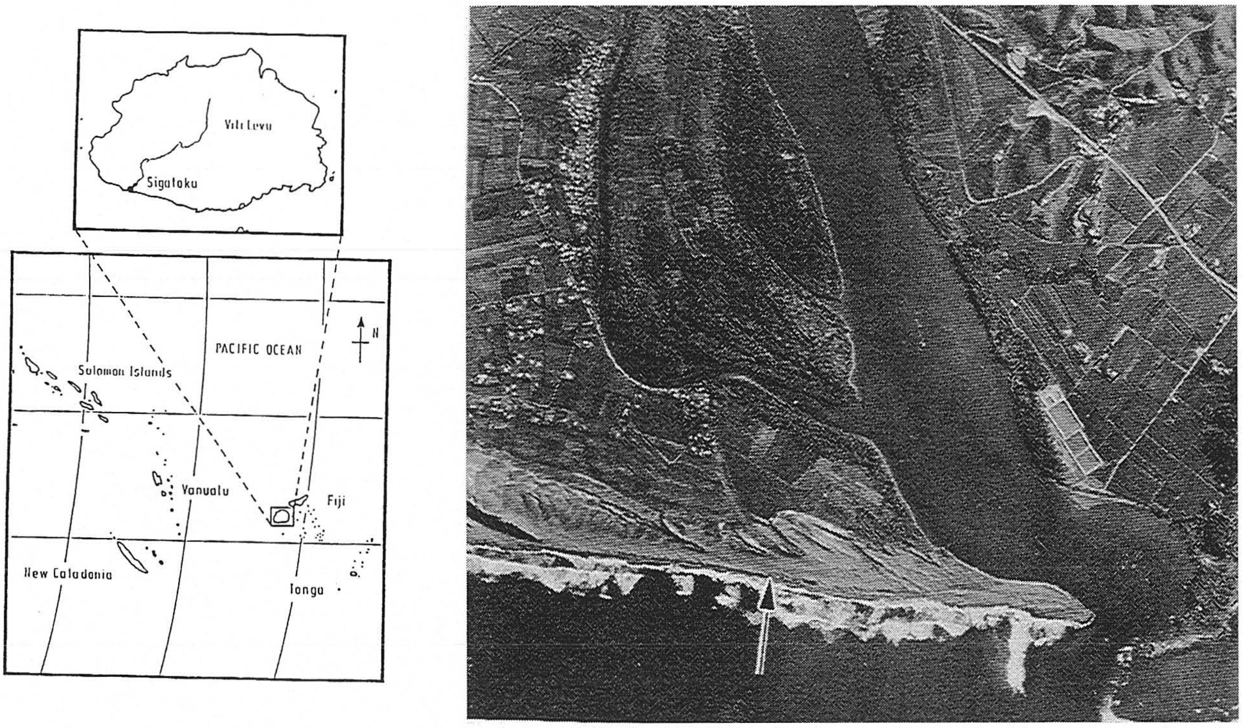
1.4 The Sigatoka dune site (VL 16/1)

The Sigatoka Dune site, Site VL16/1, is located approximately 400 metres from the western edge of the Sigatoka River mouth and lies between a low series of fore-dunes and at the edge of a major hind dune system (Figure 2.4).

The major dune system extends five kilometres along the coast and up to one kilometre inland. It is not known when the dunes first formed, but at least part of dune system post-dates settlement of VL16/1 (Birks, 1973; Best, 1989). Parry (1987) has suggested that the formation of the dune system is a recent result of human activity through forest clearance along the Sigatoka River valley. Forest clearance, particularly after 500 BC, allowed soil and sand to be eroded from the river catchment area, and to be transported down the river system where it was eventually deposited at the river mouth. The amount of sand deposited, and the intensity of loose sand blown along the coast by the trade winds, appears to have made the site periodically uninhabitable (Parry, 1987). At least three episodes occurred when the wind intensity and amount of sand deposited was reduced. These episodes are evidenced by three distinct phases of settlement at Site VL16/1.

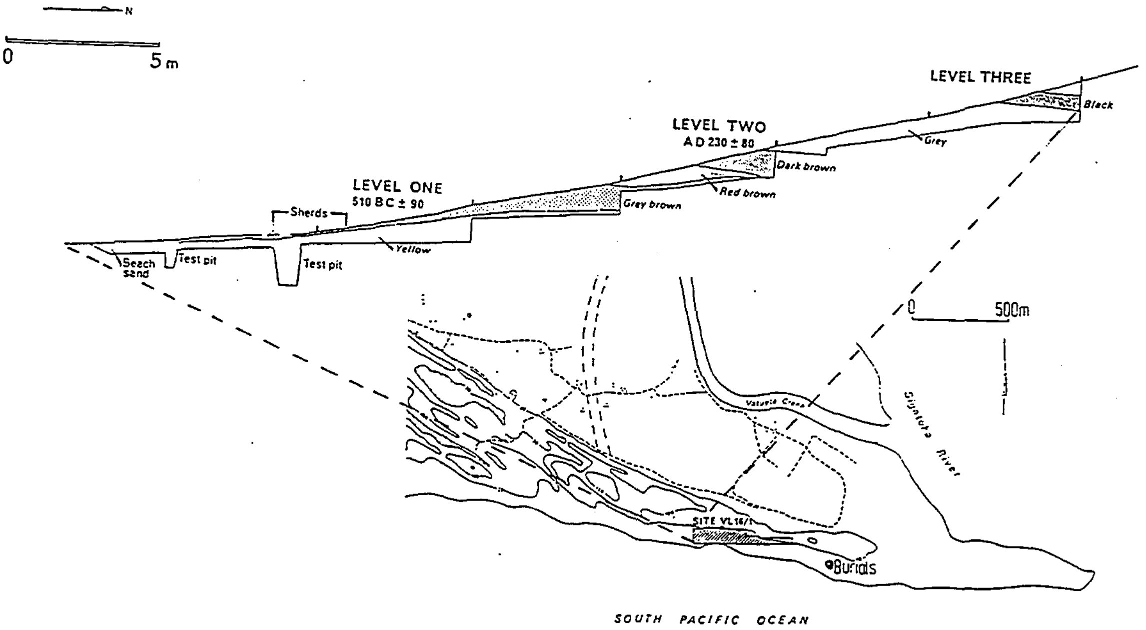
There is other evidence that suggests that the local environment has changed substantially since the site was last occupied (Parry, 1987). The Sigatoka river mouth, or a secondary branch or delta system may have flowed closer to the site, providing easy access to fresh water, and other river resources (Figure 2.4). Furthermore, the site of VL16/1 may have been on an island delta. This is evidenced by the absence of a fringing coral reef along most of the five kilometre length of the dune system. A frequent and substantial fresh water flow is required to suppress coral growth over that distance.

Figure 2.4
The location of the Sigatoka dune site, VL16/1



Site VL 16/1 was first recorded in 1944 (Green, 1963:262). The first analysis of the pottery sherds scattered on the surface was made by Gifford in the late 1940's (Gifford, 1951) and later by Green (Green, 1963). These studies were concerned with the relationship of the Sigatoka pottery to pottery recovered from other Pacific archaeological sites. The first excavation of the dune site was undertaken by Birks (1973). Birks was able to define and date three stratigraphic occupation levels and the area of cultural deposits (Figure 2.5). A brief summary of the findings of this excavation follows.

Figure 2.5
The location of the Birks excavation and the burial site. The different statigraphic levels found in the Birks excavation is also illustrated



Level One has a radiocarbon date of 510 BC ± 90 years. Very little structural evidence was found in this level. Pottery sherds constituted most of the cultural artefacts recovered. Analysis has demonstrated that this pottery was produced using similar methods, and had a similar red slip decorative pattern to the pottery that is associated with the Lapita cultural tradition at Watom Island (Specht, 1968), Tonga (Poulsen, 1987), Fijian Lapita sites (Hunt, 1980) and coastal New Guinea at Nebira and Eriama (Bulmer, 1978).

Level Two has been dated to 252 AD ± 29 (Best, 1989). No evidence of any structure was found in this level. A limited amount of pottery was recovered which differed from that at Level One. Level Two pottery was made using different manufacturing techniques and styles, such as assymetric incising and rim cord, finger pinching and finger gouging. These changes in pottery style occurred throughout Fiji and the change is contemporary with the presence of obsidian at Lakeba that has been sourced to Northern Vanuatu (Best, 1984).

Contact with Vanuatu is further evidenced by wrapped paddle decoration which has up to now only been identified in Central Vanuatu (Garanger, 1972).

Level Three has not been radiocarbon dated, nor was there any structural evidence associated with it. However, pottery, coral and stone material was recovered from this level (Birks, 1973). Pottery is less decorative and the plain ware style differed from Levels One and Two.

The lack of structural evidence in the stratigraphy, and his contention that fresh water was possibly not close at hand, lead Birks to favour the view that occupation of Site VL 16/1 was likely to have been a seasonal camp, perhaps associated with turtle catching (Birks, 1973). Pottery manufacture, salt making and coconut oil manufacture could also have taken place. Birks estimated that the length of occupation of each level of the site could be measured in decades.

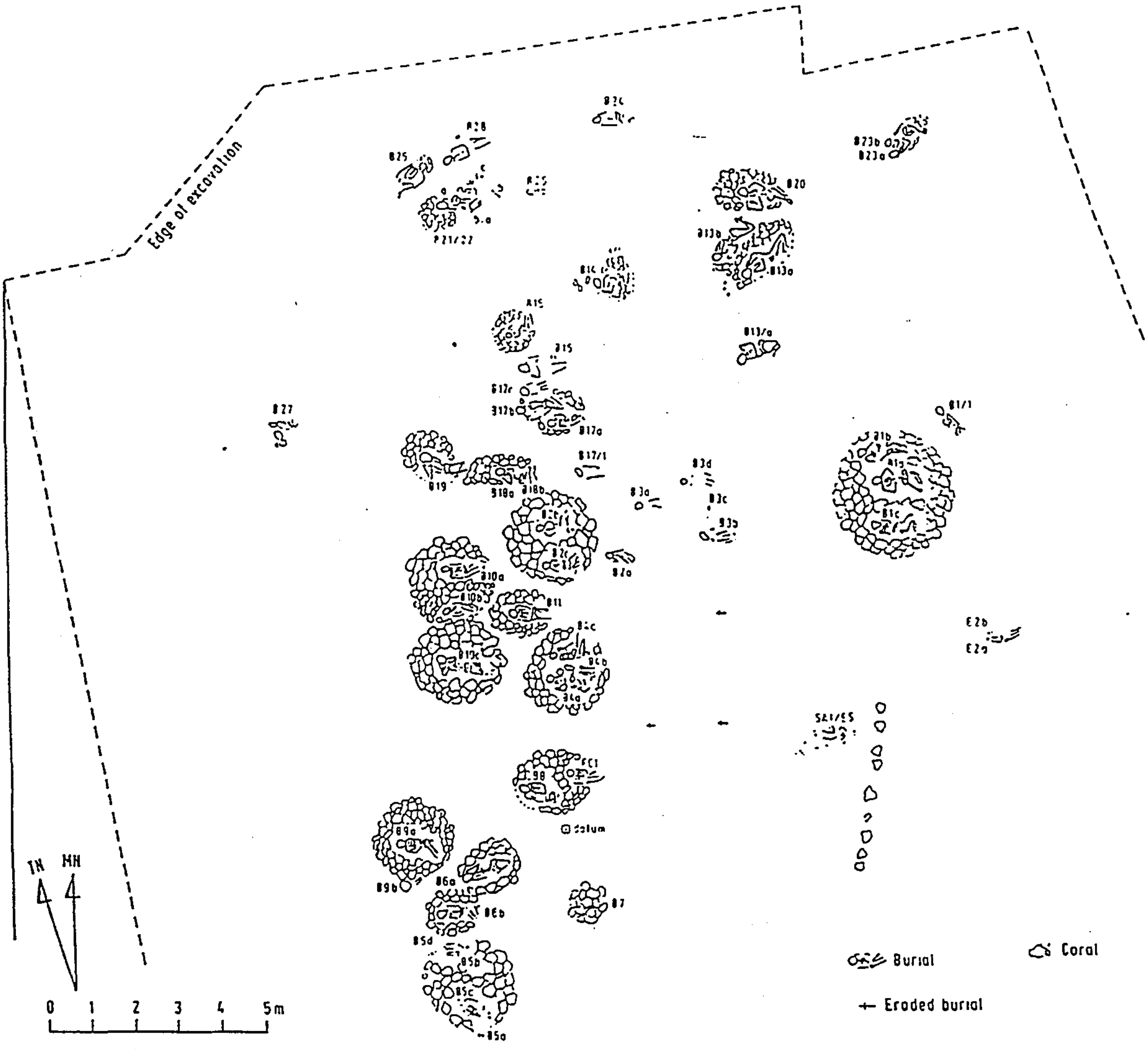
This view is now not necessarily accepted. It is now known that the different stratigraphic levels are extensive. While the Birks excavation investigated a large surface area, it only covered a small area of each layer, so that the possibility of covering structural evidence was small. Furthermore, the extensive distribution of pottery and the large number of burials recovered thus far, indicate that the site probably represents a longer and permanent occupation sequence rather than a temporary camp.

1.41 The excavation of the burial site

This study focuses on Level Two of the site. The skeletal material was recovered from this layer, some 200 meters east of the Birks excavation. Dates from the burial ground vary between 80 AD ± 70 and 270 AD ± 57. These dates and pottery similarities indicate that the burial ground dates are contemporary to Birk's (1973) Level Two. Initial excavation of the burials began in January 1987, when 14 skeletons were recovered (Best, 1987). In the following year a further 39 skeletons were excavated. Between the two seasons of excavation an unknown number of burials, possibly 10 to 20, were eroded and subsequently destroyed (Best, 1989).

The skeletons were excavated from a discrete burial ground that covered an area of circa 2,000 square metres (Figure 2.6). The burial ground was at its highest at the western end and gradually sloped off towards the north, south and east (Best, 1989). Burial positions have previously been described by Best (1989). An important observation made by Best was that most of the burials faced eastward towards the Sigatoka River mouth. This orientation is often found in Polynesian burial grounds (Davidson, 1984).

Figure 2.6
Map of the burial ground showing the distribution of the burials



Best favoured the view that the burials signified a highly stratified society based on the presence of grave goods with some burials and that the distribution of burial mounds represented a form of social ranking. Moreover, Best speculated that;

> "At present I consider that the site contained burials indicating a highly stratified society, with burial customs that included the ritual killing of wives and possibly other categories of people, the whole burial complex being laid down over a period of years" (Best, 1989:51).

The idea that at least some of the burials represented ritual killings of wives of high ranking males can at least be partially investigated in the skeletal analysis. The analysis of the Sigatoka Dune skeletal material will be presented in the following Chapters.

1.5 The excavation and preservation of the skeletal material

Differential rates of decay of the skeletal material meant that the most decayed remains consisted of a few teeth or fragmentary bone remains. The subadults in particular were poorly preserved. Very few skeletons were complete. However, in 24 cases one or more intact long bones were present at excavation. All the crania were in some way distorted and many had been completely flattened by the weight of coral stones placed over some of the individuals after burial. Frequently, the articular ends of long bones were damaged or had simply decayed leaving "bone shadows"in the sand matrix which could only be measured *in situ*. At the time of excavation, all skeletal material was extremely fragile, even after consolidation, and although great care was taken by the excavators, some data were lost.

In the second season of excavation all skeletons were treated with a plastic solution, Paraloid B72. Paraloid B72 consolidated the bones making it possible to lift many bones intact and prepare them for transportation. If Paraloid B72 had not been used most of the bones would have fragmented completely during excavation and transportation, particularly in the articular surfaces of long bones and the vertebrae. In the laboratory, excess sand was removed from the bones treated with Paraloid B72 by reversing the consolidant using acetone.

The technique of consolidating the bones was invaluable and is certainly recommended as a way of preserving fragile bones *in situ*, in preparation for transport and analysis.

1.6 **Comparative populations**

Comparative populations were chosen in order to represent as many populations as possible from New Guinea to Polynesia. This was in order to assess if differences and/or similarities exist between these populations and the skeletal material from site VL16/1. The various populations are sub-grouped according to their geographic location and immediate cultural relationships. The data of two skeletal populations are not provenanced from this geographic area, the southeast Australian Aboriginals and Tierra del Fuegans. These populations are used as climate control populations. A brief description of the most frequently used comparative populations follows.

1.61 Near Oceania

Nebira

This skeletal population was excavated from the Port Moresby region from Papua New Guinea between 1968 and 1969 (Bulmer, 1979). A total of 37 individuals are represented in this collection. The site has been radiocarbon dated to between 1240 ± 80 AD and 1851 ± 270 AD (Bulmer, 1978 :134). Red slip pottery has been found in association with the burials. Analysis of the skeletal material has previously been assessed by Pietrusewsky (1976). The author re-examined the skeletal material. Unless otherwise stated the data presented in this thesis are based upon the reassessed data.

Eriama

The Eriama material was also excavated by Bulmer in 1968-69. Eriama is *circa* five kilometres inland from the Nebira site. The skeletal material was recovered from a rock shelter. The radiocarbon dates from the site range between 40 ± 230 AD and 1623 ± 70 AD (Bulmer, 1978:213). Eriama has the same cultural associations as Nebira.

Solomon Islands

Between 1881 and 1884 the surgeon from the H.M.S. Lark obtained anthropometric measurements from coastal populations around St Christoval Island and the islands in the Bouganville Straits (Guppy, 1886). The limb and chest measurements that Guppy collected are used in this study.

Kwaio

Anthropometric data from the Kwaio people, in Central Malaita Island in the Solomon Islands were collected as part of the Solomon Islands Project (Friedlaender, 1987).

Lau

Anthropometric data from the Lau people, of coastal Malaita Island in the Solomon Islands were collected as part of the Solomon Island Project (Friedlaender, 1987).

Nasioi

Anthropometric and odontometric data from the Nasioi people, of Bougainville Island in the Solomon Islands were collected as part of the Solomon Island Project (Friedlaender, 1987) by Rhoads (1987) and Harris and Bailit (1987). These people live slightly inland and are linguistically and genetically distinct from their neighbours.

Aita

Anthropometric data from the Lau people, of inland Bougainville Island in the Solomon Islands were collected as part of the Solomon Island Project (Friedlaender, 1987)

1.62 Lapita associated skeletons

Watom Island

Incomplete skeletal remains of eight individuals were recovered from Watom Island and were found in association with Lapita pottery. The burials have been dated between *circa* 500 and 100 BC (Green and Anson, 1987). The material has previously been described by Houghton (1989^{a}) and Pietrusewsky (1989^{b}). The skeletal material was re-examined by the author. These results are used in comparative analyses.

Lakeba, Fiji

Fragmentary remains of at least two individuals were excavated by Best (1977) from Lakeba in the Lau Islands. The site from which the skeletal material was recovered is firmly associated with Lapita pottery. This material has previously been examined by Houghton (1989^{b}). This author examined the casts of the skeletal material. The data obtained from the casts are used in this study.

Tonga

Skeletal material, probably representing two individuals, was excavated by Poulsen (1987) in association with Lapita pottery at the Pea site (To.1.). The skeletal material has subsequently been analysed by Spennemann (1987), Taylor (1987), and Houghton (1989^{c}). This material was re-examined by the author and the data obtained from the re-analysis are used in this study.

Manus

The Manus skeletal material is represented by a mandible fragment which was excavated in 1981 from Baun Village, Lau Island in the Manus Province of Papua New Guinea. This fragment has been analysed by Pietrusewsky (1989). These results are used in this study.

The mandible fragment was not found in association with Lapita cultural material. However the date of the site, *circa* 150 BC (Ambrose, 1988), is contemporary with Lapita sites on Watom Island.

Natunuku, Fiji

Skeletal remains of an adult male were excavated at Natunuku (VL1/1), on Viti Levu, Fiji. The age of the site has recently been revised to circa 100 BC and contains Lapita pottery in the lower levels (Davidson *et al.*, 1990). It is not clear if the skeletal remains are associated with the Lapita culture or a later phase. Nevertheless, it has been included with other Lapita associated skeletons because of the skeleton's association with Lapita pottery.

Mussau

Teeth and skeletal fragments were recovered from a number of different sites on Mussau Island which are associated with Lapita pottery and other artefacts (Kirch, 1987). These sites are dated between 1600 and 500 BC (Kirch *et al.*, 1989). The human skeletal and dental material has been described by Kirch *et al.*, (1989). These data are used in this study.

1.63 Polynesian outliers

Namu, Taumako

The geographic location of Taumako is west of the main concentration of Polynesian cultural boundaries, nevertheless Taumako retains a distinctive Polynesian culture. A burial ground at Namu on Taumoko, Solomon Islands was excavated in 1977 and 1978. The site is dated between 1530 and 1698 AD

(Whitehead *et al.*, 1986). Some 200 skeletons were recovered and these have been examined by Houghton (nd^a). A sample of skeletons has been re-investigated by this author. The results obtained from this analysis are used in this thesis unless stated otherwise.

1.64 Vanuatu

Taplins

Skeletal and dental remains of nine individuals were recovered from two rock shelters at the Taplins site, Efate, Vanuatu. The human remains were recovered in association with Mangaasi pottery that appears shortly after Lapita pottery in Vanuatu, but it is not related to it. This site has been dated to between 1035 and 825 BC (Ward and Houghton, 1990). The skeletal and dental material was analysed by Houghton (Ward and Houghton, 1990). This author re-analysed the dental material and the new data are used in this study.

1.65 Central Polynesia

Tepoto

Thirty two skeletons were excavated from the Northern Taumotu atoll, Tepoto in 1985 and described by Dennison (nd). Of the 32 skeletons, 16 could be assigned sex with a reasonable degree of accuracy, seven were adult males and nine were adult females. The material has been dated to 1850 AD ± 50 years (Head, quoted in Dennison, nd). Both skeletal and dental material of the Tepoto people are used in comparative analyses.

Hane, Uahuka, Marquesas

The skeletal material from Hane has been examined by Pietrusewsky (1976). A total of 42 individuals are represented in the collection, which include 24 adults, 17 males and eight females.

Mangaia

Skeletal remains were recorded by Tayles (pers. comm.). Dental material obtained from casts of 150 contemporary individuals from Mangaia college by Yamada and Kawamoto (1988) was also included in the present study.

Pukapuka

Skeletal remains of 25 individuals, including six males and four females, from Pukapuka were reported by Yoshida (1988). The material has been dated to between 1550 AD and 450 AD (Yoshida, 1988). The dental data was obtained from casts of 47 contemporary individuals from Pukapuka by Yamada and Kawamoto (1988). The prehistoric skeletal material was partially destroyed by plant roots penetrating the bone.

1.66 West Polynesia

Tonga

Davidson (1969) excavated 99 incomplete skeletal individuals from two burial mounds on Tongatapu. The skeletal material was subsequently reported by Pietrusewsky (1969). Bone material was used to date the remains to more recently than 650 BC. This date probably over-estimates the age of the burials (Davidson, 1969).

1.67 Extreme Polynesia

Maori, New Zealand

The Maori data was obtained from a data base compiled by Associate Professor P.Houghton, Department of Anatomy and Structural Biology, University of Otago. This material is undated, but is generally from late prehistoric contexts.

Mokapu, Hawaii

The Mokapu skeletal material has been described by Snow (1974). The collection consists of 1,171 individuals that have an antiquity of between 1250 and 1750 AD (Snow, 1974).

Easter Islanders

The skeletal material from Easter Island has been reported by Murrill (1968). A total of 33 individuals were recovered from three mass burial sites. Of these individuals, 25 were male and eight were female. The dates of the sites range from 1100 to 1870 AD.

Moriori, Chatham Islands, New Zealand

Skeletal data of the Chatham Islanders was obtained from a data base compiled by Associate Professor P.Houghton, Department of Anatomy and Structural Biology, University of Otago. This material is undated. Because of the insufficient number of females, only male data is used in this analysis.

1.68 Climate control populations

Aboriginals

Aboriginal data was compiled from a number of different sources, however attempts were made to include skeletons and anthropometric data gathered only from southeastern Australian Aboriginals in order to compare a population that had adapted to a warm continental climate with the Sigatoka population.

Clavicle data is from the Murray Black Collection previously held in the University of Melbourne, but now reburied. The skeletal data is sourced from a "relatively" localised area in the south east of Australia (Ray, 1959). The antiquity of the material is not known.

The cranial data of 34 individuals reported on by Duckworth (1894) were used. The material has been provenanced; most crania are from South Australia, and from the Murray River in South Australia. A few crania are from New South Wales, Victoria, Western Australia and one from the Northern Territory (Duckworth, 1894). This material has not been dated.

Further data of the Australian Aboriginal body form were obtained from anthropometric information collected from the Njalia, in Central Australia (Abbie, 1957).

Tierra del Fuego

In 1886 Garson reported on the skulls of 14 adult individuals and the postcranial skeletons of six adult individuals from Tierra del Fuego. Of these, only the data of six males was adequate to allow inclusion in this study. These individuals are provenanced to localities, but are not dated. The data from Tierra del Fuego is used to represent a population that adapted to a cold climate.

1.69 Fiji

Weber skeletal series

Two different series of skeletal data from Fijians are compared to the Sigatoka people. The Fijian series have been analysed by Weber (1934) and Flower (1881). The material analysed by Weber was stored in the Liepzig museum until 1943, when it was destroyed in a war time bombing raid. The material was unprovenanced and not dated, but is thought to date from the later prehistoric period. Eighteen individuals are represented in the cranial measurements, 13 males and five females. Eight individuals provide the postcranial data consisting of five males and three females.

Fijian cranial data

The cranial data recorded by Flower (1881) are provenanced to the interior, the east coast, outlying islands of Viti Levu, and from Vanua Balavu in the Lau group. The antiquity of this material is not known. Flower (1881) suggests that they may not be older than 1800. In this report, eight males and five females were used for the nasal diameters and four males and two females were used for the mandibular variables.

Sigatoka 1991

The Sigatoka females will be compared with a small group of female skeletons excavated in 1991, some 210 meters west of Site VL 16/1 (Crosby, 1991). This group seems to have been buried in the upper layers of Level 2, thereby suggesting that they are approximately contemporary with site VL 16/1. However, their distance from site VL 16/1 and lack of clear dating means that these skeletons are considered as a separate group from VL 16/1. The osteological data from the 1991 group are presented in Appendix 2. Of the six individuals recovered, five are females. Because of their poor state of preservation, few variables could be compared to VL 16/1 females.

1.7 **Statistics**

Univariate statistics were calculated using the statistical soft ware programs Data Desk Professional and Statworks 1.1 on a Macintosh computer.

One-tailed Students *t* test is used to test the means of small samples. In this case to test the hypotheses that two samples, Sigatoka compared to others, have been drawn from the same parent population.

In the calculations of the Student's *t* statistics and the f ratio, attempts were made to use similar number of cases as the constant sample, Sigatoka. By using a similar number of cases the effects of weighted bias which is introduced when small sample sizes are compared to larger samples, is minimised. Males and females are tested separately because they tend to display different characteristics.

Students *t* tests are used only to compare each population with Sigatoka. The purpose is to identify if hypothesised differences/or patterns become evident over a number of different variables. Significant differences at the 5% level in one variable are not considered to be indicative of a difference simply because within a group comparison of 100 cases there is a 5% chance that a difference will be found.

The F ratio is applied to the variance of two samples to test that they have been drawn from the same parent population. F ratios are used to test if variances between sexes and populations are significant.

Chi Squared tests are used to test how well collected data fit a hypothetical distribution. This method is to be used to identify non metric dental associations between the sexes in the Sigatoka population. Significance levels are then presented. Levels of $P \leq 0.05$ and greater are held to be significant.

Correlation coefficients are used to measure the the association between two variables. Two methods of calculating correlation coefficients are used. One method used is Pearson's product moment correlation coefficient (r) which measures liner associations between variables. Pearson's correlations will be used to identify correlations between populations. The second method used is Spearman's rank correlation coefficient (p). Spearman's rank correlation is used when variables do not have values, and can only be ranked in order. Levels of $P \leq 0.05$ and greater are held to be significant.

Chapter Three

Census

1.0 Introduction

Census information provides the basic information for a skeletal population, such as the number of males, females and subadults, age at death, and life expectancy. Census information can be used not only to provide demographic data, but it can also provide information on the success to which a population adapted to and lived within their physical and social environment. In this Chapter each of these parameters are assessed. An assumption is made that the burial population is representative of the society in which they lived.

Assessment of sex and age follow set standards. However, the application of these standards are open to biases and subjective interpretations because because of the nature of the methods used and the variability that is encountered when studying any biological characteristics. This is because aging rates between individuals and morphological indicators of sex are variable, both as a consequence of genotypic and environmental factors. In many cases the condition of the skeletal material determines which characteristics may be used to assess sex and age. This may influence the accuracy of assessment.

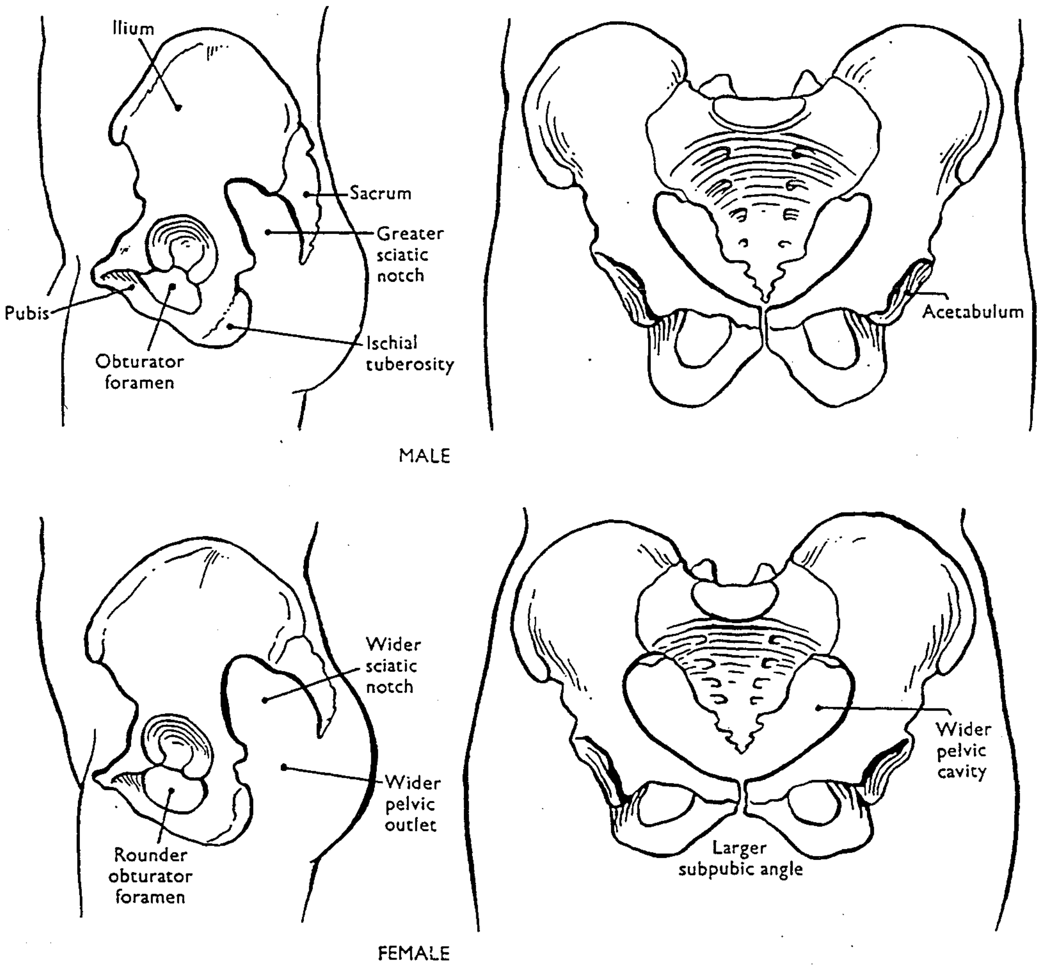
2.0 Theory

2.1 Assessment of sex

The sex of a skeleton can be determined using chemical analysis, skeletal and dental morphological and metric traits (Krogman, 1962; Bass, 1971; Dennison, 1979, Katayama, 1992). The methods used to assess sex in this study are based on a number of metric and nonmetric traits. The pelvis is the most reliable area for assessing the sex of a skeleton (Krogman, 1962; St Hoyme and Iscan, 1989). During adolescence the female pelvis enlarges to facilitate childbirth later in life. Pelvic enlargement requires alterations in morphology. The resulting characteristics are used to differentiate between the sexes. In a complete pelvis there are several morphological traits that are consistently larger in females, such as the sub-pubic angle, the greater sciatic notch, and the diameter of the pelvic basin (Meindl *et al.* 1985), (Figure 3.1). However, Tague (1988) points out that there is insufficient metric variability in the pelves to completely separate the two sexes.

Since very few of the pelves in this sample were complete, the sex of most individuals could only be assessed by examining the greater sciatic notch. An individual with a broad greater sciatic notch was subjectively assessed to be a female, and where the angle of the greater sciatic notch was narrow and deeper, the individual was assessed to be male. This has been shown to be a reliable method of sex assessment (Bass, 1971; Brothwell, 1981). Cases did arise where the greater sciatic notch was neither broad nor narrow and therefore a reliable sex assessment could not be made on the basis of this criterion alone. In these cases, and in cases where the pelvis was absent, other sex markers are used.

Figure 3.1
The morphological features of the pelvis used to assess sex. A comparison of male and female pelves.



In all cases, initial assessment of sex was independently compared with other morphological and metric sex markers. Morphological markers on the cranium were used based on the assumption that males are more muscular in life than females, and that this greater musculature is reflected on the bony skeleton. The supraorbital ridges in males are more robust than females. Males have more prominent nuchal crests, and typically have larger mastoid processes than females (Krogman, 1962; Acsadi and Nemeskeri, 1970). These traits were recorded using the Acsadi and Nemeskeri (1970) scale of +2 for the most masculine and -2 for the most feminine.

Two mandibular features are also used to determine sex. One feature involved distinguishing between the squarer chin and the presence of a symphyseal arch in the male mandible compared to a more rounded chin and the lack of a symphyseal arch in females (Krogman, 1962; Bass, 1971). The second feature used was the minimum breadth of the ramus of the mandible. Males generally have broader ramal breadths compared to females, and in most populations this difference is statistically significant (Giles, 1964; Brothwell, 1981). The Sigatoka population is no exception (Chapter Six). In this study, measurements of minimum ramal breadths were used to corroborate assessments of sex where other sex traits were absent. In these cases the minimum ramus breadth was compared to the average of males or females. Ramus breadths of one half of a standard deviation or less of the female average were assessed as females, while those greater than this were assessed as males.

Sex assessment was not attempted on individuals younger than 18 years of age. This was because sex diagnosis of immature skeletons lack accuracy (Krogman, 1962). Furthermore, the number of immature individuals was insufficient to make an accurate sex assessment based on tooth dimensions.

2.2 Assessment of age at death

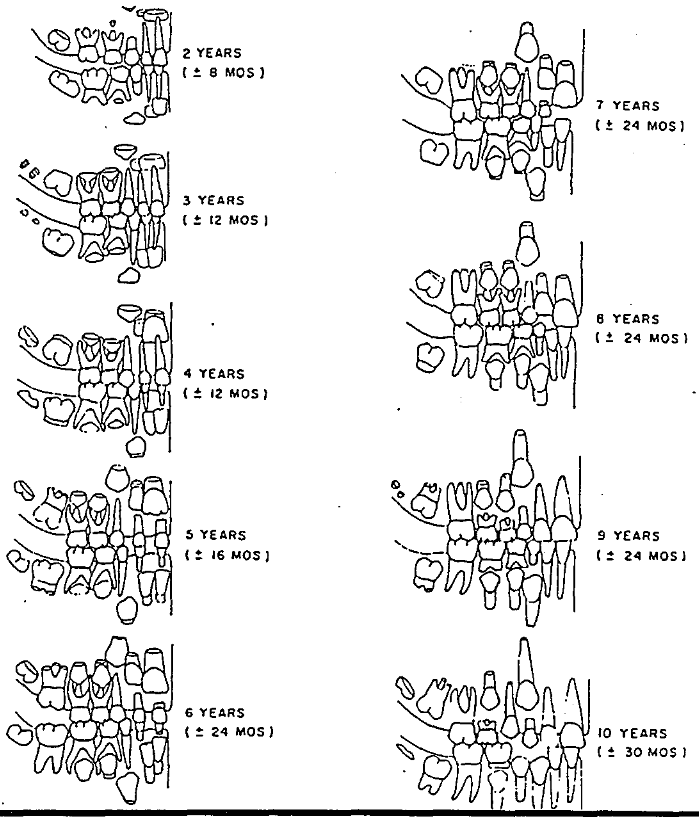
Age estimation was based on three methods. The first method involved relating the sequence of tooth eruption to age in infants and children, from 0 to *circa* 15 years. The second method was to relate the degree of epiphyseal union in the long bones to age in subadults, from *circa* 12 to 22 years of age. The third method involved estimating the rate of tooth wear in subadults and correlating this with ages estimated from the degree of epiphyseal union in the long bones. The rate of tooth wear can then be used to estimate the age of death in adults from *circa* 22 years of age. The theoretical basis of using these methods are outlined below.

2.21 Estimating the ages of infants and children

Estimation of the age at death of infants and children was based on the sequence of tooth eruption (Figure 3.2). An outline of tooth development is presented in Chapter Six. Assessment of age from tooth eruption is held to be the most reliable aging technique because during development, teeth are less influenced by environment than bone (Garn *et al.*, 1965; Buikstra and Mielke, 1985).

Figure 3.2

The sequence of tooth eruption used to estimate the age at death of children. From Ubelaker, 1978:47 and 112-113.



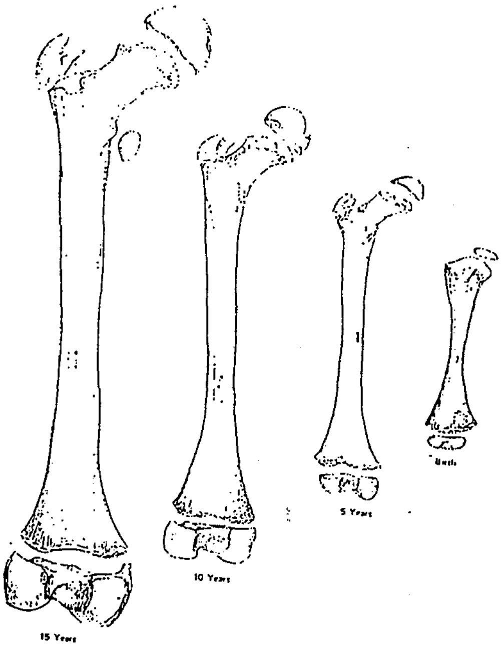
The sequences and timing of both deciduous and permanent tooth eruption are well documented (Massler *et al.*, 1941; Demirjian *et al.*, 1973). While, variations in the age of tooth eruption between populations have been found , these differences are within a 30 month age range (Everleth and Tanner, 1976; Costa, 1986; Yamada *et al.*, 1992). Biological development varies between individuals and between the sexes, hence biological age may be different from chronological age. Nutritional and "genetic factors" seem to contribute to these differences (Lee, *et al.*, 1965; Garn and Rohmann, 1966).

There is some degree of consensus in age estimation. For example, Ubelaker (1978) claims an accuracy range of ± 1.0 year at four years of age and ± 2.5 years at age 12. This degree of accuracy is reasonably consistent with the estimates of other authorities (Massler *et al.*, 1941; Hunt and Gleser, 1955; Miles, 1963). Figure 3.2 presents the tooth eruption sequences used to estimate children's age. These estimates are based on tooth eruptions from American whites, Amerindians, Negroes, Eskimo, Irish and Bengalese (Ubelaker, 1978).

2.22 Estimating subadult age

Age assessment of immature individuals with fully erupted permanent dentitions was based on the epiphyseal union of their long bones. Briefly, bone develops from a primary centre of ossification in the diaphysis, which develops into the long bone shaft. Other centres of ossification appear at either end of the shaft, these being the epiphyses. The age at which the epiphyses on differing long bones fuse to the diaphysis is known within a range. For example, femoral condyles begin fusing to the femoral diaphysis at around 16 years of age and union is completed at around 21 years of age (Figure 3.3), while the distal epiphysis of the humerus begins fusing to the diaphysis at around 12 years of age and is completed by 16 years of age (McKern, 1970).

Figure 3.3
The stages of bone growth and fusion of the femur from birth to 15 years of age. From Bass, 1971:165.



The ages at which union of the diaphysis and epiphyses occurs varies between individuals. It must be stressed that this is an assessment of biological age rather than chronological age. The standard applied here is based on modern white Americans, and it is therefore not necessarily representative of populations that experienced different nutrition, activity, and life span. Assessment of age at death based on long bone fusion followed Bass (1971), and McKern (1970). Alternative charts of bone fusion events can be found in Krogman (1962) and Williams *et al.* (1980). Figure 3.3 illustrates the stages of union in the femur as an example of long bone union.

2.23 Estimating adult age at death.

The most reliable method of assessing adult age at death is based on the sequence of bony changes on the surface of the pubic symphysis (Lovejoy *et al.*, 1985; Meindl *et al.*, 1985). Unfortunately no intact symphyseal surfaces were present in the Sigatoka skeletons.

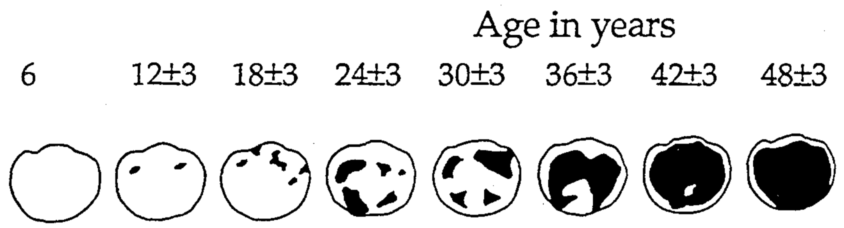
A number of alternative methods are available for estimating adult skeletal age. Several methods were initially considered, but were eventually rejected. Cranial sutures were not used to estimate age, because the age at which sutures fuse is too variable (Baker cited in Angel *et al.*, 1986). An alternative method advocated by Gustafson (1950) involves sectioning a tooth to observe age related changes such as secondary dentine, cementum deposition and root transparency. The obvious drawback is that it destroys the tooth. Other methods of aging include counting osteons in the bone. This technique is possible because bone continually remodels and an association exists between the osteon pattern and chronological age (Kerley, 1965; Stout, 1989). The two latter methods were rejected because they were considered to be too time consuming for this study. However, the possibility remains that these methods can be used to assess the age of the Sigatoka skeletons at a later date.

In this study the age of mature individuals was estimated from tooth wear. Miles (1963) established an adult age assessment procedure that estimated the age of death of individuals based on tooth wear from skeletons recovered from an archaeological context. Since Miles first used this method, a number of studies have evaluated its accuracy and have found it to be reliable within ± 10 years (Nowell, 1978; Buikstra and Mielke, 1985; Lovejoy, 1985; Costa, 1986; Kieser *et al.*, 1985; Richards and Miller, 1991). In another study, Molleson and Cohen (1990) have suggested that tooth wear related to bony union is as good as any method readily available for assessing the age of death, particularly in young adults. However, they caution that inaccurate assessment of age at death increases among older individuals. Nevertheless, the value of this method is that it is a population specific aging scale and has greater accuracy than any other method used to estimate adult age.

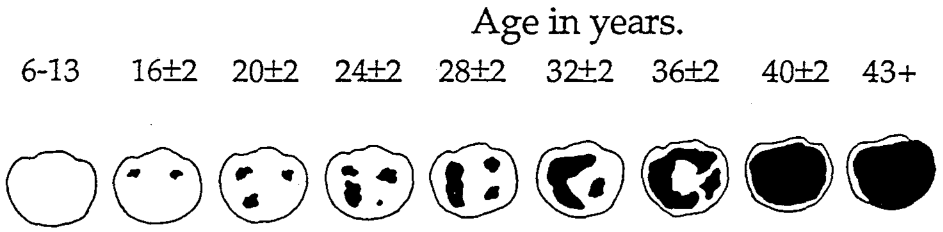
The method of age assessment used in this study follows that of the Miles method, but is based on tooth wear rates established by Molnar (1971). A tooth wear age standard was created by comparing the degree of tooth wear on individuals who had their permanent dentition, but who were aged according to the degree of epiphyseal bone union. Figure 3.4 illustrates the age ranges which have been assigned to each tooth wear category.

Figure 3.4
An illustration of age related tooth wear categories of first molars used in this study and a comparison of ages estimated from tooth wear based on Miles (1963 :204).

Miles age related molar tooth wear scale.



Modified Molnar method of aging Sigatoka adults from first molar tooth wear.



Darkened areas represent areas of exposed dentine.

2.3 Life tables

Life tables are primarily used by actuaries to estimate life expectancies of contemporary, well documented populations. When life tables are used on skeletal samples they assume the same accuracy of the data. These assumptions are:

a) That the data from the skeletal population are representative of the entire population.

b) That the population is stable.

c) That age at death and sex assessments are accurate.

These assumptions are not strictly valid in a skeletal population for the following reasons. First, although the Sigatoka population is a discrete burial group, the number of children and infants within a skeletal population are likely to be under represented because their skeletal remains are smaller and more fragile and therefore decay more rapidly than adult bones. Consequently, they are less likely to survive in an archaeological context (Howells, 1960).

Second, an assumption is made that the Sigatoka population was stable and that the skeletal population probably includes individuals from different generations. This need not present any difficulties in census analysis because a population that has lived in a stable environment for a number of generations need not fluctuate from generation to generation (Sattenspiel and Harpending, 1983).

A third point is that some commentators consider that the methods used to estimate ages in skeletal populations lack the necessary accuracy required in life tables (Angel, 1969, 1971; Cook, 1984). However, the high accuracy that is required by actuaries is not necessary in skeletal populations because life tables are used to provide a general indication of expected length of life. However, these deficiencies need to be accepted because life tables provide estimates of survivability of different age groups. This information is important in assessing the success of a population to their environment.

For the purposes of constructing life tables, the Sigatoka skeletal population can be assumed to have been a closed population. Therefore, it is possible to use a closed population model. This model holds that a population is not subject to migration. In paleodemographic studies, the most important assumption is that the mean age of death is equal to the life expectancy at birth. This assumption has been used to estimate mortality in numerous studies (Acsadi and Nemeskeri, 1970). Johansson and Horowitz (1986) have suggested this assumption is flawed. They maintain that a rise in fertility affects the age structure of a closed population. Therefore, there will be a proportional increase in the representation of younger cohorts in mortality, so that the increased proportion of younger individuals represented in the total sample will proportionally decrease estimates of life expectancy at birth. This will not significantly increase the mean age at death as long as fertility remains constant (Johansson and Horowitz, 1986).

There are a number of different methods used to estimate life expectancies (Weiss, 1973). In this study, estimates of longevity were made by constructing a standard life table (Acsadi and Nemeskeri, 1970). A life table serves to show how many individuals from an age cohort can be expected to reach the next age cohort, that is, it calculates the number of survivors from a given cohort.

Life expectancies are based on standard formulae. The formulae used in this thesis are presented below.

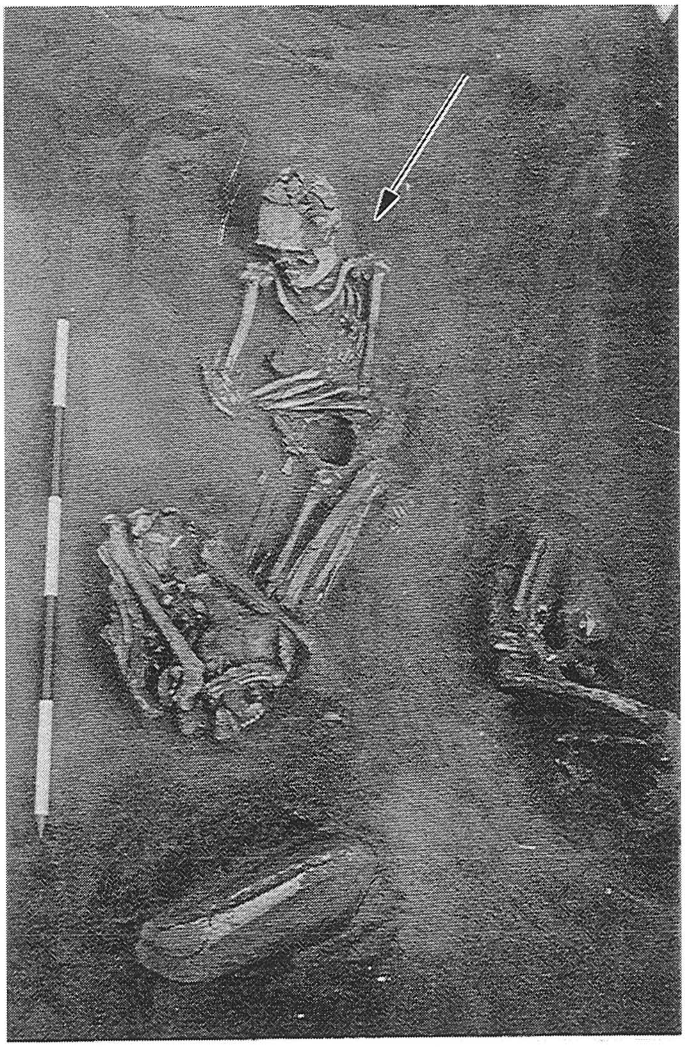
Life Table Formulae.
x = age interval - span one year up to five years of age.
n = number of individuals dying at age x.
dx = number of individuals dying at age x expressed as a proportion of a cohort of 100 individuals.
lx = survivorship, or the number of individuals living at age x, obtained by subtracting the number of deaths from the number alive at the beginning of each age interval.
qx = mortality rate, or the number of those dying expressed as a proportion of the living ($qx=ndx/lx$).
Lx = number of individuals alive between x and x+1 ($Lx=((lx+(lx+1))/2)$ multiplied by the span of each age interval.
Tx = The number of years that can be lived from the beginning of the age interval until all have died ($Lx = \Sigma+$ remaining Lx).
Ex = Life expectancy, or the average number of years of life remaining at the beginning of the age interval ($Ex=Tx/x$).
Cx = Percentage of the population who are age x in an age distribution.

3.0 Results

3.1 Number of individuals

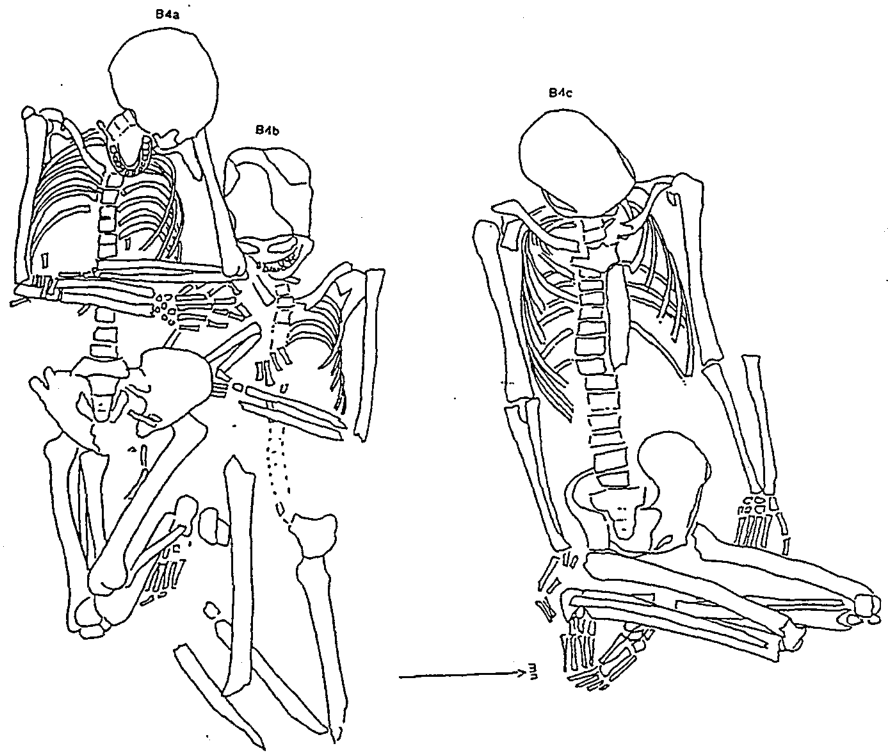
A total of 56 skeletons were recorded and available for laboratory analysis. Apart from two burials, all burials were sufficiently discrete to allow individual skeletal identification. B21b and B21c had been reburied together some time after initial internment (Figure 3.5).

Figure 3.5
The disturbed burial of B21b and B21c. B21a (identified by the arrow) was buried after B21b and B21c.



Individual skeletal identification was possible because one skeleton, B21b, was a subadult and the other, B21c, an adult. Two other skeletons, B4a and B4b were buried side by side (Figure 3.6). However, care had been taken in the field to separate each skeleton. All other burials were discrete, apart from three cases (B18a, B23a and E2a) where females were buried with infants or young children, but in these cases there was no chance of confusing individuals.

Figure 3.6
The double burial of B4a and B4b, with B4c in close proximity



3.2 Sex assessment

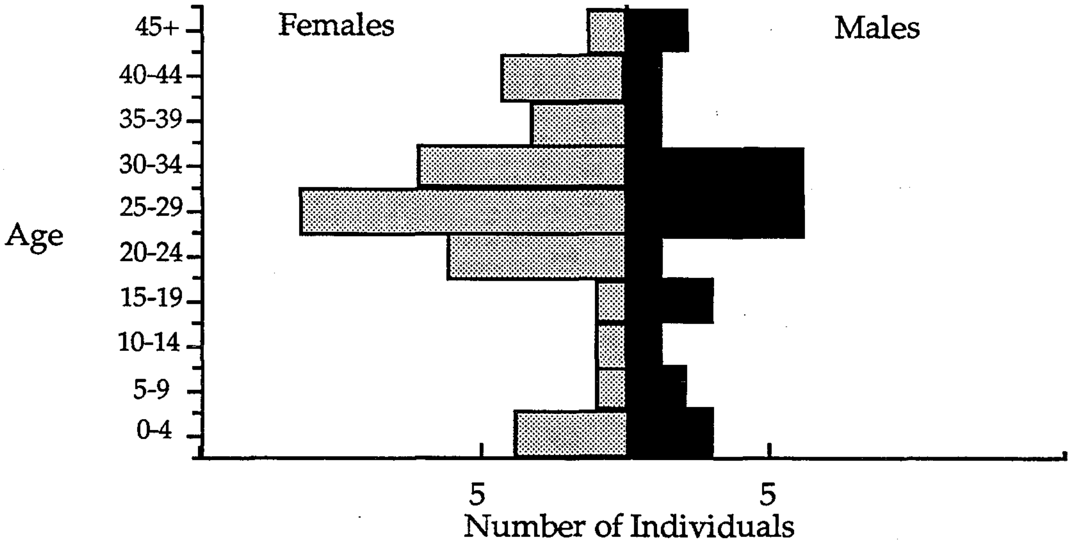
Of the 56 skeletons studied, 27 have been identified as female and 18 as male. The remaining 11 individuals were under 15 years of age and sexing was not attempted.

The male-female ratio is 1 : 1.5. This result may be distorted in favour of females. This distortion may have arisen because part of the burial area had been eroded with the subsequent loss of an unknown number of skeletons (Best, 1989). Alternatively, males may have died away from the village and therefore they were not interred at the burial ground.

3.3 Age at death

The estimated age at death of each individual recovered from the Sigatoka burial site is presented in Appendix 3. The mean age of death of 47 adults is calculated to be 30.0 years. There was a slight difference in age at death between the sexes. Males lived slightly longer than females. Mean age at death for males is 30.1, while that of females is 29.6 years. Few individuals are aged older than 40 years (Figure 3.7). The most frequent age at death was between 25 and 35 years. These distributions are typical of prehistoric Oceanic populations (Dennison, nd; Houghton, nd^{b}; Pietrusewsky, 1969, 1976; Snow, 1974).

Figure 3.7
Age structure by sex of the population excavated from the Sigatoka Dune site. Individuals under 15 years of age have been divided between the sexes.



Distributions of ages at death are illustrated in Figure 3.7. The distribution of mortality rate represents a typical bell shaped mortality curve. The number of individuals who died before the age of five may be under estimated because neolithic cultures typically experienced high infant and child mortality (Tayles, 1992). There is little reason to suggest that this did not also occur among the Sigatoka population. The absence of infants and children in the skeletal population may be due to the rapid degradation of bones in a sandy medium. The low number of subadults (10 to 19 years) probably reflects the lower mortality rate experienced by that group.

Although male survivorship was slightly better than that experienced by females, this difference is slight. Given the probable error range in the estimates of adult age, little can be read into this marginal difference. Figure 3.7. shows separately the male and female age at death.

3.4 Life Tables

Life expectancies of the Sigatoka population are presented in Table 3.1. The table shows that the life expectancy at birth was very low, just 23 years. However, it does match that of other skeletal populations (Tayles, 1992) and recent tribal groups (Weiss, 1973). At 15 years of age the life expectancy is a little higher and calculations show that on average individuals would be expected to live to 28 years of age.

Table 3.1
Sigatoka life table.

x	n	dx	lx	qx	Lx	Tx	Ex
0-1	3	4.62	1000	0.0462	977.0	22846.3	22.8
1-2	1	1.54	954	0.0161	946.5	21869.3	22.9
2-3	0	0.00	939	0.0000	939.0	20922.8	22.2
3-4	3	4.62	939	0.0319	916.0	19983.8	21.3
5-9	3	4.62	893	0.0517	870.0	19067.8	21.4
10-14	2	3.08	847	0.0364	831.5	14814.0	14.5
15-19	4	6.15	816	0.0754	785.0	10772.7	13.2
20-24	7	10.77	754	0.1428	700.0	7060.2	9.4
25-29	17	26.15	646	0.4048	515.5	4021.4	6.2
30-34	13	20.00	385	0.5195	285.0	2020.1	5.2
35-39	4	6.25	185	0.3324	154.0	922.6	5.0
40-44	5	7.69	123	0.6252	84.5	326.3	2.7
45-50	3	4.62	46	1.0000	23.0	57.5	1.3

The life expectancy estimates show that males in the 20 to 24 year old cohort had a markedly higher life expectancy than females at the same age (Tables 3.2 and 3.3). This difference possibly relates to higher rates of female deaths during child birth. In the cohorts aged between 25 and 34 years life expectancies are similar in both sexes. In the cohort aged between 35 and 44, female life expectancies were approximately two years less than males.

Table 3.2
Sigatoka male life table.

x	n	dx	lx	qx	Lx	Tx	Ex
0-1	1.5	5.77	1000	0.0577	971.0	21603.3	21.6
1-2	0.5	1.92	942	0.0204	932.5	20632.3	21.9
2-3	0	0.00	923	0.0000	923.0	19699.8	21.3
3-4	1.5	5.77	923	0.0625	894.0	18776.8	20.3
5-9	1.5	5.77	865	0.0667	836.0	17882.8	20.7
10-14	1	3.85	807	0.0477	787.5	13824.0	17.1
15-19	4	11.54	768	0.1502	705.5	10091.5	13.1
20-24	7	3.85	643	0.0599	629.0	6755.2	10.5
25-29	17	23.08	615	0.3753	499.5	3933.9	6.4
30-34	13	23.08	384	0.6010	268.5	2013.9	5.2
35-39	4	3.85	153	0.2516	134.0	1007.6	6.6
40-44	5	3.85	116	0.3348	96.0	432.6	3.8
45-50	3	7.69	77	1.0000	38.5	96.3	1.3

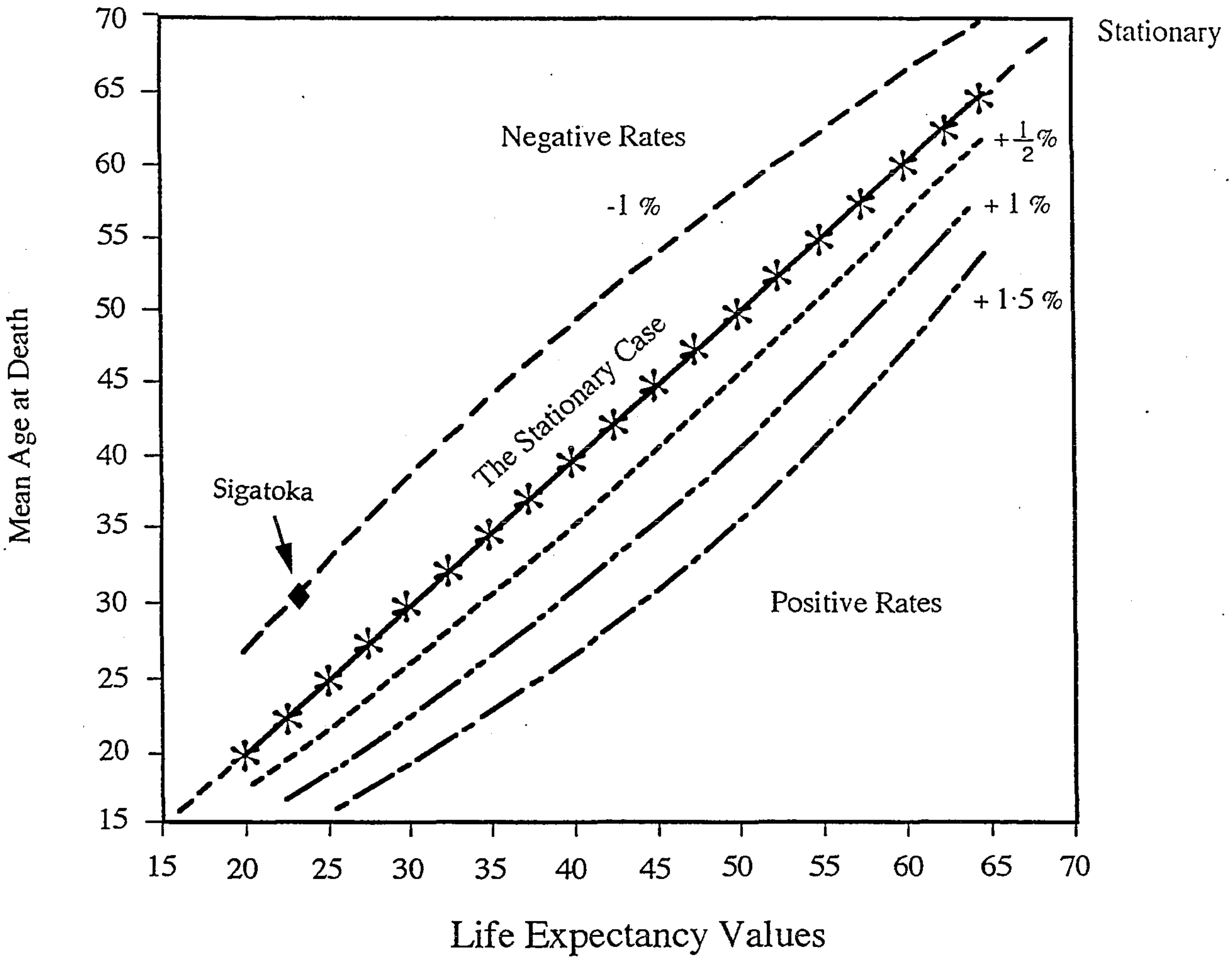
Table 3.3
Sigatoka female life table.

x	n	dx	lx	qx	Lx	Tx	Ex
0-1	1.5	3.85	1000	0.0385	981.0	23633.1	23.6
1-2	0.5	1.28	962	0.0133	955.5	22652.1	23.5
2-3	0	0.00	949	0.0000	949.0	21696.6	22.9
3-4	1.5	3.85	949	0.0406	930.0	20747.6	21.9
5-9	1.5	3.85	911	0.0423	892.0	19817.6	21.8
10-14	1	2.56	873	0.0293	860.0	15437.6	17.7
15-19	1	2.56	844	0.0302	834.0	11202.6	13.2
20-24	6	15.38	821	0.1873	744.0	7257.6	8.8
25-29	11	28.20	667	0.4228	526.0	4082.6	6.1
30-34	7	17.95	385	0.4662	295.5	2028.8	5.3
35-39	3	7.69	206	0.3733	167.5	871.3	4.2
40-44	4	10.26	129	0.7953	77.5	258.8	2.0
45-50	1	2.56	26	1.0000	13.0	32.5	1.3

The problem with the results presented above is that a life expectancy of around 23 years of age at birth allows too little time for fertility to reach replacement levels (Figure 3.8). According to this graph, the age at death and life expectancy estimates results indicate a population declining at the rate of about 1% per annum. Similar life expectancies have been calculated for the prehistoric New Zealand Maori, a population that could not have experienced a general population decline (Simpson, 1979; Houghton, 1980; Brewis, 1988).

On the basis of health and pathological evidence to be presented in Chapters Four and Five, a declining Sigatoka population is unlikely. Therefore it is suggested that the number of adults who died between the ages of 20 and 29 are proportionately over represented in the burial ground. This suggestion is based on the proposition that if the Sigatoka population was expanding, the number of younger individuals in the burial ground would be greater than the proportion of younger individuals in the living population.

Figure 3.8
Population growth rates based on life expectancies and mean ages at death. (From Coale and Demeny, 1983).



A reasonable estimation of growth rates would be between 0 an 1% per annum. There is evidence of historic Pacific communities that used traditional food sources, expanding at over 1% per annum (Houghton, pers. comm.). The rates of population increase in the early settlement period of the Pitcairn Islands and the Bass Strait Islands have been calculated to have doubled in every generation (Birdsell, 1957). For a growth rate of 0 to 1% to have occurred, life expectancy at birth would have to be around 40 years of age (Coale and Demeny, 1983). Therefore, it is suggested that the Sigatoka burial population is indicative of a growing population represented by the proportionately higher number of 20 to 30 year old individuals in the burial ground.

4.0 Summary

The estimated mean age at death and life expectancies are similar to other Oceanic prehistoric populations. Similarities in age at death between males and females suggest a society in which there were sufficient resources accessible to all individuals. Infants and children seem to be under represented. This probably relates to the rapid postmortem decay of bones of individuals under the age of five years. The male-female imbalance may reflect male loss of life at sea, during fishing or turtle catching expeditions. Alternatively it maybe a sampling error caused by erosion whereby more male than female skeletons were lost.

It is suggested that the mean age at death and estimates of length of life at birth calculated in the life tables under estimate actual length of life. Mean length of life may have been closer to 40 years of age. Given this longevity in a neolithic population, the Sigatoka population can be considered to have been successful in living in their environment in terms of their life span.

Chapter Four
Health

1.0 Introduction

The health of a skeletal population provides an indication of the degree of success the population had in adapting to the environment in which they were living. Health is assessed using the following variables; stature, body mass, fertility, enamel hypoplasia and cortical bone thickness. Each of these variables can be influenced by diet. Without direct dietary information, such as from coprolites, chemical analysis of bone will be used to identify two trace element components of diet, strontium and zinc. Strontium and zinc will provide information on the relative amounts of plant food and meat in the diet.

The main focus of the dietary analysis is to provide a broad indication of the type of diet, and whether it was sufficient to allow good health and growth. The second aim is to compare trace element concentrations in males and females to find if there is evidence of differing access to certain foods. A third aim is to identify if differences exist between presumed "high" status males and other males, and females.

2.0 Theory

2.1 Stature

Stature estimates of adults are widely used in studies of skeletal populations (Pietrusewsky, 1969, 1989[b]; Snow, 1974; Houghton, 1975; Tayles, 1992) to provide a dimensional profile, of how a population or individual appeared in life. Stature estimates also provide evidence of the growth potential reached by adulthood, and it is not subjected to the affects of age changes in later life. The stature attained by an individual may be mediated by environmental factors including illness, nutrition and living conditions (Tanner, 1962; Everleth and Tanner, 1976). These studies have shown that when these influences are relaxed stature increases.

Statures estimates have also proved to be valuable in documenting secular changes in populations through time (Tayles, 1992; van Dijk, 1991), sex dimorphism (Bayendor *et al.*, 1989), environmental adaptation (Masali, 1972; Houghton, 1989[a]), diet (van Dijk, 1991), and inter-population comparisons (Pietrusewsky, 1991). In these studies stature estimates are calculated to obtain sex and status differences, to allow inter-population comparisons, to provide some indication of how the Sigatoka people appeared, and to assess the adaptation to their physical and cultural environment.

2.2 Body mass

Mass estimates of skeletal populations have not usually been considered in skeletal studies. The few studies that have investigated the problems of estimating body mass from skeletal material primarily concern work conducted on primates and hominids (Lovejoy *et al.*, 1973; McHenry, 1975; Gingerich *et al.*, 1982). Behnke (1959) developed a regression equation for estimating lean body mass from joint diameters of radiographs from United States navy personnel for whom body composition data was available. Houghton *et al.* (nd) used a modified Behnke formula to estimate the body mass of skeletal prehistoric New Zealand Maori.

Estimates of body mass are derived by measuring the diameters of load bearing articular surfaces of the long bones (wrist, elbow, knee and ankle). The theoretical basis for using these diameters is based on the knowledge that the ends of bone that enter a joint expand to reduce the disruptive forces on the articular cartilage. Additionally, the size of the joint surface should be proportionate to body mass and the forces acting on it (Currey, 1986).

The body mass of an individual is subjected to the same range of variables affecting stature, such as health and nutrition. Unlike stature, these variables can change body mass any time during life. Therefore body mass estimates reflect the weight of an individual before death. It is valuable to have a quantitative idea of an individual's weight during life because it contributes to providing a dimensional profile of body form, along with stature, of how an individual may have appeared during life. A reconstruction of body form provides an indication of the type of climatic selective forces that operated to evolve that particular body form.

2.3 Fertility

The analysis of fertility in prehistoric skeletal populations has been investigated in many studies (Phillipps, 1980; Cox and Scott, 1992; Igarashi, 1992^{a}). This section aims to present an idea of the level of fertility a female may have attained in such a population. High fertility levels may represent a population's success at obtaining adequate levels of food resources and maintaining a stable socio-political environment, while low fertility levels may reflect a population living in equilibrium with the available food. A review of the validity of estimating separate pregnancy-parturition events from pelvic markers will also be considered.

Changes at the pubic symphysis can usually be readily identified as pits or grooves left on the dorsal surface of the bone. These are formed as the fetus develops. The weight of the fetus places mechanical stress on the inter-pubic ligaments which become stretched to the point of haemorrhage. In the final week of pregnancy the pubes can separate by as much as ten millimetres. This separation forces the inter-pubic ligaments to attach more laterally from the symphysis. This lateral attachment extends further with each subsequent pregnancy (Gilbert and McKern, 1973). Together with the combination of the hormones that stimulate the action of osteoclasts at the attachment of the ligaments, these factors can leave permanent pits or grooves on the dorsal surface of the pelvis. The formation and depth of each pit or crater has been held to be evidence of one episode of pregnancy.

Some researchers have undertaken forensic studies that aimed to identify the number of pregnancies/parturition episodes from pitting on female pelves (Angel, 1969, Putschar, 1976; Igarashi, 1992[b]). Putschar (1976) examined a sample of 198 individuals, of which 111 were females with a known reproductive history. These studies concluded that it is possible to estimate fertility from markings on the pelves that occur during pregnancy/parturition. Bony scaring in the form of pits or grooves may appear from the first month of pregnancy and may continue to be formed until parturition. During this time the bony changes are under the influence of ovarian and placental hormones. These hormones effect the pelvic ligaments and cartilages first. By the third trimester of pregnancy the pelvic bone may be affected at two sites. These are on the dorsal surface of the os pubis at the site of the interosseous ligament, and on the preauricular groove of the ilium (Kelly, 1979). The accuracy of estimating pregnancy and parturition events based on the manifested bony changes in these two areas will be reviewed.

Bony changes that occur at the preauricular groove of the ilium with each episode of pregnancy and parturition are hormonally and mechanically induced. These changes are manifest by a line of small pits that coalesce on the inferior part of the ventral sacro-ilium. It is these pits in the preauricular sulcus that make them distinct from usual ligament imprints which may be found on both males and females (Houghton, 1974). By assessing the number and depth of pits and grooves on the sacro-ilium, an estimation of the number of pregnancies may be possible.

Subsequent reviews of both these methods have advocated caution (Holt, 1978; Suchey *et al.*,1979; Spring *et al.*, 1989). Estimating past fertility from the preauricular groove has greater relevance to the Sigatoka skeletal material because the pubic symphyses have not survived in that population. However, estimating fertility events from the preauricular groove is problematic. A recent radiographic study of 190 females with known obstetric history found no evidence of past fertility based on the depth of the preauricular groove (Spring *et al.*, 1989). They concluded that presence of this groove is not a reliable indicator of past pregnancy/parity. However, using radiographs to identify pelvic scarring is not a particularly reliable method of dealing with this problem. Dunlap (1979) assessed 80 females, for whom 75% had a known fertility history. Dunlap concluded that changes to the dorsal surface of the pubis showed no significant correlation with pregnancy, but morphological changes on the preauricular sulcus were significantly associated with past parity. In contrast, a study by Cox and Scott (1992) did not identify a relationship between pitting on the preauricular sulcus (or pubic symphysis) in a skeletal population with an archival obstetrical history.

Kelly (1979) considered that the preauricular groove to be a reliable indicator of past pregnancies. This opinion was based on defining a preauricular groove in 44% of women who were known to have experienced parturition. Kelly sounded a cautionary note echoed in the studies mentioned above, because a well developed groove in over a fifth of nulliparous females was found. In short, while this method may be able to provide information on whether a female experienced pregnancy/parturition, the author considered that estimations of the number of episodes experienced are of doubtful accuracy. One possible factor that may contribute to inaccuracies of skeletal fertility assessment is the instability of the sacroilliac joint in females. This instability may place greater stress on the ligaments during life (St Hoyme and Iscan, 1989).

Recent studies by Igarashi (1992[a], 1992[b]) found that pits on the preauricular sulcus are probably related to pregnancy rather than parturition. It was found that these scars did not disappear during life. The problem with comparing contemporary sedentary Japanese females with physically active prehistoric females is that bony remodelling on the pelvis may be more rapid in prehistoric women. This is because physical activity stimulates bony remodelling.

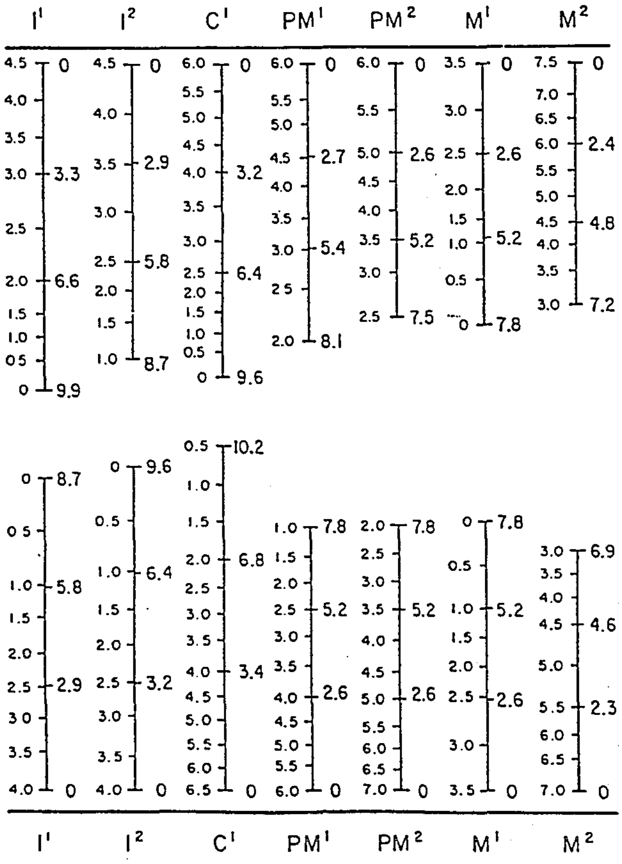
Obviously, when using this method to estimate the number of pregnancies/parturition events in a skeletal sample, the accuracy of the estimation can be expected to vary significantly from the actual number of events. Therefore, to make any estimation of individual fertility events seems to be pointless, and a more fruitful method may be to draw analogies from contemporary, stable traditional societies.

2.4 Enamel hypoplasia

Enamel hypoplasia is a deficiency in enamel thickness resulting from disrupted enamel formation during crown development (Sarnat and Schour, 1941). Enamel hypoplasia is readily identified on erupted teeth as either continuous or discontinuous transverse linear pits or bands in the enamel (Sarnat and Schour, 1941; Goodman *et al*, 1980). Disruptions to enamel formation have been associated with individual and multiple factors including episodes of under-nutrition (Huss-Ashmore *et al.*, 1982), vitamin D deficiency and infections (Scott and Symons, 1982). However, the threshold at which ameloblast disruption is initiated and the aetiology of this is not yet understood (Goodman and Rose, 1990; Goodman *et al.*, 1991; Hillson, 1992). Once enamel has been deposited it does not remodel, so an indelible record of disrupted enamel deposition is left on the tooth crown. This record of disrupted growth can be aged because it is known that amelogenesis begins at the tooth cusps and progresses to the cementoenamel junction. The rate at which enamel is deposited is assumed to proceed at a constant age rate (Massler *et al.*, 1941). Figure 4.1 shows the age related mineralisation of enamel on the permanent dentition. The third molar is an exception to this; individual development of this tooth is highly variable.

The incidence of enamel hypoplasia has been reported in numerous prehistoric skeletal populations (Goodman and Armelagos, 1985; Goodman, 1989; Lanphear, 1990; van Gerven, *et al.*, 1990). Studies of these populations have focused on the age and the number of episodes of hypoplasia using one tooth, usually the canine (Skinner and Hung, 1989; van Gerven *et al.*, 1990) or all the teeth, apart from the third molars (Goodman *et al.*, 1984; Lukacs, 1992; Tayles, 1992). This latter approach gives a better indication whether an individual experienced health stress during infancy or childhood. This is because all teeth are vulnerable to enamel hypoplasia, so the age(s) at which defects occur can be matched between the different teeth.

Figure 4.1
The age related sequence of mineralisation of enamel on the permanent dentition. The numbers on the right are the distances, in millimetres, from the cementoenamel junction to the midpoint of the hypoplasia. The numbers on the left of each line are the corresponding ages. (After Rose *et al.*, 1985).



2.5 Cortical bone area

Bone is formed by the actions of osteoblasts that are responsible for depositing minerals such as calcium. The shape and circumference of a bone is influenced by two main factors. The first factor is the biomechanical strain acting on it. The second is a reduction in the cortical area of bone in older individuals, despite the expansion of the circumference. Pathological factors such as yaws, and trauma such as fractures, can also be responsible for bony changes.

Bone is subjected to biomechanical influences throughout life that act to place forces on some locations, while less force is placed on other areas. New bone is preferentially deposited in the areas of greatest force, thus the bone is modelled to obtain the greatest resistant strength (Frost, 1985). While most bone is deposited during episodes of greatest body growth (up to around 20 years of age), bone remodelling occurs throughout life. Continued bone deposition seems to be dependent on a number of factors, particularly nutrition (Garn, 1970; Heaney, 1988), the level of physical strain a bone is subjected to (Frost, 1985), and sex (Garn, 1970; Frost, 1985; Stini, 1990). Other factors are also influential, including genetic disposition, climate and health (Ortner and Putschar, 1985).

Bone is remodelled through the coordinated and dependent action of osteoclasts and osteoblasts. Osteoclasts are activated to resorb cortical and trabecular bone, usually from the area parallel to the long axis of the bone where maximum strain occurs (Stini, 1990). Osteoblasts are stimulated by an unknown mechanism to deposit new bone in the area where strain occurs. New bone is usually deposited on the periosteal surface so that the circumference of the bone increases, while the thickness of cortical bone decreases. A reduction in cortical bone occurs when the bone resorption activities of osteoclasts accelerates faster than osteoblastic bone deposition rates (Garn, 1970; Frost, 1985; Stini, 1990).

The length of life in many prehistoric populations does not usually exceed the age when peak bone mass is reached in contemporary western society which is between 30 and 40 years of age. Therefore, age related bone loss probably did not affect prehistoric populations. However, a number of pathological, traumatic or nutritional variables may have influenced cortical bone thickness.

Potential problems may arise when comparisons of the rate and age of bone loss are made between prehistoric populations. For example, different diets, physical activities and genetic make-up may influence the deposition and later loss of bone between different populations (Dewey *et al.*, 1969; Ericksen, 1982).

2.6 Chemical analysis of diet

The analysis of trace elements in bone provides a key towards understanding the relative importance of and/or access of an individual to certain food groups. Certain trace elements accumulate in bone and these reflect the quantity of elements absorbed from food and water (Gilbert, 1985). Some trace elements, such as strontium, have been found to occur in greater concentrations in plant foods. Other elements, such as zinc, are found in high concentrations in meat and fish. An analysis of different concentrations of trace elements enable estimates to be made of the relative importance of plant to meat/fish components in the diet (Francalacci, 1989; White and Schwarcz, 1989). Not only have different concentrations of trace elements been used to interpret dietary patterns, they have also been used to identify status and sex differences (Brown, 1973; Blakely and Beck, 1981), health (Gilbert, 1985), and pregnancy and lactation (Brown, 1973; Lambert *et al.*, 1979). Other researchers have made population comparisons (Gilbert, 1975; Horwood, 1989). In this analysis comparisons with other prehistoric populations was not possible, because the human skeletal material could not be normalised with animal trace element concentrations.

Concentrations of strontium and zinc in the bone were analysed. The reasons why these two elements were chosen are presented below. High concentrations of strontium are found in plants because they indiscriminately absorb and utilise strontium (Sanzharova, 1978). At the other end of the spectrum, mammals absorb only 20 to 40% of the strontium ingested from eating plants (Spenser *et al.*, 1973), whereas fish and particularly shellfish, ingest high levels of strontium. Therefore, as strontium passes through the various terrestrial trophic levels each step reduces the amount of strontium passed to the following level (Schoengier and Peebles, 1981). The possibility of mistaking high concentrations of strontium in a sample as indicating a solely high plant diet, and neglecting the possibility of a marine based input, illustrates that it is important to have prior knowledge about the environment in which the study population lived.

Declining levels of strontium concentrations in each successive trophic level make it a useful indicator of the relative importance of plants and/or fish compared to meat in an individual's diet. However, terrestrial concentrations of strontium vary widely with geography. This makes it unreliable to undertake direct intersite comparisons (Sillen and Kavanagh, 1982). Conversely, marine strontium concentrations are uniform throughout the world.

Clinical and animal studies have demonstrated that during pregnancy and lactation concentrations of strontium increase in females. During pregnancy the placental tissue discriminates against strontium in the transfer of minerals to the fetus. Consequently, the maternal skeleton absorbs higher levels of minerals that effects an increase in the level of maternal strontium (Jacobson *et al.*, 1978; Sillen and Kavanagh, 1982). This effect does not seem to occur in contemporary western populations that have access to varied diets, have low frequencies of parturition, and short episodes of lactation. In contrast, prehistoric females lactated and/or were pregnant relatively longer in their shorter lives. Certainly, several studies of prehistoric populations have reported that strontium content in adult female skeletons is usually higher than in males (Brown, 1973; Gilbert, 1975; Lambert *et al.*, 1979; Sillen, 1981).

One further consideration is the migration of strontium into the soil or into the bone during interment. Strontium exchange does not seem to occur in most situations. Some researchers have reported evidence of strontium migration into the first millimetres of buried bone, but this evidence is usually restricted to sites with unusually high strontium levels, such as middens (Boaz and Hampel, 1978; Wessen *at al.*, 1978; Sillen and Kavanagh, 1982; Sealy *et al.*, 1991). Nevertheless, strontium results should be interpreted cautiously when there are no control samples. If diagenesis occurs it can be minimised by removing the first millimetres of cortical bone in the laboratory (Lambert *et al.*, 1989, Lambert *et al.*, 1991; Price *et al.*, 1992),

Zinc is an essential element for growth, bone mineralisation, health and some endocrine functions. Zinc is readily metabolised, although calcium and certain cereal proteins and legumes can inhibit this. The absorbed zinc becomes tightly metabolically bound in muscle, hair, skin and bone (Aufderheide, 1989). Laboratory studies based on animal models have demonstrated that muscle zinc is so immobile that even in zinc-deprived states total body zinc content remains unaltered. The availability of zinc released from bone is dependent on the rate of bone resorption. This release occurs independent of the bodily requirements. The content of zinc in different bones may differ by as much as 200%. For example, the diaphyses of the long bones have the lowest zinc content and the vertebrae have the highest (Strehlow and Kneip, 1969).

The potential of zinc as a dietary marker stems from its high levels in protein rich foods, such as meat and seafood. Filter feeders, particularly oysters, accumulate high concentrations of zinc (Sandstead, 1984). This makes zinc an ideal element to measure the differences in status and sex access to high protein resources. A temporal study of prehistoric Mayans appears to have successfully used zinc to identify the differences of male and female access to high protein foods (White and Schwarcz, 1989).

Levels of strontium and zinc in the bone were analysed because they are able to provide evidence of different sources of protein in the diet. High levels of strontium provide an indication of high plant and/or mollusc components in the diet, whereas high levels of zinc indicate the diet was rich in crustaceans, molluscs, and/or meat. High concentrations of both these elements would suggest a diet rich in molluscs.

In this study caution is required because it was not possible to estimate the levels of naturally occurring strontium and zinc in the soil. Consequently the amount of diagenesis that may have occurred cannot be calculated. Therefore a conservative approach is to be used when interpreting the results.

3.0 Methods

3.1 Stature

There are a number of formulae available for estimating stature from long bones. These formulae have been derived through regression analyses. By measuring the stature of living individuals, it is possible to apply the derived formulae to estimate the stature of a skeleton. The accuracy of the estimated stature varies depending both on the long bone and on the stature formulae used. Regression formulae based on the length of the tibiae usually give the most accurate stature estimation. Regression formulae that are available have been derived from a number of populations including Negroes, Europeans, Mongoloids, (Trotter and Gleser, 1952; Genoves, 1967; Trotter, 1970), and Polynesians (Houghton *et al.*, 1975).

In this study regression formulae derived from Polynesians are used following Houghton *et al.*, (1975). Stature estimates for the Sigatoka people derived from Polynesian regressions were found to have less error compared to equations developed for Europeans or Negroes. Stature estimates were calculated using measurements from intact long bones only. These equations are presented in Table 4.1. The derived individual stature estimates are an average based on the measurable long bone lengths. Measurements of long bones were taken based on the method described by Trotter and Gleser (1970) and used by Houghton *et al.* (1975). The final stature estimate of an individual is based on the mean stature of all the long bone estimates available for that individual.

Table 4.1

Equations for estimating stature from single long bones. From Houghton *et al.* (1975 : 333)

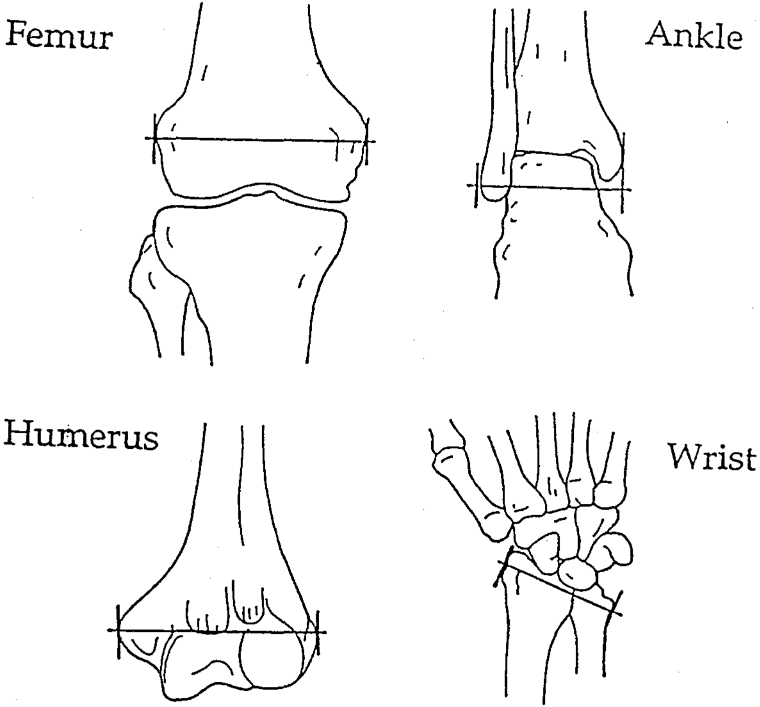
Right side	Left side
$2.137 * F - 5.184S + 830.7$	$2.176 * F - 4.528S + 796.8$
$2.210 * T - 5.247S + 978.6$	$2.077 * T - 5.602S + 1029.6$
$2.103 * f - 6.056S + 1045.0$	$2.164 * f - 5.721S + 1023.4$
$1.782 * h - 7.339S + 1226.4$	$2.520 * h - 4.440S + 963.1$
$2.475 * R - 5.642S + 1160.7$	$2.500 * R - 5.415S + 1154.8$
$2.257 * U - 6.738S + 1182.7$	$2.009 * U - 6.911S + 1257.6$

F = Femur; T = Tibia; f = fibula; h = humerus; R = Radius; U = Ulna.
S = sex (10 = males, 20 = females.

3.2 Body mass

There is an absence of body mass estimates of human skeletal populations, however some studies have attempted to develop accurate methods of estimating mass (Trotter, 1954; Behnke, 1959). Houghton *et al.* (nd) used a modified Behnke formula to estimate the body mass of 33 prehistoric New Zealand Maori. Modifications were made to the formula to take into account bone shrinkage that occurred during the more than 200 years after death. Comparisons were made with the body weight of members of the First World War Maori Battalion. Houghton *et al.* (nd) subsequently made modifications to the formula to account for a greater mean mass and probable lower fat component in the prehistoric individuals. Houghton (pers. comm.) has recently applied the modified Behnke formulae to calculate the mean body mass of a Solomon Island population with a known weight and comparing the derived estimate with actual weight. Little difference in estimated body mass compared to actual body mass was found. The modified Behnke method used by Houghton *et al.* (nd) is used in this study.

Figure 4.2
Joint diameters of the long bones used to estimate body mass. (After Houghton *et al.*, nd)



Estimates of body mass require measurements of the maximum diameters of the wrist, humeral condyle, femoral condyle, and ankle (Figure 4.2). To obtain the most accurate mass estimation, all eight diameters need to be present. However, few individuals in the Sigatoka population had all eight diameters present. To overcome this lack, Houghton's *et al.* (nd) data on estimated body mass of the prehistoric Maori were used to form regression equations to estimate the body mass of the Sigatoka skeletons for each of eight diameters. These equations are presented in Table 4.2. Each individual's body mass estimate is an average of the diameters that were able to be measured and body mass estimates calculated.

Table 4.2
Equations for estimating body mass from some joint diameters.

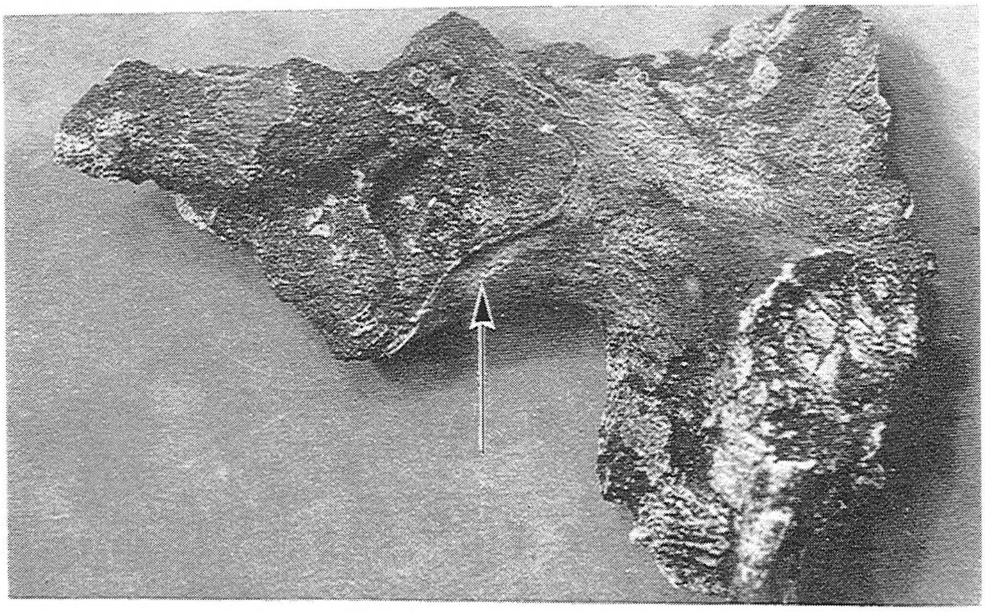
	Males	Females
Right elbow	(n * 0.9300) + 18.2300	(n * 1.2151) - 10.6057
Left elbow	(n * 0.8810) + 21.6000	(n * 1.0973) - 2.4148
Right wrist	(n * 1.4398) + 3.1338	(n * 1.9848) - 32.4672
Left wrist	(n * 1.4885) - 1.7731	(n * 1.6454) - 16.4429
Right knee	(n * 1.4325) - 42.5423	(n * 1.3530) - 42.1591
Left knee	(n * 1.3894) - 39.9411	(n * 1.2594) - 35.8417
Right ankle	(n * 0.5997) + 33.8748	(n * 1.5494) - 41.1328
Left ankle	(n * 1.2738) - 12.2755	(n * 1.7301) - 52.2548

3.3 Fertility

Assessment of pregnancy/parturition was based on Houghton's (1975) method. This involved establishing if the surface of the preauricular groove was irregular. The presence of pitting was taken as an indicator of past pregnancy and the absence of pitting was taken to indicate nulliparus females. In cases where the preauricular groove was very broad and exceeding the breadth found in the male sample, this was also taken as an indicator of past fertility (Figure 4.3). To assess the validity of using this method of establishing fertility, the male sample was studied to find out the extent and nature of preauricular sulcus remodelling.

On the basis of past studies, the accuracy of estimating the number of parturition/pregnancy events from os pubis pitting and grooving is open to doubt. For this reason, assessments were made to identify only if a female had experienced pregnancy/parturition or not. Frequencies were not estimated (Spring *et al.*, 1989; Cox and Scott, 1992). Very few individuals had intact os pubes in the Sigatoka collection, therefore the assessment of pregnancy is based on pitting and grooving on the preauricular surface.

Figure 4.3
Location of preauricular sulcus groove as an indicator of past pregnancy.



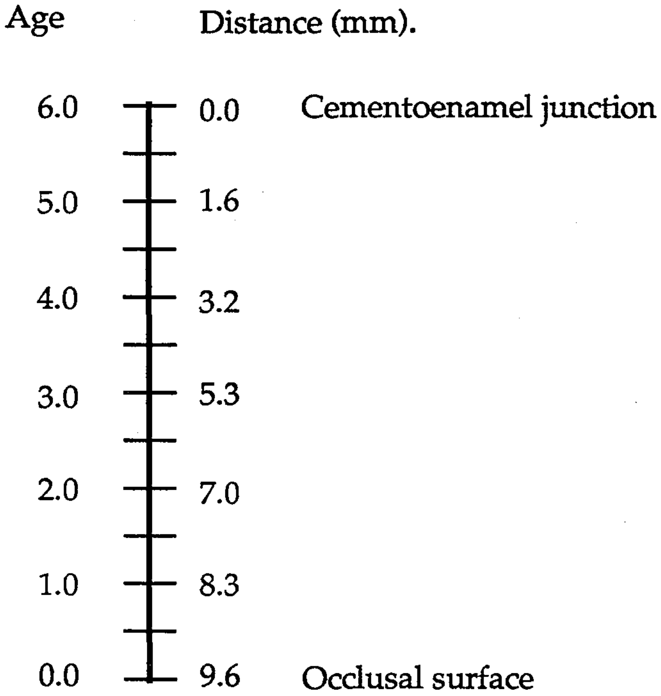
3.4 Enamel hypoplasia

Enamel hypoplasia was recorded as present in teeth only when enamel defects could be seen without the aid of a microscope. This approach was taken because it has been argued that a defect that can only be seen under magnification is likely to be too small to be reliably recorded as hypoplasia (Goodman and Rose, 1990). Classification of enamel hypoplasia was based on the Fédération Dentaire Internationale (FDI) classification (Commission on Oral Health, 1982). This classification is as follows:-

1 = Opacity. White/cream, abnormality of enamel translucency.
2 = Opacity. Yellow/brown, abnormality of enamel translucency.
3 = Pitting. Shallow or deep, in horizontal rows, or distributed over the crown.
4 = Horizontal grooves. - as above.
5 = Vertical grooves. - as above.
6 = Missing enamel from large or small areas of the crown.

Figure 4.4

Mineralisation scale of the maxillary canine used to estimate the age at which enamel hypoplasia may have formed. (After Goodman *et al.* 1980:520).



There are a number of methods used to estimate the age at which enamel hypoplasia occurred and these estimates may vary between populations (Masseler *et al.*, 1941; Schulz and McHenry, 1975; Moss and Moss-Salentijn, 1977; Rose, 1977; Goodman and Armelagos, 1985). Estimates are based on method developed by Massler *et al.*, (1941) and modified by Goodman *et al.* (1984). This method divides the distance between the cementoenamel junction and the cusps into different sections. Each section represents a period of growth during the development of the tooth. This method accounts for the different growth rates and age of development. An example of this method is presented in Figure 4.4.

Individuals with 10 or more permanent teeth were used. Fewer teeth present per individual would lead to a strong sampling bias. Third molars are included in the analysis, but the estimated age at which enamel hypoplasia occurred is interpreted with caution because of third molar developmental variability. All the teeth used were examined on all sides for enamel defects to ensure that all types of defects would be recorded.

3.5 Cortical bone area

Cortical bone area of the tibia and second metatarsals are used to provide information of the general state of health of the Sigatoka people. An examination of the rate of cortical bone accumulation and cortical bone loss in males and females will be made. Comparisons will be made between males and females, and with other prehistoric populations.

Typically, skeletal studies examining the rate of cortical bone changes have used the second metacarpal. Unfortunately, only three measurable metacarpals were present, consequently the tibia and second metatarsal were used to estimate cortical bone area. The tibia was chosen because it was available in the greatest number of all bones. Additionally, the variation of cortical area of the tibia is less susceptible to age changes than smaller bones (Garn, 1970). The tibia may provide insights into factors other than age that may affect cortical thickness. The second metatarsal was chosen as a contrast to the tibia. It has a relatively small cortical mass, and is therefore readily affected by factors influencing cortical bone.

The medullary cavity of most long bones were full of iron sand, so cortical bone thickness could not be measured from radiographs. Therefore, measurements of cortical thickness were taken directly from the midshaft of bones with naturally occurring breaks, using Mitutoyo calipers. The percentage of cortical bone area was estimated following Garn (1970);

> "[This method] relates the cross-section area, to the amount of bone present in the cross-section area, to the amount of the cross section that is bone" (Garn, 1970:60).

This method presents cortical bone thickness in three dimensions, and so it is able to measure changes in cortical bone with greater accuracy than two dimensional techniques (Garn, 1970; Ruff and Hayes, 1983).

Cortical bone was estimated using the following formula:-

$$T^2 - M^2$$

T = Total subperiosteal diameter.
M = Medullary cavity diameter.

3.6 Diet

The cortical bone from the left humerus was selected for analysis. Bone from a single anatomical region was taken because it has been demonstrated that trace element concentrations in bone vary between differing anatomical sites (Grupe, 1988). In addition, cortical bone was chosen for analysis because it is less influenced by diagenic factors than cancellous bone (Grupe, 1988). Bone samples were taken from 10 individuals, seven males and three females.

Trace elements were identified by atomic absorption analysis. Bones were prepared for analysis by removing the first one to three millimetres of cortical bone with fine sand paper to eliminate trace elements that may have intruded into the outer cortical bone during the time that it was buried (Lambert *et al.*, 1989; 1991; Lambert *et al.*, 1990). Caution is still required if bones have been buried in locations that have high levels of trace elements (Sealy and Sillen, 1988; Sealy *et al.*, 1991; Price *et al.*, 1992). The atomic absorption method of trace element identification is outlined in Horwood (1989). The analysis was carried out by J. Pilditch of the Anthropology Department, University of Otago.

There are drawbacks in interpreting the levels of strontium and zinc as indicators of relative changes in diet. The main problem is that comparisons can not be convincingly applied to a skeletal population and compared to other skeletal populations where control samples, from herbivore or carnivore bones, are absent from the same strata as the human bones. Herbivore and carnivore bones provide a background on the relative amount of trace elements to which human bones can be compared (Sillen and Kavanagh, 1982).

4.0 Results

4.1 Stature

Stature estimates are based on long bone lengths from 25 adults, 13 males and 12 females. Mean stature for males is 1740 mm. Stature ranges from 1690 mm to 1769 mm. Mean female stature is 1644 mm, with a range from 1603 mm to 1695 mm. The results of individual stature estimates are presented in Tables 4.3 and 4.4. The stature difference between the sexes is 7%. This difference is similar to that found in other populations (Stini, 1975).

Table 4.3
Adult male long bone lengths (mm) and stature estimates (mm).

Burial	Humerus		Ulna		Radius		Femur		Tibia		Mean
	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Stature
1a	319			264			469			378	1745
1b		332						437	368	368	1726
1c	330	334	282		261		451		378	375	1750
4c			280				458				1752
8a			277								1739
10a							460				1761
10b					270	266		480	375	377	1769
10c			283					450	378	380	1752
13a	327				259	259	475	478	375	377	1761
17a	312	312		268		230		438		370	1711
17b							425	432	350	345	1692
19	335	338	281	277	244	246	478	474	375	371	1750
20						238	469	436	354	351	1710

Table 4.4
Adult female long bone lengths (mm) and stature estimates (mm).

Burial	Humerus		Ulna		Radius		Femur		Tibia		Mean
	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Stature
6a	332										1671
9a	302										1618
13b	327	320	285		266			465	387		1695
13/1	307	302					430				1635
14	290	288					431	432			1626
21a	300			245							1612
21c							410				1603
23a	295	295	245		230		435	439	348	346	1695
25	315	317	231		233	240	456	458	385	391	1672

4.2 Body mass

Body mass was estimated from 20 adults, 12 males and 8 females. Individual body mass estimates are presented in Tables 4.5 and 4.6. The results of body mass estimates suggest that males weighed approximately 70 kilograms and females around 55 kilograms, a sex difference of 21%. Male body mass ranged between 60.7 and 86.4 kilograms. The female range of body mass is less than that of males, ranging between 51.8 and 59.7 kilograms. This difference is near the range of male and female variation in a well-fed western society, but much greater than less well fed populations (Stini, 1975).

While no significant difference was found between the estimate of body mass of different age cohorts, a strong correlation between stature and body mass ($r = 0.73$ $P \leq 0.01$) was evident. This is not surprising because the taller the individual the heavier the person is likely to be.

Table 4.5

The diameters (mm) of joints used to estimate adult male body mass (kg) and the mean mass estimated from these diameters.

Burial	Wrist		Elbow		Knee		Ankle		Mean
	Right	Left	Right	Left	Right	Left	Right	Left	Mass
1a	45.6	45.6	58.7		74.4		60.5	70.2	69.1
1c	49.3		59.7	60.5		66.5	66.5	65.4	70.0
4c			70.5					63.0	75.9
5d2				63.0					77.1
8a	45.0								67.9
10a			54.6	56.0					70.0
10b					90.0				86.4
13a			58.1		76.4	75.6			68.1
17a	39.5		55.5	56.4	75.9	75.7	64.9		67.1
17b								60.5	64.8
19		49.7	58.4				64.9		60.7
20			59.5	59.6	71.5	71.6		62.2	66.7

Table 4.6

The diameters (mm) of joints used to estimate adult female body mass (kg) and the mean mass estimated from these diameters.

Burial	Wrist		Elbow		Knee		Ankle		Mean
	Right	Left	Right	Left	Right	Left	Right	Left	Mass
2a			50.0	50.0	75.3				59.7
4a			55.0	55.0					52.8
13b			55.0	55.9	76.6	76.0			59.1
13/1			53.5						54.4
14				54.0	70.0	70.0			53.9
23a			50.0	50.0	70.0		49.5	56.0	51.8
24				51.4					54.0
25			55.0	55.0		76.5	55.0	56.0	58.2

4.3 Fertility

Estimates of pregnancy events could only be made on 13 of the 28 females aged 18 years and older, because no suitable pelvic bone was recovered from the remaining 15 individuals. Of those females with intact pelves, 8 females (62%), showed evidence of preauricular groove pitting (Table 4.7). The form of the groove was commonly broad but shallow, usually with one or two shallow pits with ill defined boarders (Figure 4.3). In many cases the bone had degraded to an extent where evidence of grooves and pits had been partially obliterated.

Table 4.7
The presence and absence of preauricular grooves and pits on the pelves of adult females.

Pitting & grooving		No pitting & grooving	
Name	Age	Name	Age
B3b	27	B2c	28
B6a	32	B4a	34
B9a	35	B13b	24
B13/1	37	B21c	23
B14	29	B23a	24
B18a	35		
B21a	46		
B25	30		

An important question that these results raise is, did the females without pits and grooves ever give birth? While this question cannot be answered with any high degree of assurance, it would be unlikely that they did not. The first reason for this statement is based on individual B23a, who was excavated with a young child buried on her shoulder. It is likely that this was her child, however the female did not show evidence of preauricular pits or grooves. Nor did another female, B18a, who had been buried with what appeared to be a fetus between her legs. Conversely, no males were buried with infants or children. These observations support the notion that some females were buried with their offspring.

Second, several studies have shown that the degree of pitting on the os pubis is more severe in females over 30 years of age (Suchy *et al.*, 1979). In this study the average age of females who had preauricular grooves and pits is 34 years, compared with an average age of nearly 27 for the group that had no evidence of pits and grooves. Suchey *et al.* (1979) found a correlation between pitting on the os pubis and individuals over the age of 30 years. To ascertain if age was correlated with the presence of pitting on the preauricular groove among the Sigatoka females, Spearman's rank coefficients were calculated. A significant correlation, $r = 0.55$ at the $P \leq 0.05$ level, was found, which demonstrates an association between age and pits and grooves.

To test if pits on the preauricular groove are an accurate method of assessing whether a female experienced an episode of pregnancy/parturition or not in Sigatoka females, comparisons were made with males. Of the 13 males, the preauricular groove was present in just one individual, (8%). This groove was shallow, and quite distinct from that found in the females. In the context of this study, this method seems reliable in observing if an episode of pregnancy/parturition occurred in Sigatoka females.

4.4 Enamel hypoplasia

The dentition of 42 adults, 15 males and 27 females, were examined for enamel defects. On average these individuals each had 24 teeth. Defects were recorded in 10 males (67%) and 8 females (30%). Three males had defects on a single tooth. Of these males, one individual, B10a, had few remaining maxillary teeth, which may explain why just one defective tooth was recorded in that individual.

Despite the higher percentage of males with enamel hypoplasia compared with females, males experienced slightly less episodes of hypoplasia, 1.2 episodes compared to 1.3 in females.

Summary details of the type and frequency of enamel defects are listed in Table 4.8. All teeth with defective enamel formation had linear enamel hypoplasia. The most frequent expression was enamel pitting on the buccal surface. The high frequency of stepped enamel is unusual because it is infrequent in other studies. Stepped enamel hypoplasia occurred on the premolars and molars.

Table 4.8
The type of enamel hypoplasia following FDI classifications and the number and frequency of each form in males and females.

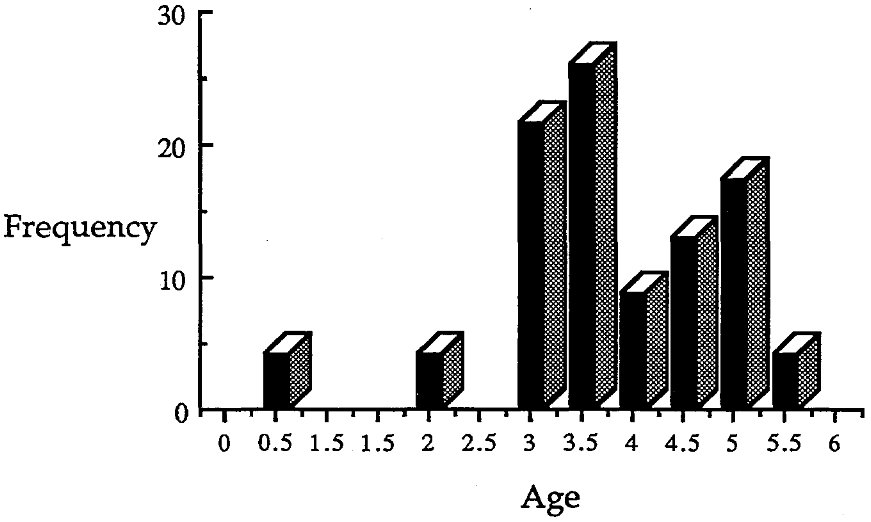
Defect Type	Males		Females		Total	
	n	%	n	%	n	%
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	7	13	9	13	16	13
4	29	56	43	61	72	59
5	1	2	0	0	1	1
6	15	29	19	27	34	28

n = number of teeth with a defect.

Of the 1016 teeth investigated (including third molars), 106 (10.4%), displayed hypoplasia. There was a slightly higher frequency in the mandibular dentition, (11.4%), compared with the maxillary dentition (9.6%). Why this should be so is not known, but it may be associated with different development rates or the mandibular teeth may be more susceptible to hypoplasia. Enamel defects were most frequently recorded on the canines (28.3%), while the first incisors (6.6%) and first molars (5.7%) had the fewest defects. The lower incidence of enamel hypoplasia on the incisor teeth may be associated with greater tooth wear which effectively obliterates evidence of enamel hypoplasia.

The age at which enamel defects occurred most frequently in the Sigatoka adult population was between 3 and 3.5 years of age (Figure 4.5). It is interesting to note the low frequency of hypoplasia up until 2.5 years of age.

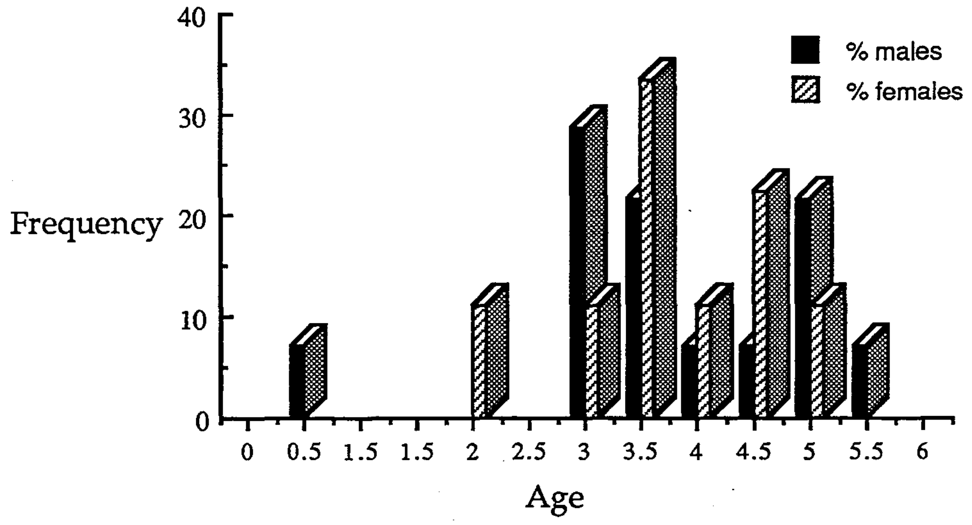
Figure 4.5
The frequency distribution by age of disrupted episodes of enamel mineralisation evident in the teeth of the Sigatoka adult population.



There is little difference in the frequency of enamel hypoplasia between males and females. However there is some difference in the ages at which it occurred. Disrupted enamel deposition tended to occur in some males in the first year of life. Females first experienced enamel hypoplasia at two years of age. The greatest frequency of enamel hypoplasia occurred 3.0 to 3.5 years and 4.5 to 5.0 years of age in both males and females (Figure 4.6).

The number of enamel defects and the estimated age at which these defects were formed are summarised in Table 4.9. These data are presented in two groups; one is adult males and females under 30 years of age, and the other is males and females over 30 years of age. The data show that formation of enamel defects occurred most frequently in two age groups, between the ages of 3.0 and 3.5, and five years.

Figure 4.6
The age frequency distribution of enamel hypoplasia in males and females.



Individuals younger than 30 years of age have a higher frequency of enamel defects per individual (2.3), compared to individuals older than 30 years of age, (0.9) (Table 4.9).

Table 4.9
The age at which enamel hypoplasia formed and the mean number of lines per adult. Adult male and females who died under 30 years of age are compared to those who died after 30 years of age.

	Age at which defect formed. (Years)	Individuals < 30 years. number of defects			Individuals + 30 years. number of defects		
		♀	♂	Total	♀	♂	Total
	0	0	0	0	0	0	0
	1	0	1	1	0	0	0
	2	0	0	0	1	0	0
	3	2	2	4	0	2	2
	4	2	2	4	3	1	4
	5	2	1	4	2	2	4
	6	0	1	1	0	0	0
Total		6	7	13	6	5	11
Number of individuals		3	5	8	7	5	12
Episodes per individual		2.0	1.4	1.6	0.9	1.0	0.9

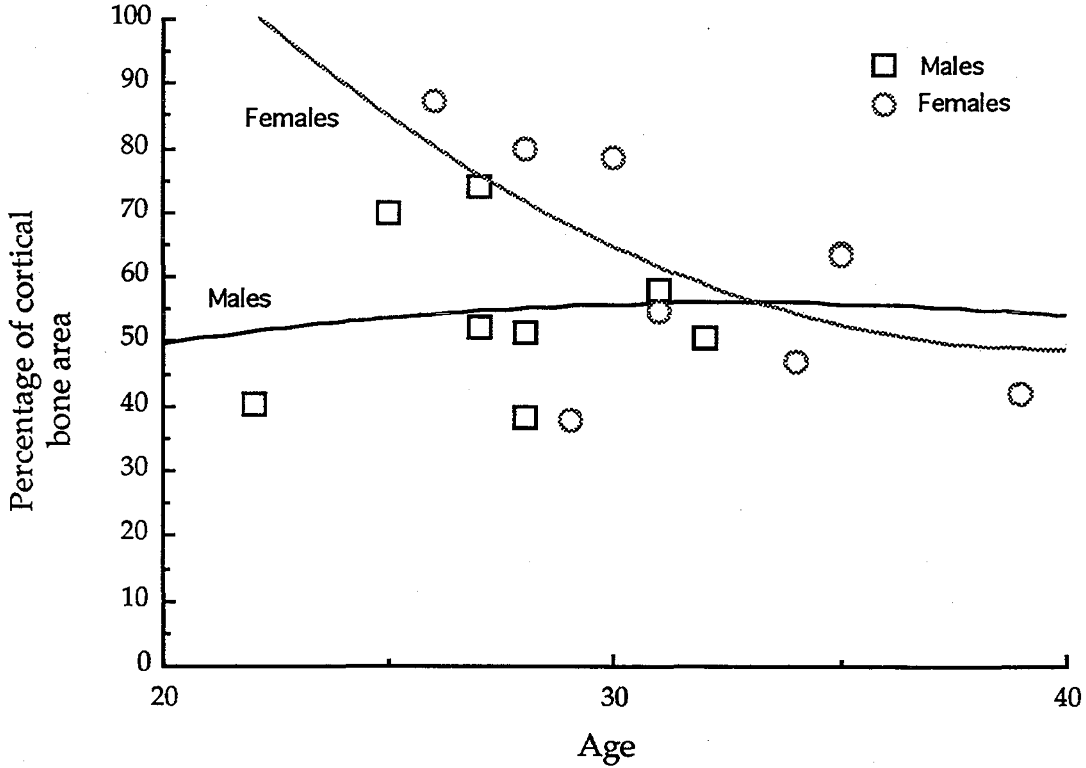
An explanation for the lower expression of defects in the older group could be because they had higher rates of tooth loss and experienced greater tooth wear than the younger age group. Tooth wear may have eroded evidence of enamel defects, as would tooth loss. An alternative hypothesis could be that the greater number of defects in younger individuals is evidence that they were more susceptible to ill-health and so died earlier than their counterparts. This suggests that individuals with enamel hypoplasia were subject to long-term poor health. Comparisons between the frequency of enamel defects in the males and females in each age group show that there is no difference between the sexes.

4.5 Cortical bone area

Calculations of the tibia cortical area were based on 30 individuals, nine males and 21 females. Calculations of the cortical area from the second metatarsal were obtained from a sample of 25 individuals, 11 males and 14 females. Based on the entire tibia sample, an expected initial gain of cortical bone area in the tibia occurred up until 23 or 24 years of age, after which there is a rapid decrease in cortical bone areas. This general observation is mirrored in the second metatarsal sample. In this bone cortical thickness peaks at around 23 years of age, although the relative percentage of cortical bone was greater in the second metatarsal than the tibia.

Figure 4.7

The rate of cortical bone area gain and loss in the tibia of males and females.

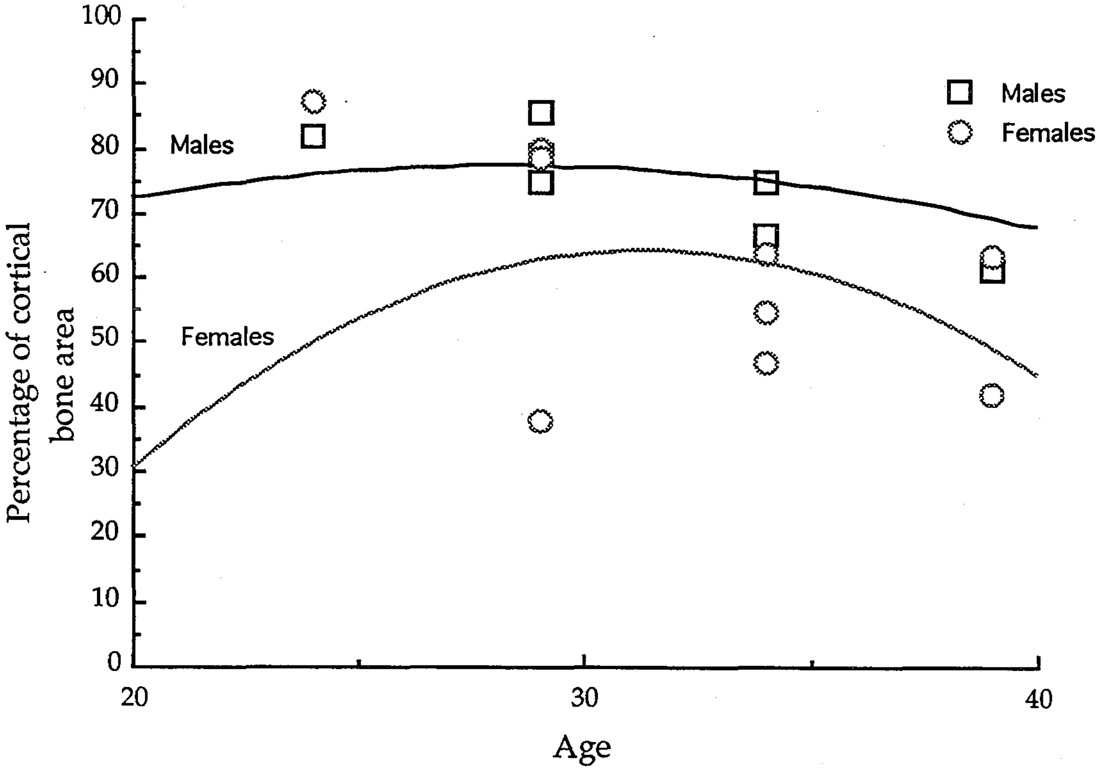


When the sexes are considered separately a different pattern emerges. Among males, cortical bone continued to be deposited on the tibia until around 26 years of age, thereafter cortical bone area declined (Figure 4.7). However, females experienced a more rapid rate of bone area loss than males.

The rate of cortical bone loss in the second metatarsal can be seen to have progressed faster than in the tibia (Figures 4.7 and 4.8). It appears that in both bones, the decline is associated with age. However, this need not be the only contributing cause of bone loss.

A comparison of male and female tibial cortical bone area shows that females have a greater percentage of cortical bone mass until about 33 years of age (Figure 4.7), while in the second metatarsal this difference favours males throughout life (Figure 4.8). Pearson's correlations were calculated between female age and the percentage of cortical bone area compared to the total bone area of the tibia midshaft circumference. A significant negative correlation was found $r = -0.53$, $P \leq 0.02$ (n = 21). This result compares with a similar significant correlation for the female second metatarsal; $r = -0.60$, $P \leq 0.02$ (n = 14). No significant correlations were found in the male tibia $r = -0.20$, $P \leq 0.10$ (n = 8), or in the second metatarsal $r = -0.49$, $p \leq 0.10$ (n= 11).

Figure 4.8
The rate of cortical bone area gain and loss in second metatarsal of males and females.



4.6 Diet

The individual results of strontium and zinc concentrations are presented in Table 4.10. The mean level of strontium concentration in the bones of the Sigatoka people is *circa* 1502 ppm.

Table 4.10.
Average strontium and zinc trace elements (ppm) in adult bone.

Sample	Sex	Age	Sr	Zn
B1/1	♂	27±	1090± 80	94±8
B6b	♂	32±	1150± 80	88±8
B8a	♂	32±	1340± 90	94±8
B10a	♂	47±	1460± 80	108±9
B10b	♂	45±	970± 70	99±9
B10c	♂	39±	1000± 80	120±9
B18a	♀	35±	2500±100	149±9
B19	♂	27±	2500±100	79±8
B21a	♀	46±	1600±100	76±8
B28	♀	42±	1410± 90	147±9

Strontium levels were markedly higher (19%) among females than males (Table 4.11.). This difference was not significant (*t* statistic = -1.1, $P \leq 0.32$).

Table 4.11
Mean strontium (ppm) concentration in males and females from Sigatoka.

Group	n	Mean	sd
Females	3	1836.7	582.3
Males	7	1358.6	533.7

Mean zinc levels were 100 ppm. Concentrations varied in both sexes by around 16%, with the higher concentrations found in females (Table 4.12). No statistical differences were found between the sexes (*t* statistic = -1.3; $P \leq 0.24$).

Table 4.12
Mean zinc (ppm) concentration in males and females from Sigatoka.

Group	n	Mean	sd
Females	3	124	41.6
Males	7	103	21.6

5.0 Discussion

5.1 Stature

Within the context of prehistory, stature estimates of the Sigatoka population indicate that they were a well nourished population. These statures also suggest that few growth disruptions occurred during individual maturation. The differences between male and female stature estimates are within the ranges experienced by human populations. Consideration is required to explain why the Sigatoka and Polynesian populations attained comparatively tall statures compared to other Oceanic populations (Table 4.13).

Table 4.13

Mean stature estimates of Oceanic populations.

	Males		Females		
Provenance	Mean	n	Mean	n	Source.
Easter Island	1748	7	1579	8	Murrill, 1968
Maori	1745	13	1618	14	Houghton *et al.*, 1975
Moriori	1712	3	-----	---	Visser, nd
Mokapu	1699	75	1603	612	Snow, 1974
Hane	1737	13	1598	3	Pietruswsky, 1976
Marquesas[1]	1703	79	1607	73	Sullivan, 1922
Tepoto	1751	7	1657	9	Dennison, nd
Society Islands[1]	1714	85	1611	68	Shapiro, 1930
Mangaia	1773	11	1600	3	Katayama *et al.*, 1988
Pukapuka	1667	3	1555	3	Yoshida, 1988
Namu	1767	13	1759	6	Houghton, nd[a]
Tonga	1747	13	1659	10	Pietrusewsky, 1969
Fakaofa[1]	1727	13	----	---	Lister, 1892
Samoa[1]	1717	---	----	---	Sullivan, 1922
Tonga[1]	1730	92	1625	88	Sullivan ,1922
Sigatoka	**1740**	**13**	**1644**	**12**	
Fiji	1743	13	1619	3	Weber, 1934
Lapita	1737	5	1594	2	Pietrusewsky, 1989[a]
Aita[1]	1604	80	1507	87	Rhoads, 1987
Nasioi[1]	1621	59	1504	63	Rhoads, 1987
Lau [1]	1625	106	1518	95	Rhoads, 1987
Kwaio [1]	1603	127	1490	114	Rhoads, 1987
St Christoval[1]	1616	13	1503	6	Guppy, 1886
Eriama	1668	10	1553	6	Visser, nd
Nebira	1636	10	1636	3	Pietruswsky, 1976
Admiralty Islands[1]	1645	9	1553	4	Clarke, 1877
Del Feugo	1656	6	----	---	Garson, 1886
Aboriginals	1690	13	1571	20	Abbie, 1951

1 Denotes anthropometric measurements. All measurements in millimetres

One of the variables related to the observed differences in stature of Oceanic populations may be nourishment. The implications of nourishment affecting stature have been described above. However, this is unlikely to be the only variable involved. This is because most of the populations investigated lived in similar environments and had similar technologies. What stands out in the data presented in Table 4.13. is that the statures of Polynesians and Sigatoka people are similar despite the large geographic distances separating them. The fact that the Polynesians have similar cultural and biological traits indicates that they had the same ancestors who had been subjected to selective processes that favoured a relatively tall stature. These aspects are discussed in greater length in Chapters Nine and Ten.

5.2 Body mass

Adult body mass estimates show that both Sigatoka males and females attained above average weight compared to Oceanic populations listed in Table 4.14.

Table 4.14.
Body mass estimates (Kg), of Pacific populations.

Provenance	Mean	n	Mean	n	Source
Easter Island	63.4	12	52.2	8	Murrill, 1968
Maori	76.1	12	58.3	19	Houghton *et al.*, (nd)
Moriori	77.6	6	----	---	Houghton, nd[c]
Mangaia	66.7	2	----	---	Tayles, pers. comm.
Namu	76.1	12	61.7	5	Visser, nd
Tonga	76.8	12	61.3	8	Pietrusewsky, 1969
Sigatoka	**71.2**	**12**	**55.0**	**8**	
Fiji	63.9	5	53.9	3	Weber, 1934
Lapita	72.5	5	-----	---	Pietrusewsky, 1989[a]
Ontong Java[1]	64.4	106	58.1	179	Rhoads, 1987
Aita[1]	59.4	81	52.2	115	Rhoads, 1987
Nasioi[1]	57.6	59	46.3	63	Rhoads, 1987
Lau [1]	64.0	141	54.0	97	Rhoads, 1987
Kwaio[1]	55.3	127	45.8	114	Rhoads, 1987
Solomon Islands	57.8	----	----	---	Guppy, 1886
Nebira	67.5	7	50.3	3	Visser, nd
Eriama	67.5	7	48.9	4	Visser, nd
Admiralty Islands[1]	59.6	3	-----	---	Clarke, 1887
Aboriginals[1]	55.8	12	45.4	20	Abbie, 1951

1 Denotes anthropometric data.

This suggests that the Sigatoka population was not only well nourished during adult life, but probably did not experience chronic diseases that may have disrupted weight gain. Males had greater body mass estimates than females, but this variation is within the range of sex differences.

The pattern of greater than average body mass of Oceanic populations listed in Table 4.14 is repeated in most Polynesian populations. This not only implies that these populations had an adequate diet and were generally free from chronic diseases, but it also reflects a body form which will be argued to have been selected for in Chapters Nine and Ten.

5.3 Fertility

The first comment that can be drawn from this material is that the width and pitting of the preauricular groove is much more defined and correlated with females over the age of 30 compared to the younger age groups. An explanation for this is likely to be associated with a combination of: the extent of hormonally induced groves and pits on the preauricular surface, the activities of a physical life style, the rapidity of bone remodelling, and the interval between pregnancy/parturition and death. A similar association has been noted in another study where the severity of pitting on the os pubis increased with age, and the interval and number of fertility episodes had little relationship (Suchey *et al.*, 1979) .

It would be surprising if the females without pitting and grooving, did not give birth, given the early mean age at death, the relatively short length of life, and the population structure. While there is insufficient data to estimate fertility, some insights may be obtained from ethnographic studies (Lee, 1980; Delgado *et al.*, 1982; Bentley, 1985; Fink, 1985; Galdikas and Wood, 1990).

Studies conducted to quantify the age of menarche in females from hunter-gatherer societies and in communities that operate on a stable, traditional level have found that it usually occurs between 14 and 16 years of age (Kolata, 1974; Shakir, 1974; Gallo, 1975, Howell, 1979; Bentley, 1985). This compares to 12 to 13 years of age in females from urbanised societies. Few early historical observations documenting the occurrence of menarche in Pacific societies exist. Elton (1888) recorded that "puberty" was reached by 15 years of age in the Solomon Islands. Early last century, Ellis commented that the age of puberty among Tahitians was about 10 or 11 years of age, although Roberton was sceptical of this comment (Ellis quoted in Roberton, 1832). A recent study has suggested that the traditional Tahitian diet was protein rich and had a high calorific value that could help explain the early age of menarche described by Ellis (Ducros and Ducros, 1987). In the Fijian Lau Islands, Thompson (1940) also recorded that some girls may have reached puberty at the age of 10 or 11 years.

Numerous factors affect the age of menarche (Brundtland and Walloe, 1976; Short, 1976; Tanner and Whitehouse, 1976; Loucks *et al.*, 1984). It is sufficient to state here that the main factors in reducing the age in modern populations are access to a good diet, a reduction in regular high levels of physical activity, and improvements in general health.

The length of time between births has an important influence on fertility and growth rates. The range of birth intervals in hunter-gatherer and traditional communities is from about 36 to 60 months (Bongaarts, 1978; Menken and Bongaarts, 1978; Potter, 1978; Wils, 1978; Konner and Worthman, 1980; Bentley, 1985; Galdikas and Wood, 1990). In historical Fiji, some missionaries commented on what they regarded as lengthy birth intervals. For example, Seemann (1862) noted that after childbirth;

> "... the husband and wife keep apart for three, even four years, so that no other baby may interfere with the time considered necessary for suckling children, in order to make them healthy and strong" (Seemann, 1862:191).

While Seemann's observations of a three to four year long birth interval may be correct, consideration needs to be given to factors that may have contributed to this birth interval length. The behavioural and biological mechanisms which may contribute to a three year plus birth interval length have been outlined elsewhere (Bongaarts, 1978). Briefly, the interval between births is determined by several factors. These include the nine months of pregnancy, plus a period of postpartum amenorrhoea which usually lasts for six weeks. Intrauterine failure has been calculated to attribute two and a half months to the birth interval (Menken and Bongaarts, 1978; Bentley, 1985). Once a female begins to menstruate regularly, she may ovulate for seven and a half months before conception occurs (Findlay, 1984).

The length of amenorrhoea may be extended by breast feeding depending on the frequency of nursing intervals (Smith, 1984). It seems that frequent breast feeding induces prolactin to be released which acts to inhibit the ovarian stimulating gonadotrophic hormones (van Ginneken, 1978). The quality of maternal nutrition (Jelliffe and Patrice-Jelliffe, 1982) and the level of female energy expenditure (Bentley, 1985) may also contribute to its length. In the absence of breast feeding, nutrition and level of energy expenditure may act to inhibit ovulation.

In historical Fiji, Williams noted that several women may nurse an infant, especially shortly after its birth (Williams 1858). This suggests that either there was a high infant mortality rate to suppose that females other than the mother were to be able to breast-feed a new born infant. Alternatively, females breast-fed an infant for a length of time during which the infant was able to have other food sources.

However, there are other behavioural factors that may reduce fertility. Bean and Mineau (1986) investigated the effects that polygamy may have on fertility. They found that fertility among secondary wives was lower than the first wife. Secondary wives were regarded more as an economic status indicator, rather than a spouse and child bearer. Polygamy was practiced in historical Fiji (Lawry, 1850; Williams, 1858; Waterhouse, 1866), and has been documented to have been widespread throughout the Pacific. Although MacGregor (1937) and Thompson (1940) reported that this was not common practice in the Tokelau and Lau Islands, and Oliver (1989) maintains that polygamy was not as common in Polynesia as it was in Fiji.

Sexual abstinence has been practiced for various reasons in different communities. A wide spread theme throughout Polynesia was that when a taboo task was being conducted, such as deep sea fishing, or any task associated with blood, restrictions on coitus were imposed (Handy, 1925; Powdermaker, 1933).

The ability to attain full reproductive potential could also have been affected by the age and early death of the male partner. Missionaries frequently expressed their exasperation that males were much older than their female partners (Seemann, 1862). The missionary, Williams, was moved to write;

> "I have seen an old man of sixty living with two wives both under fifteen years of age. Women, indeed, are regarded as a sort of property..." (Williams, 1858:169).

This statement may be exaggerated, but Waterhouse (1866) noted that an infant girl could be married to someone of her own age, or to an adult. The inference is clear, older men did marry substantially younger women. Thus, at the male partner's death, the widow would clearly lose reproductive potential, even if she was to find another partner. In Fiji and in the Lau Islands, Williams (1858) indicated and Thompson (1940:40) reported that if the male partner died, the widow usually returned to her own people.

One other factor which is consistently referred to in the historic accounts of Fijians is the practice of terminating unwanted pregnancies, although the reports are unclear in mentioning at what stage pregnancies were terminated (Lawry, 1850). Waterhouse (1866) stated that the action of aborting pregnancy frequently caused permanent injury to the mother. This "permanent injury" could refer to the inability of the female to become pregnant.

While there is some consistency in ethnographic accounts of fertility of around four births per female, it is only possible to speculate whether the Sigatoka females had similar fertility levels, given the age at menarche and life expectancy. Nevertheless it is likely that they experienced some of the factors mentioned above, which limited fertility.

5.4 Enamel hypoplasia

To assess whether the Sigatoka population had a high incidence of linear enamel hypoplasia, comparisons are made with a limited number of prehistoric skeletal populations. Sex comparisons and age estimates of when enamel hypoplasia was formed in Pacific populations are only available from the Maori.

Comparative sex differences of the frequency of linear hypoplasia of Pacific and non-Pacific populations are presented in Table 4.15. The cause of linear hypoplasia on these populations may relate to different environmental stresses. The population from Khok Phanom Di, Thailand, is reported to have suffered from high infant and childhood mortality. This high mortality rate has been partially attributed to endemic/congenital anaemias and malaria (Tayles, 1992).

Table 4.15
The frequency of linear enamel hypoplasia in adults from prehistoric skeletal populations.

	Males		Females		All Adults		Source
Population	n	%	n	%	n	%	
Maori	28	74	43	84	81	79	Evans, 1987
Namu	--	--	--	--	129	74	Evans, 1987
Tonga	--	--	--	--	60	57	Evans, 1987
Sigatoka	**20**	**50**	**22**	**55**	**42**	**52**	
Taplins	2	0	1	0	3	0	Houghton and Ward, 1990
Nebira	--	--	--	--	33	100	Evans, 1987
Khok Phanom Di	22	85	24	92	46	88	Tayles, 1992
Harappa	16	56	14	93	36	72	Lukacs, 1992
Dickson Mounds	50	62	50	66	111	66	Goodman *et al.*, 1984

The Harappa, from Pakistan (Lukacs, 1992), and North American Dickson Mound (Goodman *et al.*, 1984) populations are similar in that they experienced nutritional changes as a consequence of changes in subsistence strategies from hunting and gathering towards an increasing dependence on agricultural and horticultural products. Researchers have also identified pathological problems in Pacific skeletal populations. For example, in the Namu population, 80% of the population suffered from tertiary yaws (Houghton, nd[a]). The Nebira population also displayed high levels of skeletal pathologies consistent with malaria and malnutrition (Pietrusewsky, 1976). Furthermore, it has been suggested that the Maori experienced seasonal food shortages associated with opportunistic infections (Simpson, 1979). The skeletal populations from the Taplins and Tonga seem to have experienced better health. Pathologies were not found in the Taplins skeletons (Ward and Houghton, 1990). However, Pietrusewsky (1969) has suggested that 38% of the Tongan skeletons displayed pathology consistent with osteomyelitis or treponematosis.

Comparative data shows a trend that in populations where bony pathology is evident, nutritional/diet deficiencies were common. The frequency of enamel hypoplasia within these populations is also high. In populations where the incidence of bony pathology is low, the frequency of enamel hypoplasia is relatively low. The Sigatoka, Taplins and Tongan populations have lower incidences of linear hypoplasia compared to the other populations. The differences in the incidences of enamel hypoplasia between the high enamel hypoplasia group compared with the low enamel hypoplasia group are highly significant at $P \leq 0.02$. This significance suggests that the number of episodes where enamel amelogenesis was disrupted in the Sigatoka people was less than that experienced by many prehistoric populations. However, low incidences of enamel hypoplasia could be typical of Oceanic communities east of the furthermost malaria, and possibly yaws, infected areas.

Table 4.16. shows some examples from other skeletal populations of the peak episodes of disrupted enamel amelogenesis. Typically these populations have one main episode of hypoplasia. This contrasts slightly with the Sigatoka population who have a bimodal distribution of enamel hypoplasia (Figure 4.4). This difference may be due to the distorting affect of a small sample size.

Table 4.16
Age of peak enamel hypoplasia episodes in some skeletal populations

Population	Peak Age of Hypoplasia.	Source
Sigatoka	**3.0 - 5.0**	
Dickson mounds	1.5 - 3.5	Goodman *et al.*, 1984
Khok Phanom Di	2.0 - 4.0	Tayles, 1992
Harappa	3.5 - 5.0	Lukacs, 1992
Nubia	3.5 - 4.5	van Gerven, *et al.*, 1990

The earliest episode of enamel hypoplasia in the Sigatoka population seems to be consistent with the effects of weaning. Reports from other skeletal populations tend to interpret the peak years during which hypoplasia formed as a consequence of weaning. Weaning is suggested to cause nutritional stress and a subsequent greater susceptibility to opportunistic infections (Rose *et al.*, 1985).

The second peak episode of hypoplasia in the Sigatoka population occurs approximately one year later, between 4.5 and 5.0 years. Four or five years is the approximate the length of a birth interval in many hunting and gathering societies (Lee, 1980; Bentley, 1985) and that postulated for many prehistoric populations (Phillipps 1980; Visser, 1986). The secondary peak in hypoplasia may in some way be related to the mother's pregnancy and parturition where less attention may have been given to the nutritional status of the older sibling.

5.5 Cortical bone area

The results presented earlier in this Chapter have shown that the initial increase and subsequent decrease of cortical bone is closely associated with aging in Sigatoka males, and is significantly correlated with age among Sigatoka females. Because of different methods used to estimate cortical bone, comparisons with other populations can only be made with age of peak cortical bone mass. These comparisons are presented in Table 4.17.

Table 4.17

The age of peak cortical bone in males and females from selected prehistoric and contemporary populations.

Population	Age		Date	Source
	Males	Females		
Sigatoka	**13**	**24**	**180 AD**	
Namu	27	24	1600 AD	Houghton, nd^{a}
Maori	29	23	~1600 AD	Simpson, 1979
Khok Phanom Di	29	25	~2000 BC	Tayles, 1992
Nubia	31	21	~450 AD	Dewey *et al.*, 1969
Ohio Whites	30	40	1960 AD	Garn, 1970
Nicaragua	40	40	1960 AD	Garn, 1970
Guatemala	30	30	1960 AD	Garn, 1970

Table 4.17 shows that peak cortical bone mass was attained at a similar age in Sigatoka males and females compared with other populations. Peak cortical bone mass was attained at a much earlier age in prehistoric populations, and among females in particular, compared with contemporary populations.

The data presented in Table 4.17. suggests that peak cortical bone mass is not only associated with age. This is because a difference exists between females from prehistoric populations compared with prehistoric males and modern females who experience peak bone mass at an older age. Among prehistoric females the early onset of cortical bone loss cannot be associated with a lack of physical activity given that prehistoric populations had an active life style. However, the possibility of bone remodelling at the tibia mid shaft must be considered as a factor that influences cortical bone area.

A number of studies have found that physical activity stimulated bone remodelling, and increased bone mass (Ruff and Hayes, 1983; Pollitzer and Anderson, 1989). While this may account for bone deposition in the tibia, the second metatarsal may not experience the same stimuli as the tibia. Nevertheless, the age of peak cortical bone is similar in both bones. The later attainment of peak cortical bone area in males compared to females, is not associated with episodes of pregnancies in females, because bone has been shown to be deposited during pregnancy. However, sex differences have been shown to relate to hormonal and genetic differences (Stini, 1990). It seems unlikely that these differences would influence earlier peak bone mass in prehistoric females compared to contemporary females, because of the consistent earlier peak bone mass of prehistoric women. Garn (1970) has stated that bone loss can be stimulated by four dietary conditions; a low calcium intake so that calcium loss exceeds calcium intake: a change in the calcium-phosphorus ratio; a reduction in protein intake; an alteration in acid base balance. If nutritional restrictions do occur during growth, the result is smaller bones with less cortical mass than if this restriction was absent (Garn, 1970). The inference is that early peak cortical bone area attainment in Sigatoka and other prehistoric females is influenced by food availability during growth episodes. Studies have found that while calcium is involved in maintaining bone mass, the proportion of phosphorus to vitamins and trace elements may also be involved in bone mass maintenance (Heaney, 1988). Low levels of trace elements and vitamins in a prehistoric female diet and the combined affects of pregnancy requirements may contribute to their earlier onset of bone loss.

5.6 Diet

Chemical analysis of trace elements in bone show a difference between male and female strontium levels, a finding that is consistent with that found in other prehistoric populations (Brown, 1973). This is probably not related to greater male access to food low in strontium (meat and fish), but may be related to pregnancy and lactation. The female data is probably partially skewed by the high strontium level in one individual, B18a. This individual was excavated with a new born infant found just below her pelvis. High strontium levels in this female are consistent with the theory that strontium levels increase in pregnant women in certain dietary situations (Sillen and Kavanagh, 1982).

Higher concentrations of zinc in females, suggests that they may have consumed more shellfish than males. Females eating shellfish while gathering them has been observed in a number of ethnographic studies from Australia (Meehan, 1977), "Melanesia" (Chapman, 1987) and Polynesia (Burrows, 1936, 1937; MacGregor, 1937; Conté, 1988; Matagi Tokelau, 1991; Parslow, 1993). There may be some archaeological evidence that shellfish were consumed. This evidence is in the form of degraded shells that were excavated at the same stratigraphic level and approximate age as the burials. These shells were tentatively identified as *Trochus niloticus Linn.*, locally called the *sebesebe*. This shellfish is a reef dweller and is still used as food in Fiji (Birks, 1973). The nearest reef would have been across the Sigatoka River mouth, about one kilometre from the site.

6.0 Summary

In general and in the context of a prehistoric community, the health of the Sigatoka population does not appear to have been compromised by their environment. Estimates of body mass and stature demonstrate that the population were able to obtain adequate food resources. Dietary analysis indicates that there may have been differences in access to some foods, but these differences did not appear to have affected health. Fertility levels were likely to have been comparable to other groups living in similar circumstances. Similarly, the age of peak cortical bone does not differ substantially from other prehistoric populations. The information presented in this chapter indicates that the Sigatoka people where not subjected to the same degree of stressors that many other neolithic cultures were.

Chapter Five
Pathology

1.0 Introduction

Dental and skeletal pathology provides information on the frequency of: age related diseases; task related activities; sex differences; nutrition; exposure to infection; and perhaps the cause of death. The degree of success a skeletal population had in adapting to a particular environment can be assessed by examining these variables. This chapter considers the dental and skeletal pathologies of the Sigatoka people. Pathologies which may be related to task activities, cultural activities and sex differences are investigated. Patterns and levels of pathologies evident in other Pacific populations are compared to those of the Sigatoka people.

Teeth are the most enduring part of the skeleton and as such information regarding dental pathology is readily recovered. In this chapter, abscessing of the alveoli, antemortem tooth loss, alveolar resorption, caries, and tooth wear will be examined. Although many of the Sigatoka skeletons were badly decayed, some bony pathologies were able to be recorded on the vertebrae and temporomandibular joint.

2.0 Theory

2.1 Dental theory

2.11 Evidence of bony abscessing

A dental abscess is identified as a localised, purulent area surrounded by inflamed periapical tissue (Lawler *et al.*, 1987). If the pathological process has destroyed the bony surface of the maxilla or mandible, the result is readily recognisable in skeletal material as a cavity in the bone (Lukacs, 1989). Abscessing results when bacterial infection is able to penetrate into the alveolar bone. A common route of infection proceeds through the periodontal pocket and into the periodontal tissue. Periapical abscesses form where infection develops in an exposed dental pulp chamber and then spreads to the tooth apex. A secondary complication of abscessing is that it provides a source for haematogenous infection. Additionally, susceptibility to diseases may be increased when acute abscessing occurs.

2.12 Antemortem tooth loss

Antemortem tooth loss can be recognised by resorption of the alveolus. However, remodelling and resorption of the alveolus after tooth loss makes it difficult to identify the cause of loss. Tooth loss may be caused by pathologies that destroy the tooth, or resorb and weaken the bone surrounding the tooth. Trauma, or ritual ablation may also be a cause of tooth loss.

2.13 Alveolar bone resorption

The effects of periodontal disease may cause bone porosity and periostitis and eventual resorption of the alveoli (Lukacs, 1989). Periodontal disease is initiated by bacteria that accumulate in plaque formations. These accumulations induce inflammation of the soft tissue. Inflammation allows the bacteria to move deeper into the gingiva tissue supporting the tooth, and eventually into the periodontal ligament. The periodontal ligament is progressively destroyed by the bacteria and the alveolar bone is resorbed as gingiva is destroyed (Hillson, 1986).

Susceptibility to periodontal disease may be influenced by a complexity of factors including genetic factors, nutritional status, immune responses, and hormonal changes. Oral health, tooth loss, calculus and caries can also affect susceptibility to periodontal disease (Pawlak and Hogg, 1984). Clarke (1990) has questioned the role that periodontal disease has in resorbing the alveolar bone in prehistoric individuals under 40 years of age. However, examination of the status of alveolar bone from prehistoric skeletal material is important because it can provide information on such factors as oral health and tooth loss, that contribute to an understanding of the health of a population.

2.14 Caries

Caries are formed by the concentrated action of acidogenic bacterial organisms that progressively demineralise the tooth. These bacteria rapidly multiply in the sucrose rich environment formed around a tooth by plaque (Mandel, 1979; Legler and Menaker, 1980). Other factors that may increase the susceptibility of a tooth to caries include genetic and developmental aspects such as tooth size, tooth morphology, contact between teeth, and the physical and chemical composition of enamel, dentine, and saliva (Powell, 1985). A clear link has been made between caries formation and diet, particularly a diet rich in sugars (Larsen, 1983; Hillson, 1986). Additionally, susceptibility to caries seems to be increased when an individual experiences enamel hypoplasia (Alfano, 1980). Caries may form a line around a tooth following a band of defective enamel, and eventually destroy the tooth.

The results of dental caries have been widely reported from many skeletal populations. This is because they have the advantage of not being as prone to postmortem burial changes and decay as bony based pathologies (Anderson and Popovich, 1977; Powell, 1985; Hall *et al.*, 1986; Lukacs, 1992; Tayles, 1992).

2.15 Excessive tooth wear

Excessive tooth wear becomes pathological when the dental pulp chamber is exposed. Exposure of the pulp chamber allows bacteria to enter the tooth and infect the supporting tissue. In prehistoric populations an association exists between moderate tooth wear and a reduced prevalence of caries formation. This association occurs because cusp patterns on the occlusal surface of the teeth are obliterated quickly. The erosion of cusp patterns prevents plaque from forming in the cusp fissures. The removal of occlusal enamel through heavy tooth wear is in part compensated by the formation of secondary dentine, which protects the pulp chamber. In populations with examples of rapid tooth wear, such as the prehistoric Maori, tooth wear was often so rapid that dentine formation was not able to compensate for this loss so that the dental pulp chamber is exposed (Houghton, 1975; Simpson, 1979).

2.2 Skeletal theory

Discussion of skeletal pathology is mainly limited to the vertebrae, and the temporomandibular joint because little evidence of pathology was identified in other areas of the Sigatoka skeletons.

2.21 Vertebral osteoarthritis

Osteoarthritis is a degenerative disease that is commonly associated with the destruction of the synovial joint cartilage and bone. The process of osteoarthritis is initiated when the joint cartilage is gradually worn away. The underlying bone then becomes exposed and may then degenerate. Ossification of cartilaginous material forms as a response to initial degeneration to increase the articular area. An increase in joint bone acts to restrict movement of that joint. The main aetiological factors that are associated with osteoarthritis are trauma and the aging of joint tissue (Burke, 1967). In the spine, the apophyseal joints of the vertebrae frequently show various stages of osteoarthritis (Ortner and Putschar, 1985). Different stages and location of degeneration of the vertebral joints between males and females can provide information of the age of initial degeneration and different patterns of physical behaviour of a skeletal population.

2.22 Vertebral osteophytosis

Osteophytes are bony protrusions extending from the cortex of the vertebral body (Ortner and Putschar, 1985). It is held that the vertebral osteophytes act as a mechanism to absorb the strains associated with an upright posture and the strain placed upon the spine during episodes of physical activity (Nathan, 1962; Chapman, 1972; Beckers and Bekaert, 1991). Excessive strain on the intervertebral discs leads to their degeneration. It is argued that the degenerated discs do not dissipate the applied forces uniformly to the vertebral end plates so that the shock-absorbing ability of the spine is impaired (Nathan, 1962). One consequence of osteophyte development on the vertebral column is that osteophytes may lend support to the vertebral bodies which absorb excess pressure when force is applied.

Nevertheless, osteophyte formations are highly variable and differ between individuals. They usually begin forming after 20 years of age, although this is dependent upon the pressure that the vertebrae have experienced (Kohlbach, 1991). Osteophytes are infrequent before the age of 40 years in individuals who experience slight compressive forces on the spine (Stewart, 1958). The natural history of osteophytes occurring after 40 years seems to be a consequence of aging (Lestini and Wiesel, 1989). Ankylosing of the spine, which occurs when the superior and distal cortex of the vertebrae fuse over the intervetebral disc, and advanced stages of osteophytosis may occur later in life. However, this is highly variable and depends on factors such as the degree of physical strain and perhaps diet.

Localised spinal osteoarthritis and osteophytosis can be caused by different activities. Nathan (1962) proposed that osteophytes form in the cervical vertebrae because of the freer extension movements of the cervical spine. Freer movements cause pressure on the posterior part of the cervical vertebrae. Similarly, Merbs (1983) has suggested that osteophyte development in the lumbar region can occur when the pelvis and legs are immobile and the spine is flexed. However, Ortner and Putschar (1985) have noted that degeneration of the vertebral disc is not a necessary precursor to osteophyte formation. For example, Schmorl and Junghans (1971) noted that osteophytosis is likely to be associated with the disruption of bony fibres that insert in to the epiphysis of the vertebral bodies.

In the thoracic vertebrae the most severe examples of osteophytosis correspond to the concavities of the vertebral column. For instance, 50% of thoracic and lumbar fractures are found to occur in the transitional zone between the tenth thoracic vertebra and the first lumbar vertebra. This area experiences the greatest torsional sheer forces that contribute to degeneration (Malmivaara, 1989). Degeneration in this region may occur as a result of flexion and lateral bending of the thoracic spine during strenuous physical activity. Thoracic degeneration has been identified in a number of skeletal populations. Kelly (1982) attributed degeneration in this area to general physical stress in skeletal samples of prehistoric hunter-gatherer populations. Stirland's (1985) analyses of the vertebrae of the sailors from the *Mary Rose* concluded that thoracic degeneration resulted from strenuous physical activity, probably associated with lifting and hauling.

Lumbar vertebrae experience the greatest overloading pressures (Beckers and Bekaert, 1991). As a consequence the earliest signs of vertebral degeneration usually occurs in the lumbar spine, but this is dependent on the location of the strain. A study of prehistoric hunter-gatherer Amerindians found a high prevalence of lower lumbar osteophytosis (76%) and osteoarthritis (15%). Similar prevalences of lumbar degeneration have been observed in other prehistoric Amerindians (Bridges, 1989), Lapps, and Inuit (Thieme, 1950). The type of behaviour leading to degeneration in the lumbar vertebrae in these populations is not clear. Arthritic degeneration may result from repetitive lifting. This action places compressive forces on the vertebrae and at the same time subjects the vertebral discs to sheer forces.

2.23 Temporomandibular joint

Studies of prehistoric and historic skeletal populations have shown that degeneration of the temporomandibular joint (TMJ) afflicted many individuals and that differences between populations exist (Filce-Leek, 1973; Griffen *et al.*, 1979; Richards and Brown, 1981; Webb, 1989; Richards, 1990; Whittaker *et al.*, 1990; Hodges, 1991; Sheridan *et al.*, 1991; Owen *et al.*, 1992). Additionally, the frequency of TMJ degeneration is more common in females than males, although it is rare for more than 40% of either sex to be afflicted (Oberg *et al.*, 1971; Richards and Brown, 1981; Richards, 1988; Webb, 1989; Hodges, 1991;

Sheridan *et al.*, 1991). The high prevalence of TMJ degeneration in some prehistoric populations is suspected to result from repetitive overuse of the joint usually when the teeth are used as tools (Webb, 1989).

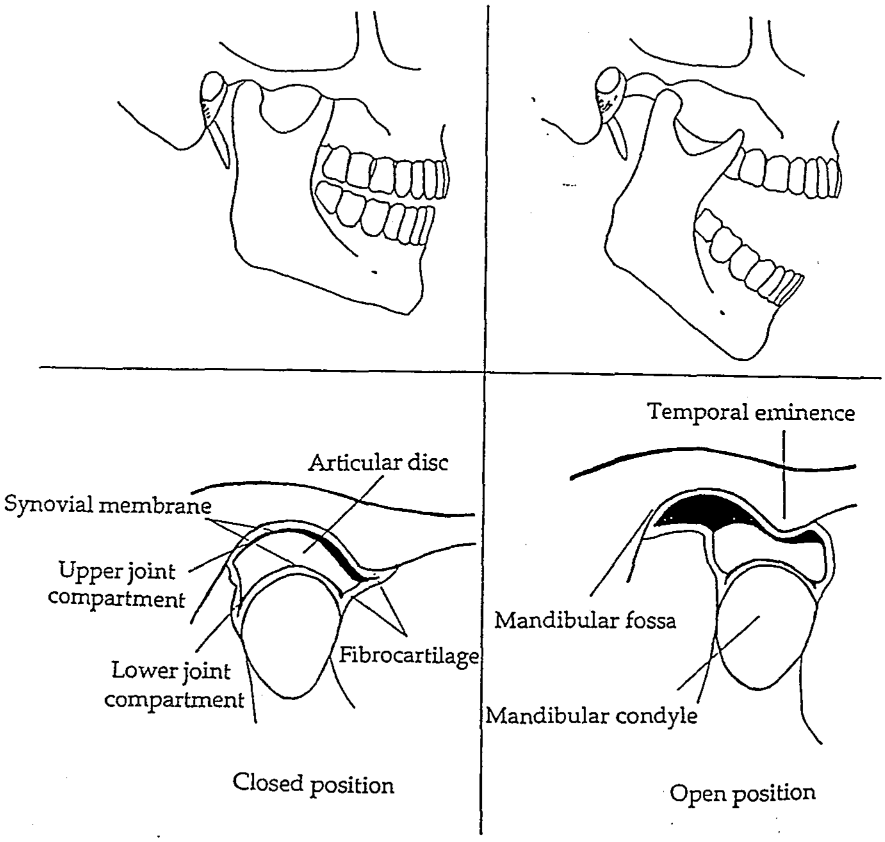
The principle factors leading to TMJ degeneration differ between populations. Most studies have found a strong correlation between tooth wear and TMJ degeneration, and a low association with tooth loss (Griffen *et al.*, 1979; Richards and Brown, 1981; Richards, 1988; Hodges, 1991; Sheridan *et al.*, 1991; Owen *et al.*, 1992). However, two studies have found contrary associations, with evidence of a strong correlation with either posterior tooth loss (Sheridan *et al.*, 1991) or anterior tooth loss (Richards, 1990) and TMJ degeneration.

A number of Australian studies have compared the prevalence of TMJ degeneration among different Aboriginal skeletal populations (Richards, 1988, 1990; Webb, 1989). The strongest associations with TMJ degeneration were found with aspects of orofacial morphology, such as facial angles and ramal breadth. These studies suggest that in populations with robust orofacial characteristics, tooth retention is important for survival and is therefore biologically selected for. Once teeth are lost, the masticatory apparatus is disrupted and TMJ degeneration follows, consequently chewing becomes inefficient and painful.

Clinical and skeletal evidence suggests that biomechanical forces and occlusal dysfunction through tooth loss and/or tooth wear play important roles in TMJ dysfunction (Brown, 1965; Oberg *et al.*, 1971; Hansson and Nordstrom, 1977; Griffen *et al.*, 1979; Whittaker *et al.*, 1990). Recent studies have maintained that tooth loss and tooth wear are not the only variables involved, and have argued that TMJ degeneration has a multifactorial basis (Parker, 1990; Richards, 1990). Consideration should therefore be given to the physiological adaptability of the entire masticatory system.

The functional biomechanics involved in chewing are complex. Briefly, the TMJ is a synovial joint between the temporal mandibular fossa and mandibular condyles (Figure 5.1). The joint space between the articulating condyle and temporal bone contains a nonrobust fibrocartilagenous disc, which is thickest at its posterior end (Ryan, 1989). The convex shape of the condyles and concave mandibular fossae allow the main movement of the mandible to be a hinged upward and downward movement, but gliding protrusive and retractive movements are also possible. Gliding actions can be accomplished by pivoting on one condyle so that the other condyle glides from the fossa in a scything movement (Shipman *et al.*, 1985). Five main muscles are responsible for effecting these movements: the digastric, medial and lateral pterygoids, temporalis and masseter (Figure 5.2).

Figure 5.1
Representation of the structure of the temporomandibular joint in the open and closed positions.



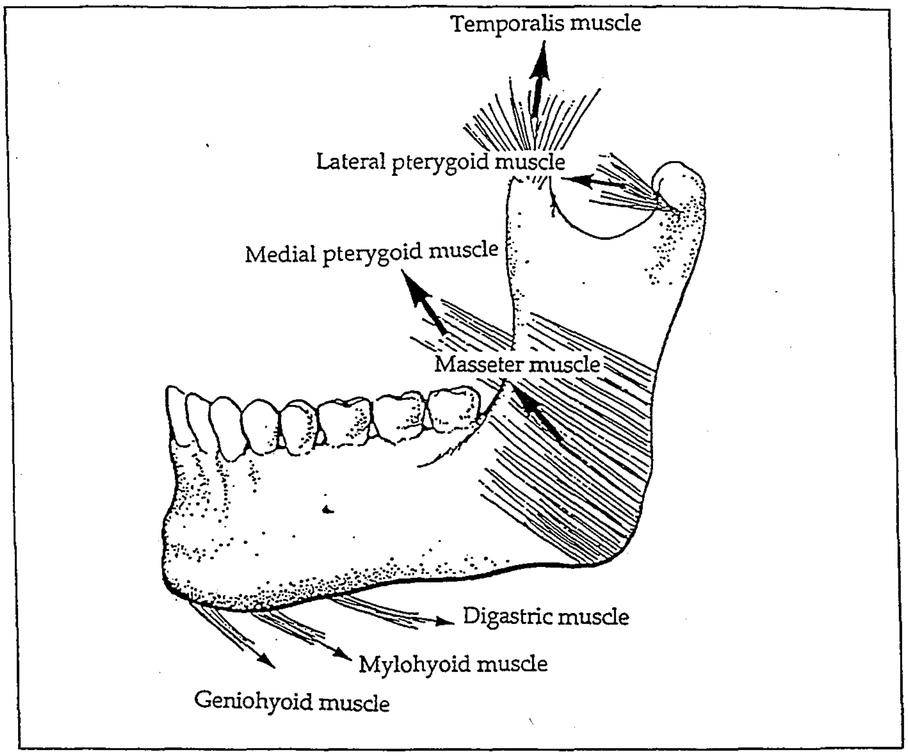
Closed position

Open position

Molar mastication involves an asymmetrical chewing cycle because most people chew on one side of the mouth at a time and frequently have a preferred chewing side (Shipman *et al.*, 1985). The way in which the chewing cycle works is that during the opening movement, the lateral pterygoid relaxes on the chewing side. This keeps the condyle in the mandibular fossa and slightly skews the mandible to that side. On the other side, the contracting lateral pterygoid pulls and holds the condyle on the eminence. During the chewing power-stroke, the medial pterygoid and posterior temporalis bring the mandible onto the midline, while the masseter and anterior temporalis muscles contract to move the mandible simultaneously upward and medially to crush the food.

The balancing condyle remains on the temporal eminence and absorbs the chewing force. During the closing stroke, the lateral pterygoid relaxes on the balancing side, and the posterior temporalis returns the condyle to the mandibular fossa. The masseter and medial pterygoid on the working side relax, and the mandible returns to the resting position.

Figure 5.2
The main muscles involved in mastication. The arrows indicate the approximate direction of the muscles.



In the actions of the chewing cycle, there is a working side where most of the food is located and chewed, and a balancing side which absorbs the bite force. This action occurs because the mandible is attached to a muscular sling under the cranium. Consequently, as one side is pulled anteriorly and distally on the articular eminence, the other side must respond by moving posteriorly and superiorly to dissipate the force (Shipman, 1985).

The greatest focus of sheer force acts upon the cartilage on the balancing side as the condyle is pulled and slightly rotated out of the mandibular fossa. Pathological problems first arise on the subchondral bone, and thereafter the fibrocartilaginous disc begins to degenerate (Ryan, 1989). The pathology of TMJ bony degeneration involves two types of remodelling. Progressive remodelling is the result of articular cartilage being converted into bone by osteoblastic activity. This remodelling involves gradual changes to the temporal eminence, from a convex shape to a concave shape, but these changes do not involve osteoarthritic changes. The other type of remodelling is regressive, which involves the loss of cortical bone by osteoclastic resorption. This is a degenerative process that leads to osteoarthritis. In severe cases the temporal eminences and condylar heads are eroded and the efficiency of the joint becomes compromised (Cherrick, 1979). During normal physiological conditions progressive and regressive remodelling occurs simultaneously, so that the contours of the TMJ articular surfaces are maintained. When the joint experiences excessive strain this relationship is disrupted, so that one remodelling process becomes dominant.

In the present study a number of factors that may have caused TMJ degeneration are considered: (1), The association between tooth wear, tooth loss and TMJ changes; (2), The correlation between condyle skewing and temporal eminence degeneration; (3), An assessment of sex differences in three facial diameters, and TMJ changes; (4), Consideration will be given to cultural activities leading to a biological responses causing TMJ degeneration.

3.0 Methods

3.1 Dental methods

3.11 Evidence of bony abscessing

Bony abscesses are relatively easy to identify in skeletal material. They are usually recognisable by the presence of an irregular cavity where the bone has been resorbed (Hillson, 1986). It can be difficult to assess the presence of an abscess when the alveolar bone has been resorbed to such a degree as to partially obliterate evidence of an abscess or, when bony remodelling has occurred after the abscess has healed during life. In these cases abscesses may be identified by variations in the bone that indicate remodelling of an abscess cavity. In the Sigatoka population, the presence or absence of abscessing is in all individuals with permanent dentition. All abscesses were recorded, including remodelled cavities.

3.12 Antemortem tooth loss

Tooth loss data was collected from adult individuals who had intact mandibular and maxillary alveolar bone. Two categories are defined. One category identifies antemortem tooth loss, indicated by the partially or complete remodelling of the alveolar bone. The second category identifies postmortem tooth loss and in situ teeth. Tooth loss frequencies are calculated by adding the total number of teeth observed with the number of teeth lost postmortem. This total is then divided by the number of teeth lost antemortem.

3.13 Alveolar bone resorption

Alveolar bone loss may involve horizontal bone resorption or irregular bone resorption of the alveolar crest. There are a number of methods that are used to estimate bone loss (MacPhee and Cowley, 1975; Karn *et al.*, 1984). The method used to assess the degree of alveolar bone loss in this study was based on the amount of tooth root exposed. The following scale was used:-

0 = No alveolar bone loss.
1 = No alveolar bone change, but evidence of porous bony regions on the compact surface of the bone.
2 = One third of tooth root exposed, porous compact bone surrounding half of the tooth socket.
3 = Two thirds of tooth root exposed, porous compact bone surrounding the tooth socket.
4 = Tooth loss, porous compact bone.

The alveolar bone of the maxilla and mandible of all adults was investigated for evidence of bone resorption. The degree and frequencies of alveolar bone loss in each tooth group (molars, premolars and incisors) is assessed using the scaling system described above. Males and females are investigated separately.

3.14 Caries

The permanent dentition was examined for caries. A number of studies have established standards for recording caries (Moore and Corbett, 1973; Powell, 1985). In the Sigatoka study, caries were identified by gross examination. Caries were scored only on the basis of their presence or absence, and only those cavities which were unequivocally carious were recorded. The frequencies of carious teeth are compared between males and females and between age cohorts.

3.15 Excessive tooth wear

Analysis of all permanent tooth wear is based on Molnar's eight point scale (Molnar, 1971). According to this scale, teeth with grade six wear or more were classified as having excessive tooth wear. Teeth that have exposed pulp chambers are included in the analysis. This method has been described in Chapter Three. Maxillary and mandibular teeth are investigated separately for four different age cohorts in males and females.

3.2 Skeletal methods

3.21 Vertebral osteoarthritis

To establish if males and females experienced different rates and locations of joint degeneration of the articular processes of the vertebrae, the degree of joint degeneration is compared between different age cohorts, from 15-19 to 40 plus. The cervical, thoracic and lumbar vertebrae were examined separately. Both the superior and inferior articular process surfaces of the right and left sides of the vertebrae were examined. The data were then combined for the assessment of the prevalence of vertebral osteoarthritis.

The stages of vertebral joint degeneration were scored on a scale from 0 for no degeneration to 4 for complete degeneration and fusion. These stages are outlined below:-

0 = None. No degeneration.
1 = Slight marginal lipping and/or pitting of 10% of the articular surface.
2 = Moderate marginal lipping and/or pitting of 10-50% of the articular surface.
3 = Severe marginal lipping and/or pitting of > 50% of the articular surface and any eburnation.
4 = Ankylosis. Arthritic union of one or more adjacent vertebrae.

3.22 Vertebral osteophytosis

The investigation and analysis of osteophytosis on the vertebral bodies also involved establishing age cohorts from 15 - 19 to 40 plus years in males and females. The degree of osteophytosis is compared between the different cohorts. Again the cervical, thoracic, and lumbar vertebrae were examined separately. The degree of oseophytosis on the superior and inferior aspects of the vertebral body were examined. The stages of osteophytosis were scored following Jurmain's (1990) method. These stages are presented below:-

0 = None.
1 = Slight (Small osteophyte).
2 = Severe. (Very large remodelled concave osteophyte).
3 = Ankylosis.

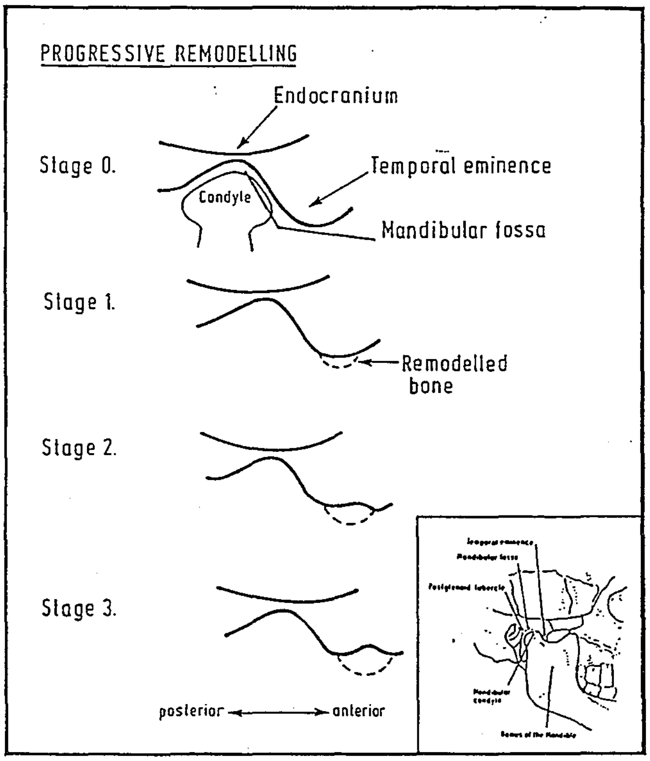
3.23 Temporomandibular joint

A subjective scoring scale was developed for progressive remodelling on the temporal eminence. Points on this scale are:-

0 = Normal.
1 = Slight wear and curvature.
2 = Moderate wear. Curvature more pronounced.
3 = Severe wear. Curvature as a shallow U-shape.

The different stages of progressive remodelling are illustrated in Figure 5.3. To locate the area of remodelling, the surface was divided into lateral, central and medial areas.

Figure 5.3
Progressive remodelling on the bony surfaces of the temporomandibular joint. A sagittal section of the mandibular fossa and temporal eminence illustrating the four stages of progressive remodelling.

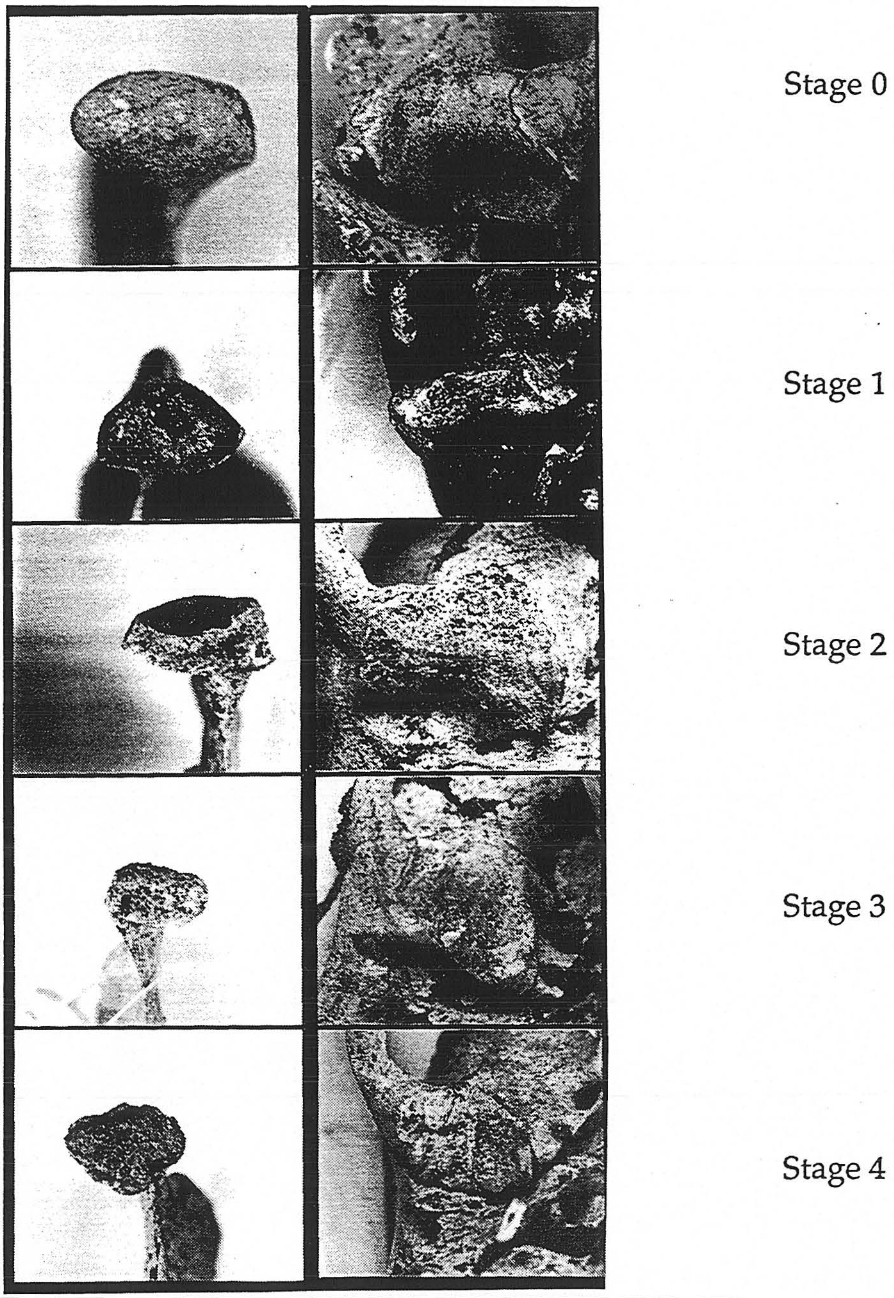


Degrees of TMJ regressive remodelling were scaled according to Richards and Brown (1981:297). These scalings are: -

0 = Normal. No degeneration.
1 = Localised deterioration, affecting one articular surface in any region.
2 = Localised proliferation, affecting both articular surfaces in any region.
3 = Generalised proliferation, affecting one or both articular surfaces in up to five regions.
4 = Eburnation or changes affecting one or both articular surfaces in more than five regions.

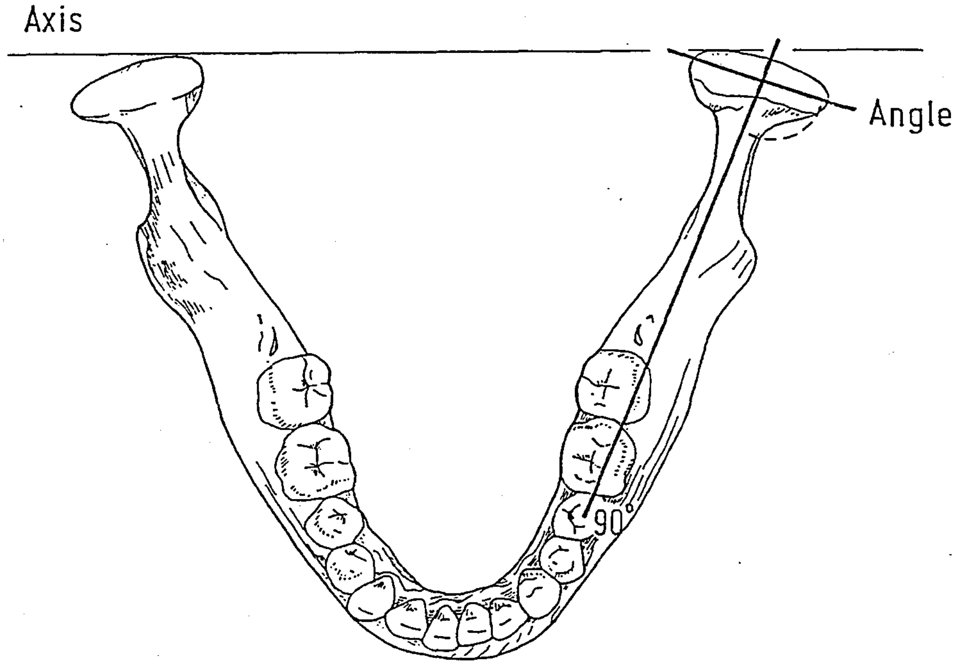
Figure 5.4 illustrates each stage of regressive remodelling of the condylar and temporal surfaces. Each articular surface was divided into nine regions. On the temporal articular surface, three anteroposterior divisions are represented: the temporal eminence, mandibular fossa, and postglenoid region. These are further subdivided into lateral, central and medial areas. On the mandibular condyles the divisions are taken as three 60° sectors from a hypothetical axis (Richards and Brown, 1981).

Figure 5.4
Regressive remodelling on the bony surfaces of the temporomandibular joint.



The orientation of the mandibular condyles was assessed to investigate a possible correlation between the angle of the condyles and degenerative changes on the bony TMJ. The angle of orientation was calculated by measuring the maximum mediolateral diameters of the condyle (Figure 5.5). A transect was taken from the midpoint of the mediolateral diameter to the centre of the first premolar crown. An angle was formed where this transect intersected the midpoint of the condyle mediolateral diameter (Figure 5.5). When this angle deviated more than 10° from the perpendicular, the deviation was recorded as condyle skewing. Condyle skewing was measured to the nearest five degrees.

Figure 5.5
Orientation of the mandibular condyles.



Tooth wear is often cited as a cause of TMJ regressive remodelling (Richards and Brown, 1981; Whittaker *et al.*, 1990). To assess this association in the Sigatoka sample, the rates of tooth wear were scaled according to Molnar (1971). Molnar's scale ranges from one, for no tooth wear, to eight, for wear on the root surface. Rank correlations were used to calculate whether an association existed between mean tooth wear and TMJ regressive remodelling. A separate correlation was made between molar tooth wear and TMJ regressive remodelling. Molar tooth have an important role in crushing food and absorbing the forces exerted during chewing. Therefore, molar tooth wear was assessed separately to test the theory that severe wear in molar teeth is closely correlated to TMJ regressive remodelling.

4.0 Results

4.1 Dental results

4.11 Evidence of bony abscessing

A summary of the data on the frequency of bony abscessing in the maxilla and mandible is presented in Table 5.1. Evidence of remodelled and active abscess cavities was recorded in 13 of the 40 (33%) adults. Of these 13 individuals, 12 (82%) had more than one abscess cavity.

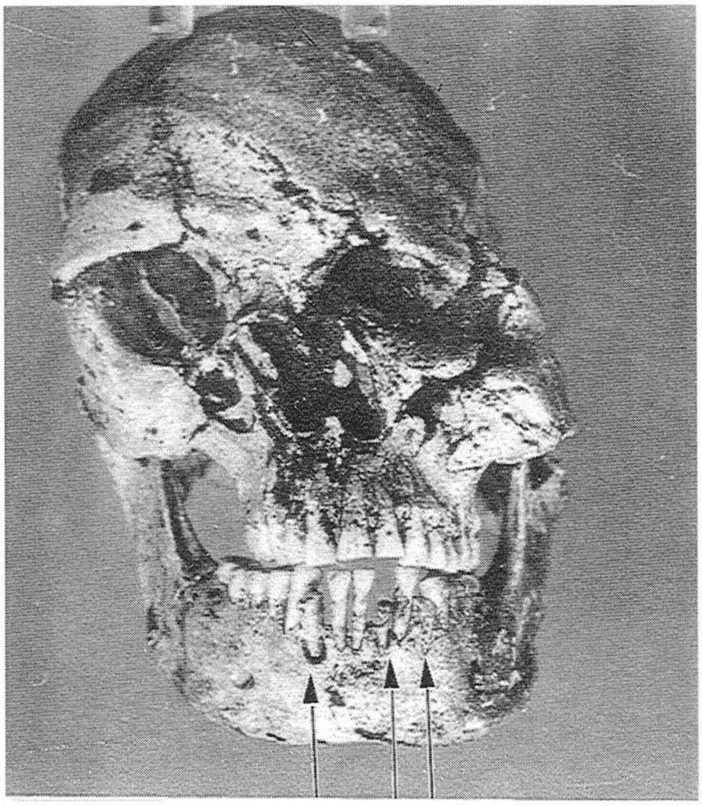
Table 5.1
The number and frequency of bony alveolar abscess cavities in male and female age cohorts.

	Males		Females	
Age	No.	% with abscesses	No.	% with abscesses
15-19	2	0	0	0
20-24	1	0	4	50
25-29	7	0	6	33
30-34	5	0	7	43
35-39	1	0	3	100
40+	3	100	1	0

Just under 50% (10 out of 21) of females had abscess cavities. Abscess cavities are evident in females who died between 20 -24 years of age, and becomes more common in older cohorts. Among individuals who died between 20 and 34 years of age, abscess cavities are found in equal numbers in the mandible and maxilla. Those individuals who lived beyond 35 years of age had abscess cavities predominantly located in the maxilla.

Among females, abscess cavities were more common on the anterior alveolar bone, specifically around the incisors (43%) and premolars (34%). Most of the abscess cavities appear at the sites of teeth where the dental pulp chamber has been exposed through excessive tooth wear, rather than in association with carious teeth or periodontal disease (Figure 5.6).

Figure 5.6
An example of bony abscessing associated with excessive incisor tooth wear.



In males, abscess cavities are evident only in the oldest cohort (40 plus). These cavities occurred mostly in the maxilla. In both sexes abscess cavities are associated with teeth with excessive wear that have exposed dental pulp chambers.

4.12 Antemortem tooth loss

A summary of antemortem tooth loss data is presented in Table 5.2. There is a progressive increase in tooth loss with age in both sexes. The frequency of tooth loss increases in the 30-34 year age cohorts, and accelerates in the oldest cohort. The acceleration of tooth loss is more marked among females than males. Tooth loss is expressed as a frequency of total tooth loss in Table 5.2. Molars tend to be the first teeth lost in the younger age cohorts of both sexes. In the two oldest cohorts, tooth loss in the other tooth groups increase.

Table 5.2
Antemortem tooth loss in males and females.

	Age Cohort	No. of Teeth	No. of teeth lost	% of tooth loss.
Males	15-19	64	1	2
	20-24	32	0	0
	25-29	128	4	3
	30-34	128	10	8
	35+	128	29	23
	Total	480	44	9
Females	15-19	---	--	--
	20-24	160	3	2
	25-29	256	7	3
	30-34	192	18	9
	35+	224	63	28
	Total	832	91	11

Both sexes experienced a similar rate of increase in the frequency of caries and similar rates of tooth loss (Tables 5.2 and 5.5). Among the oldest female cohort, a significant correlation exists between the number of teeth lost antemortem and the prevalence of caries ($p \leq -0.2$. P = 0.05). There is no significant correlation ($p \leq 0.2$. P = 0.13) among the oldest male cohort.

4.13 Alveolar bone resorption

Table 5.3 presents a summary of the data on alveolar bone resorption in adults. There is little alveolar bone resorption before 29 years of age in either sex. From 30 years of age alveolar bone resorption rapidly increases to an average of 2.5 units in both sexes. Females tend to experience greater alveolar bone resorption, particularly around the molars, compared with males.

Table 5.3
Average unit grade of alveolar bone resorption in male and female age cohorts at the location of maxillary and mandibular tooth groups.

			Maxilla			Mandible		
	Age Cohort	#	Molars	Premolars	Incisors	Molars	Premolars	Incisors
Males	15-19	2	0.0	0.0	0.0	0.1	0.0	0.0
	20-24	1	0.7	0.7	0.2	0.3	0.7	0.8
	25-29	7	1.0	0.8	0.5	1.8	1.4	1.3
	30-34	4	2.4	1.9	1.8	1.7	1.2	1.8
	35+	4	2.6	2.5	2.8	2.4	2.0	2.4
Females	20-24	4	0.3	0.3	0.0	0.7	0.5	0.5
	25-29	5	1.1	0.5	0.1	1.6	1.2	1.2
	30-34	6	2.7	2.5	2.1	2.2	2.3	2.5
	35+	6	3.1	2.5	1.7	2.9	2.3	2.4

Alveolar bone resorption tends to be most severe around the maxillary molars in both sexes and in all age cohorts. Alveolar bone resorption began earlier and tended to be present at a greater number of tooth sites in females, compared to males (Table 5.3). Rapid alveolar bone resorption afflicted males who were older than 29 years of age. While alveolar bone resorption was equally severe in both sexes, in the oldest cohorts the loss was more evenly distributed around the dental arcade in males than in females.

Table 5.4
Alveolar bone resorption and porous alveolar bone in males and females in age at death cohorts.

	Males			Females		
Age	Alveolar Resorption	No of individuals	% of teeth associated with porous alveoli	Alveolar Resorption	No. of individuals	% of teeth associated with porous alveoli
15-24	0.3	3	16	0.4	4	65
25-34	1.4	11	61	1.7	11	68
35+	2.5	4	85	2.5	6	60

The prevalence of alveolar resorption and porous bone seems to be associated with tooth loss in females (Table 5.4). However, early tooth loss possibly lowers the prevalence of porous alveolar bone. An explanation for this may be that there is no likelihood of infection occurring around the tooth.

4.14 Caries

Nearly 75% of the population aged 15 years and older had at least one carious tooth. The frequency of carious teeth to total teeth is just over 7%. A summary of these data is presented in Table 5.5. The prevalence of carious teeth increases rapidly after 25 years of age in both sexes. This difference is highly significant ($p \leq 0.002$). Older females experienced another rapid increase in caries after 35 years of age ($p \leq 0.002$). The increase in the caries proportion between each successive male cohort is not significant.

Table 5.5
The number and frequency of carious teeth in males and females.

Age Cohort		No of Teeth	No of Carious teeth.	% of carious teeth.
Males	15-19	58	2	3.4
	20-24	30	1	2.9
	25-29	202	17	8.4
	30-34	119	10	8.4
	35+	91	6	6.6
Females	15-19	---	--	----
	20-24	113	0	0
	25-29	236	17	7.2
	30-34	146	10	6.8
	35+	147	28	19.0

The frequency of carious teeth is similar between most male and female cohorts. In the oldest cohort, females have a higher prevalence of carious teeth than males. In both sexes caries most commonly formed interproximally on the molars.

The frequency and distribution of carious teeth in each tooth group varies between the age cohorts and the sexes. These data are shown in Tables 5.6 and 5.7.

Table 5.6
The frequency of caries compared to the total number of teeth present in four tooth groups of the maxilla and mandible of male age cohorts.

	15-19 (n=2)			20-24 (n=1)			25-29 (n=7)			30-34 (n=5)			35+ (n=4)		
	Teeth	Caries	%	Teeth	Caries	%	Teeth	Caries	%	Teeth	Caries	%	Teeth	Caries	%
Maxillary															
Molars	12	0	0	6	0	0	41	10	24	19	3	16	12	3	25
Premolars	7	0	0	2	0	0	27	1	4	15	0	0	12	0	0
Canines	3	0	0	2	0	0	14	2	14	8	1	13	6	2	33
Incisors	6	0	0	4	0	0	26	0	0	12	1	8	10	1	10
Mandible															
Molars	12	2	17	6	1	17	31	2	6	25	1	4	20	6	30
Premolars	8	0	0	4	0	0	24	0	0	16	0	0	14	3	21
Canines	4	0	0	2	0	0	13	1	8	10	2	20	8	0	0
Incisors	6	0	0	4	0	0	26	1	4	14	2	14	9	0	0

The distribution of caries differs between the various age cohorts in males. In the younger cohorts (15-19 and 20-24 years) caries are uncommon (Table 5.6). In the 25-29 and 30-34 cohorts the posterior dentition and the maxillary molars experienced carious destruction more commonly than other tooth groups. Caries are most prevalent in the maxillary canines, incisors and mandibular molars in the oldest male cohort. The high frequency of caries in the maxillary canines is unusual and may be a reflection of the small data set.

Table 5.7
The frequency of caries compared to the total number of teeth in four tooth groups of the maxilla and mandible of female age cohorts.

	15-19 (n=0)			20-24 (n=4)			25-29 (n=8)			30-34 (n=6)			35+ (n=7)		
	Teeth	Caries	%	Teeth	Caries	%	Teeth	Caries	%	Teeth	Caries	%	Teeth	Caries	%
Maxillary															
Molars	0	0	0	16	0	0	42	2	5	18	4	23	23	5	22
Premolars	0	0	0	15	0	0	32	1	3	20	2	10	22	4	18
Canines	0	0	0	7	0	0	15	0	0	10	0	0	11	0	0
Incisors	0	0	0	14	0	0	30	0	0	22	2	9	21	1	5
Mandible															
Molars	0	0	0	22	0	0	41	10	24	28	0	0	19	7	37
Premolars	0	0	0	16	0	0	30	1	3	20	1	5	19	4	21
Canines	0	0	0	8	0	0	15	0	0	10	1	10	12	1	8
Incisors	0	0	0	15	0	0	31	3	10	18	0	0	20	5	25

Among females, the frequency and distribution of carious teeth varies between the age at death cohorts (Table 5.7). There are no caries in the female 20-24 cohort. In the 25-29 cohort the prevalence of carious teeth is greatest in mandibular molars and incisors. There are no carious maxillary incisors in this cohort. In the 30-34 cohort, nearly a quarter of the maxillary molars and premolars have caries. A trend of increasing prevalence of caries in the maxillary and mandibular molars is continued in the oldest cohort. The observed number of teeth per individual declines markedly in the cohorts over 30 years of age. This difference corresponds to an increased frequency of caries among females who died before 30 years of age.

4.15 Excessive tooth wear

Tables 5.8 and 5.9 presents the summary data of excessive tooth wear in males and females.

Table 5.8
The frequency of excessive tooth wear compared to the total number of teeth in four tooth groups of the maxilla and mandible in male age cohorts.

	15-24 (n=3)			25-29 (n=7)			30-34 (n=5)			35+ (n=4)		
	Teeth	Excess wear	%	Teeth	Excess wear	%	Teeth	Excess wear	%	Teeth	Excess wear	%
Maxilla												
Molars	18	0	0	42	0	0	18	1	6	11	3	27
Premolars	11	0	0	27	0	0	15	0	0	11	6	55
Canines	5	0	0	14	0	0	8	1	13	6	6	100
Incisors	10	0	0	26	0	0	12	5	42	9	4	44
Mandible												
Molars	18	0	0	31	0	0	25	1	4	17	4	24
Premolars	12	0	0	26	0	0	15	1	7	13	9	69
Canines	6	0	0	13	0	0	8	0	0	8	6	75
Incisors	10	0	0	26	0	0	13	5	39	9	4	44

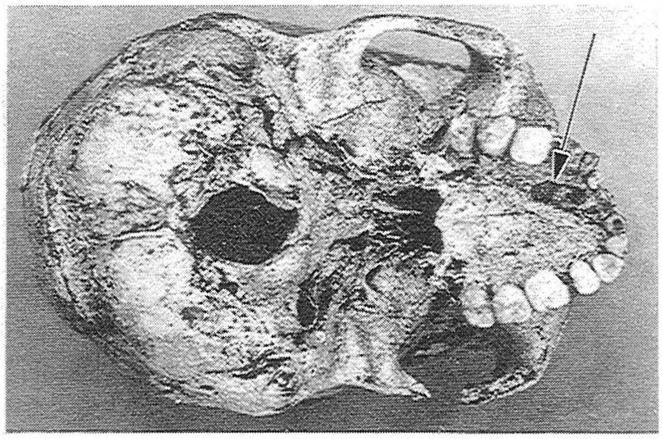
Of the 41 individuals studied, 22 (54%) had excessive tooth wear at the time of death. A greater frequency of females (64%) had excessive tooth wear compared to males (37%). Excessive tooth wear was only found in males over 29 years of age. The incisor teeth were the first teeth to reach this stage. In older cohorts, canines in particular had excessive wear.

Table 5.9
The frequency of excessive tooth wear compared to the total number of teeth in four tooth groups of the maxilla and mandible in female age cohorts.

	15-24 (n=4)			25-29 (n=6)			30-34 (n=6)			35+ (n=7)		
	Teeth	Excess wear	%	Teeth	Excess wear	%	Teeth	Excess wear	%	Teeth	Excess wear	%
Maxilla												
Molars	23	0	0	30	0	0	23	0	0	23	4	17
Premolars	16	0	0	23	0	0	20	0	0	21	13	62
Canines	7	0	0	12	0	0	11	1	9	11	7	64
Incisors	16	0	0	24	0	0	21	5	24	21	10	48
Mandible												
Molars	16	0	0	28	0	0	22	1	9	15	4	27
Premolars	16	0	0	23	2	9	17	0	0	19	10	53
Canines	6	0	0	12	0	0	8	0	0	13	6	46
Incisors	11	0	0	23	5	22	17	1	6	20	11	55

Excessive tooth wear occurs at a younger age in females (Table 5.9). Half of the females who died between the ages of 25-29 experienced excessive wear on the mandibular incisors. In all, 22% of female incisors were affected (Table 5.9). Conversely at the same age, no males had excessive tooth wear (Table 5.8). Among the remaining two age cohorts excessive tooth wear is focused on the incisors in both males and females. Equal proportions of individuals had at least one tooth with excessive tooth wear (Tables 5.8 and 5.9). Females displayed greater variation in the number of teeth with excessive wear, while the male frequency was not nearly as varied (Figure 5.7).

Figure 5.7
An example of excessive tooth wear. Note the exposed dental canals and abscessing in the hard palate.



Individuals who experienced excessive tooth wear commonly had evidence of alveolar abscessing. To assess if an association existed between these pathologies, Spearman's correlations were calculated. Very significant correlations were found among males aged over 40 years ($p \leq 0.4$; P = 0.004), and among females aged between 35 and 39 years of age ($p \leq 0.5$; P = 0.0001).

4.2 Skeletal results

The results presented in Figures 5.8 and 5.9 show a pattern of vertebral degeneration that increases in frequency among individuals over 20 years of age in both sexes. The prevalence of degeneration increased more rapidly among males than females. There are also different patterns of degeneration between the cervical, thoracic and lumbar vertebral joints. These changes are discussed in detail below.

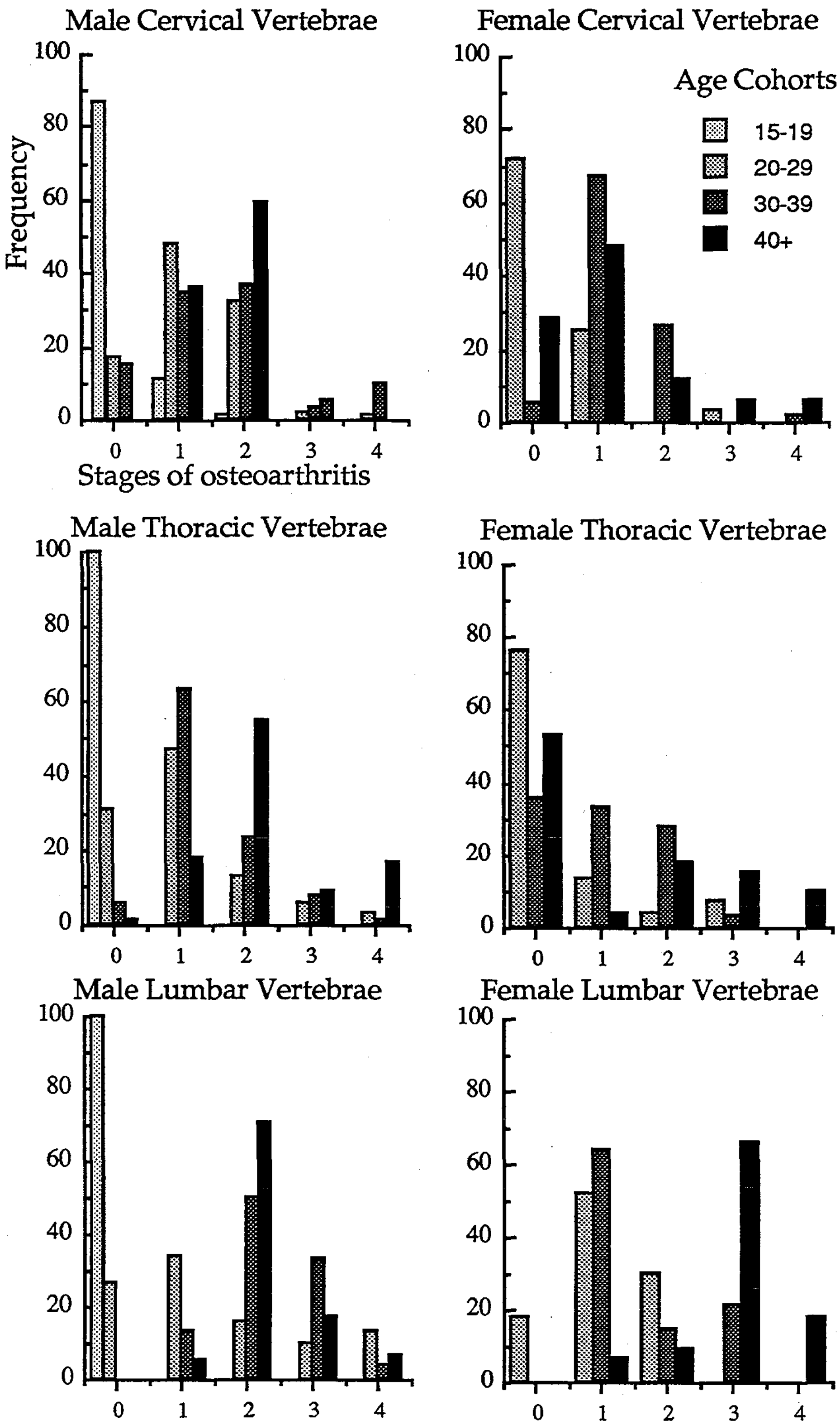
4.21 Vertebral osteoarthritis

Vertebral osteoarthritis in males begins to appear after 20 years of age. Those males aged 40 years and above exhibit at least moderate osteoarthritis (Figure 5.8). The prevalence of cervical osteoarthritis is low among females, with no more than 30% of the females appearing to have this pathology in that region (Figure 5.8).

The degeneration of the synovial joints in male thoracic vertebrae progressively increases between each of the male cohorts. The prevalence of moderate degeneration increases rapidly between the 30-39 and the 40-49 year old cohorts. The pattern of osteoarthritis in females differs from males, in that the females experienced a gradual increase in degeneration between each cohort.

The degeneration of lumbar vertebral joints in males and females increases rapidly in individuals over 20 years of age. Females experienced the greatest frequency of osteoarthritis in the lumbar vertebrae. They show a rapid increase in moderate and severe degeneration from 30 years of age onward. Among males the trend towards osteoarthritis was more rapid. Approximately 40% of the males in the 20-29 age cohort experienced moderate or severe osteoarthritis, while very few individuals aged over 30 years were free of lumbar osteoarthritis (Figure 5.8). The first and second lumbar vertebrae experienced less severe degeneration than the third, fourth and fifth.

Figure 5.8
The incidence of vertebral osteoarthritis in male and female age cohorts.



4.22 Vertebral osteophytosis

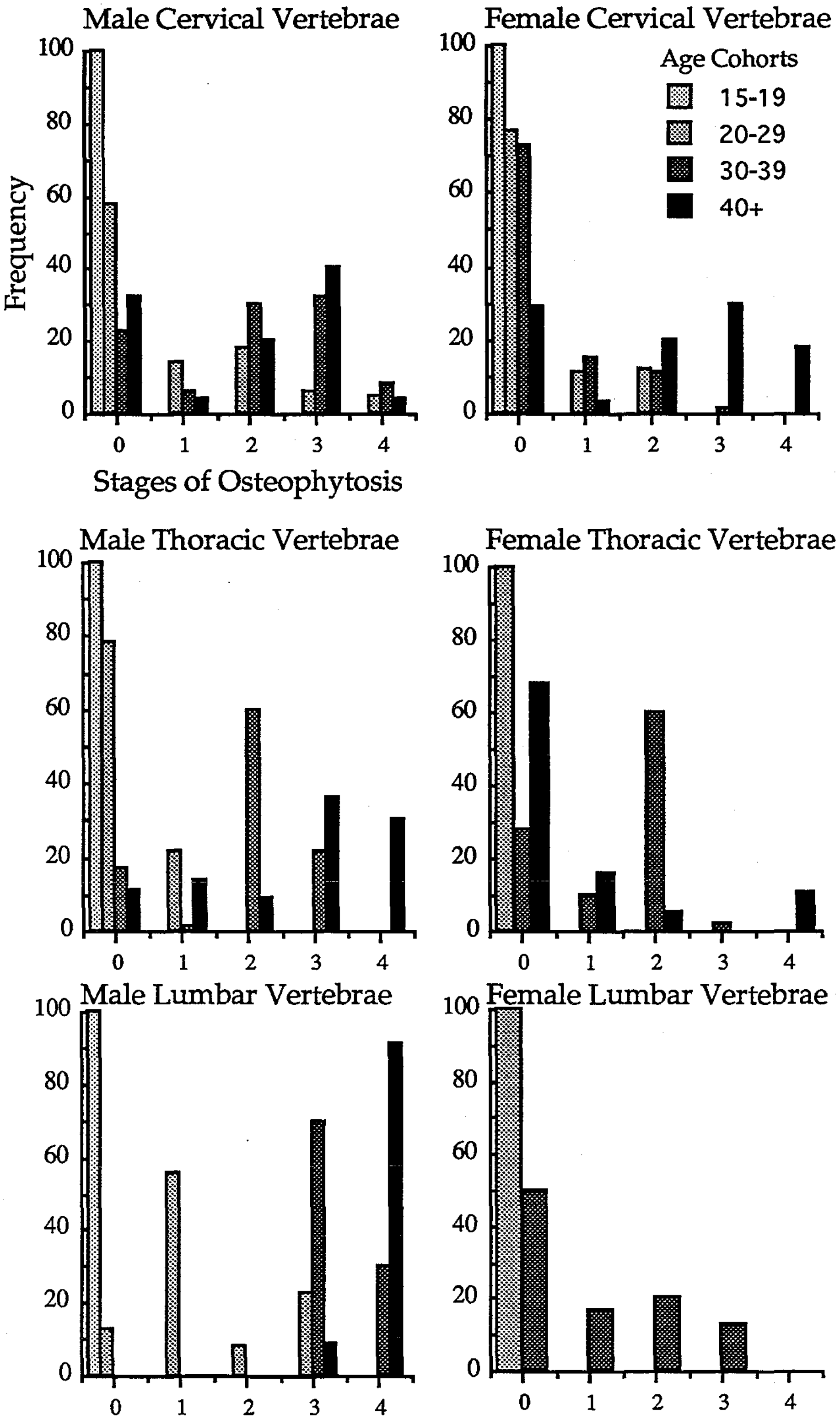
Cervical osteophytosis first appears in males over the age of 20 years. The frequency among males remained reasonably constant, between 30 and 40 years of age. Females experienced a rapid increase in the frequency of cervical osteophytosis after 40 years of age. Nevertheless, males tended to have more severe osteophytosis than females.

The development of osteophytosis in the thoracic vertebrae appears after 20 years of age in both sexes. In the male 30-39 year age cohort a rapid rise in the frequency of moderate osteophytosis is evident, while among the 40-49 year cohort the severity of osteophytosis rapidly increases (Figure 5.9). Females however, experienced a slower onset of osteophytosis.

A similar rapid trend towards the formation of osteophytes was noted in male lumbar vertebrae. Osteophytosis of the vertebrae was well advanced among individuals in the 20 to 29 year old cohort. Among individuals over 30 years of age, all lumbar vertebrae showed signs of severe osteophytosis. (Figure 5.9). The development of lumbar osteophytosis among females occurred at a later age. The age related trend towards lumbar osteophytosis is nevertheless evident.

Spearman's correlations were used to identify if any association existed between the onset of osteoarthritis and osteophytosis in the vertebral column. In all male and female cohorts a very significant correlation ($P \leq 0.0001$), was found between the two degenerative diseases.

Figure 5.9
The incidence of vertebral osteophytosis in male and female age cohorts



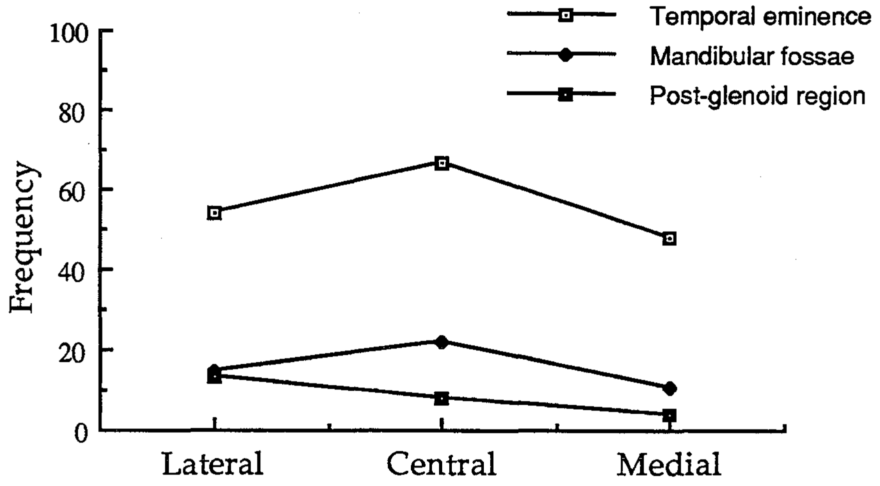
4.23 Temporomandibular joint

The sample size used in this study was restricted because many individuals were represented only by fragmented bones. On a number of the better-preserved skeletons the bony articular surfaces of the TMJ had decayed. Consequently, 18 adult male and 14 adult female TMJ's were studied.

From of a sample of 14 females, only two individuals showed slight TMJ regressive remodelling. Although regressive remodelling was found on the anterior temporal eminence and central posterior condyle, 58% of the females from this same sample exhibited progressive remodelling on the central temporal eminence. No changes were observed on the mandibular fossae or post glenoid tubercle.

In contrast to females, most males experienced regressive remodelling. Of the 18 males, 15 showed differing stages of TMJ regressive remodelling, which occurred equally on both sides of the joint. A high frequency of regressive remodelling (70%) occurred on the temporal articular eminence (Figure 5.10). A lower frequency (20%) was noted in the mandibular fossae, where it was mostly restricted to the central areas. Little regressive remodelling was observed in the post-glenoid fossae areas.

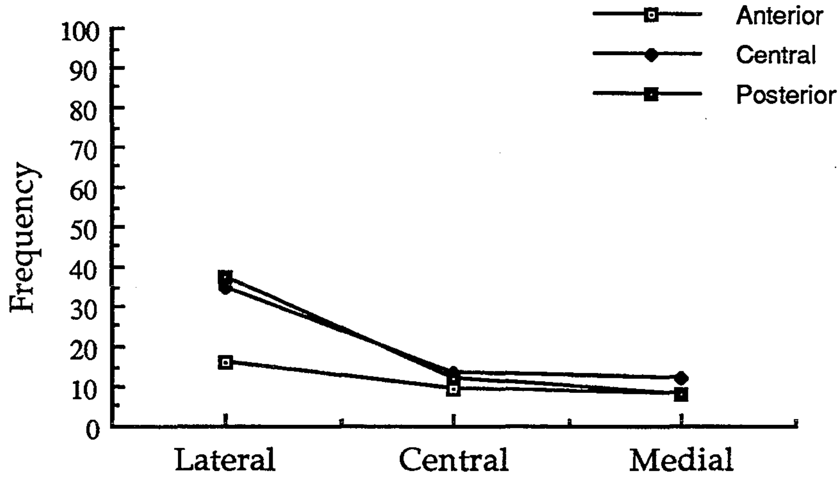
Figure 5.10
The frequency distribution of regressive remodelling on the nine regions of the male temporal articular surface (n=26)



In severe cases, regressive remodelling of the temporal eminence was such that either the eminences were eroded to the level of the mandibular fossae, or the reactive bone on the posterior aspect of the degenerated temporal eminences extended over the mandibular fossae. This made it impossible for the condyles to articulate within the mandibular fossae, thereby forcing them to articulate on the eroded eminences.

Regressive remodelling was greatest on the central parts of male mandibular condyles, where 44% of the observed changes occurred. Regressive remodelling was evenly distributed elsewhere on the condyle (Figure 5.11).

Figure 5.11
The frequency distribution of regressive remodelling on the nine regions of the male mandibular condyles. (n=24)



A characteristic pattern of tooth wear among the Sigatoka population was that as wear advanced, there was a corresponding increase in tooth loss, particularly of the molars. The initial effects of this wear were found on individuals at a young age. To establish whether advancing dental attrition and loss of molar tooth support among males was concomitant with advancing TMJ regressive remodelling, rank correlations were calculated.

Table 5.10
Male TMJ regressive remodelling correlations with tooth wear and age. (n=15)

	p =	P ≤
Age	0.64.	0.010
Dental wear	0.74	0.002
Molar wear	0.84	0.002
Condyles	0.74	0.002

The results show that among males, there is a very significant correlation between total tooth wear and TMJ degeneration ($P \leq 0.002$). This correlation is equally strong when only the molar teeth are included in the calculation ($P \leq 0.002$). When we consider this association among females, TMJ regressive remodelling was negligible even though they experienced similar wear on all teeth. Furthermore, no statistical correlation was found between total tooth wear and TMJ degeneration in females, nor was there any association between molar wear and TMJ regressive remodelling (Table 5.12). Certainly, the causal relationship between tooth loss, tooth wear and TMJ regressive remodelling is not secure.

Table 5.11
Female TMJ regressive remodelling correlations with tooth wear and age. (n=12)

	p =	P ≤
Age	0.56	0.038
Dental wear	-0.18	0.536
Molar wear	-0.05	0.888
Condyles	1.00	0.740

During analysis, it was noted that males who experienced more severe TMJ regressive remodelling also displayed severe unilateral skewing of the condyle. Characteristically, the medial end of the condyle had rotated posteriorly. Skewing was observed in male cases with only stage one degeneration. Degeneration and condyle skewing showed a very significant correlation ($P \leq 0.002$). No condyle skewing was observed among females.

Although female mandible dimensions were smaller than males (Table 5.12), only the minimum ramus breadth was found to be significantly dimorphic ($P \leq 0.03$). Ramal height approached significance ($P \leq 0.08$). The larger male ramal dimensions demonstrate that they had greater masseter musculature that enabled them to achieve a more forceful bite than females.

Table 5.12
Student's *t* test of mandibular variables to identify if significant differences occur between males and females.

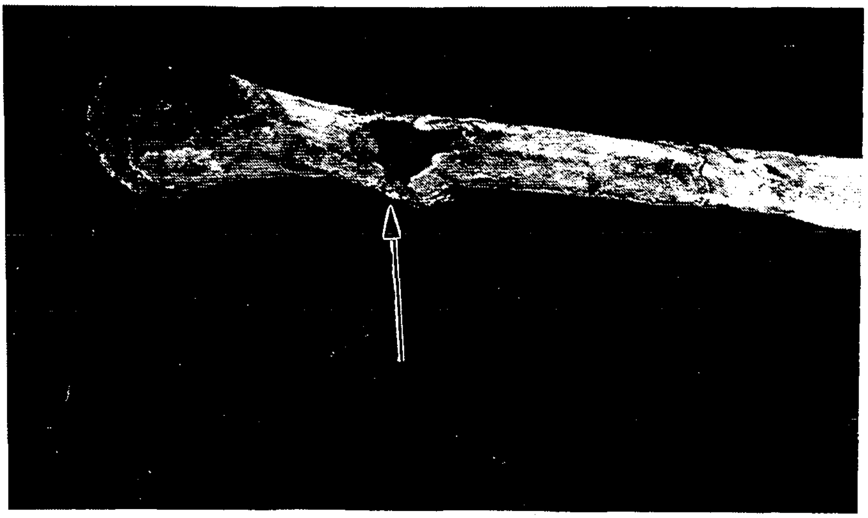
	Males			Females			*t* test
Variable	Mean	s.d	n	Mean	s.d.	n	P ≤
Ramus Breadth	40.6	2.5	14	38.4	2.9	19	0.028
Ramus height	65.2	5.2	14	61.2	6.2	13	0.075
Mandible Angle	116.9	5.3	17	116.1	6.5	21	0.686

4.24 Other observations

Several individuals showed bone evidence of pathology and trauma that are of note. Osteoarthritis was observed on the articular surfaces of long bones and the acetabulum. Comprehensive analysis was not possible because of the decayed and fragmented nature of many of the articular surfaces. However, some information was able to be obtained from the acetabulum. It was found that 89% of the individuals aged 30 years and older experienced osteoarthritis, while only 27% of the individuals aged under 30 years had some evidence of osteoarthritis. It would seem then that occurrence of osteoarthritis in the acetabulum was in some way associated with age and function.

One unique occurrence of trauma was evident on a female (B14). There is bony evidence that a projectile, 10 mm in circumference, pierced the right humerus at an oblique downward angle, entering from the lateral side and exiting on the medial side of the bone (Figure 5.12). The projectile was lodged in the bone for some time after the trauma. Bone was laid down on the medial side of the humerus, following the outline of the projectile. The medullary cavity was not exposed at death, and the amount of bony deposit suggests that this individual survived longer than about two months after experiencing the trauma. There is no evidence of associated pathology, which is unusual considering the strong chance of infection.

Figure 5.12
Traumatic injury in the proximal humerus of B14.



5.0 Comparisons

Comparisons with other prehistoric Pacific populations are made so that the levels of pathology in the Sigatoka population can be assessed. The main problem with comparative data is the level of inter-observer error, particularly in assessing the amount of alveolar bone resorption. Comparisons should be interpreted with greater latitude than observations made by one observer.

5.11 Evidence of bony abscessing

The frequencies of abscessing in individuals from Sigatoka are compared to other Pacific populations in Table 5.13. The Sigatoka people, particularly females, had a moderately high frequency of bony alveolar abscessing. The high frequency of abscessing in the Maori is unusual and probably relates to rapid tooth wear and a gritty diet (Taylor, 1963; Houghton, 1978). In the Sigatoka and Maori populations abscessing is almost always associated with heavily worn teeth with exposed dental pulp chambers (acute pulpitis). In the Namu population it is likely that abscesses were formed as a result of infection spreading between the tooth (usually the first molar) and gum through the periodontal pocket (chronic pulpitis). Conversely, among the Maori population the frequent exposure of the tooth dental pulp chamber has been argued to be associated with a coarse, gritty and sometimes excessively fibrous diet, which rapidly wore away the enamel and dentine (Taylor, 1963; Houghton, 1978; Simpson, 1979).

Table 5.13
The proportion of individuals with at least one abscess in selected prehistoric Pacific populations.

Population	No. of individuals	No. with abscesses	%	No. of Males	No. with abscesses	%	No. of females	No. with abscesses	%	Source
Maori	30	21	70	19	13	68	11	8	73	Visser, nd
Hawaii	163	75	46	--	--	--	--	--	--	Chappel, 1927
Namu	27	7	26	16	5	31	11	2	18	Visser, nd
Marquesas	43	5	12	29	1	3	14	4	29	Pietrusewsky, 1969
Sigatoka	**40**	**13**	**33**	**19**	**3**	**16**	**21**	**10**	**48**	
Nebira	56	1	2	32	1	3	24	0	0	Pietrusewsky, 1969

The difference between the Sigatoka population and the comparative populations is that Sigatoka females have a greater frequency of abscessing compared to Sigatoka males. The cause of this difference seems to be related to non-dietary tooth wear (See Chapter Seven).

5.12 Alveolar bone resorption

In Table 5.14, comparisons of alveolar bone resorption of Sigatoka adults aged between 25 and 35 years are compared with other populations. These comparisons show that the Sigatoka group experienced lower levels of alveolar bone resorption than other groups, although these differences are not marked. Generally alveolar bone resorption among the Sigatoka people was consistent with that of other groups.

Table 5.14
The amount of alveolar bone resorption experienced at the time of death in individuals from Pacific populations aged between 25-35 years.

Population	Alveolar resorption	No. of Individuals	Source
Maori	3.0	30	Visser, nd
Namu	3.0	67	Evans, 1987
Tonga	2.8	23	Evans, 1987
Sigatoka	**2.5**	**21**	
Nebira	2.9	15	Evans, 1987

NB Sigatoka adjusted to classification Evans (1987).

5.13 Caries

In Table 5.15 the prevalences of caries per individual from different Pacific populations are presented.

Table 5.15
The number and frequency of individuals with caries in some prehistoric Pacific populations.

Population	No. individuals with caries	Total No. of individuals	% of individuals with caries	Source
Maori	4	30	13.3	Visser, nd
Wairau Bar	2	37	5.4	Evans, 1987
Tepoto	10	34	29.4	Dennison, nd
Namu	6	163	3.7	Evans, 1987
Marquesas	9	43	20.9	Pietrusewsky, 1976
Tonga	20	75	26.7	Evans, 1987
Sigatoka	**30**	**44**	**68.2**	
Lapita (Watom)	0	2	0.0	Visser, nd
Vanuatu	0	7	0.0	Evans, 1987
Nebira	7	34	20.6	Evans, 1987
Eriama	2	6	33.3	Evans, 1987

These data show that at death nearly 70% of Sigatoka adults had at least one carious tooth. This is markedly greater than for any other Pacific population. The higher prevalence of caries cannot relate only to diet, given the assumption that coastal Pacific populations had similar diets.

The frequencies of teeth with caries are compared between the different Pacific populations. These data are presented in Table 5.16.

Table 5.16
The number and frequency of carious teeth in some prehistoric Pacific populations.

Population	No. of teeth with caries	Total No. of teeth	% of teeth with caries	Source
Maori	4	593	0.7	Visser, nd
Wairau Bar	6	562	1.1	Evans, 1987
Hawaii	481	1965	24.5	Chappel 1927
Namu	12	2084	0.6	Evans, 1987
Tonga	86	985	8.7	Evans, 1987
Sigatoka	**89**	**1142**	**7.8**	
Watom	0	24	0.0	Visser, nd
Vanuatu	0	52	0.0	Evans, 1987
Nebira	44	725	6.1	Evans, 1987
Eriama	4	27	14.8	Evans, 1987

Populations from Eriama and Hawaii exhibit a very high frequency of carious teeth. The frequencies of caries in the Sigatoka people are similar to Tonga and Nebira. However, these frequencies are higher than that found in the remaining comparative populations. Similar frequencies of caries as that found in the Sigatoka population have been found in prehistoric Amerindians (Powell 1985) and prehistoric Southeast Asians (Tayles, 1992). Turner (1979) collated a vast amount of data on the frequency of carious teeth on populations with differing subsistence strategies. Although Turner's study did not consider the implications of genetic differences or cultural variation, it did show that a particular subsistence strategy influenced the frequency of caries. The prevalence of carious teeth was lowest in hunter-gatherer groups (0-5%), and increased in mixed hunter-gatherer-horticulture groups (0.4-10.3%). Horticultural based subsistence groups had a high prevalence of caries (2.3-26.9%). The frequency of caries found in the Sigatoka population is near the average of Turner's (1979) range for groups with horticulturally based subsistence economies. However, it is likely that marine resources contributed a large part of the Sigatoka diet, and therefore it was not entirely a horticulturally based economy. Nevertheless, the prevalence of carious teeth in tropical Polynesian populations is high.

The frequencies of caries cannot be fully explained as the result of dietary differences. Consideration must also be given to the form of fissures and pits on the cusp, and to the interproximal aspects of teeth where tooth abutment occurs. These sites tend to accumulate food residues that provide a rich environment for cariogenic bacteria.

Trace elements contained or lacking in the diet and water have been implicated in causing differences in the thickness of enamel deposition between populations (Khanna and Bibby, 1966; Powell, 1985). For example, selenium and magnesium may weaken enamel deposits, while fluoride has been shown to enhance the resistance of enamel to cariogenic bacteria (Powell, 1985).

5.14 Tooth wear

Average tooth wear of selected prehistoric Pacific populations are shown in Table 5.17. As a general observation, the Sigatoka sample have a slightly higher than average total tooth wear score. Specifically, they have greater incisor and premolar wear than all other comparative populations, other than the Maori. The comparative populations tend to have relatively uniform tooth wear in the premolars and molars.

Table 5.17
Tooth wear of individuals aged between 25 and 35 years at death from selected Pacific populations.

Population	No of individuals	Molars	Premolars	Canines	Incisors	Total Tooth Wear	Source
Maori	9	3.62	3.69	4.33	5.00	4.1	Evans, 1987
Namu	67	2.96	2.70	3.15	3.56	3.0	Evans, 1987
Tonga	23	2.25	2.00	2.50	3.00	2.9	Evans, 1987
Sigatoka	**24**	**3.03**	**3.44**	**3.95**	**4.53**	**3.6**	
Lakeba	3	2.50	2.61	3.30	3.46	2.6	Evans, 1987
Nebira	15	2.95	2.56	3.48	3.90	3.2	Evans, 1987

Among the Maori population rapid tooth wear quickly obliterated cusp patterns, reducing the chances of plaque forming and subsequent bacterial decay of the enamel. The Sigatoka people also appeared to have had an abrasive diet. Although tooth wear was not as severe as the Maori, it was greater than most other Pacific populations. An explanation for rapid tooth wear in the Sigatoka people may be that sand from the environment in which they lived infiltrated into their food. Sand and the force exerted by large masticatory musculature per unit area on the small sized teeth may also be an added element in accelerating tooth wear (See Chapters Eight and Ten).

5.15 Vertebral degeneration

Few studies of skeletal populations from the Pacific area have included comprehensive data on vertebral degeneration. Unfortunately, the data that is available does not distinguish between the sexes or age cohorts (Pietrusewsky, 1976).

In studies where sex differences in prevalences of osteophytes and osteoarthritis between the sexes have been investigated, males experienced degeneration at an earlier age than females (Merbs, 1983; Bridges, 1989; Jurmain, 1990; Tayles, 1992). For example, Tayles (1992) found that female vertebral degeneration increased in age groups and tended to be concentrated in the lower vertebrae, while males experienced a more uniform degeneration pattern. Merbs (1983) also found that females experienced greater lumbar osteoarthritis than males, compared with males who experienced greater degeneration in the cervical and thoracic vertebrae. This compares to the Sigatoka population in which males and females experienced an age associated increase in osteoarthritis. Osteoarthritis was evenly distributed in the vertebrae of males, but in females, the lumbar vertebrae show early signs of degeneration.

Merb's (1983) study of the prevalence of osteophytosis in the Inuit showed that females had greater osteophyte development in the mid thoracic vertebrae. Males had greater development in the lumbar region. Generally osteophyte development on the vertebral column was associated with the three primary curves of the spine. This differs from Sigatoka in which females had comparatively low levels of vertebral osteophytosis, while males had greater lumbar osteophytosis.

6.0 Interpretation

6.1 Dental variables

There are associations between each aspect of dental pathology in the Sigatoka people; alveolar bone resorption, tooth wear, bony abscessing, caries, enamel hypoplasia, and antemortem tooth loss. Findings have shown that differences exist between the sexes in the prevalences of dental pathology. In older cohorts females have a higher frequency of bony abscessing and antemortem tooth loss, greater tooth wear in early adulthood, and a higher prevalence of carious teeth compared with males. One explanation why sex differences occur may concern sex based divisions of labour and differing access to food. Several studies have shown that differences in diet of the sexes are evident in hunter-gatherer and horticulturally based societies. These dietary differences are also accompanied by differences in dental pathology, particularly caries (Hill and Hurtado, 1989; Walker and Hewlett, 1990). Similar sex differences in dental pathology to those found in Sigatoka people have been identified in a number of skeletal studies (Larsen, 1983, 1984; Lukacs, 1992; Tayles, 1992).

The comparatively rapid tooth wear and high prevalence of caries is indicative of a gritty and carbohydrate rich diet. Some of the foods that may have been consumed, such as from coconuts, yams and taro have high starch and sugar content. These foods promote plaque depositions on and around the teeth, particularly at the interproximal areas, creating a favourable environment for cariogenic bacteria (Alfano, 1980).

The greater proportion of excessive tooth wear in the anterior dentition compared to the posterior teeth indicates that diet was mainly soft and required comparatively little chewing. This supports the notion of a gritty carbohydrate rich diet. Different patterns of excessive tooth wear in some females, and on a small number of their anterior teeth seems to relate to a nonmasticatory function. This has been discussed in detail in Chapter Seven and elsewhere (Visser, 1994). Teeth used for nonmasticatory functions typically experience a different pattern of wear and a more rapid rate of attrition than teeth used for masticatory wear (Merbs, 1983).

6.2 Vertebral degeneration

In comparison to females, males experienced earlier onset and more severe forms of both osteoarthritis and osteophytosis of the vertebral bodies. These pathologies follow a pattern that would be expected with aging in a prehistoric population (cf Tayles, 1992). However, the sharp rise in osteophytosis of the lower thoracic vertebrae of males from 30 years of age appears to be consistent with the effects of pressure loading, associated with lifting and/or hauling heavy objects (Merbs, 1983).

Evidence that the greatest vertebral strain was placed on the lumbar vertebrae in both sexes is provided by the rapid increase in osteoarthritis and osteophytes from 20 years of age. Not only did the lumbar vertebrae seem to have been subjected to the effects of pressure loading, but also sheer forces from bending and lifting. Males experienced the degenerative effects of these actions earlier than females. The same actions may be associated with the development of osteophytosis in the male thoracic vertebrae.

Sex differences in vertebral pathology may relate to the way in which the Sigatoka people organised their work activities. While it is impossible to reconstruct the daily round of male and female activities, it is likely that the early onset of pathology in the lower spine of males indicates different activities compared to females. The Sigatoka burial and village sites have a large scattering of pottery sherds surrounding them (Birks, 1973; Best, 1989). Males may have been responsible for collecting clay for pottery, fishing, digging, and gardening which required flexion of the lower back while the legs and pelvis remain immobile. Female tasks that involved spine flexion possibly involved long periods of sitting, perhaps while making pots or time spent collecting shellfish. Ethnographic accounts from Fiji and the wider Pacific usually describe only females doing these tasks (Gordon-Cumming, 1882; Parslow, 1993). In Chapter Four an argument was forwarded suggesting that females collected shellfish.

6.3 Temporomandibular joint

The different correlation results of male and female tooth wear and tooth loss patterns compared to TMJ regressive remodelling show that there is no primary relationship between tooth wear and loss and joint degeneration. In light of this there must be another causal mechanism contributing to TMJ regressive remodelling.

Among males, the temporal articular eminences and the lateral portion of the condyles absorbed most of the force generated during chewing. Early indications of regressive remodelling were evident in young adult males. Remodelling became rapidly more severe in older male age groups, suggesting repetitive and forceful chewing.

The progressive destruction of the TMJ in Sigatoka males has been described previously (Visser, 1994). Briefly, repetitive forceful chewing in a scything action progressively destroyed the articular cartilage of the joint. Greatest force was applied to the central and anterior eminence and the central posterior condyle where cortical bone was thin. The structure of the bony trabeculae was formed in a position so that they could not absorb and compensate for the force. This inability resulted in the remodelling of the condylar head and glenoid fossa.

There does not seem to be any histological reason why female TMJ tissue should have been more resistant to these forces. On the contrary, clinical and skeletal evidence points to females being more susceptible to TMJ degeneration (Grosfeld *et al.*, 1985; Hodges, 1991; Sheridan *et al.*, 1991). Moreover, there are indications that condyle skewing is also more common among females (Oberg *et al.*, 1971).

Among the Sigatoka population, TMJ regressive remodelling occurred 12 times more frequently in males than females. It would seem that although both sexes in the Sigatoka population had an equally abrasive diet, the chewing action of females did not involve the repetitive, forceful, and shearing movements that males experienced. Therefore, it is probable that sex-specific behavioural activities were responsible for this difference.

A resolution to this question may lie in cultural activities. Tooth wear patterns among males excludes the possibility that TMJ regressive remodelling was the consequence of processing fibrous plant material for fishing nets, lines, or any similar activity. Industrial wear patterns were evident only among some females. An answer to the greater frequency of TMJ regressive remodelling in males compared to females can be found in kava processing and use (Visser, 1994).

Kava is a narcotic beverage made by pulverising the roots of the plant *Piper methysticum* Forst. *f.* either by pounding or, more commonly in the past, chewing the root. The processed product is then mixed with water and drunk. The kava drink acts as a tranquiliser. Processing the roots releases the relaxants, pyrones, methysticin, dihydromethysticin and dihydrokawain. Their general effect inhibits sensory stimuli and motor responses (Pfeiffer *et al.*, 1967).

At the time of early European contact, kava root was processed by chewing or grating (Williams, 1858). The chewing method involved cutting the kava root up into small pieces and then distributing it to a group of young men to chew (Williams, 1858; Rowe, 1860). They chewed the kava into a finely masticated fibre that was seen to "take some time" (Gordon-Cumming, 1882:51). On the basis of these observations, processing kava by chewing would require repetitive force and a reasonable amount of time. This would certainly involve the necessary conditions to initiate TMJ dysfunction.

One of the effects of kava chewing is that it inhibits sensory stimuli to the brain from the proprioceptor nerves, located in the periodontal ligaments and TMJ. As a result, the sheer and compressive forces produced during chewing would be somewhat uncontrolled. Any pain experienced would be at least partially inhibited by the released relaxants. Even small amounts of kava inhibit the recognition of external stimuli and produce a lack of muscle co-ordination (Frater, 1952). A reduction in sensory stimuli and a lack of muscle control while chewing forcefully, particularly in a scythe like action, could quickly lead to cartilage deterioration and TMJ dysfunction.

7.0 Summary

As a consequence of post depositional skeletal decay the most detailed investigations of pathology are based on the maxillary and mandibular skeleton and the teeth. No evidence of infectious disease was found in the Sigatoka population. Dental disease in the form of bony abscessing and severe tooth wear appears to have increased susceptibility to secondary infections in many individuals. These pathologies probably resulted as a consequence of cultural activities rather than dietary deficiencies. For example, in some females excessive tooth wear and abscessing are likely to have been associated with non-dietary tooth wear. This point is elucidated in Chapter Seven. However, the high prevalence of caries may be explained by a carbohydrate and sugar rich diet providing a congenial environment for cariogenic bacteria.

Skeletal pathologies are also related to activity rather than infectious diseases. Sex differences in patterns of vertebral pathologies and temporomandibular joint degeneration indicate different behaviour patterns between the sexes.

Compared to most comparative Pacific populations used in this study the Sigatoka people have greater dental health problems. Given the proposition that the Sigatoka population had access to similar foods and lived in a similar environment to many of these Pacific populations, dental pathology appears to be closely related to culture and living conditions. The higher prevalence of dental disease and the rapid rate of tooth wear in the Sigatoka population compared to most other comparative Pacific populations suggest that their dentition had not fully adapted to the masticatory and nonmasticatory requirements placed on the teeth. As a final comment on Sigatoka skeletal and dental pathologies, most causes seem to be a consequence of behavioural activities rather than disease associated changes.

Chapter Six

The analysis of Sigatoka skeletal and dental traits.

1.0 Introduction

This Chapter presents skeletal and dental data collected from the Sigatoka skeletal series. Comparisons of skeletal and dental traits between the sexes and populations are explored. First, consideration is given to differences reflecting environmental factor, such as a physical activity or nutrition, and the affect these behaviours have on the skeleton. Skeletal measurements are compared to identify whether different behaviours occurred between the sexes. The second aspect of the analysis is the level of biological or genetic differences between individuals and between the sexes, based on tooth morphology and size. Heterogeniety may suggest a large gene pool, and perhaps contact and mixing between populations. Homogeniety suggests community isolation and perhaps a limited gene pool in Fiji. With these objectives in mind, an assessment of the degree of variability within the population is made using univariate techniques. The theory of growth and development of teeth and the bony skeleton are discussed first.

2.0 Theory

2.1 **Dental theory**

2.11 Tooth development

Epithelial cells on the developing foetal dental lamina grow and swell into tooth germs. Within the tooth germs, enamel and dentine will be deposited by two types of cells. Cells derived from the epithelium develop into an enamel organ that is responsible for depositing enamel. The other cell type, mesenchyme, becomes the dental papilla responsible for dentine and pulp formation. As the tooth germ develops, it passes from a cap stage where the enamel organ grows and becomes indented on the side away from the dental lamina, into a bell stage where these indentations continue to grow. During this growth hard tissue deposits occur. At this time the organ begins to acquire the crown contours for cusps and ridges. The intercusp distances may be genetically set, and it seems that these distances set the final tooth diameters (Harzer, 1987). Meanwhile, cells on the edge of the papilla differentiate into odontoblasts. Dentine is the first hard tissue to be deposited, while inside the enamel organ epithelial cells differentiate into enamel depositing ameloblasts (Hillson, 1986).

Initial enamel deposition forms the basis for the main ridges and cusps. These are built up by successive layers of enamel until the cusps gradually merge. Enamel deposition ceases when ameloblasts cover the cusp tips and reach the end of their organic matrix (Hillson, 1986). Enamel is then layered around the sides of the crown. Similarly, successive layers of dentine are deposited by odontoblasts within the developing tooth.

It is known that crown formation, and consequently tooth size, are dependant on the level of ameloblast activity during development. Whether or not ameloblast activity reaches the genetic potential has been shown to be related to nutrition and health status. Other variables such as potential tooth crowding may also be implicated (Garn *et al.*, 1979; Townsend, 1985).

The way in which size and morphology of teeth are determined, and the variability between individuals and populations, is uncertain. However, many studies have considered why teeth reach a particular size or acquire a morphological trait. A review of these traits provides a basis for analysing the Sigatoka material.

2.12 Metric dental traits

Heritability studies of tooth size in house mice initially suggested that much of the tooth size is genetically determined, particularly for the lower molars (Bader and Lehmann, 1965; Leamy and Hrubant, 1971). Follow up studies by Leamy and Touchberry, (1974) and Leamy (1981) identified the genes responsible for molar buccolingual diameter. After identifying these genes, the researchers were able to conclude that the first molar was under the greatest genetic control and that the third molar was the most unstable tooth. The variability of the second and third molars was attributed to genetic instability and secondary influence, including nutrition and the limitations of space within the dental arch.

While it has not been possible to obtain the same experimental results in humans, studies of monozygotic and dizygotic twins indicate that tooth size has a strong genetic component. Garn *et al.* (1965) suggested that the genetic component may determine up to 90% of tooth size variation. Other researchers have been more conservative, suggesting a genetic control of around 50% to 60% (Townsend, 1980; Goose and Roberts, 1982).

More recent studies have concentrated on identifying the genetic components responsible for tooth size. By 1985, research had demonstrated that genes on the Y chromosome influenced not only tooth size, shape and height, but also bone development (Fitch *et al.*, 1985; Townsend and Alvesalo, 1985). The search for the loci of these genes narrowed to near the centromere on the Y chromosome (Lau *et al.*, 1989). This may account for male-female differences, but it still does not explain tooth size controls in females, therefore other genes must be implicated.

There is a growing body of evidence that suggests that tooth size is not under single genetic control. Rather, tooth size may be determined by many genes, each contributing subtle characteristics to a tooth (Townsend and Brown, 1978; Calcagno and Gibson, 1988). It seems that tooth size is initially set by the size of the tooth germ, the size of which reflects the rate and length of mitosis (Martain and Boyd, 1984; Harzer, 1987). If this is so, it would seem that tooth size is a reflection of the genes controlling the development regulating process rather than the enzyme system. These genes may be sensitive to the space available within the mandible and maxilla and therefore regulate tooth size to fit the area available (Townsend and Brown, 1983).

Despite possible gene regulation to minimise tooth crowding in the developing dentition, crowding does occur and may affect the mesiodistal diameter of teeth. It has been pointed out that molar teeth may not attain their full genetic potential because space limitations in the maxilla and mandible can result in tooth crowding. In effect, this restricts the mesiodistal diameter either by gene regulation or through the physical constraint of abutting teeth (Korkhaus, 1930; Lundstrom, 1948; Garn *et al.*, 1965). On this basis the buccolingual diameter may prove to be the best measurement for assessing genetic relationships (Begg, 1954; Moorees, 1966; Gruneberg, 1965; Leamy, 1981).

2.13 Morphological dental traits

Studies of nonmetric dental traits using laboratory animal models provide a foundation for determining that these traits have a genetic basis in humans. It is not known how important the genetic basis is. In most cases there seem to be a number of genes controlling the phenotypic expression of a trait (Sofaer, 1969; Palomino *et al.*, 1977; Goose and Roberts, 1982). Studies of inbred strains of mice have demonstrated that minor variations of tooth shape were consistent enough to show the presence of a particular mouse strain (Gruneberg, 1965;

Wickramarante, 1974). However, the longer a tooth takes to develop, the less genetic control tends to influence the shape of the tooth (Sofaer, 1969). This can be observed in particular in the third molar, where within families there is a range of variability of tooth size and patterns.

The presence of morphological traits within family groups has been tested. Berry (1978) studied a group of monozygotic twins and found that on average the traits matched each other at a frequency between 50% and 70%. Others have found that environmental factors influence dental traits (Kolakowski *et al.*, 1980). Hillson (1986) pointed out that genetic effects may act in opposing ways and so cancel the expression of each trait.

2.14 Maxillary shovel shaped incisors

Maxillary shovel shaped incisors have a concave lingual surface often accompanied by marked marginal ridges. The degree of shovelling is variable, but it has been argued to be one of the most reliable traits to score when assessing relationships between individuals and populations (Sofaer *et al.*, 1972). Even with this level of confidence in using shovel shaped incisors as a diagnostic tool, there remains little genetic understanding of why the trait occurs. A recent statistical analysis of morphological patterns of teeth within family groups has shown that a strong argument exists for the presence of a dominant gene responsible for the expression of shovel shape in the maxillary central incisors (Nichol, 1989). The same study found that the genetic involvement in the lateral incisors is much more "confusing" and that incisor shovelling in these teeth may be a polygenetic trait. The inference that may be made from that study is that different gene aetiologies are responsible for shovel shape in lateral and central incisors.

2.15 Protostylid

Protostylid refers to features located on the buccal surface of the mandibular molars. These features may vary from a simple pit or groove to a small cusplet. Following Dahlberg's (1950) classification, a protostylid may be a pit and/or groove that may extend up to the distal part of the cusp that separates the protoconid from the hypoconid. The categorisation of the pits as a partial expression of protostylid has been questioned (Nichol, 1989).

There seems to be very little known about relative genetic or environmental roles in the expression of protostylids. Dahlberg (1950) speculated that protostylids are expressed when particular recessive gene combinations occur. Nichol (1989) calculated a series of genetic transmissibility estimates for the expression of protostylids. He concluded that environmental influences play a large part in determining the development of the trait. However, a possibility remains that a major genetic influence contributes to the degree of protostylid expression.

2.16 Cusp patterns

Mandibular and maxillary molars have different cusp patterns. Variability also extends to the expression of cusp patterns between individuals. Cusp pattern formation has been assumed to be a function of the shape of the developing crown. In rats, it seems that when tooth maturation is interrupted, the cusp pattern is not affected, even when later forming parts of the cusp remain incomplete (Johnson, 1986). This suggests that cusp patterns are determined by an underlying genetic mechanism. Studies of the human mandibular molar have shown that the number of cusps is significantly related to crown size (Dahlberg, 1961; Garn, *et al.*, 1966; Nichol, 1985). Not all researchers have found this to be the case. For example, the Y pattern found on some mandibular molar crowns has been held to be related to the presence of another morphological crown feature, the deflecting wrinkle (Morris, 1970).

The role of environmental and genetic influences on cusp patterns have been assessed by Bailit (1966). That study found that tooth morphology was controlled by 60% genetic and 40% environmental factors in the first molars, and 5% genetic and 95% environmental in the second molar. More recent studies have found that the second molar may be under greater genetic control.

Johnson's (1986) and Nichol's (1989) work on the morphology of the molars suggests that the hypocone may by controlled by a recessive allele, particularly in the second molar. In short, there seems to be an underlying weak genetic mechanism influencing the expression of crown cusp patterns. However, this may be over-ridden by additive factors, both genetic and environmental.

2.17 Hypodontia

The third molar is the most commonly absent tooth. This absence is correlated with the size of an individual's mandible and maxilla. It seems that the smaller the mandible and maxilla, the greater the likelihood that teeth will be absent (Woodworth *et al.*, 1985). After the third molar, the second incisor and second premolar are most likely to be absent (Level and Moore, 1973; Lebot and Salmon, 1977). There is also a pattern whereby individuals who have one tooth missing or who have small imperfectly formed and variable teeth are more likely to have more teeth missing (Garn *et al.*, 1962; LeBot and Salmon, 1977).

The genetic basis for hypodontia is unclear. In mice, a semi-dominant gene appears to be associated with the failure of the lower incisors and third molars to erupt. This same gene may also be responsible for smaller tooth size (Sofaer *et al.*, 1972). More recently, Townsend (1983) has suggested that hypodontia results from an increase in the number of genes involved and their interaction. These interactions are responsible for a tooth's absence, or for a reduction in tooth size initiated by the sending of incorrect signals to odontoblasts and ameloblasts. This results in abnormal odontoblast activity and an absence of ameloblasts. Disrupted cellular activity inhibits dentine and enamel deposition.

2.18 Sex differences in teeth

In the 1960's, Garn and his associates published a series of brief papers addressing the difference in tooth size between brother and sister siblings. They established that a strong genetic component located on the Y chromosome is involved in fixing tooth size (Garn *et al.*, 1965). This finding was later confirmed by a number of other studies (Townsend, 1980; Goose and Roberts, 1982; Lau *et al.*, 1989; Alvesalo *et al.*, 1991).

One paper considered the differences in the mesiodistal and buccolingual diameters of the sexes and found that the expression of sex differences in the canines varied markedly between the two diameters (Garn *et al.*, 1966). It appeared that sex differences relate to different tooth shapes in the sexes. Males tended to have "rectangular" teeth, and females tended towards greater buccolingual diameters. Sex differences were most strongly expressed in the mesiodistal diameter of the mandibular canines, and were found to decrease in each tooth the further the tooth was from the canine (Garn *et al.*, 1967[a]). Furthermore, if a sex difference was found in one type of tooth, then the other teeth are also likely to express greater dimorphism than would be expected within a population (Garn *et al.*, 1967[b]).

There are a number of major variables, besides genetic potential, which should be considered when discussing sex differences in teeth. Perhaps the most obvious is the close association between body size and tooth size (Garn *et al.*, 1967[a], 1967[b], 1967[c]). Within a population there is a tendency for individuals with a larger body size to also have larger teeth.

The mode of inheritance of dental morphological traits of teeth and differences between the sexes are not as well understood as the influences affecting metric variation. Recent studies have attempted to statistically identify the genetic significance of sex differences in morphological tooth characteristics (Nichol 1989). Nichol found significant male-female sibling differences in the frequency of hypercone expression in the maxillary molars. These differences were 75% in the first molar and 66% in the second molar. Nichol (1989) also noted that the incidence of shovel shaped lateral maxillary incisors differed significantly between the sexes. No significant sex differences were found in mandibular molar groove patterns or protostylid expression. Nichol (1989) concluded that the variation expressed among these traits seems to be related to environmental factors.

2.2 Skeletal theory

Differences in body form, size, structure and shape exist between the sexes. These differences are related to genetic and environmental factors. Physiological expressions of sex differences occur in the three main growth episodes (Tanner, 1962). The first growth differential occurs at birth, or earlier. Sex differences in the length of the forearm and the arm length to leg length ratio become evident early in life. At birth, female lungs are more mature than males (Tordy *et al.*, 1981).

The second differential growth episode occurs during childhood. Female growth occurs earlier than in males, and is concentrated on the limbs and head. Sex differences in epiphyseal bone growth and dental development of up to 10% have been documented in radiological studies (Hunt and Gleser, 1955; Bailit and Hunt, 1964).

The third differential growth episode occurs at adolescence, and is primarily influenced by sex hormone production, specifically androgens and oestrogens (Weber, 1985). The female growth spurt occurs earlier than in males, but growth ceases at an earlier age. Therefore, the growth episode in females is of shorter duration than that of males. Sex hormone production in males occurs later than in females, and the longer growth period enables males to obtain greater bone dimensions and taller stature than females. This differential growth rate is particularly evident in the proportions of arm and leg lengths to trunk lengths (Damon, 1977). Male shoulders increase in breadth and muscle size, to attain differences of between 5% and 10% greater than the same dimensions in females (St Hoyme and Iscan, 1989). This increase also reflects the increase in male muscle mass. One of the most notable physical changes during adolescent growth in females compared to males is the broadening of the pelvis and increases in fat deposits in preparation for childbearing and lactation (Frisch, 1988).

The mechanisms which control growth episodes are not fully understood. It is known that growth can be interrupted through disease, malnutrition or some other factor, and that once this stress has been removed the body regains its growth momentum. The indications are that this "catch-up" mechanism has a genetic basis that is stronger in females than males (Greulich, 1951; Stini, 1975). Another controlling mechanism is hormone feedback regulation. The pituitary gland secretes hormones that affect target glands such as the thyroid, adrenal and gonads. The level of hormones secreted is adjusted to the level produced by the target gland.

Growth interruptions and sexual dimorphism have been intensively examined in anthropomorphic and skeletal studies. These studies have found a 5% to 10% sexual difference in many long bone and some skull dimensions. A genetic explanation alone cannot comprehensively account for these differences (Gray and Wolfe, 1980). A consensus has emerged which holds that during life, environmental factors, both cultural and physical, act in shaping the phenotype (Stini, 1985; Brock and Ruff, 1988; Bridges, 1989). Because growth is not interrupted in populations exposed to low levels of environmental stress, sexual dimorphism may be greater in these populations compared with populations experiencing greater levels of environmental stress (Greulich, 1951; Greulich *et al.*, 1953; Tanner, 1962; Stini 1972, 1975; Tobias, 1972). However, a complex interaction of numerous other factors, including genetic differences, may have different effects on populations. Some of these factors are considered below.

Numerous studies have examined this theory from different approaches. Greulich (1951) compared body growth, skeletal maturation and body composition in a nutritionally stressed group and a non-stressed group. Greulich found that males in the stressed group were shorter, weighed less and had greater deficits in weight-to-height ratios and skeletal maturation than the non-stressed group. The difference between females in the stressed and non-stressed groups was considerably less. The identification of that difference has lead to the notion that males are less buffered against stresses during growth and development than females.

The problem with Greulich's (1951) idea is that it focuses on weight and stature differences and does not define the effect of different stresses on different parts of the body. More recent studies have shown that skeletal maturation is less affected by environmental factors than linear growth (Frisancho *et al.*, 1970, 1977)

Efforts have been made to identify the effect of stress on different parts of the body by comparing differences in male and female growth, body size and composition in populations that experienced episodes of nutritional deficiencies (Hiernaux, 1968; Stini, 1972; Tobias, 1972; Hiernaux and Boedhi-Hartono, 1980). These researchers found that sexual dimorphism in stature was less in under nourished groups compared to well nourished populations. Consequently, they argued that these results supported the notion that in nutritionally stressed groups sexual dimorphism is reduced. One problem with this conclusion is that it assumes a basic level of sexual dimorphism in each of the variables studied (growth, body size and body composition), and that deviations from the expected level are interpreted as sex differences in response to environmental factors. However, studies of different ethnic groups who live in 'non-stressed' conditions display differing levels of sexual dimorphism (Ashcroft *et al.*, 1966; Eveleth, 1975; Stini, 1972; Bogin and MacVeen, 1982). These sex differences may reflect genetic rather than nutritional differences.

Little consideration has been given to behavioural implications in sex differences. Studies of arm muscle found that circumference was reduced in under nourished populations, while the degree of sexual dimorphism remained similar compared to well nourished populations (Black *et al.*, 1977; Stini, 1972). Black *et al.* (1977) suggested that the maintenance of this difference may be the result of function, whereby male upper arm use was greater compared to females.

Another approach has been to compare genetically different populations living in similar environments. This approach holds that male body proportions would be more similar to each other compared with females. The basis for this reasoning is the assumption that male growth is affected by environmental conditions to a greater extent than females. A number of studies have investigated the effects of altitude on stature. It was found that sexual dimorphism in stature decreased in populations living at altitudes over 4000 metres where living conditions were more severe than at lower altitudes (Haas, 1976; Stinson, 1985). Other studies that have considered temperature gradients found that male growth and body size differ more widely than females

(Schreider, 1950; Eveleth, 1966). However, one recent study found differing expressions of sexual dimorphism in the femur in two neighbouring African groups (Macho, 1990). Macho concluded that environmental conditions can affect bone in differing ways, and that linear growth is just one aspect of a complex interaction of variables. The problem with the environmental approach is determining similarities of environments from which comparative populations can be selected for study. Additionally, these studies attempt to limit one variable from a complex set of variable interrelationships that help define sex differences.

Other studies have focused on secular trends of increasing stature and sexual dimorphism (Tobias, 1975). Many of these studies measure the statures of immature individuals before and after they were given nutritional supplements. It was found that males experienced a catch up growth phase with females after nutritional supplements were given. Females did not experience the same growth rates as males. The problem with this is determining the extent to which females are buffered against nutritional deficiencies and the speed at which they regain their growth potential (Greulich, 1951; Tanner, 1962; Frisancho *et al.*, 1977; Malina *et al.*, 1981; Susser, 1981).

Estimates of stature and body mass based on skeletal material provide a valuable indication of differences between sexes in different populations, but they are not a reliable indicator of behavioural differences (Eveleth, 1975; Gray and Wolfe, 1980). Postcranial skeletal dimensions are more likely to reflect behavioural experiences, because bone deposition and remodelling responds to mechanical force (Ruff, 1987). The understanding of these changes stems from the work of Julius Wolff (1892). He observed that changes in the function of bone preceded changes in bone shape and geometry. Wolff proposed a law that states that new bone is preferentially deposited at the points of greatest strain on a bone. Following the principle of this law, that is that bone formation reflects biomechanical function, any change in function will cause a change in bone structure. Therefore, although bones have a basic, genetically determined form, environmental and functional activities do contribute to the final form. Bony changes may provide information that relates to specific environmental functional activities. To assess the degree of sexual dimorphism as an expression of behavioural differences, it is important to select variables that reflect these differences. Muscles involved in abduction and rotation are important because these movements produce features on the bone where muscle tendons insert or originate. The same force acts on either end of the muscle, but the insertion point is usually smaller than the point of origin. Thus, greater force is applied per unit area at insertion compared to the point of origin (France, 1988). Consequently, more bone will be deposited at the muscle insertion point than at the muscle origin. Bone measurements taken at the point of insertion may be used to show activity or occupation related differences that act as a means to differentiate between the sexes (Burr *et al.*, 1977; France, 1988).

Ruff (1987) observed that both femoral and tibial anteroposterior midshaft diameters and sexual dimorphism is less in agriculturalists compared to hunter-gatherers. He considered the different diameters to be a consequence of different subsistence strategies, while a decline in sexual dimorphism was regarded to be a consequence of differing task activities between the sexes. Similar trends have been found in other skeletal populations (Frayer, 1980; Howard, 1982; Geesink *et al.*, 1984; Brock and Ruff, 1988; Bridges 1989). However, Stirland (1993) suggests that there are difficulties with associating bony changes to function that may bias the results.

It is held that sexual dimorphism declines in a population when environmental (cultural and physical) stress increases in that population (Stini, 1975, 1985; Tobias, 1975; Relethford and Hodges, 1985). Thus, the degree of sexual dimorphism is a measure illustrating the degree of success a population has in adapting to an environment, and illustrates the degree of sexual stratification (access to resources) in a population.

2.21 The clavicle:

Clavicle length and circumference

Clavicle length provides an indication of the shoulder breadth of an individual. Males tend to have broader shoulders and therefore longer clavicles than females. These differences are associated with a release of androgens during the final growth spurt in males (Thieme, 1957; McCormick *et al.*, 1991). Clavicle length and circumference have been found to be useful in identifying sex differences. A recent study found that females on average have greater ratios of body length to clavicle circumference and clavicle length than males, but only the former ratio was a reliable indicator of sex (McCormick *et al.*, 1991).

2.22 The humerus:

Humerus length and diameter

The length of the humerus has been shown to be sexually dimorphic (Hanihara, 1958; Holman and Bennett, 1991; Thieme and Schull, 1957). However, the length of the humerus may be subjected to episodes of arrested growth during ill health or dietary deprivation. The affect of these factors will be to reduce the levels of sex differences.

The deltoid muscle abducts the arm and attaches the bone to the shoulder. The deltoid muscle is the prime mover of arm abduction. It is also involved in flexion, extension, and rotation depending on whether the anterior or posterior muscle fibres are active. Measurements of the midshaft deltoid tubercle area provide an indication of upper body use. A number of studies have found measurements of the midshaft of the humerus to be accurate in predicting sex (Dittrick and Suchey, 1986; France, 1988). This difference may be seen to indicate behavioural differences rather than genetic differences (McCormick *et al.*, 1991).

2.23 The femur:

Femur midshaft circumference, diameters, and indices

Measurements and indices used in the analyses of the femur and tibia were chosen because they reflect the size of the bone and the response the bone had to muscle loading strain. The dimensions of the femur that were considered reflect the forces of the upper limb muscles that acted on the bone. The bone dimensions that are considered are the primary sites of the thigh muscle origins or insertions. The forces that these muscles produce are reflected on the bone where they originate or insert. These actions may contribute to bending the bone in a certain direction, or they may be associated with increasing the size of the bone at a particular site. For example, anteroposterior bending stress on the bone is associated with walking, running and climbing activities (Ruff and Hayes, 1983; Collier, 1989). At least one study (Ruff, 1987) considers that the cross sectional diameters of the lower limb bones more accurately reflect behavioural differences between the sexes than do bone length or overall robusticity.

Male and female differences in the cross sectional diameters of the femur may be partially attributable to the wider interacetabular breadth of the female pelvis. This seems to increases mediolateral bending loads on the femur, and therefore causes the mediolateral diameter in the female femoral shaft to increase compared to males (Macho, 1990; Ruff, 1987; Ruff and Hayes, 1983). This may explain why the midshaft femur is a reasonably reliable sex indicator (Davivongs, 1963; DiBennardo and Taylor, 1979, 1982; Dittrick and Suchey, 1986; Ruff, 1987).

It must be stated here that statistical analyses of indices have disadvantages in that indices may be relatively inaccurate and that their distributions may not be normally distributed. The advantage of using indices in this study is that they allow a meaningful interpretation of some biological processes that operate on the limbs.

2.24 The tibia:

Midshaft circumference, diameters, and indices

The measurements of the tibia midshaft do not accurately reflect behavioural activities because this area is subjected to the least muscle strain (Ruff and Hayes, 1983). However, marked midshaft differences between the sexes are evident in many skeletal populations (Iscan and Miller-Shaivitz, 1984; Collier, 1989).

2.25 Body proportions

Following Allen's rule (1877), variations in body proportions such as the brachial index, the crural index, arm length-to-stature and leg length-to-stature, are able to give some indication of adaptation to a cold or warm environment. It has been demonstrated that in colder climates people have longer trunks, shorter limbs and bigger chests (Newman, 1953; Coon, 1982).

Sex differences in body proportions are investigated, as similar proportions in both sexes indicate a climatic influence (or commonality of influences), while differences indicate a non-climatic influence, such as diet and genetics.

2.26 Nasal dimensions:

Height and breadth

Nasal height and nasal breadth are influenced by different factors. They differ in the rate of growth and timing of growth spurts, therefore they should be investigated separately. Both nasal height and nasal breadth are also influenced by environmental factors (Davies, 1929; Franciscus and Long, 1991). Nasal height appears to be sexually dimorphic in most populations. This difference seems to be related to the greater oxygen requirement of males (Houghton and Kean, 1987).

Nasal breadth may be less influenced by environmental factors than nasal height (Houghton and Kean, 1987). Therefore, it may be a useful tool in identifying differences within a population. Variation in nasal breadth has been associated with temperature and humidity (Franciscus and Long, 1991).

2.27 The mandible:

Ramus height, ramus breadth and coronoid height

The dimensions of the ramus are influenced by the mechanical demands imposed by the masticatory muscles and its functional requirement to articulate with the maxilla (Enlow, 1990; Kilaridis, 1989). Thus, the expectation is that more heavily muscled males will exhibit larger ramal dimensions than females. The location of these dimensions are illustrated in Figure 6.1.

Bigonial breadth

Eversion or gonial flaring of the bigonial breadth is variable, because it reflects anatomical, functional and muscular influences, particularly of masseter and pterygoid development (Enlow, 1990).

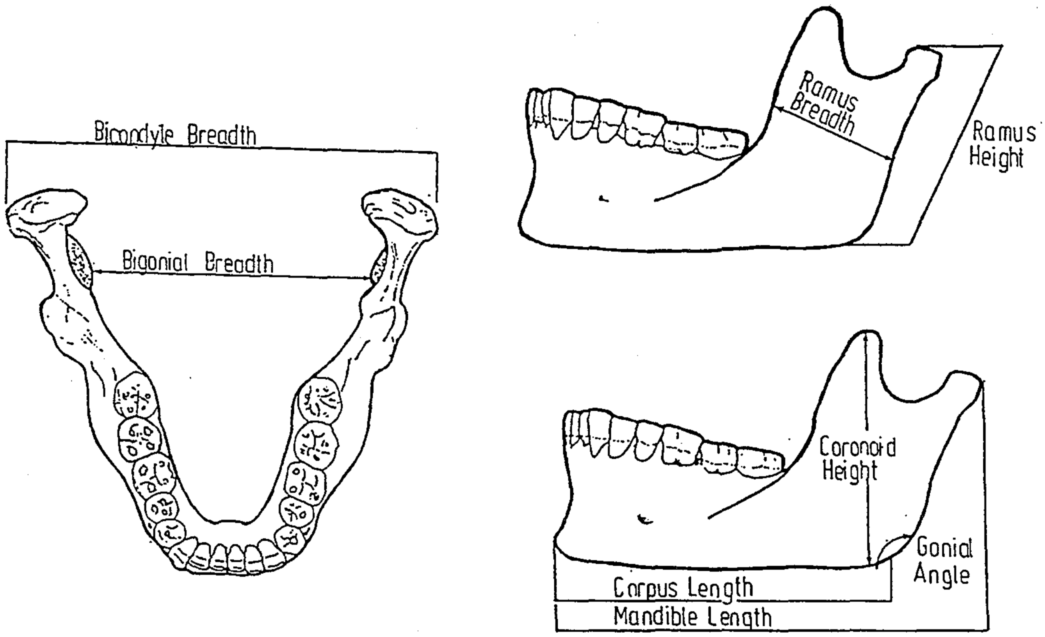
Bicondylar breadth

Bicondylar breadth is a requirement of the mandible to adapt to the earlier maturation of the central and frontal lobes of the brain and their bony support, particularly the temporal bone (Enlow, 1990) (Figure 6.1). This adaptation is necessary to maintain biomechanical efficiency of the mandible as a lever and as an apparatus in the masticatory system.

Mandible length and corpus length

The mandible length and the corpus length (Figure 6.1) develop in response to cranial changes, and to maintain efficient occlusion with the maxillary arch (Enlow, 1990). These two variables have displayed low levels of variation within a population that may suggest that they have similar genetic and/or environmental influences (Wolpoff, 1975).

Figure 6.1
Mandible dimensions used in this study.



Gonial angle and gonial physical angle

The biological basis of the factors affecting the gonial angle are not well understood and differs from head type to head type (Enlow, 1990). Some studies have shown that the angle may change depending on whether muscles are inserted more posteriorly or anteriorly along the body of the mandible (Horowitz and Shapiro, 1955; Avis, 1959; Moss and Simon, 1968; Horaist, 1974).

Other studies have identified a decrease in the gonial angle in association with advancing tooth wear (Fishman, 1976), although this may not always occur (Richards, 1984). It is known that the removal of muscle insertions on the mandible have been shown to change the size and shape of the gonial process (Horowitz and Shapiro, 1955; Avis, 1959). On average the mandible angle is less in males than females (Figure 6.1).

Gonial angles are held to be a reflection of genetic influence because of its requirement to adapt to the cranial base angle, which seems to be under strong genetic control (Houghton and Kean, 1987; Enlow, 1990). As the gonial angle of the mandible seems to be under indirect genetic control, in order to obtain and maintain lever efficiency masseter muscle size increases relative to increases in the acuteness of the gonial angle (Houghton and Kean, 1987). This theory holds that there is an inverse relationship between the gonial angle, the cranial base angle, and mandibular dimensions (and muscle size).

Alternatively, while the gonial angle is indirectly influenced by the cranial base angle, it is also able to be modified by the force of the masticatory musculature. For example, in a robust population, the masticatory musculature would be correspondingly robust. To support larger musculature, the ramal dimensions would be required to be correspondingly large. The growth and development of the mandible and gonial angles are further elaborated on in Chapter Ten. Some of the considerations raised above are investigated in this chapter.

3.0 Methods

3.1 Dental traits

3.11 Buccolingual and mesiodistal diameters of the first molars

The discussion presented above indicated that the first molars are held to be the most stable tooth in mice. Similarly, in humans first molars show the least variability compared to the second and third molars (Hillson, 1986). On the basis of these studies, the maximum diameters of the first molars were measured. Molar teeth with wear exceeding Molnar's (1971) grade five were excluded from the sample. Measurements of the maxillary and mandibular tooth diameters are considered separately. Only individuals who had been sexed and aged over 15 years were included in the analysis.

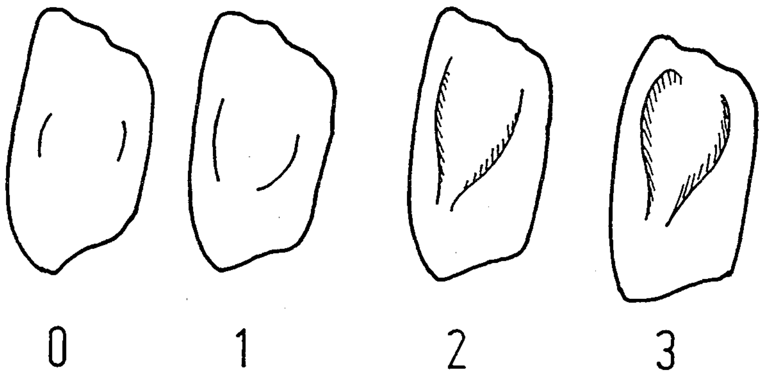
3.12 Maxillary shovel shaped incisors

Maxillary shovel shaped incisors are identified by a concave lingual surface with pronounced marginal ridges. At the cervix of the tooth where the two ridges meet there is a pit rather than the usual smooth bulging surface (Figure 6.2) (Hillson, 1986). The lateral and central maxillary incisors from both sides of the dentition were studied. The frequency of the presence or absence of shovelling traits on each tooth was scored separately. Male and female data are considered separately.

The following scale was used to score the presence or absence of shovel shaped incisors:-

0 = Absent.
1 = Trace. Slight ridging on the lingual margins.
2 = Semi shovel shaped. Medium ridging on the lingual margins.
3 = Shovel shaped. Strong ridging on the lingual margins.

Figure 6.2
The forms of maxillary incisor teeth.



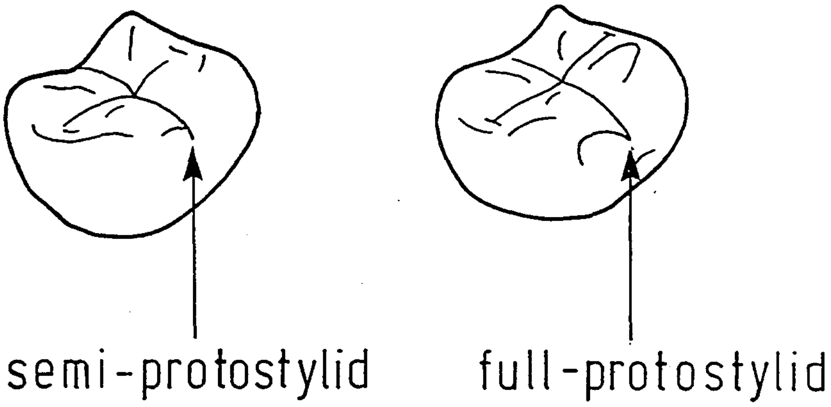
3.13 Molar protostylids

The presence or absence of protostylids on the buccal surface were recorded in all the mandibular molars. The data from the left and right sides are combined for each tooth. For example, data from the left first molar are combined with the right first molar. Male and female data are considered separately.

The protostylid has been graded following Dahlberg (1961). (See Figure 6.3). The scale used was as follows:-

0 = Absent.
1 = Pit present.
2 = Fissure present.
3 = Pit and fissure present.
4 = Cusplet partially present.
5 = Cusplet present.

Figure 6.3
The forms of protostylids on the buccal molars.



3.14 Molar cusp patterns

The cusp patterns of the first and second maxillary molars are recorded. Data from the left and right sides are combined. Males and females are investigated separately.

The method of recording the maxillary molar cusp patterns followed Dahlberg's (1951) scale. This was as follows:-

4+ = Four well-developed cusps.
4- = Hypocone reduced in size.
3+ = Hypocone represented by a small cusplet.
3 = Three cusps only.

As with examining the maxillary molar cusp patterns, only the first and second mandibular molar cusp patterns are investigated. Again, data from the left and right sides are combined. Males and females are investigated separately.

The mandibular molar scaling system followed Dahlberg (1951). The following classification was used:-

Y-5 = Five well developed cusps.
+5 = Fifth cusp reduced in size.
Y-4 = Fifth cusp represented only by a cusplet.
+4 = Four cusps only.

3.15 Hypodontia

The method used to record hypodontia was to note a tooth's absence. Only complete adult dentitions, or dentitions where hypodontia was obvious, were used. Comparisons are made between males and females.

3.2 **Skeletal traits**

3.21 The clavicle:

Length and circumference

Clavicles from adult males and females were used for analysis. The left clavicle was preferentially measured. In individuals where this was not possible, the right clavicle was used. Clavicle lengths are obtained by measuring the maximum distance from the medial sternal end to the distal acrominal end of intact bones. Clavicle circumference was measured at the midshaft of the bone.

3.22 The humerus:

Length and anteroposterior diameter

Humeral measurements were obtained from adult males and females. The left humerus was preferentially measured. In individuals where this was not possible, the right humerus was used. The maximum length of intact humeri, from the humerus head to the trochlea, are measured. The anterioposterior diameter of the humerus is taken from the site of the deltoid tubercle on the proximal third of the humerus.

3.23 The femur:

In this analysis, the left femur was preferentially measured. In individuals where the left femur was unable to be measured, the right femur was used. These measurements are taken from the femora of adult males and females.

Platymeric index

The platymeric index is based on the anteroposterior and mediolateral diameters of the subtrochanteric femoral shaft. The following formula was used to obtain the platymeric index:-

$$\frac{\text{Subtrochanteric anteroposterior diameter}}{\text{Subtrochanteric mediolateral diameter.}} \times 100$$

Midshaft robusticity

Calculating femoral midshaft robusticity involved measuring the anteroposterior and mediolateral diameters at the middle of the femoral shaft. Adult femora from males and females are measured. The formula used to obtain the robusticity index was as follows:-

$$\frac{\text{Anteroposterior + mediolateral midshaft diameter}}{\text{Maximum femoral length}} \times 100$$

Pilastric index

The pilastric index is obtained from the anteroposterior and mediolateral diameters of the femoral midshaft. To obtain the index the following formula was used:-

$$\frac{\text{Anteroposterior midshaft diameter}}{\text{Mediolateral midshaft diameter}} \times 100$$

3.24 Lower limb-stature ratio

Lower limb-stature ratios were obtained adding the maximum lengths of the left femur and left tibia of adult males and females. The sum of these bones was then divided by the stature of the individual. Stature was obtained from regressions calculated from the length of long bones following Houghton, *et al.* (1975).

3.25 Upper limb-stature ratio

The method used to obtain the upper limb-stature ratio involved summing the maximum lengths of the left humerus and left radius of adult males and females. The sum of these two bones was then divided by the stature of the individual.

3.26 Brachial index

The brachial index is derived from the maximum lengths of the left humerus and left radius. Male and female indices are investigated separately.

The brachial index was calculated by using the following formula:-

$$\frac{\text{Maximum radius length}}{\text{Maximum humerus length}} \times 100$$

3.27 Crural index

Where possible individuals with both the left femur and left tibia were used to calculate crural indices. Males and females indicies are to be investigated separately.

The crural index was calculated by using the following formula:-

$$\frac{\text{Maximum tibia length}}{\text{Maximum femur length}} \times 100$$

3.28 Nasal diameters:

Nasal height and breadth

Only adults are to be used to obtain nasal diameters. Male and female are considered separately. Nasal height measurements are taken from the nasion to the lowest point of the nasal aperture (Howells, 1973).

Nasal breadth is taken as the distance between the anterior edges of the nasal aperture at the widest point (Howells, 1973).

3.29 Mandible Dimensions:

Only adults are to be used to obtain mandibular diameters. Males and females dimensions are to be considered separately. Measurements from the left side are to be used. If no measurements are unable to be taken from the left side then the right side will be included in the results. Mandibular measurements are described below. The measurements taken are based on standard anatomical landmarks. References to these anatomical landmarks can be readily found in Bass (1971).

Ramus height

To obtain ramus height, the ramus was measured from the mid-point of the gonial angle to the superior surface of the mandibular condyle (Figure 6.1).

Ramus breadth

Ramus breadth is the measurement of the minimum distance between the anterior and posterior boarders of the mandibular ramus (Figure 6.1).

Coronoid height

Coronoid height was measured following the minimum distance from the superior surface of the coronoid process to the base of the mandible corpus (Figure 6.1).

Bicondylar breadth

Bicondylar breadth is the maximum distance from the lateral condyle to lateral condyle (Figure 6.1).

Bigonial breadth

Bigonial breadth is a measurement of the maximum distance between the lateral aspects at the gonial angle (Figure 6.1).

Mandibular length

Mandibular length is the maximum length of the mandible. The measurement is taken from the symphysis to the posterior condyles (Figure 6.1).

Corpus length

Corpus length is the measurement from the mandibular symphysis to the gonial angle (Figure 6.1).

Gonial angle

The gonial angle is measured by placing the mandible on a level surface and measuring the angle of the ascending ramus from the corpus body using a goniometer (Figure 6.1).

Gonial physical angle

To obtain the gonial physical angle, the mandible was placed on a level surface. The mandible position was then aligned so than the occlusal surfaces of the teeth were horizontal to the level surface. The angle of the ascending ramus was then measured using a goniometer (Figure 6.3).

4.0 Results

4.1 Dental results

4.11 Tooth size

Table 6.1. presents the number of teeth in the sample, the mean, and standard deviation of mesiodistal and buccolingual diameters of the sexes.

The third molars have the largest standard deviations in both sexes. Large standard deviations are also found in both male and female maxillary teeth, particularly when compared to mandibular teeth.

The third molar diameters of females have the greatest variability proportional to tooth size, while the mandibular first and second molars and maxillary incisors are the least variable. In males, large variations are not only found in the third molar diameters, but also in the lateral incisors and the buccolingual diameter of the maxillary premolars. The first and second molars are the least variable teeth in males. The mesiodistal diameter of the second premolar also has comparatively low standard deviations.

Greater variability occurs in the maxillary teeth compared to mandibular teeth. This contradicts Bailit (1966) who predicted that maxillary teeth are more genetically stable. The lower levels of variability found in the buccolingual and mesiodistal diameters of the first and second molars make these teeth more appropriate variables for future analyses in males. Among females, the diameters of the maxillary premolars should be included with the first and second molars as the least variable teeth.

Table 6.1
Summary statistics of all tooth diameters of males and females from Sigatoka.

	Males			Females		
	Mean	n	s.d.	Mean	n	s.d.
Maxillary Teeth Mesiodistal						
M3	94.1	21	12.4	92.8	36	12.5
M2	108.7	29	9.1	99.5	32	10.2
M1	107.7	34	7.8	101.5	36	11.5
P2	71.5	28	4.0	69.2	41	6.4
P1	72.6	24	4.8	71.0	34	7.0
C	79.1	27	6.1	76.8	35	7.4
I2	71.9	20	7.9	72.9	30	6.6
I1	76.1	23	7.2	81.3	28	8.6
Maxillary Teeth Buccolingual						
M3	112.6	22	9.8	109.4	36	12.9
M2	117.4	32	10.2	113.6	41	10.5
M1	114.4	33	9.6	112.1	39	9.5
P2	94.2	27	9.5	94.5	41	7.3
P1	93.9	26	11.8	96.3	36	6.8
C	85.4	27	8.0	81.2	34	6.1
I2	68.1	21	7.3	66.0	30	4.9
I1	74.2	22	7.0	71.0	29	4.0
Mandibular Teeth Mesiodistal						
M3	113.4	30	9.4	111.4	31	11.8
M2	113.7	34	8.6	111.2	36	6.6
M1	112.8	33	7.6	108.0	35	7.2
P2	71.9	32	6.5	71.3	44	6.5
P1	72.1	28	7.8	70.6	33	5.7
C	71.6	32	6.4	67.8	38	4.7
I2	59.9	22	7.0	58.1	32	5.9
I1	51.3	24	6.7	51.5	23	4.6
Mandibular Teeth Buccolingual						
M3	104.3	30	10.5	105.0	31	7.5
M2	107.2	33	7.1	106.7	35	5.8
M1	107.7	34	6.9	107.4	35	5.8
P2	85.0	31	6.0	85.0	40	5.5
P1	82.5	27	6.4	80.5	35	5.4
C	77.4	31	7.9	74.0	38	3.4
I2	60.9	23	8.3	60.5	33	6.5
I1	58.0	21	7.1	56.8	24	3.7

Measurements in millimetres.

To test the significance of male-female tooth differences, a Student's *t* test was applied to the data. These results are presented in Table 6.2. Six tooth diameters show a significant sex difference at the level $P \leq 0.05$. Of the four canine diameters only the mesiodistal maxillary canine was not significantly sexually dimorphic. Very significant differences were found between male and female mesiodistal diameters of the first and second maxillary molars.

The results presented in Table 6.2 show that most of the tooth diameters have very low levels of sexual dimorphism. Mandibular teeth, particularly the second premolar, differ only slightly between the sexes in both dimensions. The canines are the only teeth that are consistently sexually dimorphic. This finding is expected and has shown to exist in many sexual dimorphism studies (Garn *et al.*, 1966, 1967[a]).

Table 6.2
The results of Student's t tests and f ratios comparing the tooth diameters of males and females.

	Teeth	t statistic	f ratio
Maxillary Teeth Mesiodistal			
	M3	0.4	0.0
	M2	3.9*	0.4
	M1	3.8*	0.9
	P2	1.6	1.6
	P1	1.0	0.0
	C	1.3	0.7
	I2	-0.5	1.2
	I1	-1.6	0.2
Maxillary Teeth Buccolingual			
	M3	1.0	0.1
	M2	1.6	1.7
	M1	1.0	0.1
	P2	-0.2	0.4
	P1	-1.0	0.6
	C	2.3*	0.4
	I2	1.2	0.6
	I1	2.1	0.6
Mandibular Teeth Mesiodistal			
	M3	0.7	0.5
	M2	1.4	0.3
	M1	1.0	1.9
	P2	0.4	0.5
	P1	0.8	1.2
	C	2.8*	0.8
	I2	1.0	0.4
	I1	-0.2	1.9
Mandibular Teeth Buccolingual			
	M3	-0.3	0.7
	M2	0.3	0.6
	M1	0.3	2.0
	P2	0.0	1.0
	P1	1.3	0.6
	C	2.4*	1.7
	I2	0.2	4.3*
	I1	0.7	0.5

* $P \leq 0.05$

4.12 Maxillary shovel shaped incisors

Table 6.3 summarises the shovel shaped incisor data. Of the 143 maxillary incisors assessed for the incidence of shovelling, 41% show some expression of shovelling. Shovel shape is more frequent on the lateral incisors (52%), compared to central incisors (58%). Semi or full shovel shape occurs in only 14 of the 143 teeth.

Table 6.3
The frequency of shovel shaped teeth in males and females.

Trait	Males	%	Females	%	Total	%
Absent	24	61.5	42	51.8	85	59.4
Trace	11	28.2	31	38.3	44	30.8
Semi	4	10.3	6	7.4	12	8.4
Full	0	0.0	2	2.5	2	1.4
Total	39	100.0	81	100.0	143	100.0
Chi Squared		29.91		55.55		126.36
Significance		0.10		0.10		0.10

Comparative sex results show that females are slightly more likely to display a degree of incisor shovelling than males. Chi squared associations between the sexes based on the central incisors or the lateral incisors, could not be calculated. Therefore, data from the central incisors and lateral incisors were pooled for chi squared analyses. The result demonstrates that male and female incisor shapes are very similar (X^2 =0.0002, P = 99%).

4.13 Molar protostylid

Table 6.4 summarises the protostylid data. Of the 123 molars, 85% had some degree of protostylid expression, although the majority were subtly expressed as buccal pitting or fissures. Just one individual, B16, displayed a protostylid cusplet.

Table 6.4
The frequency of molar protostylid expressions in males and females.

	Males						Females					
	n	M.1.	n	M.2.	n	M.3.	n	M.1.	n	M.2.	n	M.3.
0	1	6.3	0	0.0	7	33.3	8	25.0	10	28.6	13	44.8
1	6	37.4	8	42.1	5	23.8	1	3.1	3	8.6	1	3.4
2	8	50.0	8	42.1	3	14.3	21	65.6	16	45.7	9	31.0
3	1	6.3	3	15.8	2	9.5	2	6.3	5	14.7	3	10.3
4	0	0.0	0	0.0	4	19.1	0	0.0	0	0.0	2	6.9
5	0	0.0	0	0.0	0	0.0	0	0.0	1	2.9	1	3.4

Sex comparisons in protostylid expression were made using chi squared tests. There was insufficient data to calculate accurate assessments of sex associations in each tooth group. Therefore, the data was pooled into groups, one comprising of the first and second molars, and another comprising all adult molars. These results were not significant.

An analysis of the relationship between the type of protostylid expression on the first and second molars of 24 individuals was made using Spearman's rank correlations. Individuals with two or more absent molars were excluded from the sample. A correlation of the same trait appearing on the first molars was found $p = 0.71$ ($P \leq 0.5$). In the second molars the correlation was less pronounced at $p = 0.57$, although still significant ($P \leq 0.05$). The strongest correlation was found between the right first and second molars, $p = 0.77$ ($P \leq 0.05$). In the left first and second molars the correlation was only $p = 0.53$, but the result was significant ($P < 0.05$).

This level of correlation is surprising because the first and second molars develop at different times. Therefore, if environmental factors were responsible for the expression of the trait in both teeth, as suggested by Nichol (1989), environmental factors would have to remain relatively constant for it to be expressed. A genetic basis seems more likely because of the trait's consistent appearance in the first molars, and progressively more varied expression in the third molars (Dahlberg, 1950; Nichol, 1989). However, there is a strong association with the appearance of a trait, principally a fissure, on the first molars to imply a (poly) genetic influence.

4.14 Maxillary molar cusp patterns

Adult cusp patterns from 70 molars (28 first molars and 42 second molars) were recorded. These data are presented in Table 6.5.

Table 6.5

The frequencies of the types of maxillary molar cusp patterns in males and females.

	Males				Females			
Trait	First Molar		Second Molar		First Molar		Second Molar	
	n	%	n	%	n	%	n	%
4^+	4	40	3	18	7	39	6	26
4^-	6	60	11	64	11	61	8	35
3^+	0	0	3	18	0	0	7	30
3	0	0	0	0	0	0	2	9
Total	10	100	17	100	18	100	23	100

The dominant trait is 4- which occurs in just over 51%. Expressions of 4+ trait occurs at the next highest frequency, 28.6%. The expressions of 3+ and 3 traits occur at low levels. Importantly, the expression of a trait on a first or second molar on the left and right side of the dentition is very significantly correlated. In the first molars this correlation was $p = 1.0$ ($P \leq 0.001$), and $p = 0.96$ ($P \leq 0.001$) in the second molars.

The expression of two cusp pattern traits on the first molar in males and females may indicate that this tooth is genetically more stable. However, the sample size is small and it may therefore be an unreliable indicator of genetic links. The second molar cusp expression is more variable, and is probably influenced by environmental factors during tooth formation and genetic traits (Bailit, 1966; Nichol, 1989).

There is a strong association between male and female cusp patterns on the first molars. Analysis shows $X^2 = 0.02$ ($P \leq 99.5\%$). However, no significant association was found between male-female second molars.

4.15 Mandibular molar cusp patterns

The data for the mandibular molar cusp patterns are presented in Table 6.6. Cusp patterns from 50 first and second mandibular molars were recorded.

Table 6.6
The frequency of the types of mandibular molar cusp patterns in adult males and females.

	Males				Females			
Trait	First Molar		Second Molar		First Molar		Second Molar	
	n	%	n	%	n	%	n	%
Y-5	5	62.5	0	0	1	9	3	18
+5	1	12.5	7	54	8	73	6	35
Y-4	1	12.5	2	15	0	0	1	6
+4	1	12.5	4	31	2	18	7	41
Total	8	100.0	13	100	11	100	18	100

The +5 cusp pattern is clearly the most frequent cusp expression, occurring in nearly 45% of the molars. The Y-2 cusp pattern is the least occurring trait, represented in just over 8% of the molars. This unequal distribution is reflected in the chi squared value, $X^2 = 21.75$, $P \leq 0.1$.

While there is a difference in the overall frequency of a trait being present, there was a 100% correlation between the same trait occurring on either the first molars or second molars.

Chi square was used to test the association between male and female cusp patterns. Analysis shows that a significant difference exists between males and females in the first molars ($X^2 = 9.38$. $P \leq 0.05$). Significant differences were not found between the sexes in the second molar cusp patterns. According to Bailit (1966) and Nichol (1989), the first molar is under greater genetic control than the second molar. Therefore the similarities in the first molars may reflect a primary genetic association, while the differences in the second molar may be a reflection of the greater role that environmental influences have in determining cusp pattern formation.

4.16 Hypodontia

The congenital absence of teeth occurred in two locations, the lateral mandibular incisors and the third molars of the maxilla and mandible. Third molar hypodontia occurred at a frequency of 7.1%. Four females and one male experienced third molar hypodontia. The frequency of tooth absence was nearly equal between the mandibular and maxillary teeth, 7.0% in the mandible and 7.3% in the maxilla. One female (B3b), experienced an absence of all four third molars. Two other individuals, B24 and B1/1, experienced bilateral absence in the maxillary and mandibular third molars, respectively. The remaining two individuals were hypodontic in just one tooth. One male, B21b, had bilateral absence of mandibular lateral incisors. This represented a frequency of 1.3% of lateral incisor absence.

4.2 Skeletal results

4.21 Post cranial traits

Comparative results of post cranial traits and the significance between males and females are given in Table 6.7. Twenty five postcranial variables including estimates of body mass and stature were investigated. In males and females the variables with the greatest standard deviations are those associated with bone length. However, little variability was noted in body proportions (crural, brachial, leg-to-stature and arm-to-stature).

Student's *t* tests were applied to the male and female data to assess which variables differed beyond the $P \leq 0.05$ confidence level. These results are presented in Table 6.7. Nine variables proved to be significantly sexually dimorphic. Most of these variables were associated with body size. Body mass and stature were both found to differ very significantly between the sexes. High levels of sexual dimorphism are also evident in the midshaft anteroposterior diameters of the femur and tibia and the humeral circumference.

Differences between the sexes were found in few of the metric traits. Student's *t* tests revealed a significant difference between the male and females right clavicle circumference. This distinction was not present between the left clavicles. The difference between males and females in the femoral circumference, femoral anteroposterior diameter, and tibial anteroposterior diameters were all significant beyond the $P \leq 0.05$ level. No differences were found in the platymeric, pilastric or robusticity indices in the femur. None of the variables differed significantly in variance.

Table 6.7

Comparisons and univariate results of skeletal and body size variables between males and females.

	Males			Females				
Variable	Mean	n	sd.	Mean	n	sd.	*t* statistic	f ratio
Clavicle, length	145.0	3	11.5	132.5	3	0.7	1.5	0.0
Clavicle, circumference(r)	39.3	8	2.6	35.3	6	2.4	3.0**	0.0
Clavicle, circumference(l)	37.3	4	2.1	34.5	9	2.7	1.8	1.4
Radius, length	252.4	5	14.5	243.0	3	20.0	0.8	0.5
Humerus, length	329.0	5	10.1	304.0	5	13.8	3.2**	3.8
Humerus, anteroposterior(r) diameter	18.1	8	1.8	16.0	19	1.8	1.8	0.5
Humerus, anteroposterior(l) diameter	18.2	11	1.8	15.5	14	1.5	4.0**	3.9
Humerus, circumference	64.8	10	5.6	59.3	14	4.6	2.7**	2.7
Femur, length	453.1	8	20.7	449.0	4	15.4	0.4	0.0
Femur, platymeria index	83.7	12	7.0	79.8	14	5.0	1.7	0.3
Femur, pilastric index	11.8	14	0.8	11.5	16	1.3	0.7	0.1
Femur, robusticity index	12.4	8	1.1	12.0	4	0.5	0.6	0.4
Femur, circumference	88.6	14	6.6	84.4	16	4.7	2.0*	0.4
Femur, anteroposterior diameter	30.8	12	2.6	28.2	14	2.8	2.4*	2.3
Femur, mediolateral diameter	26.1	12	2.2	24.7	16	1.8	1.9	3.0
Tibia, length	365.4	11	17.0	355.6	4	21.1	0.9	0.1
Tibia, circumference	82.1	7	9.6	76.0	6	3.4	1.5	0.0
Tibia, anteroposterior diameter	33.1	11	2.9	28.3	9	3.4	3.4**	0.2
Tibia, mediolateral diameter	21.9	13	1.7	20.6	9	1.3	1.9	0.0
Brachial index	74.4	4	3.3	73.7	3	3.2	0.3	10.1
Crural index	81.1	8	2.8	82.7	3	2.4	-0.9	0.8
Leg-to-stature index	47.1	9	1.2	46.8	2	1.1	0.3	—
Arm-to-stature index	32.9	5	1.0	32.8	3	1.4	0.2	0.9
Stature	1739.5	12	40.4	1659.5	11	41.0	8.0**	3.8
Body Mass	70.3	12	6.7	55.5	8	3.1	5.8**	0.6

Significance level * $P \leq 0.05$ **$P \leq 0.01$. Measurements in millimetres. r = right. l = left.

4.22 Crania

The results of cranial measurements are presented in Table 6.8. A difference of 17% was found between males and females in nasal height. This difference proved to be significant beyond the $P \leq 0.05$ level. In both sexes the degree of within sex variation exceeded 10%. Little difference was found between the sexes in nasal breadth. However, male variables that are associated with musculature, (ramus breadth and ramus height), proportionately have the smallest standard deviations. These standard deviations are also proportionately smaller than females, and this may reflect similarities in male musculature.

Eleven variables were chosen to assess the degree of sexual dimorphism in the facial area, two from the skull and nine from the mandible. Student's *t* tests show that sexual dimorphism is significant in mandible length, bigonial breadth, coronoid height, ramus breadth, and nasal height.

Table 6.8

Comparative and univariate results of male and female cranial dimensions.

	Males			Females				
Variable	Mean	n.	sd	Mean	n	sd	*t* statistic	f ratio
Nasal height	54.4	8	6.3	45.0	8	4.9	3.3**	1.0
Nasal breadth	26.9	8	2.7	25.9	13	2.0	1.0	0.9
Mandibular length	110.0	15	6.5	105.8	12	5.9	2.3*	0.7
Corpus length	83.7	15	6.5	82.3	21	6.4	0.6	1.4
Bicondylar breadth	125.2	13	7.8	120.4	10	7.6	1.2	0.7
Bigonial breadth	107.5	14	10.3	97.9	21	7.3	3.3**	0.7
Coronoid height	70.7	13	5.2	65.8	11	4.9	2.4*	0.1
Ramus height	65.2	14	2.5	61.2	13	6.2	1.9	2.8
Ramus breadth	40.6	14	2.5	38.4	19	2.9	2.3*	0.0
Gonial angle	116.9	17	5.3	116.1	21	6.5	0.4	1.6
Gonial physical Angle	104.6	17	6.4	104.8	17	6.4	-0.1	0.0

Significance level* $P \leq 0.05$; **$P \leq 0.01$. All measurements in millimetres, except angles.

Sex dimorphism in nasal height may be associated with greater oxygen requirements in males because of their greater muscle mass. To assess whether any association exists between body mass, stature and nasal height, Pearson's correlations were calculated. These results are presented in Table 6.9.

Table 6.9

Pearson's correlations of nasal height and breadth with stature and mass.

	Males.		Females	
	Pearson's r	n	Pearson's r	n.
Mass-nasal height	-0.20	7	0.93	3
Stature-nasal-height	0.33	8	0.40	6
Mass-nasal breadth	0.02	7	0.62	5
Stature-nasal breadth	0.60	7	0.39	6

Within the limits of a small sample size, these results show that the female nasal diameters are closely correlated with body mass and less so with stature. This does not seem to be the case in males. The male results are more typical of other populations (Houghton, pers. comm.). This is because males have a greater muscle mass and hence oxygen requirements compared to females.

Four of the nine mandibular measurements considered in Table 6.8 have significant sex differences beyond the $P \leq 0.05$ level. These variables are the ramus breadth, bigonial breadth, mandible length, and coronoid height. Apart from coronoid height, all of these variables are associated in some aspect with the air passage and pharynx (Enlow, 1968; 1990). Coronoid height is a reflection of the temporalis muscle attachment. The lack of sex differences in other mandibular dimensions suggests that they experienced similar functional influences.

A theory presented earlier in this Chapter outlined the influences on mandibular shape. Aspects of this theory are considered, in order to assess the influences on the Sigatoka craniofacial form. The Sigatoka mandibles have broad ramal diameters, and in most cases the antegonial notch is absent. The mandibles, especially those of males, display very robust muscle insertions, particularly of the lateral and medial pterygoid and masseter muscles. They show a tendency towards rocker jaw type, but the corpus is not bowed as in the classic rocker jaw described by Houghton (1978). Nevertheless, the Sigatoka mandibles have acute gonial angles that are associated with rocker jaws, and should therefore comply with the theory of a negative association between the gonial angle and size of musculature as indicated by muscle attachments on the ramus. To test if these associations are present in Sigatoka adults, Pearson's correlations of mandibular dimensions are calculated in Tables 6.10 and 6.11.

Table 6.10

Pearson's correlations of male mandible dimensions

	Bigonial breadth	Corpus length	Mandible length	Ramus breadth	Ramus height	Coronoid height	Gonial angle	Gonial physical angle
Bigonial breadth (13)	1.000							
Corpus length (15)	0.449	1.000						
Mandible length (15)	**0.669	0.337	1.000					
Ramus breadth (14)	-0.368	**-0.662	-0.223	1.000				
Ramus height (14)	*0.557	*0.589	-0.018	-0.349	1.000			
Coronoid height (14)	0.426	0.347	0.225	-0.236	**0.793	1.000		
Gonial angle (17)	0.307	-0.041	**0.645	-0.118	-0.456	-0.201	1.000	
Gonial physical angle (17)	0.303	0.220	*0.573	0.415	-0.350	0.077	**0.793	1.000

Significance levels * $P \leq 0.05$ ** $P \leq 0.01$. NB. Maximum ramus height could not be accurately measured because of pathology in the TMJ. Figures in brackets are the number of individuals.

The male and female mandible correlation results differ. Some of the significant correlations in the male variables appear to contradict Houghton and Kean (1987). The most telling of these is the positive correlation between mandibular length and both gonial angles. In other words, as the mandible length increases, the gonial angle becomes less acute. This association is to be expected because opening the gonial angle inevitably increases the total length of the mandible. However, the association is not present in females.

Table 6.11

Pearson's correlations of female mandible dimensions.

	Bigonial breadth	Corpus length	Mandible length	Ramus breadth	Ramus height	Coronoid height	Gonial angle	Gonial physical angle
Bigonial breadth (23)	1.000							
Corpus length (15)	** 0.601	1.000						
Mandible length (15)	-0.076	-0.079	1.000					
Ramus breadth (14)	-0.190	-0.120	-0.252	1.000				
Ramus height (14)	-0.213	-0.298	-0.245	-0.083	1.000			
Coronoid height (14)	-0.007	-0.103	-0.158	-0.071	**0.819	1.000		
Gonial angle (17)	0.182	0.121	-0.205	-0.272	-0.190	0.137	1.000	
Gonial physical angle (17)	**-0.644	*-0.479	0.078	0.166	-0.430	0.118	-0.207	1.000

Significance levels* $P \leq 0.05$ ** $P \leq 0.01$

Among females, the corpus length of the mandible increases relative to ramus breadth. This arrangement makes the mandible an inefficient lever. However, ramal height and bigonial breadth increase, seemingly to offset this inefficiency. This may be a response to increased forces applied by the pterygoid muscles. However, there remains the problem of the ramus breadth contribution to the mandible length, which will affect these relationships.

Male mandible correlations reflect a closer relationship to Houghton and Kean's (1987) idea, because the longer the mandible, the more efficient the bony lever. The corpus length shows the expected relationships to the gonial angle in males, but not in females. Anticipated significant negative correlations exist between bigonial breath and corpus length with the gonial physical angle. Corpus lengths, coronoid height, and ramus height are significantly correlated to bigonial breath. These diameters illustrate a trend toward the development of strong musculature and a wide bigonial breadth to efficiently move the mandible lever. Yet there is a noticeable lack of significant inverse relationships with the dimensions of the ramus and the gonial angle(s).

While the results lend support to the lever idea, there is also ambiguity between male and female results. This ambiguity between the sexes suggests little or no link between greater musculature and the acuteness of the gonial angle in the Sigatoka people. In order to test this suggestion, the degree of tooth wear and TMJ (temporomandibular joint) pathology were assessed. To identify the influences these factors may have had, both sexes were divided into two age cohorts, those over 35 years and those under 35 years (Tables 6.12 and 6.13).

Progressive dental wear does not necessarily reduce facial height, partially because teeth are able to "super erupt" to compensate for the loss of crown height (Fishman, 1976; Murphy, 1959). However, an inability of the teeth (or bone), to completely compensate for crown loss can lead to a reduction in facial height (Talgren, 1957; Barrett, 1969; Richards and Brown, 1981). Facial height reduction tends to occur in groups with a particularly abrasive diet where the rate of dental wear exceeds the rate of compensatory eruption.

The rate and degree of dental wear is not only related to masticatory function. It has also been shown to be influenced by changes in aspects of the craniofacial skeleton (Blackwood, 1966). For example, an association has been found between extreme tooth wear and tooth loss with mandibular protrusion (Richards, 1984). However, not all craniofacial changes influence the rate of tooth wear. Regressive remodelling in the TMJ is demonstrative of the inability of bone in the joint to adapt to changing functional loads placed on that joint by masticatory function (Richards, 1984, 1988; Westersson, 1985; Sheriden *et al.*, 1991; Owen *et al.*, 1992). Many of the Sigatoka males experienced severe TMJ regressive remodelling, however there was no difference in the degree of tooth wear between individuals with TMJ regressive remodelling and those with no remodelling (Visser, 1994).

To test the hypothesis that an association exists between tooth wear on the molar and canine teeth and mandible dimensions, two male and female age cohorts were compared. Two groups were used because the younger cohort typically have less tooth wear on the canines and molars than the older cohort.

Table 6.12

Probability results of Spearman's correlations between tooth wear and mandible dimensions of males aged under 30 years and those aged older than 30 years.

	20-34 cohort		35 plus cohort	
Variable	Canine wear	Molar Wear	Canine Wear	Molar Wear
Bigonial breadth	0.915	0.802	0.000	0.000
Mandible length	0.296	0.839	0.800	0.553
Corpus length	0.587	0.078	0.600	0.106
Ramus breadth	0.395	0.106	0.600	0.106
Gonial angle	0.262	0.789	0.400	1.000
Gonial physical angle	0.405	0.591	0.800	0.106

Tables 6.12 and 6.13 present the results of Spearman's correlations between tooth wear and mandibular variables of age cohorts and sexes. Notably, there are no significant correlations in the younger cohorts. This is probably because there is little tooth wear in these groups. In the female cohort older than 35 years, there is a weak correlation between anterior tooth wear and gonial angles. However, there is no significant, or even relative age related change in the female gonial angles. Thus, this correlation can be discounted. Among males older than 35 years of age, advancing tooth wear correlates strongly with lateral eversion of the gonial process as indicated by bigonial breadth. This seems to be an age associated trait in males but not females.

Table 6.13

Probability results of Spearman's correlations between tooth wear and mandible dimensions of females aged under 30 years and those aged older than 30 years.

	20-34 cohort		35 plus cohort	
Variable	Canine wear	Molar Wear	Canine Wear	Molar Wear
Bigonial breadth	0.119	0.246	0.682	0.610
Mandible length	0.945	0.171	0.262	0.244
Corpus length	0.077	0.496	0.461	0.770
Ramus breadth	0.288	0.488	0.354	0.770
Gonial angle	0.719	0.840	0.068	0.772
Gonial physical angle	0.945	0.171	0.003	0.244

Severe TMJ regressive remodelling and condyle skewing have been shown on all males in the older cohort (Chapter Five). A smaller proportion of younger males had TMJ degeneration compared with older males. This was generally less severe than in older individuals. Similarly, condyle skewing was either less pronounced or not evident in younger individuals. TMJ changes were not evident among females.

There seems to be more than biomechanical and pathological factors influencing the shape of the mandible. While it is outside the scope of this study to make a detailed investigation of the biomechanical and structural interplay of the masticatory system in the Sigatoka people, some hypotheses may be proposed. One suggestion is that there seems to be an effort to maximise muscle efficiency by broadening the bigonial breadth and increasing the ramal height. The positive correlations between mandible length and the gonial angles are unexpected. This correlation does not occur in females therefore it may be related to TMJ degeneration.

In an effort to analyse age trends and changes in the mandible bony structure, Student's *t* test were used to calculate whether differences occurred between the age and sex cohorts. These results are presented in Table 6.14.

Table 6.14
Probability results of Student's *t* tests showing the significance of differences in mandibular changes between age cohorts.

Variable	♀ 20 - ♂ 20	♀ 20 - ♀ 35	♀ 20 - ♂ 35	♂ 20 - ♀ 35	♀ 35 - ♂ 35	♂ 20 - ♂ 35
Bigonial breadth	0.14	0.00	0.00	0.04	0.00	0.03
Corpus length	0.86	0.06	0.61	0.40	0.03	0.28
Mandible length	0.24	0.09	0.05	0.89	0.02	0.05
Ramus breadth	0.21	0.41	0.35	0.02	0.04	0.63
Ramus height	0.21	0.51	0.04	0.09	0.05	0.13
Gonial angle	0.46	0.64	0.64	0.30	0.47	0.30
Gonial physical angle	0.82	0.13	0.13	0.96	0.34	0.10
Canine wear	0.53	0.04	0.01	0.00	0.19	0.00
Molar wear	0.28	0.01	0.00	0.00	0.52	0.00
TMJ degeneration	0.00	—	0.00	0.00	0.00	0.05

There are two conclusions that can be drawn from the data presented in Table 6.14. One is that the gonial angles do not significantly vary with age or sex. Secondly, males over 35 years of age display the most variable dimensions compared to other cohorts. This is particularly evident when they are compared with females from the same age cohort. The results suggest that while the gonial angle does not significantly alter with male age, the condyle neck and condyles do. This does not seem to be only related to age, because females do not show the same patterns. Rather, it probably also relates to advanced TMJ regressive remodelling and condylar skewing (Visser, 1994). Degeneration of the TMJ in older males is significantly different from all other groups. The broadening of the bigonial breadth and the increase in ramal height may be expressions of the orientation and development of the masseter muscles. The masseter muscles are involved in protracting the mandible at the TMJ. This has been discussed in Chapter Five. Moss and Simon (1968) have pointed out that age associated increases in the masseter protracting the mandible relate to changes in the muscle position, rather than a change in the structure of the muscle or changes in the mandibular angle. This pattern seems to have occurred in the older Sigatoka males.

Females did not experience TMJ degeneration (Visser, 1994), nor did they seem to have experienced the same amount of pterygoid influence on the mandible dimensions. This is indicated by the finding that all ramal dimensions are significantly correlated with each other. It seems that the mandible maintained efficiency as a lever and maintained optimum occlusal effectiveness by broadening the bigonial breadth. This arrangement shortened the lever arm and so did not require significant increases in mandibular musculature.

5.0 Summary

5.1 Dental

There is little variability in tooth size and morphology between the sexes and among individuals. The largest sex differences in size were in the canines. Sexual dimorphism in the canines is found in most human populations. The mandibular first molar has been identified as the tooth most likely to express the same traits within the Sigatoka population. The mandibular first molar is considered to be the most genetically stable tooth (Leamy and Hrubant, 1971). The low level of variation in this tooth, and to a less extent in other teeth, is consistent with the idea that the Sigatoka people formed a genetically homogeneous population.

5.2 Stature, body mass and long bone lengths

Stature and body mass are shown to be highly sexually dimorphic. Males had a bigger and probably more muscular body form than females. These differences can be interpreted within the hypothesis presented earlier in this chapter, which holds that sex differences increase in a population that is not nutritionally or environmentally stressed (Greulich, 1951; Stini, 1972). Consequently, the difference in long bone growth (stature) between the sexes is partially a reflection of hormonal differences. It is also an indication of a well balanced and regular diet during the growth episodes whereby males were able to obtain a greater body size within the limits of their genotype.

5.3 Nasal-mandibular dimensions

The gonial angle may be influenced by masticatory musculature. The greater the musculature, the more acute the angle will be. It seems that other factors, such as tooth wear and TMJ degeneration, were also associated with mandibular dimensions in older males. The mandible and nasal dimensions are influenced by oxygen requirements demanded by the muscles. This notion partly explains the reasons for the degree of sexual dimorphism among different facial dimensions. Significant correlations between some nasal dimensions with body mass and stature in females may suggest that they did not reach their genetic potential in body size.

5.4 Behavioural indicators

Consistent sex differences occur in the midshaft of the long bones. The midshaft circumference of the right clavicle is significantly sexually dimorphic. Similarly, sex differences occur in the midshaft circumference of the humerus. These differences are probably a reflection of greater male upper body use.

The anteroposterior diameter and the midshaft circumference of the femur are the only significantly sexually dimorphic dimensions in the lower limb. These differences probably exist because males are heavier and have greater lower limb musculature, consequently a greater body mass and more muscle force would have been applied to the male lower limbs. This finding is consistent with the notion that bone is preferentially deposited were the greatest force of this mass is applied to the femur shaft (Ruff and Hayes, 1983; Macho, 1990).

There are no sex differences in the femur indices. The lack of significant sexual dimorphism in femoral platymeria follows the idea that it is expressed at similar levels within a population, whether it be genetically determined or culturally influenced.

What these results show is that males used their upper bodies much more than females. This suggests that males may have been involved in tasks such as collecting clay, canoeing or digging, all of which require upper body strength.

5.5 Body proportions

A lack of difference in limb indices between the sexes from Sigatoka implies that they were both subjected to the same environmental influences. Similarly, in each sex, limb proportions have the smallest standard deviations of the different skeletal variables.

The relative circumferences of the clavicle and humerus between sexes give an indication of the degree of upper body use that occurred during life. No significant difference between the male and female left clavicle existed. A very significant difference was found between the male and female right clavicle.

The minimum diameter of the humerus may not only be a reflection of male - female bone mass differences, but may also be an indication of different activities between the sexes. Differences between the left and right clavicles and humeri firstly signify that right arm use was favoured over the left arm. Secondly, the activities of males and females seem to have been strenuous. The reasons why these skeletal differences occurred is associated with the daily activities of the Sigatoka people. The burial area and the settlement site excavated by the Birks (1973) is associated with a large amount of pottery. This pottery may have been manufactured at the site. Clay used in pottery manufacture had to be dug and carried back to the site. Canoeing and gardening were other activities that the Sigatoka people possibly did.

The lack of sex differences does not imply that the population experienced environmental stress. The sex differences in stature and mass are associated with musculature, but differences are not evident in traits which have a stronger genetic basis, particularly dental traits. The sex differences in stature and body mass and the cranial variables may reflect access to a good diet, allowed growth rates which enabled them to attain a size which was closer to their genetic potential. Females may have had a similar diet. However, as seems evident in other human populations, their genetic potential in body mass and stature would seem be less than males.

Chapter Seven

Social stratification in the Sigatoka Burial Site

1.0 Introduction

In his description of the Sigatoka burial ground, Best (1989) postulated that the distribution of burials was likely to reflect the sociopolitical structure of the society. He proposed four possibilities (Best, 1989:51):-

a) Collective cemetery for a high ranking chief.
b) Burial ground for a chiefly clan.
c) Village burial with internal social- political divisions.
d) Village burial ground with no divisions.

These proposals are considered in this chapter. The objective of this chapter is to use evidence from skeletal and dental data to investigate whether burial arrangements reflected social associations or social differentiation within the Sigatoka population. Comparisons are made with different burials and burial groups of the same sex. An attempt to identify whether close associations exist between individuals buried next to each other will also be made.

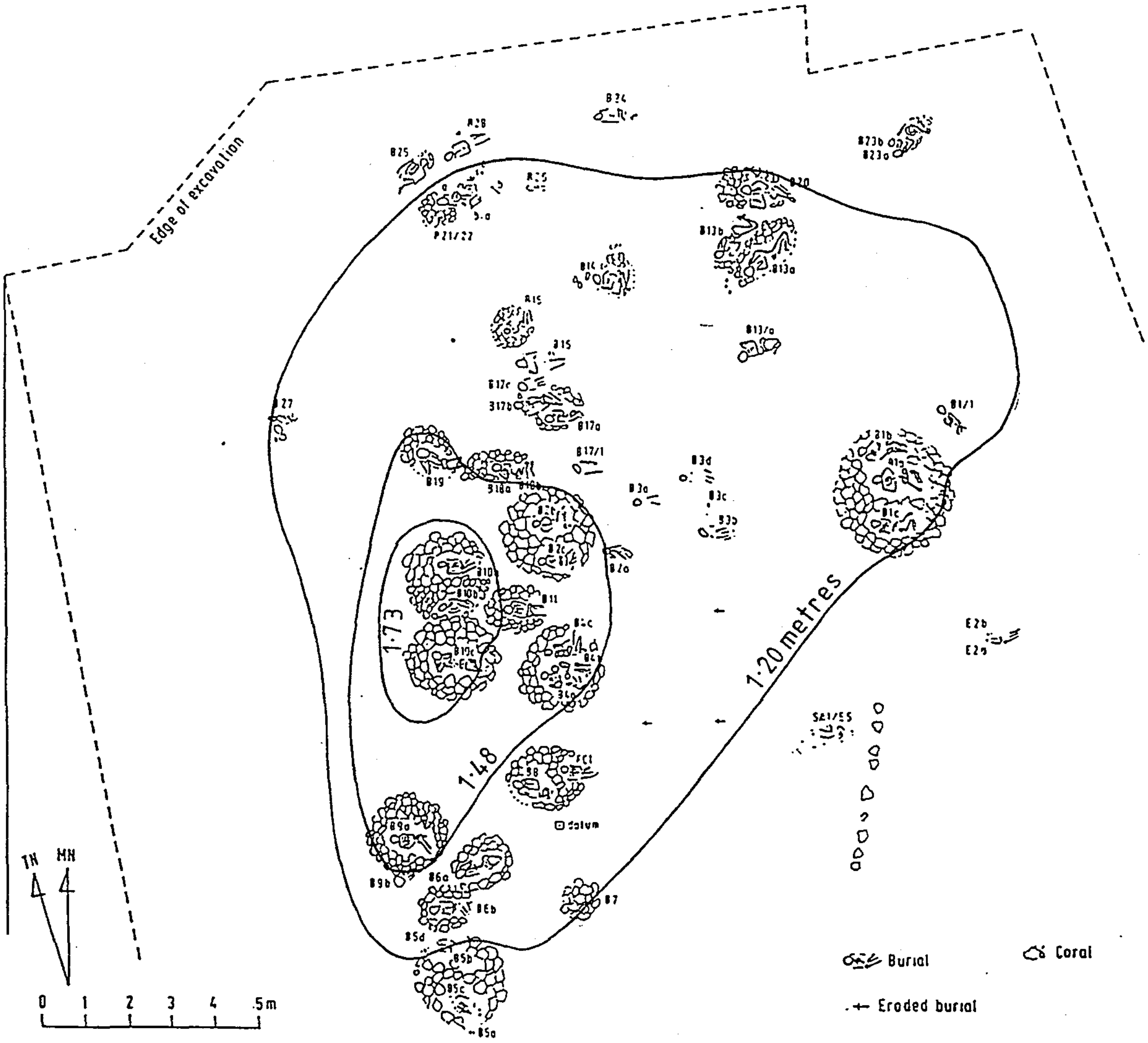
A number of studies of skeletal populations have assigned particular changes in the skeleton to specific activities and social status (Tainter, 1980; Dutour, 1986; Stirland, 1993). Other studies have related joint degeneration to specific functions and status (Merbs, 1983; Kennedy *et al.*, 1986). In historical and contemporary Polynesia tall stature and heavy body mass are associated with high status (Morrison, 1935; Levy, 1973; Kirch, 1984). Burial clusters are examined to assess whether these differences occur. Ages at death are compared to examine if there is a difference in life span between the comparative groups.

2.0 The variables

2.1 Male burial differences

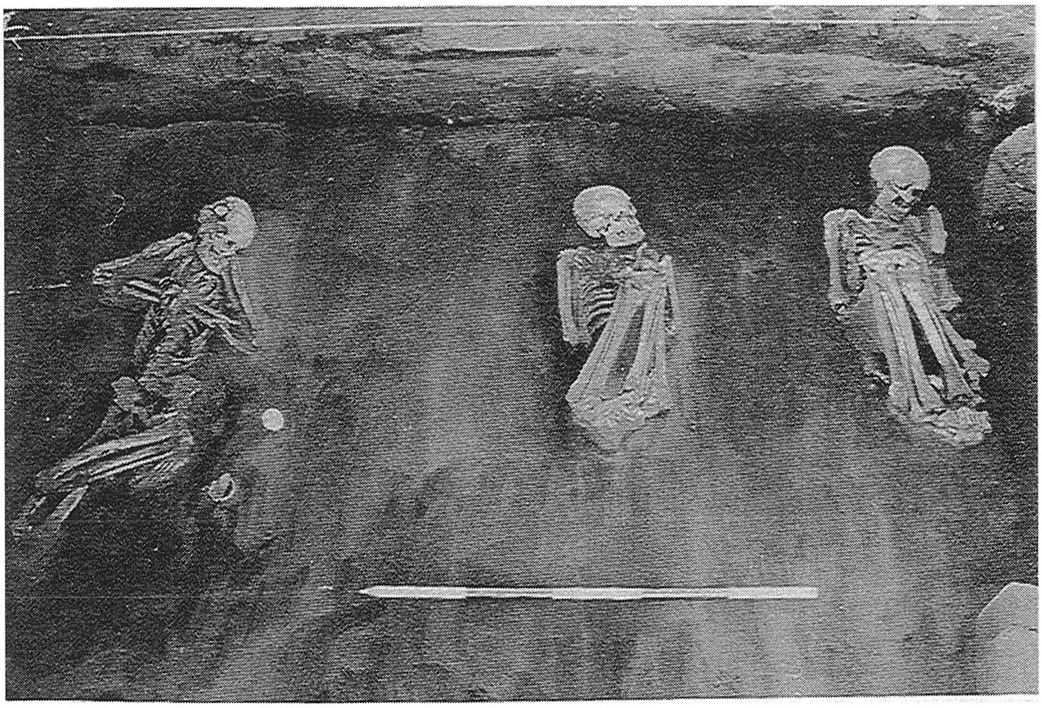
Burial height refers to the height at which an individual was buried on the burial mound. One group, consisting of three males (B10a, b and c), was buried on the highest point of the burial mound and under the largest coral mound (Figure 7.1).

Figure 7.1
The height and positioning of the burials in the Sigatoka burial ground.



The oldest individual was B10a who was aged 47 ± 5 years. This individual was buried on the highest point of the mound with the only substantial non-pottery grave goods found, an adze, cowrie shell and shell bracelet (Figure 7.2). In Fiji the possession of a cowrie shell has traditionally indicated high status (Thompson, 1940). Likewise, burials located on the highest point of a burial ground or in large burial mounds are traditionally associated with higher status in Fiji and Polynesia (Fison, 1881; Davidson, 1984). Males from the B10 burial mound are compared to other males, because of these differences.

Figure 7.2
Illustration of the B10 male burial arrangement after the coral mound had been removed. Note that one male, B10a, is associated with grave goods.



2.2 Female enamel hypoplasia comparisons

Females (B16, B21c, and B25) who had moderate to severe enamel hypoplasia are compared to other females with none to slight enamel hypoplasia. The former are buried on the lower slope, towards the northern fringes of the burial ground (Figure 7.1). The causes of enamel hypoplasia have been outlined in Chapter Four. Briefly, the frequency and severity of enamel hypoplasia may be caused by such factors as poor nutrition, or illness, which interrupted enamel deposition during tooth development in infancy or childhood. An aim in comparing these groups is to determine whether any of the other variables, such as skeletal dimensions and length of life, differed between the "enamel hypoplasia" group and the other females. The premise is that females of lower social status were more likely to have had moderate to severe enamel hypoplasia than higher status females.

2.3 Control groups

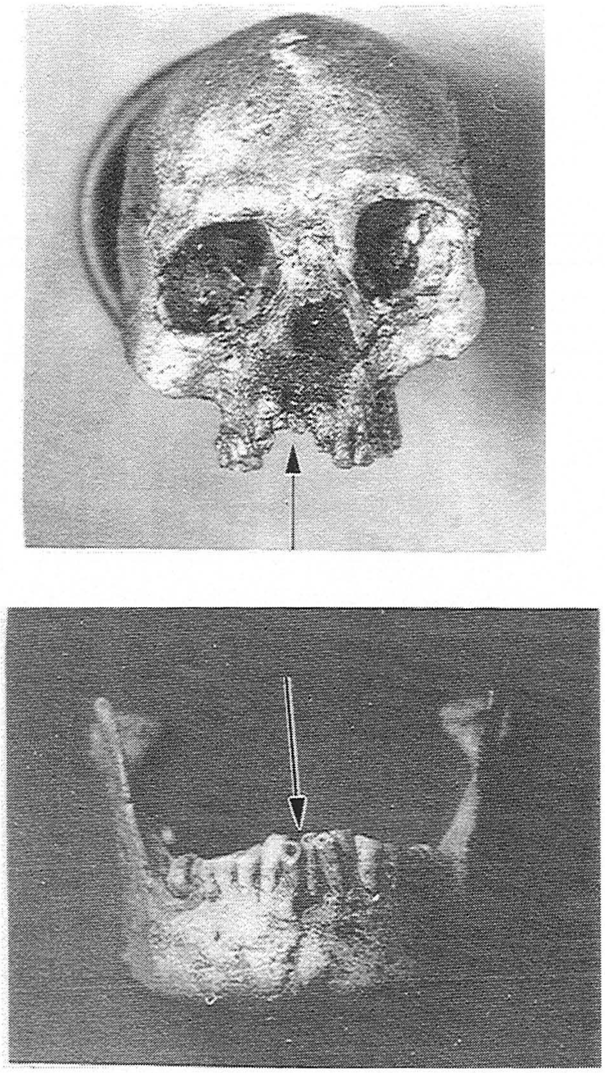
To test the assumption that the B10 males and the group of females with enamel hypoplasia differ in other skeletal aspects from the remainder of their respective sexes, comparisons were made with other groups within the burial ground. Comparisons are made with the B1 male burial group and all other males. The B1 males are buried on a low level on the eastern edge of the burial ground (Figure 7.1). Female comparisons are made between those individuals who were interred on the outer perimeter of the burial ground, and to all other females (Figure 7.1).

2.4 Female non-dietary tooth wear patterns

Tooth wear patterns resulting from non-dietary activities have been reported in populations from different geographic locations and antiquity (cf Merbs, 1983). Many of these studies have provided descriptions of interproximal lesions (Ubelaker *et al.*, 1969; Berryman *et al.*, 1979; Formicola, 1987; Brown and Molnar, 1990). Reports of occlusal lesions and excessive wear patterns on individual anterior teeth are less frequent (Schultz, 1977; Larsen, 1985).

Differences in tooth wear patterns exist between some Sigatoka females compared to patterns in other females and all males. This tooth wear is focused on one or two anterior teeth, including the first premolars. Initial wear occurred on the mesial side of the tooth; thereafter the occlusal surface becomes worn. In some cases one side of the tooth experienced severe wear while the other side experienced the same wear as surrounding teeth. However, there is no evidence of either occlusal or interproximal grooving. As these wear patterns are unusual and specific to a group of females, it is not considered to be a result of dietary wear. The tooth that experienced the wear is commonly worn to the cemento-enamel junction exposing the dental pulp (Figure 7.3). Frequently, the tooth is carious, and in some cases abscessing is associated with decay of the tooth.

Figure 7.3
Non-dietary tooth wear patterns in the maxillary and mandibular incisors of females.



The first aim of this section is to assess if these unusual tooth wear patterns are an age related phenomenon. The second aim is to assess which tooth group most frequently shows this wear pattern. Lastly, an assessment will be made to identify if different frequencies of this trait relate to differing task activities, status, or burial location among females.

2.5 Shovel shaped teeth and burial relationships

An attempt was made to identify whether a correlation in the type of shovel shaped teeth existed between females and infants who were buried in close proximity to each other. The method used to assess shovel shaped teeth has been outlined in Chapter Six.

3.0 Results

3.1 Male burial differences

The univariate results comparing B10 males to all other males are presented in Table 7.1. The variables used to compare these two groups have been discussed in previous chapters

Table 7.1
Comparisons and univariate analyses of burial heights and biological traits of B10 males compared to all other males.

	B10 Males			Other Males				
Variable	Mean	s.d.	n	Mean	s.d.	n	*t* Statistic	f Ratio
Femoral length	463.3	15.3	3	452.6	17.9	9	0.9	0.1
Femoral anteroposterior diameter	32.8	1.5	3	29.2	2.2	11	2.7*	0.0
Femoral robusticity	13.0	0.2	3	12.1	0.1	6	1.1	10.1
Tibial length	378.5	2.1	3	366.9	12.3	8	4.7**	0.5
Stature	1761.0	3.2	3	1738.0	23.6	10	2.3*	0.0
Body Mass	78.7	10.9	2	69.7	4.0	10	2.3*	0.0
Age	43.7	4.2	3	28.8	5.1	14	4.7**	0.5
Burial height	1700.0	0.0	3	1170.0	213.0	16	4.4**	0.0

Significance levels * $P \leq 0.05$; ** $P \leq 0.01$ Measurements in millimetres.

The mean burial height of the B10 males is significantly higher than all other males. Their ages are also significantly greater than all other males. Other variables show that in all cases, males from the B10 burial group had greater bone dimensions. However, significant differences were found only in femoral anteroposterior midshaft diameters and tibial length. Significant differences were also evident in body mass and stature, but in both cases the distributions were within one standard deviation of each group. No significant differences in the variances were observed.

Table 7.2
Burial height and biological traits of the lowest burial group, B1 males, compared to all other males.

	B1 Males			Other Males				
Variable	Mean	s.d.	n	Mean	s.d.	n	*t* Statistic	f Ratio
Femoral length	452.3	16.0	3	456.2	18.5	9	0.32	0.1
Femoral anteroposterior diameter	30.8	2.3	4	30.5	2.5	11	-0.19	0.1
Femoral robusticity	13.2	0.0	1	12.3	1.2	7	——	——
Tibial length	373.7	5.1	3	362.3	19.1	8	-0.99	0.9
Stature	1749.0	11.2	3	1741.0	25.0	10	0.56	12.0
Body Mass	69.6	0.6	2	71.5	6.6	10	0.40	0.9
Age	29.3	7.6	4	31.9	7.5	14	0.63	0.0
Burial Height	1200.0	0.0	4	1270.0	300.0	15	-0.40	0.0

Measurements in millimetres.

The stature of individuals in the B10 burial group is significantly greater than other males. Similarly, a difference in body mass exists between those individuals buried on the highest part of the mound, B10a and B10b, compared to the other males. This difference is nearly ten kilograms, or 12%. A Student's *t* test shows that this difference is significant (Table 7.1). This finding matches differences in stature and age between these two groups.

Table 7.2 presents the results of Student's tests from the control group, comparing the B1 male burial group to all other males. No significant statistical differences evident in any of the biological variables or burial height. Comparative variables are very similar in both groups.

3.2 Female enamel hypoplasia comparisons

The methods used to identify enamel hypoplasia are outlined in Chapter Four. The biological variables of age at death, stature, and the lengths, diameters, circumferences and indices of some long bones are compared to assess if statistically significant differences exist between the two groups. The methods and reasoning behind using these variables are discussed in Chapters Three, Four and Six.

Three females with moderate and severe enamel hypoplasia are compared to other females with none to slight hypoplasia. Two females (B21c and B25) with moderate to severe enamel hypoplasia were buried within one metre of each other at the northern end of the burial ground (Figure 7.1). Two other individuals (B24 and B28) buried within 1.5 metres of B25 and B21c also experienced hypoplasia. One other female (B21a) buried in association with these burials was not included in this analysis because she was nearly edentulous. The remaining female with moderate to severe enamel hypoplasia (B16) was buried about four metres from B21c and B25 (Figure 7.1). Two males (B17a and B17b) with slight hypoplasia were buried within 1.5 metres of B16. Individual B17c was excluded from the analysis because this individual had few remaining teeth. In general then, individuals with enamel hypoplasia tended to be buried in proximity with each other, rather than being buried in a scattered arrangement throughout the burial ground.

Comparisons of the variables between females with moderate to severe enamel hypoplasia and females with none to moderate enamel hypoplasia are presented in Table 7.3.

Table 7.3

Univariate analyses of females with moderate to severe enamel hypoplasia compared to females with none or slight enamel hypoplasia.

	Females with hypoplasia			Other females				
Variable	Mean	s.d.	n	Mean	s.d.	n	*t* Statistic	f Ratio
Femoral length	433.3	32.5	2	445.7	17.0	3	-0.6	0.0
Femoral anteroposterior	28.5	2.6	3	28.2	2.7	13	0.9	6.9
Femoral robusticity	12.0	1.0	3	12.0	1.0	3	0.3	0.0
Tibial length	363.2	30.9	3	360.3	23.1	3	-0.1	0.0
Humerus circumference (l)	62.9	6.7	3	58.3	3.6	11	1.7	0.7
Humerus circumference (r)	65.1	5.9	3	59.3	3.6	11	2.2*	0.7
Stature	1664.0	86.3	2	1647.0	37.7	8	-0.3	0.1
Age	24.0	1.7	3	31.0	6.7	26	-1.7	0.0
Burial Height	1070.0	300.0	3	1150.0	300.0	17	-0.4	0.0

Measurements in millimetres. * $P \leq 0.05$

No significant differences were found in stature or any of the lower limb long bone dimensions (Table 7.3). Significant differences were found on the mid shaft circumference of the right humerus ($P \leq 0.05$), although the two samples are within one standard deviation of each other. On the left humerus circumference, the mean difference between the two groups is marked, but not significant. There was no significant difference in variance between the samples.

A Student's *t* test was calculated to find if a difference existed between individuals with enamel hypoplasia compared to those that do not. Seventeen burials within a radius of 4.5 meters of B21c and B16 were used as a comparative sample. It was found that individuals who had not experienced hypoplasia were buried further away from the three females, compared to individuals who were identified as having slight enamel hypoplasia. This difference was highly significant ($t = -3.0$. $P \leq 0.02$).

The univariate results of females who were buried on the perimeter of the burial ground compared to all other females are presented in Table 7.4. No significant differences in the means or variances were found between the groups.

Table 7.4

Biological traits and burial heights of females interred on the perimeter of the burial ground compared to all other females.

	Outer females			Other females.				
Variable	Mean	s.d.	n	Mean	s.d.	n	*t* Statistic	f Ratio
Femoral length	448.5	13.4	2	436.0	27.6	3	0.6	0.0
Femoral anteroposterior diameter	28.7	2.2	3	28.1	2.1	15	-0.5	3.7
Femoral robusticity	12.0	0.6	2	12.1	0.6	2	-0.1	0.0
Tibial length	360.5	31.8	2	358.7	24.8	3	0.4	0.0
Humerus circumference (left)	59.8	6.7	3	59.2	4.1	12	0.2	42.8
Humerus circumference (right)	62.0	7.9	2	60.3	4.4	12	0.5	0.0
Stature	1652.0	29.0	2	1636.0	31.3	8	0.6	0.0
Body mass (Kg)	54.7	3.3	3	56.0	3.2	5	-0.6	0.0
Age	30.0	7.3	5	32.0	6.3	18	-0.6	0.9

Measurements in millimetres

3.3 Non-dietary tooth wear patterns

The assessment of non-dietary tooth wear involved investigating the anterior dentition of 22 females and 18 males. The total number of teeth in the sample was 574, representing the incisors, canines, and first premolars of the maxilla and mandible. This total was made up of 329 female teeth, of which 167 were mandibular teeth and 162 were maxillary teeth. The remaining 245 teeth were from males, of these 120 were mandibular and 125 were maxillary teeth.

Tooth wear and the wear plane were graded following Molnar (1971). Caution is necessary when interpreting the results, because of the limited number of complete individuals. The range of variables and small sample sizes may lead to distortion of the results.

A number of females displayed tooth wear patterns which varied from a usual dietary related tooth wear pattern. Normal tooth wear is focused evenly on the anterior dentition and first molars. Eleven of the 23 females (48%) show tooth wear patterns consistent with expected tooth wear patterns. Examples of non-dietary tooth wear patterns are illustrated in Figure 7.3.

Two females with non-dietary wear patterns had severely worn anterior incisors. These individuals are excluded from further analysis because wear patterns had been obliterated by caries. Four females had notched wear patterns on several maxillary teeth, and three also had non-dietary wear on mandibular teeth. The remaining individuals had notched wear patterns on only one tooth. The summary descriptive results are presented in Table 7.5.

Table 7.5
The frequency of non-dietary wear patterns in female tooth groups.

	1st Premolars		Canines		Incisors.	
Mandible	n = 42	4.8 %	n = 44	18.2 %	n = 79	22.8 %.
Maxilla	n = 44	0.0 %	n = 42	7.5 %	n = 82	9.8 %.
No individuals = 23						

Teeth operate within a functional unit in which the opposing maxillary and mandibular teeth occlude. Therefore, the association of tooth wear between mandibular teeth and the corresponding maxillary teeth was investigated. No correlation in wear patterns was found.

Teeth displaying non-dietary wear patterns had oblique buccal wear. Teeth displaying buccally angled occlusal plane tooth wear were compared with other teeth that did not demonstrate notching, excessive wear, or have a strong buccal occlusal wear plane. A Student's *t* test was used to determine whether there were differences between those teeth with a buccal wear plane angle compared with those teeth without this wear angle. The results are presented in Table 7.6.

Table 7.6
Student's *t* test calculations identifying differences in non-dietary tooth wear plane angles compared to teeth with usual wear angles.

Tooth group	*t* Statistic	d.f.	Significance
Premolars	- 3.42	14	0.008
Canines	- 3.42	14	0.004
Lateral Incisors	- 6.74	22	0.000
Central Incisors	- 3.77	12	0.003

The Student's *t* test results in Table 7.6 show a highly significant difference between teeth that have non-dietary wear plane angles compared to those teeth with usual wear angles. These results indicate different tooth use in those teeth with oblique wear angles.

Another Student's *t* test (Table 7.7) was calculated to assess whether there were any differences between the amount of wear on non-dietary used teeth and the average tooth wear of the individual. Premolars were excluded from the analysis because of the small sample size.

Table 7.7
Student's *t* test identifying differences between the amount of non-dietary tooth wear compared to usual tooth wear on other teeth.

Tooth group	*t* Statistic	d.f.	Significance
Canines	- 3.53	8	0.008
Lateral Incisors	- 3.17	9	0.011
Central Incisors	- 2.19	6	0.071

Differences in the amount of wear on the central incisor approached significance. The tooth wear plane on the lateral incisors and canines did significantly differ from other tooth wear. This difference indicates different tooth function.

The average age of females who experienced non-dietary related wear and those who did not, were compared to establish if there was an age association with wear. This is based on the data presented in Table 7.8. A Student's *t* test revealed that there was no significant difference between the age of females with non-dietary wear and the average age of those females with normal tooth wear. Similarly, no significant difference was found between the ages of females with maxillary non-dietary wear and females with dietary wear.

Table 7.8

The ages of females with non-dietary tooth wear compared to other females.

		n	Age	*t* statistic	P ≤
Mandible	Non-dietary	11	30.7	0.41	0.69
	Normal	12	31.8		
Maxilla	Non-dietary	3	35.7	0.92	0.41
	Normal	3	31.4		

From the results presented in Table 7.5 it can be seen that the mandibular incisors and canines experienced the greatest frequency of non-dietary related wear. Consider Table 7.9 in which the frequency of this wear is presented only from females who displayed non-dietary wear patterns. Clearly, the lateral incisors were exposed to non-dietary wear more frequently than other teeth. The frequency of wear in the other teeth is similar.

Table 7.9

The frequency of non-dietary tooth wear patterns in the mandible.

	No	Frequency
Premolar	18	16.7 %
Canine	18	22.2 %
Lateral Incisor	18	44.4 %
Central Incisor	18	22.2 %

Spearman's rank correlations were calculated to assess if any significant differences exist between non-dietary tooth wear on the anterior teeth. This correlation aims to identify if two adjacent teeth were involved in non-dietary related activities. Significant wear correlations greater than $P \leq 0.05$ were found in only two groups, the premolars and canines. This indicates that wear occurred when both teeth were used simultaneously. An example of when this type of tooth wear can occur is when fibrous material is pulled from side to side over the teeth.

The lack of any significant correlation between the incisors is not surprising. This may be because the typical wear pattern is that the mid point of the occlusal surface of the incisor initially experiences a V shaped notch. This wear then progresses to cover the whole occlusal surface of the tooth, commonly with a lingual wear plane.

3.4 Shovel shaped teeth and burial relationships

Three females were buried with children, B23a with B23b, E2a with E2b and B9a in association with B9b (Figure 7.4). These burials are assumed to be mother-child burials. The maxillary shovel shaped incisors of each mother are compared to the child's maxillary incisors. This is because shovel shaped teeth are held to have a high genetic component (See Chapter Six). The incidence and types of shovel shaped teeth may indicate affinity between these individuals.

Figure 7.4
A female -child burial (B23a and B23b)

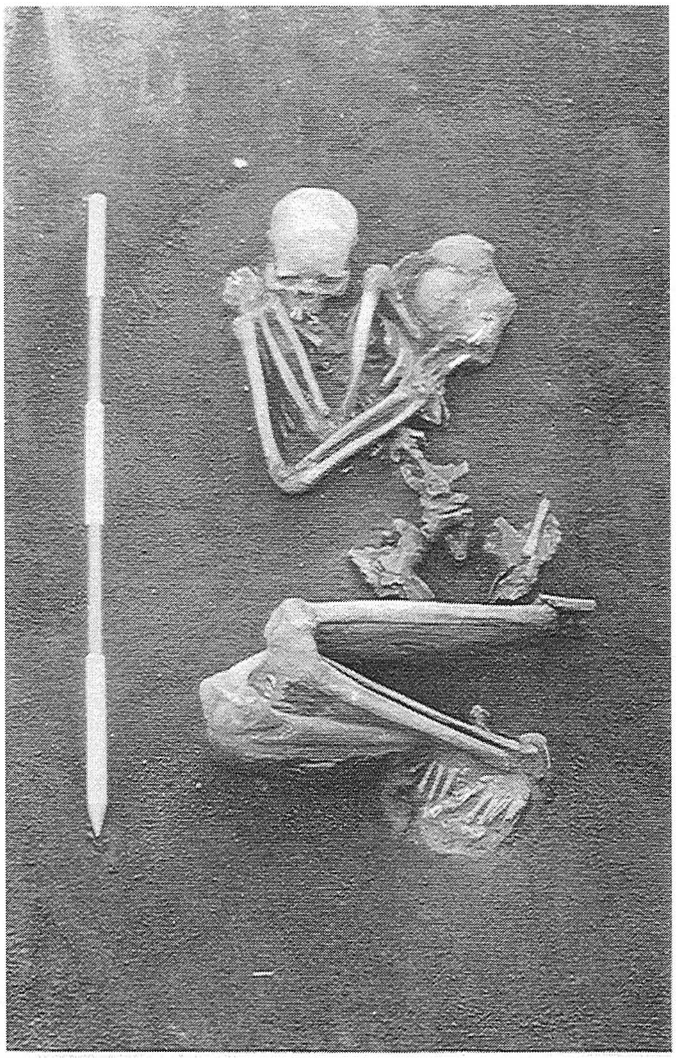


Table 7.10 shows the absence or presence of shovel shaped teeth using the scaling method outlined in Chapter Six. No further analysis was attempted because of the small sample sizes. It can be seen from the data presented in Table 7.10 that B9b mirrored B9a in tooth form. B23a and B23b could not be compared because of excessive tooth wear in B23a's maxillary incisors. The comparisons of shovel shaped incisors of the E2 burials are more variable. The lack of similarity in the lateral incisors can be explained by the variable influences that effect shovel shape in this tooth, as outlined in Chapter Six. There is only a slight difference in the more genetically stable central incisor.

Table 7.10

Comparisons of shovel shape incisors in female - child burials.

Individual.	Tooth			
	Central right incisor	Lateral right incisor	Central left incisor	Lateral left incisor
B9a	0	0	0	0
B9b	0	0	0	0
E2a	2	3	2	3
E2b	1	0	1	0

4.0 Interpretation

4.1 Male burial differences

Despite the limited sample size and range of variables, there is a clear trend that indicates that the B10 males are of greater stature and body mass compared to other males. The way in which greater stature can be attained is through good diet during the final growth period that ends at around 20 years of age (Tanner, 1962; Eveleth, 1975). The greater body mass estimates of the B10 males could have been maintained through adult life.

While it is possible that high status individuals were selected on the basis of larger body size, this does not seem likely. Higher status individuals in historical Fijian and Polynesian societies had better access to food than individuals of low rank (Williams, 1858; Ellis cited in Oliver, 1974: 782-784). If this was the case, individuals of higher status were more likely to attain taller stature and heavier body mass than low status individuals.

Burial height has been shown to be associated with status in Polynesian and Fijian society (Fison, 1881; Davidson, 1984). The finding in the Sigatoka burial ground that not only were the B10 males taller and heavier, but they also lived longer than other males is a further indication of high status. Longer length of life of high status individuals may have been possible because they were given greater care during illness or old age. Ethnographic accounts mention that individuals of high status were cared for during illness and old age, while those of lower rank would not be given lengthy care (Williams, 1858). Alternatively, it is possible that older individuals had greater status than younger individuals and accordingly, they were treated with greater respect. This proposition is unlikely because they would have attained their adult stature before they gained higher social status, and on that basis this notion can be discounted.

Significant differences in mean femoral anteroposterior diameters between high status males and other males, may be an expression of a combination of biological factors. Longer femoral length and greater body mass, combined with strain placed upon the midshaft of the bone during activities such as walking and squatting may have contributed to a more robust bone in high status males (Ruff and Hayes, 1983).

4.2 Female enamel hypoplasia comparisons

The lack of significant difference in stature and long bone length between any of the female groups suggests that diet was adequate in both groups. However, significant differences in the circumference of the right humerus at the site of the deltoid muscle insertion in females with enamel hypoplasia, may suggest that a division of labour existed among females. It may be that the females with enamel hypoplasia were involved in physical activities that demanded greater use of the upper body than compared with other females. In other words, females of lower status may have had to work harder than other females.

4.3 Non-dietary tooth wear patterns

Females with non-dietary tooth wear were buried in two loosely defined areas in the burial ground. One group of seven women were buried at the northern end of the burial ground. The remaining five women were buried near the centre of the burial mound, to the east of the B10 burials. If non-dietary tooth wear was not associated with social status, as indicated by biological traits, it is unlikely that the individuals displaying it would have been buried in two discrete locations. Non-dietary tooth wear may be an indication that particular women were engaged in specific activities, or had a specific way of doing a particular task within a family environment.

Non-dietary tooth wear patterns occurred much more frequently on the mandible than on the maxilla. This unequal wear distribution indicates that non-dietary wear was not caused by clenching an object between the teeth (cf Molnar, 1971; Kennedy, 1989). For the same reason, non-dietary wear can not be related to any dietary use of the teeth because wear differs from male tooth wear patterns and other females.

The significant association between non-dietary tooth wear patterns on the premolars and canines suggests that wear occurred simultaneously on the teeth concerned. In such cases, the expected wear patterns produced on two adjacent teeth would be wear angled toward the adjacent tooth. More commonly, wear probably occurred on one tooth at a time.

The absence of a correlation between any of the lateral and central incisors suggests that one tooth was used in a task-related function. The pattern of carious lesions in the mandibular incisors, presented in Chapter Five, demonstrates progressive tooth wear from younger to older individuals. It seems that a tooth was used for non-dietary reasons until the dental pulp became exposed.

Task activities that may produce corresponding wear patterns on teeth on either side of the mandible could involve pulling a tough fibrous material, such as coconut palm fibres, over the teeth. Ethnographic accounts have been used to explain a similar type of wear pattern in Aboriginals (Brown and Molnar, 1990), Amerindians (Molnar, 1971) and Inuits (Merbs, 1983).

The non-dietary tooth wear patterns may have been caused by repeatedly rubbing an instrument, such as wood fibre or plant material, through selected teeth. Whatever task produced these particular wear patterns it did not involve all females, and was not age related. It may be that tasks that caused this wear were performed by a few females from each age group.

4.4 Female-child burial relationships

It is difficult to determine if the different burial groups reflect family graves. Although the data set is small, comparisons of the absence and presence of maxillary shovel shaped incisors and burial arrangements make it seem likely that those females who were buried with infants are probably mothers. This idea is consistent with the presence of pits and grooves on the preauricular sulcus that are associated with pregnancies and parturition (See Chapter Four). However, it is not possible to statistically assess if each burial group reflects a family group.

5.0 Summary

It may be inferred from the information presented in this chapter that the Sigatoka society was socially stratified and complex. Each sex may have been stratified into at least two social tiers. A division of labour probably occurred, within which different groups were able to perform specialist tasks. The people who lived there were probably not temporary coastal dwellers, but the 'products' of a reasonably stable, well-fed society. The burial ground possibly reflects family burial arrangements between mothers and their children. High ranking male adults were buried at a higher elevation than individuals of lower status.

Chapter Eight

Comparisons between the Sigatoka skeletal population and other Fijian skeletal series

1.0 Introduction

This chapter compares skeletal remains of the 2000 year old Sigatoka population with other Fijian skeletal material of more recent antiquity. The aim is to examine differences and similarities in skeletal body form and body proportions between the Fijian populations. A second aim is an examination of skeletal differences between the sexes in each population. As much of the cranial skeletal material is fragmented, only nasal and mandibular dimensions will be examined. The post cranial diameters examined here are dependant on the bony material available.

2.0 Materials

Two recent skeletal series from Fijians are compared to the Sigatoka people. The Fijian series have been recorded by Weber (1934) and Flower (1881). Fijian stature estimates have been calculated in this study using the stature formulae for Polynesians from Houghton *et al.* (1975). Body mass estimates were calculated with the same regression formulae used to estimate the body mass of the Sigatoka people presented in Chapter Four.

The Sigatoka females are also compared with a small group of females who were excavated in 1991, 210 metres west of Site VL 1/16 (Crosby, 1991).

Estimates of stature and body mass from these groups are commonly based on one of eight diameters. Therefore, these diameters cannot individually be compared to the Sigatoka population.

The background information on these two skeletal populations has been presented in Chapter Two. The theoretical basis and methods of analysis for variables used in this chapter have been discussed in Chapters Four and Six.

3.0 Results

3.1 Comparisons between Sigatoka and recent Fijian skeletons

The comparisons and the results of univariate analysis of males are presented in Table 8.1.

Table 8.1
Comparisons and univariate analyses of biological traits from Sigatoka and recent Fijian males.

	Sigatoka			Fiji				
Variable	Mean	n	sd	Mean	n	sd	*t* Statistic	f Ratio
Nasal height	54.3	8	6.2	50.9	30	3.2	3.2**	5.3
Nasal breadth	26.9	8	2.7	26.1	31	2.3	-0.7	0.4
Ramus height	65.2	14	5.2	62.2	15	4.2	1.5	0.6
Ramus breadth	40.6	14	2.5	34.8	13	2.9	5.4**	0.6
Gonial angle	116.9	17	5.3	123.4	15	7.1	-2.9**	0.1
Bigonial breadth	107.5	14	10.3	97.7	15	5.5	2.9*	1.9
Bicondyle breadth	125.2	13	9.8	119.4	13	5.5	0.9	0.5
Coronoid height	70.7	13	5.2	66.8	5	5.2	1.4	0.0
Corpus length	83.7	15	6.5	80.4	10	3.8	1.5	0.2
Stature	1742.8	13	22.4	1692.0	5	50.4	3.0**	8.5
Body mass (Kg)	71.2	12	6.0	63.2	5	6.5	2.2*	9.4
Clavicle length	145.0	3	11.5	137.1	4	5.7	1.2	0.0
Left Tibia (mm)	365.4	11	17.0	360.3	5	26.3	0.5	2.7
Arm - stature index	32.9	5	1.0	32.1	4	1.9	0.0	0.0
Leg - stature index	47.3	8	1.1	46.5	5	1.5	1.1	1.4
Brachial index	75.3	5	3.6	76.8	4	2.0	-0.8	1.7
Crural index	80.4	11	3.9	84.7	5	2.0	-2.4*	0.2
Femoral platymeria	84.5	10	7.5	94.5	5	9.8	-2.2	0.1

Significance levels *P ≤ 0.05 **P ≤ 0.01 Measurements in millimetres.

The results of Student's *t* test demonstrate that six of the seven variables that differ significantly are associated with body size and musculature. The only exception is the crural index. Other limb ratios are similar. There are no significant differences in the f ratio results.

Comparisons and results of Sigatoka and Fijian female univariate analysis are presented in Table 8.2. Three of the four female differences evident in the Student's *t* test results seem to be associated with head form and head musculature. Only the bigonial breadth, ramus breadth and femoral platymeria differences are consistent with the results from males. There are no significant f ratio results between the two groups of females.

The most significant differences between the populations occur in ramal breadth and bigonial breadth in both sexes. Male gonial angles differ at highly significant levels. In this case, the Sigatoka males have a more acute angle, but this difference is not evident among females. Likewise, nasal height of Sigatoka males is significantly greater than among Fijian males. Among Sigatoka females the coronoid height is significantly greater than Fijian females. This difference is not evident in the male groups.

Table 8.2
Comparisons and univariate analyses of biological traits from Sigatoka and recent Fijian females.

	Sigatoka			Fiji				
Variable	Mean	n	sd	Mean	n	sd	t Statistic	f Ratio
Nasal height	45.0	8	4.9	46.7	11	2.2	-1.0	2.1
Nasal breadth	26.3	10	1.9	25.2	6	1.5	1.3	2.3
Ramus height	61.8	9	7.3	59.0	6	3.2	0.9	3.3
Ramus breadth	38.4	19	2.9	32.7	7	4.2	-14.9**	1.8
Gonial angle	116.1	23	6.4	119.5	6	5.9	-1.2	0.8
Bigonial breadth	97.9	21	7.3	90.4	7	1.9	2.6**	0.5
Bicondyle breadth	118.7	9	8.1	114.3	6	3.7	1.2	0.0
Coronoid height	65.8	11	4.9	53.0	2	0.0	3.6**	---
Corpus length	82.2	21	6.4	80.8	6	6.8	0.5	0.4
Stature	1656.8	10	44.5	1619.4	3	6.9	1.4	25.5
Body mass (Kg)	55.5	8	3.0	53.9	3	3.0	0.8	1.1
Clavicle length	132.5	2	0.7	128.2	3	11.1	0.5	0.0
Arm - stature index	32.8	5	1.4	33.4	3	0.3	-0.7	60.2
Leg - stature index	46.9	2	1.1	47.7	3	1.1	-0.8	---
Brachial index	75.3	5	3.6	76.8	4	2.0	1.7	0.0
Crural index	82.0	4	2.9	83.7	3	1.9	-0.9	1.2
Femoral platymeria	79.8	10	5.0	86.3	3	2.8	-2.2*	0.9

Significance levels *P ≤ 0.05 **P ≤ 0.01. Measurements in millimetres.

In the post cranial skeleton, the results show that the Sigatoka population has a significantly greater expression of femoral platymeria. On the other hand, Sigatoka males are significantly taller and heavier than the Fijian males, but there is little difference between females. The crural index was significantly less in the Sigatoka males. This indicates that the relative length of the tibia was longer in the Fijian population. The lack of significant differences in the variances is probably due to the small sample sizes. The consistent lack of significant difference in variance makes any attempt at multivariate analysis superfluous. Therefore, interpretation of the data can only be based on the results of Student's t tests.

Table 8.3 shows that variables that reflect body size and the resulting changes in the naso-mandibular skeleton, such as nasal height and bigonial, breadth caused by requirements for greater oxygen demands (Houghton and Kean, 1987), are significantly greater in males than females in both populations.

Significant differences are evident in ramus breadth and coronoid height between the Sigatoka sexes, but this difference is not present among recent Fijians. The sex differences in the Sigatoka population probably reflects greater masticatory musculature.

Table 8.3
Comparisons of sex differences in the Sigatoka people and recent Fijians using Student's *t* test.

	Student's *t* statistic	
Variable	Sigatoka	Fiji
Nasal height	3.3**	4.0**
Nasal breadth	1.0	0.9
Ramus height	1.9	1.7
Ramus breadth	2.3**	1.3
Bigonial breadth	3.3**	3.4**
Bicondyle breadth	1.2	2.0
Corpus length	0.6	0.2
Stature	8.0**	2.4
Body mass	5.8**	2.5*
Clavicle length	1.5	1.4
Arm-stature index	0.2	1.1
Leg-stature index	0.3	1.1
Brachial index	0.3	0.5
Crural index	0.9	0.7
Femur platymeria	1.7	1.4

Significance levels *$P \leq 0.05$ **$P \leq 0.01$

Sex differences in clavicle lengths were not significant, although there is a marked difference between the sexes in each population. This lack of difference is probably a reflection of small sample sizes rather than a biological similarity.

The lack of sex differences in body proportions in both populations is consistent with the theoretical model using Allen's and Bergmann's rules (Bergmann, 1847; Allen, 1877). In this case, the rule predicts that there would be little difference in limb to body proportions and body size within a population because they reflect adaptation to the environment in which that population lived.

3.2 Sigatoka 1991 series

Table 8.4 presents the results of comparisons and univariate analysis of females in the main burial ground in Sigatoka and those excavated at Sigatoka in 1991. No significant differences were found in any of the variables. However, marked differences in nasal breadth and ramus breadth are evident. In general, the 1991 Sigatoka individuals had less pronounced masticatory muscularity and possibly narrower faces than the Sigatoka females, but little can be said with certainty because of the small sample sizes.

Table 8.4
Comparisons and univariate analyses of females from Sigatoka and the Sigatoka 1991 series.

	Sigatoka			Sigatoka '91				
Variable	n	Mean	sd	n	Mean	sd	*t* Statistic	f Ratio
Nasal breadth	10	26.3	1.9	3	24.5	1.9	1.5	1.0
Ramus breadth	19	38.4	2.9	4	35.8	3.2	1.6	---
Gonial angle	23	116.1°	6.4	2	115.5°	6.4	0.1	---
Stature	10	1656.8	44.5	2	1676.7	10.3	0.6	---
Body mass (Kg)	8	55.5	3.0	3	55.5	5.4	-0.0	5.8
Femoral platymeria	10	79.8	5.0	3	75.4	12.0	1.2	0.2

Measurements in millimetres.

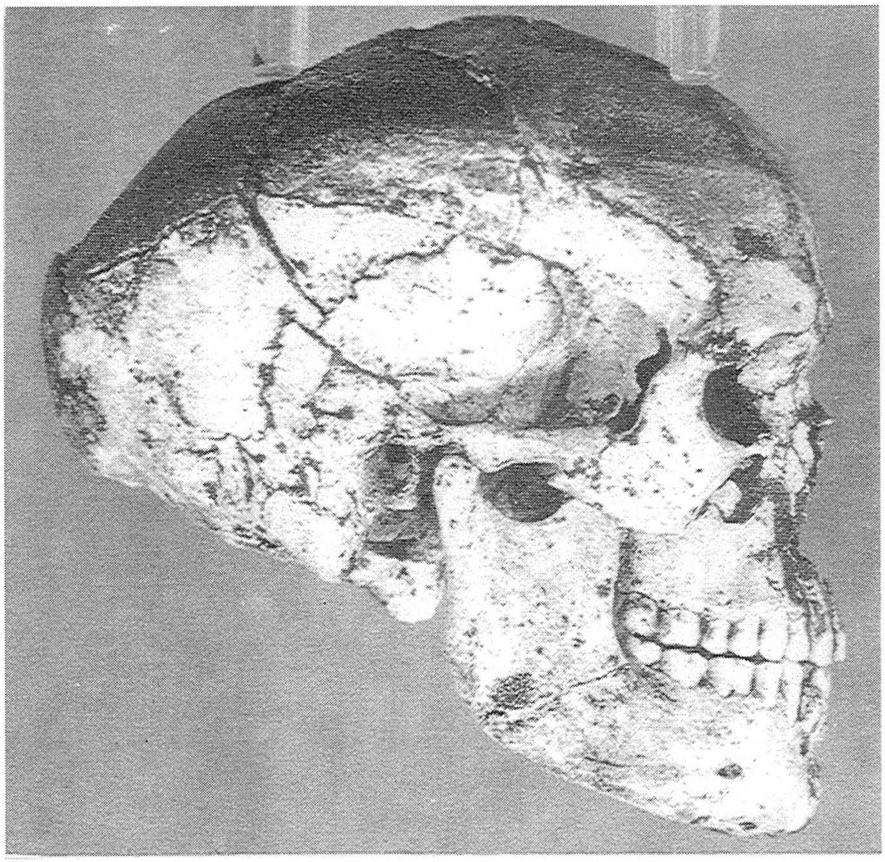
4.0 Interpretation

The recent Fijian and Sigatoka populations differ most sharply in their mean values of the mandible dimensions and nasal height, particularly between the two male samples. Mandibular differences reflect variation in skull shape so that it is possible to create a picture of facial form. The "average" facial profile and frontal view of the Sigatoka people, males in particular, have a longer upper facial height (nasal height) and their faces are less prognathic. In frontal view, their broader lower facial breadths, particularly at bigonial and less so the bicondylar breadth, distinguishes them most from Fijians. Figure 8.1 compares the profile of a Sigatoka male with an illustration from Flower (1881).

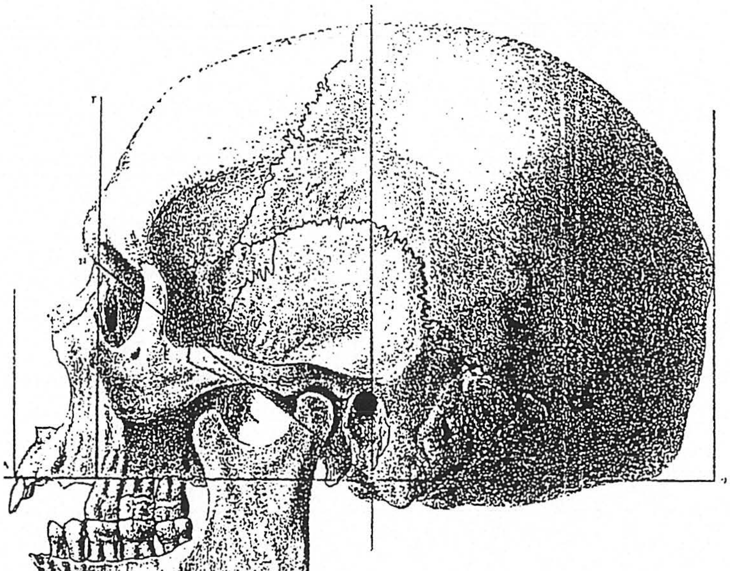
Not only do these differences illustrate variations in the form of the mandible, they also reflect differences in facial musculature. Ramal breadth and coronoid height differences are more pronounced between males than females in both populations. When the ramal breadth and coronoid height of the Sigatoka population are compared to Fijians, it is evident that the muscles of mastication, especially the masseter and temporalis muscles, which insert into these areas, are more massive than those found in the recent Fijian group.

Figure 8.1
An illustration of the different mandible profile between a recent Fijian and a Sigatoka male. The cranium of the Sigatoka male was distorted during the 2000 years it was buried.

Sigatoka male



Fijian male



Sigatoka females displayed the same differences evident in males when compared to Fijian females, but these differences are not as strongly expressed. Male and female differences seem to relate to body size differences. It has been suggested that differences between populations, particularly in nasal height, mandible breadths, and to a lesser extent, ramal dimensions, are in part influenced by the development of the nasal air passage and pharynx, both of which are involved in providing oxygen to the lungs (Houghton and Kean, 1987; Enlow, 1990). This explanation can account for the frequently observed nasal and mandibular differences between Sigatoka and the more recent Fijians. The smaller nasal and mandibular differences between Sigatoka females and recent Fijian females seems to relate to their similarities in body mass estimates. Conversely, significant differences exist between the two male samples in both body mass and stature estimates. The greater clavicle lengths exhibited in the Sigatoka males compared to later Fijian males provides evidence that the Sigatoka people had greater chest circumferences. Not only is greater chest circumference associated with larger oxygen capacity of the lungs, it is also considered to be a cool climate adaptation. Heat loss is minimised by decreasing the body surface to body size ratio (Houghton, 1991[a], 1991[b]).

The lack of significant differences in brachial and stature-to-limb ratios between the two populations do not appear to fit well with the hypothesis of adaptation to the Fijian environment. The limb ratios of the Sigatoka people were consistently less than the Fijian population. In the case of males, the crural index was significantly less than Fijian males (Table 8.1). Therefore, the variables that suggest cool climate adaptation differ slightly. Alternatively, the more recent Fijian population may have been less influenced by the marine environment because they were strongly influenced by more recent migrants from the west, probably from Vanuatu. In this case, limb ratios reflect adaptability of both groups to the Fijian terrestrial environment. An additional observation is that similarities in measurements and indices between the two groups were obvious in only one or two variables.

Comparisons of Sigatoka females with the females excavated in 1991 reveal no significant differences in the few variables studied. However, it seems that the 1991 series had smaller nasal and mandibular dimensions, resulting in smaller facial musculature. There was very little difference in the post cranial skeleton. Stature and body mass estimates are very similar. The few variables available suggest an equally tall but a facially less robust group, appearing to have a closer phenotypic relationship with the Fijian skeletal material. It is difficult, if not impossible, to reach a firmer conclusion with such an incomplete data set. However, these differences are important if the 1991 skeletons date from a later context (Crosby, 1991).

5.0 Summary

The paradox of the lack of mean differences in body proportions but significant differences in body size (body mass and stature) may be resolved if the effect of environmental adaptation is taken into account. This hypothesis holds that if both populations lived under the same climatic conditions, following Bergmann's and Allen's rules, body proportions should be similar. The similarities in body proportions between the Sigatoka and more recent Fijian populations are consistent with Bergmann's and Allen's rules (Tables 8.1 and 8.2). The larger body size of the Sigatoka people may be a reflection of stronger selective pressures operating on them and their direct descendants compared to more recent Fijians.

Differences in mean values and the small standard deviations from these means in facial and mandibular dimensions, and to a lesser extent differences in some postcranial features, suggest that the Fijian population is not likely to be directly descended from the Sigatoka people. The statistical differences between the two populations reflect biological differences.

Some aspects of the more recent Fijian body form may have been influenced by selective pressures in the Fijian environment. However, the time period and the selective pressures operating on them was likely to have been insufficient to have altered the body form, particularly mandibular form, from that evident in the Sigatoka people to the more recent Fijians. Differences between the two populations are more likely to reflect post 180 AD immigration into Fiji from the west, probably Vanuatu. Botanical evidence suggests that contact with Vanuatu occurred before 180 AD (LeBot, 1991; Visser, 1994). Archaeological evidence indicates that significant episodes of contact probably occurred with Vanuatu after 1100 AD (Green, 1963). It would seem highly probable that later immigrants to Fiji from the west substantially altered the genotype and phenotype from that expressed in the Sigatoka people.

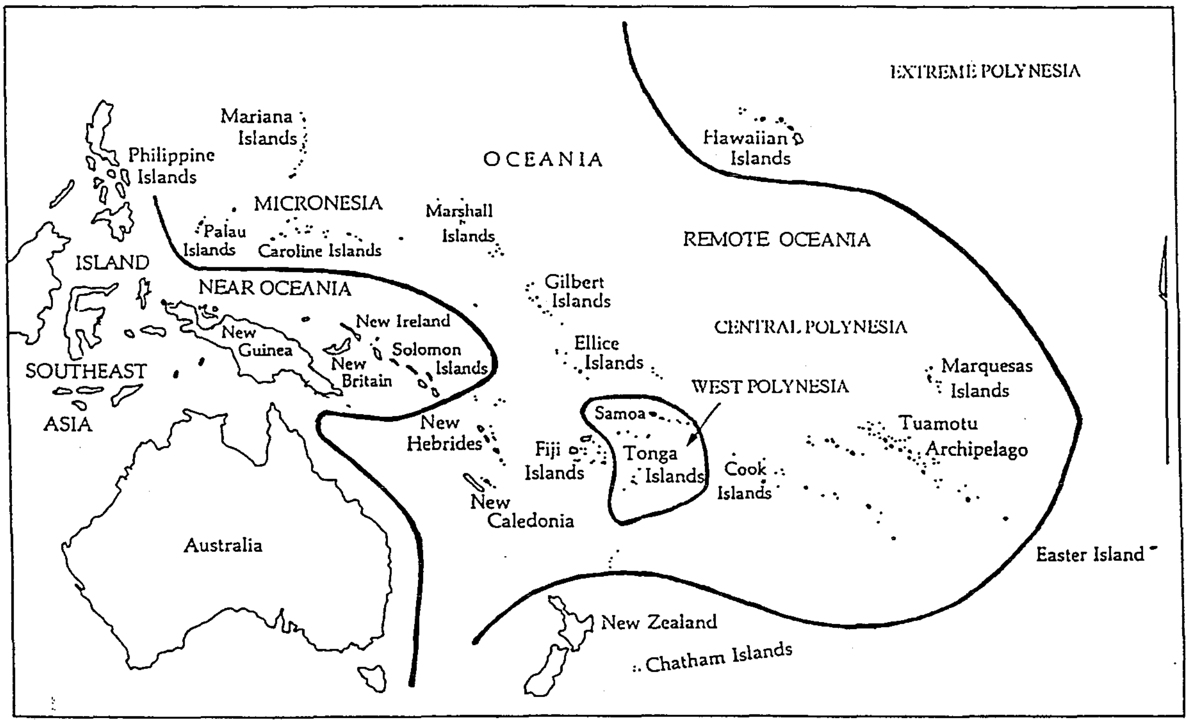
Chapter Nine

Biological comparisons of Pacific populations

1.0 Introduction

The aim of this section is to compare the Sigatoka population to other Pacific populations using skeletal and dental traits. Pacific populations are divided into subsets based on geographic provenance in Near Oceania; (Solomon Island populations, Nebira and Eriama), environmental controls (Australian Aboriginals and Tierra del Fuego), Lapita culture associated skeletons, recent Fijians and Polynesian populations. Polynesian populations are sub divided into extreme Polynesians (Maori, Moriori, Mokapu and Easter Islanders), east Polynesians (Marquesas, Tepoto, Pukapuka and Mangaia), West Polynesia (Tonga), and outlier Polynesia (Namu). Figure 9.1 illustrates the geographic location of these populations.

Figure 9.1
The geographic divisions of some of the comparative Pacific populations.



Anthropometric data from a number of Pacific populations are compared with Sigatoka. While recognising that differences between anthropometric data and the metric values of skeletal data will occur, some measurements such as stature and body mass can be validly used as comparative data (Houghton, 1991^{a}, 1991^{b}). The traits analysed in this chapter have been chosen for the following reasons: they are argued to have a large genetic component determining their form; or they are regarded as providing an indication of body size; or they reflect a particular attribute within a series of populations.

The questions of Sigatoka relationships to other populations which are posed and investigated are:-

(1) How do the Sigatoka skeletons compare with the skeletons associated with the Lapita cultural complex, and what does this indicate about their relationship with Sigatoka?

(2) What, if any, is the biological relationship between certain Remote Oceanic (Polynesian) populations and the Sigatoka people?

(3) What are the biological relationships between the Sigatoka people and some populations from Near Oceania?

2.0 Theory

The theory and methods of most variables investigated in this chapter have been considered in previous chapters. The theoretical basis of using variables that have not been discussed are outlined below.

2.1 Body mass

Differences in body mass between populations have been shown to be responsive to differences in climate (Newman, 1956; Roberts, 1953). These studies have shown that populations in cool climate zones will weigh more than those populations in warm climates. Body mass is, of course, also sensitive from other environmental circumstances such as diet and health. Additionally, mean body weight of a group that has migrated to another climatic area can differ to the parent population within one generation. This generational difference is an example of genetic plasticity (or acclimatisation), rather than evolution.

Contemporary Polynesian populations from warm tropical island environments have a characteristically heavy body mass compared to other warm climate populations and even cool climate populations (Houghton, 1990, 1991^{a}, 1991^{b}; Pawson, 1986). There appears to be only small differences in body mass between Polynesians living in warm climates compared to those living in cool climates, such as the Maori. The characteristic of a heavy Polynesian body mass has been proposed as an adaptive feature to a cool tropical marine environment (Houghton, 1990, 1991^{a}, 1991^{b}). This hypothesis is examined in the following two chapters.

2.2 Femoral platymeria

Femoral platymeria has been used to compare differences between males and females from Sigatoka in Chapter Six. However, it's use as a tool in comparing populations has not yet been discussed. Most human populations exhibit mediolateral flattening of the subtrochanteric area of the femoral shaft. The extent to which platymeria is consistently expressed among Polynesian populations appears to be a characteristic of these populations (Houghton, 1980). Why Polynesians exhibit high platymeria is not clear. Hay (nd) has proposed that platymeria occurs as a result of differential bone deposition on the subtrochanteric mediolateral aspect of the femur. Hay suggests that the reason why bone is preferentially deposited on the mediolateral aspect of Maori femora is as a result of activities such as squatting, performed during the growth phase of the bone.

The relationship between the femoral head and the acetabulum in the Maori is different to that in Europeans and Indians (Houghton, pers. comm.). In the Maori, the axis of the femoral head tends toward the anterior of the acetabulum. This model suggests that the gluteus maximus and gluteus medius develop strongly to retain the femoral head within the acetabulum. The attachment of these muscles to the proximal femoral shaft and ilium indicates that not only is the degree of platymeria different in Maori, but the ilium also differs. The ilium tends to have a lateral curve on the superior surface, probably to accommodate muscular strain.

While the genetic and functional basis of femoral platymeria is not yet clear, there is a demonstrably high incidence in Polynesian populations. In using femoral platymeria as a Polynesian trait, it may be possible to identify a cline among Pacific populations based on geographic distribution.

2.3 Tooth size

Total tooth area involves calculating the area of each tooth in the dentition and then adding the results together. Brace and Hinton (1981) used total tooth area to map a decline in tooth area size temporally and spatially from Southeast Asia to the Pacific islands. Brace and Hinton (1981) explained their observation of dental reduction within a hypothesis called the "Probable mutation effect theory" (PME). This theory holds that selective mechanisms for large teeth are relaxed in populations who have a soft diet. Selective relaxation enables genetic mutations for small teeth to dominate in a population. Brace and Hinton (1981) argued that the cultural-technologically more advanced Asians had smaller teeth that Melanesian and Australian populations. The final point of their argument was that Polynesians could not be derived from this Melanesian-Aboriginal grouping because of their smaller teeth. Therefore, they proposed a swift pre-Polynesian migration from Southeast Asia through island Melanesia into Polynesia.

However, there are notable flaws with this proposition. First, it supposes that tooth size is under primary control of a gene, or at most a very restricted number of genes. This has been shown to be unlikely (Fitch *et al.*, 1985; Townsend and Alvesalo, 1985; Lau *et al.*, 1989). A single mutant gene is unlikely to effect the size of a tooth, but is more likely to result in a change of structure in either the enamel, dentine or cementum. In addition, it appears likely that mutant genes work only in one direction. Tooth size can equally increase in size as decrease in size (Townsend, 1983).

Second, the probable mutation theory does not consider how modifications in the teeth will affect the craniofacial skeleton. The teeth and the craniofacial skeleton are part of an interrelated functional masticatory system. A change in one component may affect other components. Leading on from this is the third main problem: it has been shown that as technology and food processing increase, a concomitant reduction in tooth size does not necessarily follow (Scott, 1979).

Given these theoretical limitations of the PME theory, greater emphasis has been placed on presenting an idea that holds that changes in the craniofacial skeleton and teeth are linked. These changes occur through the mechanism of natural selection. This theory is applied to the question of why teeth are small in Polynesian populations.

The natural selection theory of tooth reduction rests on the supposition that large teeth and soft diet do not mix. This is because large teeth have more fissures and cusps than smaller teeth and are therefore more susceptible to caries and dental decay. Untreated carious lesions can lead to secondary, life threatening infections (Anderson and Popovich, 1977). The theory also argues that problems arise when relatively large teeth are contained within a relatively small mandible. With teeth competing for limited space the inevitable result is tooth crowding and third molar impaction. Impacted teeth and malocclusion are both deleterious to the well-being of an individual. It has been claimed that if this occurs in a population through time, individuals are selected who have shorter mesiodistal diameters. This prevents crowding and allows for mesial migration so that the third molars can be accommodated within the mandible and maxilla (Begg, 1954).

Largely in response to Brace and Hinton (1981), Harris and Smith (1983) proposed the hypothesis that no east-west cline in tooth size exists in Pacific populations. Harris and Smith (1983) felt that three major factors influenced total tooth size area in these populations. These are: function, size required differences (body size), and inherited effects. They argued that larger tooth size does not have any particular adaptive value, but rather it is a reflection of body size. Harris and Smith (1983) observed that Aboriginals and "Melanesians" have large teeth to head measurements, while the Polynesians have small teeth to body size. They concluded that Polynesians do not have disproportionately smaller teeth, but rather "Melanesians" do.

A problem with the Harris and Smith argument is that they view the various populations in "Melanesia" as homogeneous. This has been shown to be incorrect (Friedlaender, 1987^{b}).Consequently, it is not possible to present Melanesia and Polynesia as containing two dichotomous populations. However, the theoretical basis of Harris and Smith's hypothesis remains valid, because tooth size should not be studied in isolation to the masticatory system in which they operate. The maxilla and mandible are important in this system. Their forms are partially genetically determined but are also influenced in response by the muscular forces produced during chewing and the resting position of the mandible (Enlow, 1968). Experimental work with rat jaws has shown that soft diet requires less chewing and therefore less masticatory muscle activity. As a response, bone deposition in the jaw was less compared to a control group with a fibrous diet (Corrucini and Becher, 1982). In other words, environmental processes can alter the size and shape of areas of the mandible, within genetically defined limits (Calcagno and Gibson, 1988). Teeth are accommodated by the mandible and maxilla, therefore their size may be affected by the size of these bones. Concomitant with this, mesiodistal lengths decrease which further reduces the likelihood of crowding and third molar impaction. At the same time, early wear would result in the loss of cusps and grooves that are susceptible to caries (Calcagno and Gibson, 1988). In cases where diet becomes softer, cusps and fissures remain unworn and therefore susceptible to caries. Mesial drift does not occur when teeth are unworn, nor is the bone of the maxilla and mandible stimulated sufficiently to obtain their optimal size. Consequently, the amount of space able to accommodate the dental arcade is reduced, and tooth impaction and crowding may occur. In this scenario, selection will work in favour of small teeth, because caries will attack the teeth of large toothed individuals during childhood and adolescence. The health of these individuals could have have been compromised and perhaps they were more likely to die before they could reproduce, compared to individuals with smaller teeth.

Within the dentition, each tooth group has a specialised function molars for chewing, canines for tearing and incisors for biting. Each tooth and tooth group must retain efficient function because mastication and eating are vital to an individual's chances of survival, for obvious reasons. If reduction in tooth size does occur it may affect the various tooth groups differently. In this case, the changes in the Polynesians, Sigatoka and Lapita people, as well as population groups from the Melanesian area can be mapped. Given the problem with total tooth size, this approach is excluded from the analysis.

2.3 Maxillary shovel shaped teeth

An outline of the theoretical basis of maxillary shovel shaped tooth formation has been presented in Chapter Six. Here, a brief outline on the use of shovel shaped teeth as a comparative tool is presented. The use of shovel shaped maxillary incisors as a tool in comparing populations has a long history in the Pacific. Hrdlicka (1920) used this trait, in association with others, to place the Hawaiians within a racial taxonomy. Since then, many scholars have used shovel shaped incisors in this way (Chappel, 1927; Resienfeld, 1959, Suzuki and Sakai, 1964; Turner, 1978). Initially, genetic evidence for the validity of using this trait was scant. In 1957, Moorrees published a comprehensive analysis on the dentition of Inuits. On the basis of correlations, he suggested that maxillary shovel shaped incisors can be considered a good indicator of racial affinity. Suzuki and Sakai (1964) observed that the frequency of shovel shaped incisors was greater in Polynesian populations compared to other population groups. Furthermore, they found that:

> "...the percentage frequency [of shovel shape] of the central incisors of the Polynesians is very different from that of any other race." (Suzuki and Sakai 1964:70).

A number of recent studies have expressed the same confidence in the ability of shovel shaped incisors to discriminate between populations (Baume and Crawford, 1978).

3.0 Methods

Statistical methods have been outlined in previous chapters. The methods used to measure those variables assessed in this chapter that have not yet been discussed are presented here.

3.1 **Skeletal traits**

3.11 Stature

Stature estimates of other Oceanic populations that have been used in this chapter are based on the Polynesian stature formulae from Houghton *et al.* (1975). These methods and formulae have been presented in Chapter Four.

3.12 Body mass

Body mass estimates of other Pacific populations that have been used in this chapter are based on the Maori formulae of Houghton *et al.* (nd) and the results of regression analyses. These methods and formulae have been presented in Chapter Four. Measurements of the wrists and ankles are not available in most studies of Oceanic populations. Consequently, body mass estimates of these populations are based on bicondyle breadth of the distal femur and the bicondylar breadth of the distal humerus.

3.2 **Dental traits**

3.21 Tooth group correlations

Tooth size areas of tooth groups from both the maxilla and mandible are considered. Tooth groups are made up of: first and second molars; first and second premolars; canines; and central and lateral incisors. Tooth size areas are calculated by adding the maximum mesiodistal and buccolingual diameters of a tooth. The methods used to calculate tooth diameters have been outlined in Chapter Six. The result is then added to the areas of other teeth within a tooth group area. The correlation of each tooth group was investigated to identify tooth group uses.

A problem with using the raw diameters of teeth is that body size is not taken into account. For example, the larger the individual, the larger the teeth. By using raw data it becomes difficult to make an accurate assessment of variation between populations. Body size is taken into account by relating tooth diameters to another body measurement to obtain a new scaled value. Tooth diameters are scaled by dividing the mean buccolingual diameter of the an individual's teeth by the mean minimum ramus breadth of the same individual.

Thus; $\frac{r}{t} \times 100$

Where r = minimum ramus breadth.
t = tooth diameter.

3.22 Maxillary shovel shaped incisors

A number of different researchers have collected information on the frequencies of maxillary shovel shaped incisors in different Oceanic populations. There may be some variation in the recording of examples of trace shovel shaped teeth. However, these differences should not affect the identification of the presence or absence of shovel shaped incisors, which is the focus of investigation. The methods used to identify and classify shovel shaped incisors have been presented in Chapter Six.

3.23 Molar protostylid

There is insufficient data from Oceanic populations for comparisons of all forms of protostylid expression to be made, because researchers have generally recorded only the presence or absence of the protostylid cusp on the mandibular molars.. The methods used to identify and classify protostylids have been presented in Chapter Six.

3.24 Molar cusp patterns

The method used to classify maxillary molar cusp patterns have been outlined in Chapter Six. Molar cusp patterns were identified from the second molars in adult males and females. The second molar is genetically stable and has the added advantage of usually having less wear than the first molar (Leamy and Hrubant, 1971; Leamy, 1981).

The classification system used to compare cusp patterns in the mandibular molars follows Turner (1979). The scaling system is as follows:-

0 = Y Groove.
1 = Four cusps.

By using this system, comparisons between the Sigatoka population and a number of other Oceanic populations already described and that have only investigated cusp patterns on the second molar can be made.

4.0 Results

4.1 Skeletal traits

4.11 Stature

Consideration is given first to stature and body mass comparisons. The stature estimates of the Sigatoka people are presented in Chapter Four. In Table 9.1, the mean stature estimates of Sigatoka males are compared with stature estimates from provenanced skeletal and anthropometric cases from Oceanic populations.

Table 9.1

Univariate results and comparisons of stature estimates of Oceanic populations with Sigatoka.

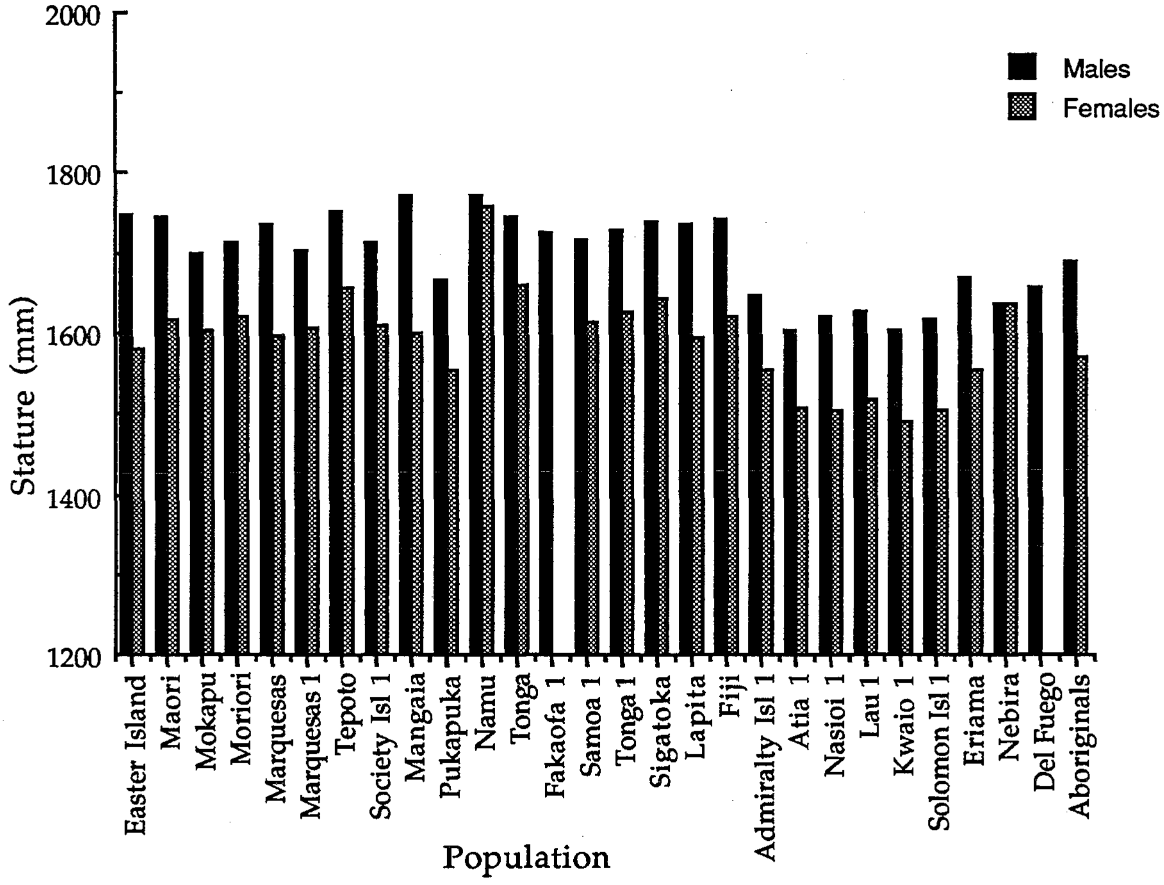
	Males					Females					
Provenance	Mean	n	sd	*t* statistic	f ratio	Mean	n	sd	*t* statistic	f ratio	Source.
Easter Island	1748	7	35.1	-0.4	2.1	1579	8	38.2	4.4 **	0.3	Murrill,1968
Maori	1745	13	34.4	-0.2	4.9*	1618	14	37.4	3.0 **	0.0	Houghton, nd[c]
Mokapu	1699	75	12.5	3.2 **	1.0	1603	612	15.0	3.4 **	18.5	Snow, 1974
Moriori	1712	3	19.9	2.2 *	1.0	1619	2	7.7	1.2	----	Visser, nd
Marquesas	1737	13	32.7	0.2	3.6	1598	3	4.0	2.6 *	0.1	Pietrusewsky, 1976
Marquesas[1]	1703	79	51.2	----	----	1607	73	51.1	----	----	Sullivan, 1922
Tepoto	1751	7	30.5	-0.6	5.2	1657	9	25.6	-0.7	1.4	Dennison, nd
Society Isl[1]	1714	85	59.4	1.8	2.0	1611	68	52.1	39.4	----	Shapiro 1930
Mangaia	1773	11	36.5	-2.6	0.1	1600	3	21.0	2.4 *	7.8	Katayama *et al.*, 1988
Pukapuka	1667	3	34.0	4.5**	7.1	1555	3	75.7	3.4 **	18.5	Yoshida 1988
Namu	1771	13	29.4	-2.8*	5.9*	1759	6	28.9	-7.0 **	1.7	Visser, nd
Tonga	1747	13	29.8	-0.4	0.0	1659	10	0.0	-0.6	4.3	Pietrusewsky, 1969
Fakaofa[1]	1727	13	-----	----	----	----	---	----	----	----	Lister, 1892
Samoa[1]	1717	----	52.5	----	----	1612	---	49.2	----	----	Sullivan, 1922
Tonga[1]	1730	92	52.1	----	----	1625	88	58.3	----	----	Sullivan, 1922
Sigatoka	**1740**	**13**	**23.3**	----	----	**1644**	**12**	**28.7**	----	----	
Lapita	1737	5	34.2	-1.6	1.7	1594	2	---	---	----	Pietrusewsky, 1991
Fiji	1743	13	22.4	0.0	8.5	1619	3	6.9	1.4	25.5	Weber, 1934
Admiralty Isl[1]	1645	9	49.1	-6.3 **	0.4	1553	4	36.4	4.9 *	6.4	Moseley, 1877
Aita[1]	1604	80	---	----	----	1507	87	---	---	---	Rhoads, 1987
Nasioi[1]	1621	59	---	----	----	1504	63	---	---	---	Rhoads, 1987
Lau [1]	1625	106	---	----	----	1518	95	---	---	---	Rhoads, 1987
Kwaio [1]	1603	127	---	----	----	1490	114	---	---	---	Rhoads, 1987
Solomon Isl[1]	1616	13	39.4	10.1 **	2.5	1503	6	74.3	5.9 *	1.0	Guppy, 1886
Eriama	1668	10	19.8	8.3 **	0.6	1553	6	34.9	5.7 **	---	Visser, nd
Nebira	1636	10	4.3	7.5 **	0.0	1636	3	4.3	0.6	22.8	Visser, nd
Del Fuego	1656	6	39.7	6.1 **	29.0	---	---	---	---	---	Garson, 1886
Aboriginals	1690	13	47.3	3.6 **	1.2	1571	20	48.2	4.9 **	0.1	Abbie, 1951

Significance levels P ≤ *0.05. P ≤ **0.01 difference with Sigatoka

1 Denotes anthropometric measurements. Measurements in millimetres

In general terms, Table 9.1 indicates that there are marked differences in stature between populations from Remote Oceania compared to populations from Near Oceania. Within this broad division, Near Oceanic populations are either markedly shorter, or statistically significantly shorter compared to Sigatoka. Remote Oceanic populations are generally similar in stature to each other and to Sigatoka. The exceptions to this are the statures of males from Mokapu and Pukapuka that are significantly shorter than that of Sigatoka.

Figure 9.2
Graphic comparisons of stature estimates of Oceanic populations illustrating a geographical cline of stature between Remote and Near Oceania.



The greatest difference from the stature of Sigatoka males is evident in populations from Near Oceania, Tierra del Fuego, and the Aboriginals, which are all significantly shorter than Sigatoka males. The populations from Eriama and Nebira are also significantly shorter than Sigatoka. The Namu population is contrary to this cline. The Namu people have strong Polynesian cultural associations, and this association also seems to be reflected in stature. These stature comparisons are illustrated in Figure 9.2.

The geographical cline in stature is also evident among females. Females from Remote Oceania are markedly taller than those from Near Oceania, other than the Polynesian related population from Namu. Sigatoka females are similar in stature to Tepoto, Tonga and Namu females, but they are significantly taller than many of the other Remote Oceanic populations. (Figure 9.2).

4.12 Body mass

Comparative results of body mass are presented in Table 9.2. These data show a trend wherein Remote Oceanic populations have greater body mass than populations from Near Oceania and the Aboriginals. Body mass estimates of Sigatoka males and females are within the lower Remote Oceania range. Tongans, Maori and Namu males have significantly greater body mass than Sigatoka males.

Table 9.3
Univariate results and comparisons of body mass estimates of Pacific populations with Sigatoka.

	Males					Females					
Provenance	Mean	n	sd	*t* statistic	f ratio	Mean	n	sd	*t* statistic	f ratio	Source
Easter Island	71.0	19	3.4	0.1	0.0	52.2	8	4.5	1.7	0.3	Murrill, 1968
Maori	76.1	12	5.2	-2.2 *	0.1	58.3	19	5.9	1.3	0.0	Houghton, *et al.*, nd
Moriori	77.6	6	11.7	1.6	0.1	----	---	---	----	----	Houghton, nd[c]
Mangaia	66.7	2	0.0	1.0	0.0	----	---	---	----	----	Tayles, pers. comm.
Namu	76.1	12	3.4	-2.5 *	18.8 **	61.7	5	5.5	-2.7 *	0.7	Visser, nd
Tonga	76.8	12	6.2	-2.3 *	3.8	61.3	8	8.3	1.9	0.3	Pietrusewsky, 1969
Sigatoka	**71.2**	**12**	**6.0**	**----**	**----**	**55.0**	**8**	**3.5**	**----**	**----**	
Lapita	72.5	5	6.7	----	----	-----	---	---	----	----	Pietrusewsky, 1991
Fiji	63.9	5	6.5	2.2 *	9.4	53.9	3	3.0	0.8	1.1	Weber, 1934
Ontong Java[1]	64.4	106	----	----	----	58.1	179	---	----	----	Rhoads, 1987
Admiralty Isl[1]	59.6	3	5.9	3.0 **	1.8	-----	----	---	----	----	Moseley, 1877
Aita[1]	59.4	81	----	----	----	52.2	115	---	----	----	Rhoads, 1987
Nasioi[1]	57.6	59	----	----	----	46.3	63	---	----	----	Rhoads, 1987
Lau[1]	64.0	141	----	----	----	54.0	97	---	----	----	Rhoads, 1987
Kwaio[1]	55.3	127	----	----	----	45.8	114	---	----	----	Rhoads, 1987
Solomon Isl	57.8	12	8.4	-4.5 **	1.2	----	----	---	----	----	Guppy, 1886
Nebira	67.5	7	2.8	1.5	1.2	50.3	3	0.4	2.8 *	0.1	Visser, nd
Eriama	67.5	7	2.8	1.5	1.2	48.9	4	5.3	2.8 *	0.9	Visser,nd
Aboriginals[1]	55.8	12	8.3	5.2 **	4.5	45.4	20	5.8	4.6 *	0.4	Abbie, 1951

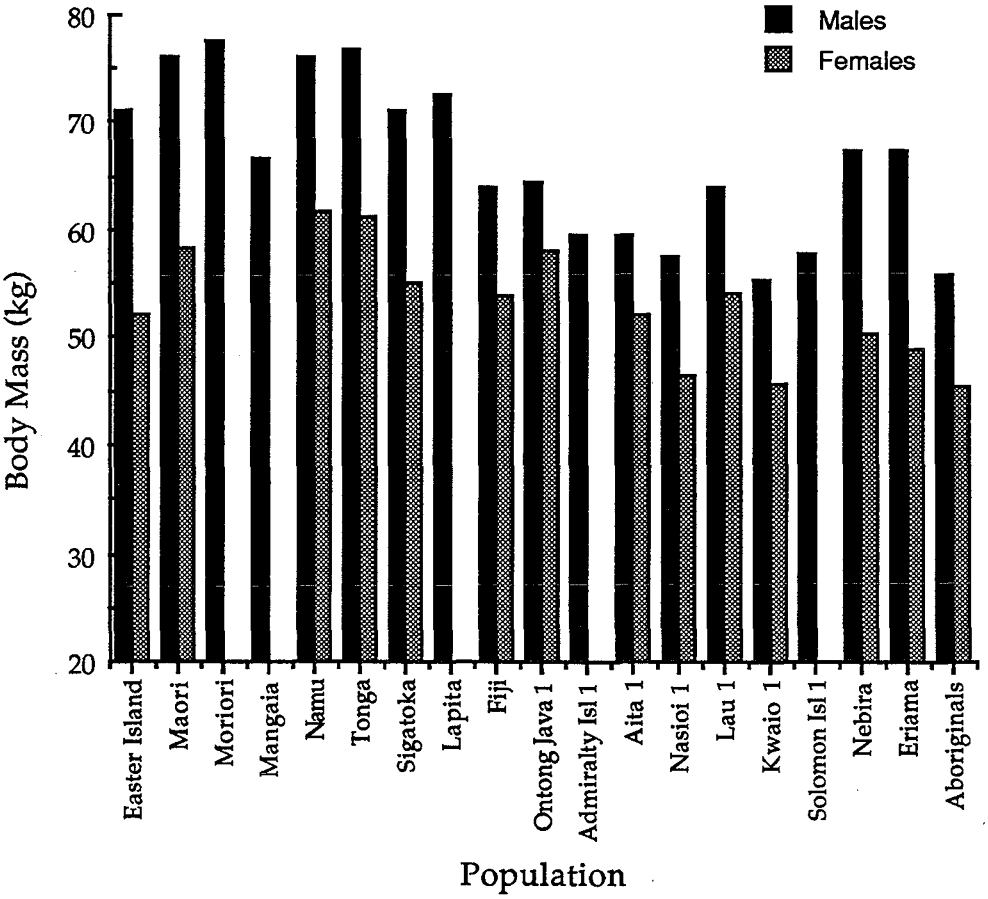
Significance levels * $P \leq 0.05$. ** $P \leq 0.01$ difference with Sigatoka
1 Denotes anthropometric data. All weight in kilograms.

Estimated body mass of Sigatoka and Lapita associated males are similar. Body mass estimates of Eriama and Nebira are less than Sigatoka, but the differences are significant only between females (Table 9.2). Aboriginals have significantly less body mass than the Sigatoka people.

The range of different body mass estimates among females is less than males (Table 9.2). Sigatoka females have a significantly greater body mass than those from Near Oceania. Namu males have similar weights as Polynesians, while Namu females have significantly greater body mass estimates than Sigatoka females.

Population differences in body mass differences are illustrated in Figure 9.3. This graph shows the trend of decreasing body mass from Remote to Near Oceania.

Figure 9.3
Illustration of body mass estimates of Oceanic populations showing a geographic cline in decreasing body mass from Remote to Near Oceania.



4.13 Femoral platymeria

The comparative results of femoral platymeria in Pacific populations are presented in Table 9.3.

The expression of femoral platymeria increases from Tonga towards eastern Polynesia. The most extreme forms are in the Maori and Moriori. The Sigatoka males have a comparatively slight expression of femoral platymeria, which is more typical of most Near Oceanic populations.

Table 9.3
The expression of femoral platymeria in Oceanic populations and their comparison to the Sigatoka population.

	Males					Females					
Provenance	Mean	n	sd	*t* statistic	f ratio	Mean	n	sd	*t* statistic	f ratio	Source
Easter Island	71.3	11	4.4	5.0 **	0.1	68.7	8	4.5	5.2 **	0.4	Murrill,1968
Maori	65.5	30	4.8	9.3 **	0.0	63.8	30	4.1	11.2 **	0.0	Houghton nd[c]
Moriori	66.1	6	2.5	5.7 **	0.2	----	---	----	----	----	Houghton, nd[c]
Mokapu	71.7	65	4.6	2.7 *	0.0	70.0	103	4.9	3.1 **	7.3	Snow,1974
Mangaia	71.2	12	4.4	5.2 **	49.6	70.4	3	5.5	2.9 *	12.2	Katayama *et al.*, 1988
Namu	78.5	14	8.6	1.8	0.1	82.6	4	15.3	-0.6	6.4	Visser, nd
Marquesas	73.6	12	1.1	2.4 *	0.0	72.3	3	6.3	2.3	7.7	Pietrusewsky, 1976
Tepoto	81.0	5	3.0	0.8	0.0	67.4	3	0.6	4.2 **	8.5	Dennison, nd
Pukapuka	78.1	5	7.1	1.3	0.3	76.7	4		1.2	17.5	Yoshida, 1988
Tonga	83.4	11	5.1	0.4	0.6	78.5	7	8.0	0.4	3.7	Pietrusewsky, 1969
Sigatoka	**83.7**	**12**	**7.0**	----	----	**79.8**	**14**	**5.0**	----	----	
Lapita	84.1	3	2.1	0.1	0.0	----	---	----	----	----	Pietrusewsky, 1989
Eriama	79.1	9	6.3	1.7	0.1	----	----	----	----	----	Visser, nd
Nebira	82.4	10	5.6	0.7	0.0	82.1	10	2.8	-1.3	1.4	Pietrusewsky, 1976
Aboriginals	78.8	3	7.4	1.1	0.0	78.8	110	7.4	0.3	7.3	Davivongs, 1963

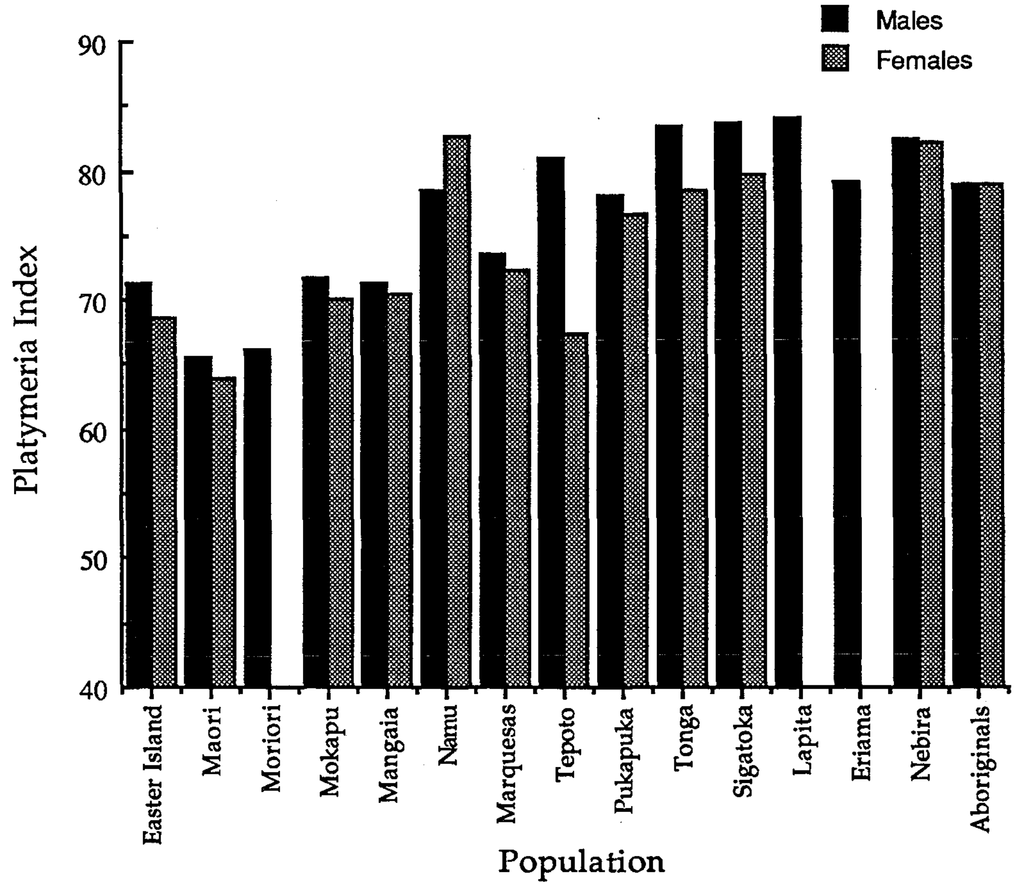
Significance levels * $P \le 0.05$ **$P \le 0.01$ difference with Sigatoka.

Among males, differences in the expression of femoral platymeria show the greatest geographical distinction of the postcranial variables. Excluding Tepoto and Pukapuka, Polynesians have greater expressions of platymeria than the Sigatoka population. These differences are significant or very significant (Table 9.3). All other populations have platymeric indices that do not differ significantly different from the Sigatoka males.

Among females, the expression of femoral platymeria mirrors that found in males from eastern Polynesia and extreme Polynesia (Figure 9.4). Femoral platymeria in females from eastern Polynesian populations is significantly greater than Sigatoka, Tonga and Pukapuka. The Aboriginals, have a similar degree of platymeria to Sigatoka. In the Nebira and Namu populations, femoral platymeria is less than Sigatoka.

The consistently high frequency of femoral platymeria in each of the east and extreme Polynesian populations sets them apart from other population groupings (Figure 9.4).

Figure 9.4
Illustration of decreasing femoral platymeria from Remote to Near Oceanic populations.



4.2 Dental traits

4.21 Tooth group area sizes

Tooth group sizes are considered when identifying population relationships, and whether any changes in group size occurred from west to east. This applies in particular to molar size.

In Table 9.4, the tooth group area size (TS) and the percentage of these to total tooth area are given. These results show a wide range of tooth group area sizes in Near Oceanic populations as well as in the Polynesian groups. As a commentary on Brace and Hinton (1981), it is to be expected that the area that molars in particular (and to a lesser extent premolars), make up of the dental arcade would be greater in Near Oceanic populations than in Remote Oceania. In the populations studied here, including Australian Aboriginals, that assumption does not hold. Molar teeth constitute a similar range in crushing area in the Near Oceanic populations as in Polynesians. There is no decline in molar area as a proportion of total tooth size. If anything, the premolar area increases in Polynesian populations, effectively providing Polynesians with a greater tooth crushing area than that found in populations to the west.

Table 9.4

Tooth group area sizes and percentage of tooth group areas to total tooth group area in some Pacific populations.

Population	Molars	%	Pre-molars	%	Canines	%	Incisors	%	Source
Maori	462	46.3	245	24.5	129	13.7	162	16.2	Visser, nd
Mokapu	511	46.0	285*	25.6	131	11.8	185*	16.6	Snow, 1974
Tepoto	612	45.9	335	25.1	151	11.3	236	17.7	Dennison, nd
Mangaia	508	45.6	278	25.0	134	12.0	194	17.4	Yamada and Kawamoto, 1988
Pukapuka	531	46.3	285	24.8	136	11.8	196	17.1	Yamada and Kawamoto, 1988
Namu	533	45.6	317	27.1	135	11.5	185	15.8	Visser, nd
Tonga	476	48.3	236	24.0	114	11.6	159	16.1	Visser, nd
Sigatoka	**494**	**46.2**	**269**	**25.1**	**131**	**12.2**	**176**	**16.4**	
Lapita	478	48.5	229	23.2	115	11.7	163	16.5	Pietrusewsky, 1991
Nasioi	524	42.6	300	24.4	156	12.7	249	20.3	Harris and Bailit, 1987
Nakanai	464	48.1	227	23.5	114	11.8	159*	16.5	Harris and Bailit, 1987
Nebira	486	46.0	258	24.4	126	11.9	186	17.6	Visser, nd
Lufa	554	45.9	289	23.9	141	11.7	223	18.5	Doran and Freedman, 1974
Goroka	548	45.3	300	24.8	139	11.5	223	18.4	Doran and Freedman, 1974
Aboriginals	604	46.9	309	24.0	158*	12.3	218	16.9	Smith and Wood, 1981

Significance level * $P \leq 0.05$ difference with Sigatoka.

Nakanai and Tonga have the greatest molar tooth area and the smallest premolar tooth area. While the Maori generally have small tooth sizes, their canine size is almost as large as many of the other populations. In the Sigatoka population, mean tooth group sizes are within the narrow Polynesian ranges, (and within the more variable Near Oceanic ranges). However, the skeletons associated with the Lapita cultural complex differ markedly from most of the Polynesian populations, except Tonga. These two populations have a low premolar area.

The smallest percentages of tooth group area sizes are between the Lapita associated skeletons and Sigatoka. These differences are between 0.1% and 2.1%. This compares with ranges for Polynesia that are between 1.6% and 2.7%. In contrast, the Near Oceanic population range of tooth group differences is between 2.2% and 5.5%.

The ratio of each tooth group area to the total tooth size area, excluding the third molars, is considered. Tooth group size may indicate the amount of functional importance of each group. For example, a large molar area provides a large crushing surface. The adaptive significance of a larger crushing surface may relate to the demands of an abrasive diet. A large crushing surface probably also requires an increase in masticatory musculature. Conversely, reduction in molar area will mean that the anterior teeth cover a comparatively larger area and masticatory musculature may decrease. Tooth group areas probably change slowly within a population when selection is relaxed. Therefore, tooth group areas may provide information on the relationships between populations.

The tendency of tooth group size area in Polynesia and Sigatoka is towards smaller molars and larger premolars, compared to populations from Near Oceania. Tongans, however, have greater molar than premolar tooth group size. The size of the molars is weakly negatively correlated with the size of the premolars ($r \leq 0.01$) in the Namu and Tepoto populations, while people from Nebira and Sigatoka have a weak positive correlation ($r \leq 0.23$). A negative correlation effectively means that molar size is reduced compared to an increased premolar size. In the remaining populations there were expected strong positive correlations.

Sigatoka showed a moderately strong negative correlation between incisors and canine tooth area sizes ($r \leq 0.43$). This means that canine size increased relative to incisor size. Maori ($r \leq -0.13$) and Watom ($r \leq 0.10$) show no correlation between the two tooth groups.

The most striking feature of tooth group correlations is the variability between the populations. The only pattern to emerge is that the canine and incisor tooth area sizes have a slight to high correlation (0.38 - 0.83) among the Polynesian populations. As expected, the populations from Near Oceania demonstrated considerable variability in all tooth group correlations. The Sigatoka population has a moderate negative correlation between the canine and incisor tooth groups. This result varies from all other populations.

4.22 First molar diameters

Comparisons of the buccolingual and mesiodistal diameters between Sigatoka and Pacific populations were made to assess any potential relationships. A further enquiry in this area is an examination of the general concept of an east to west first molar tooth size cline. If a cline is evident, it should be possible to place Sigatoka broadly within this framework.

The diameters of the first molars are presented in Tables 9.5 and 9.6. Only male data are used because more male than female information is available in the literature. Mesiodistal and buccolingual data supports the concept of a west to east decline in tooth size. However, a number of variable cases arise. For example, the Polynesian population from Tepoto have the largest tooth dimensions of all the populations, while the Solomon Island population of Nakanai have one of the smallest. Additionally, there is greater variability in mandibular tooth diameters compared to maxillary teeth. The mandibular teeth of Polynesian populations also demonstrate greater variability than the Near Oceanic populations.

Sigatoka males have consistently smaller mandibular first molar diameters than most populations, but are most similar to the Maori, Lapita, Lau, and Nakanai, and somewhat similar to Tonga. These similarities are also evident in the maxillary first molar. The size distribution of this tooth in Polynesian populations usually clusters together. The Near Oceanic populations vary, and there are a number of statistically significant differences with Sigatoka. The Aboriginals have consistently larger first molar diameters than Sigatoka, while the coastal Solomon Island population from Lau is consistently similar to Sigatoka.

Table 9.5
The univariate results and comparisons with Sigatoka of the buccolingual and mesiodistal diameters of mandibular first molars of males from Oceanic populations.

	Mandible buccolingual					Mandible Mesiodistal					
Population	Mean	n	sd	*t* statistic	f ratio	Mean	n	sd	*t* statistic	f ratio	Source
Maori	104.7	3	8.8	0.7	3.0	107.7	3	7.3	1.1	3.0	Visser, nd
Mokapu	111.3	25	3.6	-0.9	3.0	114.8	25	5.5	-0.5	5.0	Snow, 1974
Tepoto	120.6	5	5.8	-3.2 **	3.0	132.2	5	2.8	-4.4**	3.0	Dennison, nd
Mangaia	110.6	35	4.0	-0.7	3.0	118.5	3	4.9	-1.3	3.0	Yamada and Kawamoto, 1988
Pukapuka	111.8	19	4.6	-1.0	2.8	122.5	3	3.5	-2.2	3.0	Yamada and Kawamoto, 1988
Namu	111.9	21	4.5	-2.5 *	0.0	124.8	23	5.0	-6.6 **	1.2	Visser, nd
Tonga	109.0	4	4.4	-0.4	0.0	121.6	12	3.8	-3.8 **	0.8	Visser, nd
Sigatoka	**107.6**	**34**	**6.9**			**112.8**	**33**	**7.6**			
Lapita	109.3	6	7.3	-0.6	0.0	109.5	6	8.8	1.0	10.2	Pietrusewsky, 1991
Nakanai	105.0	98	5.0	1.1	1.2	115.0	90	5.6	-0.5	3.0	Harris and Bailit, 1987
Nebira	111.2	17	3.0	2.0 *	0.3	112.5	14	8.2	0.1	0.1	Visser, nd
Eriama	116.0	6	4.8	3.0 **	1.6	117.7	9	6.1	-1.8	1.2	Visser, nd
Nasioi	110.8	3	5.3	-1.1	1.5	116.8	3	6.4	-0.9	3.0	Harris and Bailit, 1987
Lau	107.7	3	7.3	0.0	3.0	110.5	3	9.7	0.5	3.0	Harris and Bailit, 1987
Aboriginals	114.0	7	5.0	-1.6	3.0	123.0	7	6.0	-2.3 *	3.0	Smith and Wood, 1981

Significance level * $P \leq 0.05$. ** $P \leq 0.01$. Measurements in millimetres

The results presented in Table 9.6 suggest that a first maxillary molar tooth cline does not exist between Near and Remote Oceania. The maxillary tooth diameters indicate that Sigatoka, Tonga, the Maori and Lapita skeletons cluster together. Tepoto is an isolate, while the remainder of the Remote Oceanic populations cluster together. Near Oceanic populations tend to be more variable.

Table 9.6

The univariate results and comparisons with Sigatoka of the buccolingual and mesiodistal diameters of maxillary first molars of males from Oceanic populations.

	Maxilla buccolingual					Maxilla mesiodistal					
Population	Mean	n	sd	*t* statistic	f ratio	Mean	n	sd	*t* statistic	f ratio	Source
Maori	116.0	3	6.0	-0.3	0.3	102.0	3	7.9	0.7	56.3	Visser, nd
Mokapu	119.2	26	5.5	-0.8	0.3	111.0	26	6.7	-1.3	56.3	Snow, 1974
Tepoto	126.5	5	9.5	-2.1*	0.3	113.0	5	5.2	-1.7	56.3	Dennison, nd
Mangaia	119.5	36	5.3	-0.9	0.3	106.8	36	4.8	-0.3	56.3	Yamada and Kawamoto, 1988
Pukapuka	119.8	21	4.0	-1.0	0.3	109.8	21	0.4	-1.0	21.0	Yamada and Kawamoto, 1988
Namu	117.7	17	6.7	-1.3	0.0	113.8	15	3.8	4.0*	0.0	Visser, nd
Tonga	114.6	5	12.5	0.0	0.7	109.6	8	6.2	-1.5	13.8	Visser, nd
Sigatoka	**114.4**	**33**	**9.6**			**105.3**	**21**	**7.5**			
Lapita	119.7	3	3.1	0.9	27.0	104.0	3	8.7	0.3	0.0	Pietrusewsky, 1991
Nakanai	115.0	98	7.0	-0.1	10.5*	111.0	98	6.1	0.6	0.3	Harris and Bailit, 1987
Nebira	118.6	21	6.5	-1.7	0.4	111.4	20	8.4	-2.5	0.0	Visser, nd
Eriama	123.5	5	4.5	1.9	6.8	118.3	7	6.7	4.1**	1.2	Visser, nd
Nasioi	121.9	3	6.2	1.8	0.0	110.2	3	6.4	-1.1	56.3	Harris and Bailit, 1987
Lau	109.0	3	8.5	0.9	0.3	103.0	3	8.1	0.5	56.3	Harris and Bailit, 1987
Aboriginals	129.0	9	5.0	-2.6*	0.3	119.0	9	6.0	3.0*	56.3	Smith and Wood, 1981

Significance level * $P \leq 0.05$. ** $P \leq 0.01$. Measurements in millimetres

Notably, Polynesians demonstrate greater homogeneity than the populations from Near Oceania. The Sigatoka people have consistently smaller first molar dimensions than the low end of the Polynesian range. Likewise they are smaller than all Near Oceanic populations, apart from the Lapita associated skeletons.

Scaled data of the first molar diameters were used to see if the cline of tooth reduction is real, and whether it could be used to shed light on population affinities. This process involved dividing the minimum ramus breadth diameters with tooth diameters to obtain a molar tooth size index. These results are illustrated in Figure 9.5.

Scaled tooth diameter results demonstrate that the range of variation is greater among Near Oceanic populations (34%), compared to those in Polynesia (13%). This difference is consistent with the biological heterogeneity of populations in Near Oceania. In comparison, Polynesians exhibit a certain amount of homogeneity. Sigatoka and the Lapita associated skeletons tend to form a separate grouping.

Figure 9.5
Mean scaled first molar diameters of males from some Oceanic populations.

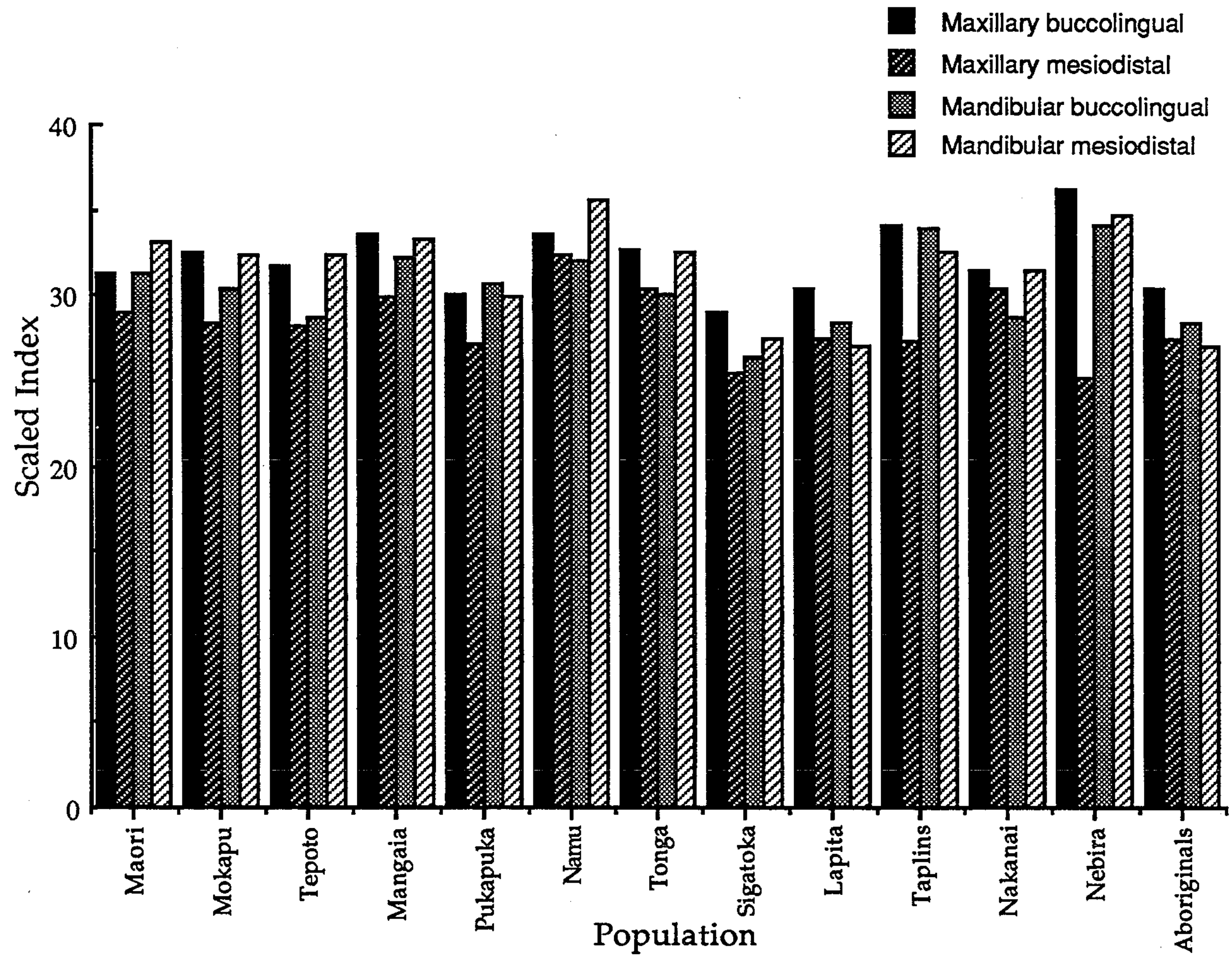


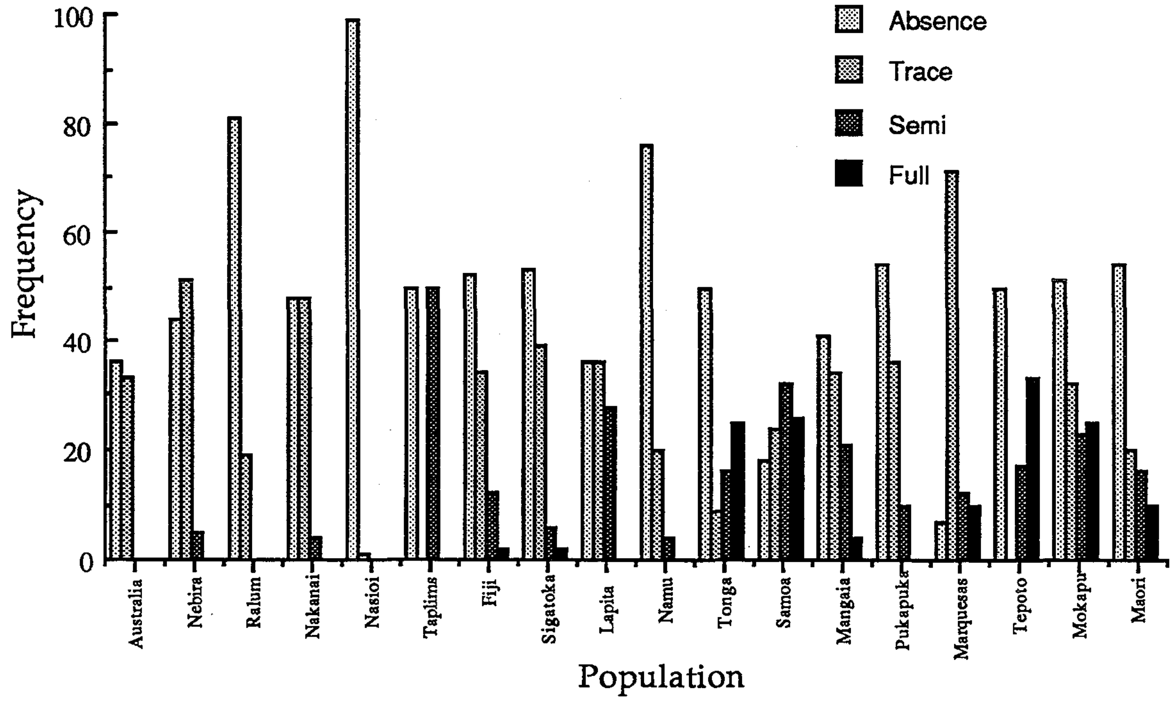
Figure 9.5 shows that Sigatoka and Lapita are similar, and that these two populations differ from the other populations. In all first molar ratios, the Sigatoka population has values between 4% and 10% lower than the Polynesian range. On the other hand, the Lapita associated skeletons vary between 0% and 9% from Polynesian values. These results suggest that the Sigatoka people have some affinity with Polynesians.

This leaves us to define the relationship between Lapita associated skeletons and the Sigatoka people. Buccolingual and mesiodistal diameters indicate that there is only a 2% to 7% difference between the two groups. A correlation based on the first molar ratio buccolingual and mesiodistal diameters between the two populations is $r = 0.69$ ($P < 0.01$). The inference from these two variables is that the Sigatoka and Lapita skeletons have closely related dental dimensions.

4.23 Maxillary shovel shaped incisors

Figure 9.6 illustrates the frequencies of shovel shaped teeth in Oceanic populations. It is evident that the frequency of semi and full shovel shaped teeth tends to increases from Near Oceanic populations to Remote Oceanic populations.

Figure 9.6
The incidence of maxillary shovel shaped incisor teeth in Oceanic populations.



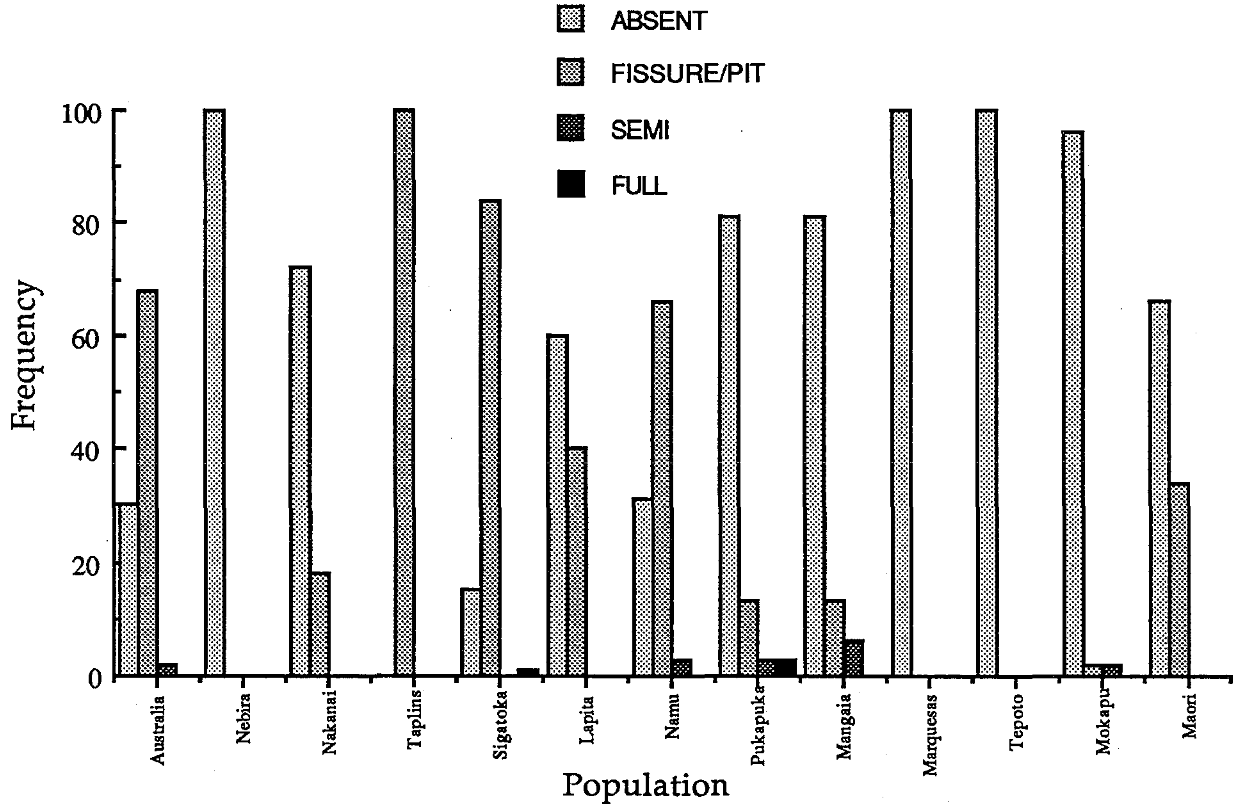
To establish if there was a statistically significant difference in the occurrence of the types of shovelling, populations were tested separately, using chi square. The prevalence of the types of shovelling tested was not significantly different in four populations, the Maori, Samoa, Lapita and Tepoto. However, the limited sample sizes of the Watom and Tepoto populations are small enough to arouse suspicion as to their accuracy. The remaining populations have a chi squared value of P ≤ 10.0, indicating that one or two variations of the trait are dominant within a group. The pattern that these results express is that populations from Fiji westward have a lower frequency of semi-shovel or full-shovel shaped incisors (Figure 9.6).

Populations east of Fiji tend to have a higher frequency of shovel shaped teeth than Sigatoka or the Lapita associated group. In three Polynesian populations, Maori, Tepoto and Samoa, the difference between the traits is not significant. The Sigatoka population has a very similar frequency of expression of the four traits to the Fijian population, unlike the Polynesians or the populations to the west.

4.24 Molar Protostylid

These data are presented in Figure 9.7. The expression of either semi-protostylid or full-protostylid is rare in all the populations examined.

Figure 9.7
Protostylid expression in male Oceanic populations.



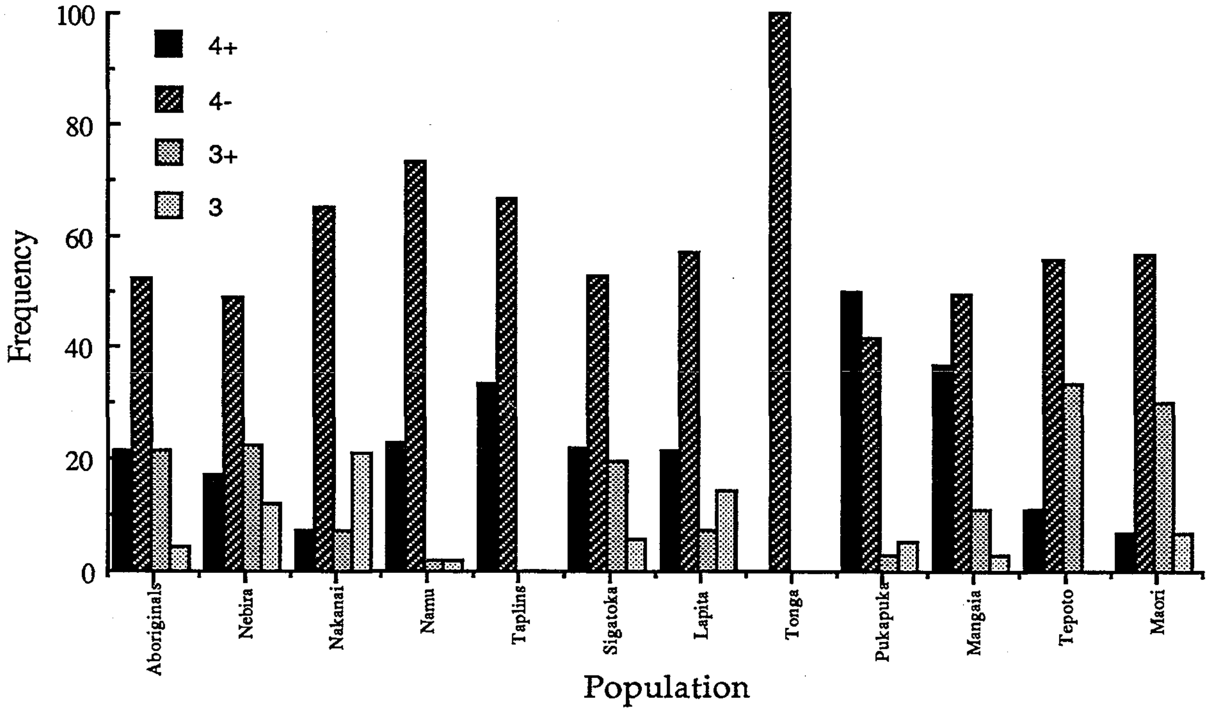
From these data, protostylid expression is found in low frequencies in most Polynesian populations. Semi-protostylid expression was found in just one population west of Fiji, in the Polynesian related Namu population. Low level frequencies were also recorded in the Aboriginal population. The presence of pitting and fissures in the buccal surface of the molars was greater among populations from Sigatoka, Taplins and Namu.

The Sigatoka population has similar frequencies of protostylid expressions as the entire Polynesian group. However, this is not the case when compared to individual Polynesian populations. Figure 9.7 shows that the frequency of these traits varies between populations and with Sigatoka. Given the concept that Polynesians form a homogeneous group, this variation is unexpected. A similar pattern of variability is evident among the populations from Near Oceania, this is consistent with dental and skeletal differences found in those populations.

4.25 Maxillary first molar cusp patterns

A slightly reduced hypocone expression was the most dominant expression found in the 12 population groups studied (Figure 9.8).

Figure 9.8
Maxillary first molar cusp patterns in male Oceanic populations.

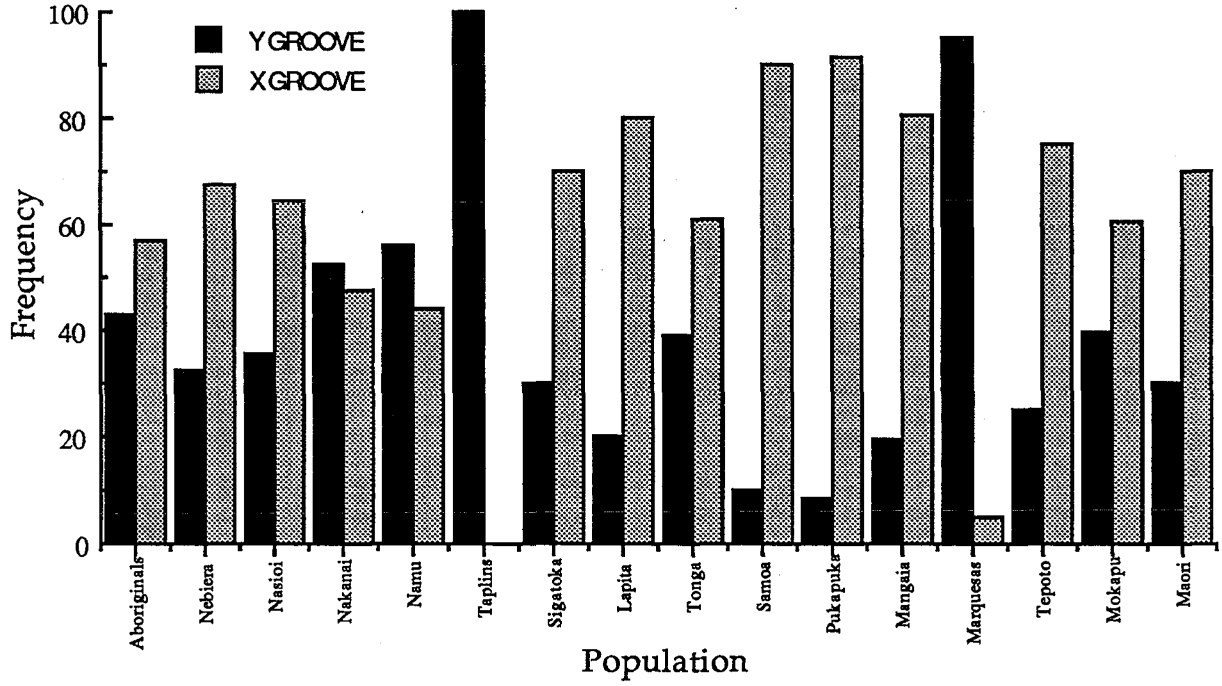


Just two traits were expressed in the Lapita associated sample, a slightly reduced hypocone, and hypocone absence that was dominant. In the Pukapuka sample, a well developed hypocone was slightly more common than a reduced hypercone. The frequent expression of a strong to moderate hypocone suggests the genotype for this trait is dominant in all populations. The higher frequency of hypocone absence in Polynesian populations suggests that the recessive genotype that may be responsible for protostylids is much more infrequent compared to other populations.

4.26 Mandibular molar cusp patterns

Figure 9.9 illustrates comparative molar cusp patterns from 16 Oceanic populations. There is a slight decreasing cline in the frequency of four cusp expressions, and conversely an increasing cline of Y cusp pattern from west to east.

Figure 9.9
Mandibular molar cusp patterns in Oceanic populations.



The variability of an expression of a particular cusp pattern is much smaller among the Polynesians (22%) than the Near Oceanic populations (31.6%), even when small sample sizes are excluded. The Marquesas result is unusual when compared to other Polynesian populations, and may relate to interobserver differences in identifying traits. The Lapita and the Sigatoka populations have cusp pattern expressions that are similar to the Near Oceanic mean. However, to reiterate, the Near Oceanic cusp pattern expressions are variable, and comparisons with a mean value from such a diverse group of peoples could be misleading.

5.0 Summary

Estimates of stature, body mass, femoral platymeria and dental traits suggest that the Sigatoka people have greater biological affinity with Remote Oceanic populations, particularly Polynesians, compared to any population from Near Oceania. However, these results suggest that the Sigatoka people did differ from Polynesians in a number of traits that have strong gene control, such as shovel shaped incisors and tooth diameters. Nevertheless, the comparisons show that the Sigatoka population approaches Polynesian ranges in many traits. In particular, a number of traits expressed close similarity with the to Tongans. Sigatoka and the Lapita associated skeletons have similar expressions of many skeletal and dental traits. These similarities suggest a close affinity between these two populations.

Variability exists within the larger Polynesian grouping. For example, Tepoto differs substantially in some traits compared to other Polynesian populations. One explanation for this difference may be the Founder Effect, whereby a small group with a limited gene pool settles an area and remains genetically isolated. In the Tepoto example, the founding population seems to have had a genotype for large body size and large teeth. It is unlikely that they form a non-Polynesian biological group. The Maori are at the other end of the Polynesian spectrum. They have small teeth. This seems to be an adaptive disadvantage because they have severe dental problems in the prehistoric series, and have relatively large mandibles and facial features (Taylor, 1962; Houghton, 1977; Simpson, 1979). Similarly, Sigatoka males have small teeth and large mandibles and experienced more dental pathologies compared to other populations (Chapter Five). These findings show that small teeth are not related to gracile masticatory musculature, and the relationship between these features is highly complex. (Taylor, 1962; Houghton, 1977; Simpson, 1979).

The only dental trait which Sigatoka and recent Fijians could be compared with was the types of shovel shaped maxillary incisors. The comparisons indicate an affinity between the two populations. However, the extent of this relationship is unclear.

Dental traits and body form results shows that Sigatoka has the closest biological association with Lapita associated skeletons. In the following Chapter this association is examined in more detail. Near Oceanic populations and the Aboriginals have individual traits that are similar to Sigatoka. However, these traits seem to be randomly expressed and offer little evidence of biological associations. It is important to note that different Sigatoka dental and skeletal traits are found in different Pacific populations. These similarities may not be random, but reflect biological affinities.

The basis of biological features evident in Pacific populations are discussed in the following chapter. Further comparisons of Pacific populations with Sigatoka are made within an adaptive framework.

Chapter Ten

Adaptation: comparisons between Sigatoka and other Oceanic populations

1.0 Introduction

This Chapter outlines factors considered to have influenced craniofacial growth and body form in the Sigatoka males. Consideration is given to the selective forces that may have operated to evolve particular traits examined in the Sigatoka males. The relationship of the Sigatoka population to other Oceanic populations is considered within this context.

As outlined in Chapter Nine, Oceanic populations are divided into subsets based on geographic provenance. Australian Aboriginals and Tierra del Fuegans, as well as the Moriori, are included because they represent populations who had adapted to hot and cold environments. Populations from isolated areas, such as Tepoto and extreme Polynesia in Remote Oceania, are used as examples of genetic bottle necks. These populations will be compared to the Sigatoka males using stature, body mass estimates, body proportions, nasal diameters, mandibular measurements, and morphological features. Only male data is used because little female data is available from Oceanic populations. The theoretical basis for employing the selected skeletal traits to compare different populations with Sigatoka are outlined below.

2.0 Theory

2.1 The clavicle

2.11 Clavicle length

The clavicle is a major component of the shoulder, or pectoral girdle. A function of the clavicle length is that it allows the arms to move freely from the chest (Williams *et al.*, 1989; Marieb, 1992). Clavicle length can therefore be used to provide an indication of chest breadth of an individual. Chest breadth is important because it assists in establishing body proportions and may provide an indication of the type of environment a population had adapted to. For example, Bergmann's rule suggests that a narrow shoulder breadth would be evident in a population from a hot climate. Conversely, broad shoulders would be evident in a population from a cold climate (Masali, 1969; Filce-Leek, 1973).

2.2 Body proportions

2.21 Limb-to-stature ratio

Limb proportions are able to provide an indication of adaptability to a cold or warm environment, following Allen's rule (1877). Allen's rule states that the cooler the environment, the shorter the length of the extremities. The operation of this rule has been demonstrated in human populations such as Europeans, Africans, West Asians (Crognier, 1981), North Americans (Newman, 1953), and Aboriginals (Macho and Freedman, 1987). Bergmann's rule (1847), which holds that mammals in colder climates tend to have a larger trunk and bigger chests, has also been shown to operate in human populations (Newman, 1953; Roberts, 1953; Coon, 1982).

2.3 The nasal and mandibular skeleton

The nasal and mandibular skeleton are examined to identify similarities and differences among Oceanic populations in facial musculature, naso-pharyngeal, facial and head form. Facial musculature is represented on the mandible by ramal diameters. The naso-oropharyngeal complex can be investigated by using nasal height, nasal breadth, bicondyle breadth, bigonial breadth, and to a lesser extent mandible length and corpus length. Facial and head form can be inferred by the variables presented above as well as gonial angles. The reasons for examining these variables are outlined below.

The nasal and mandibular skeleton has long been used as one of the cranial characteristics used to identify 'racial' types (Flower, 1881; Scott, 1895; Howells, 1973; Pietrusewsky, 1990). More often than not, these studies have not considered the physiological and environmental variables that have a considerable influence not only in determining nasal and mandibular form, but the entire craniofacial skeleton. In this section, the theory of biological development of the nasal and mandibular skeleton is discussed.

Before continuing, one essential concept of facial development needs to be understood. The development of the nasal and mandibular skeleton, and the entire skeletal structure, is an ongoing process that aims to reach and maintain a state of "aggregate, composite structural and functional equilibrium" (Enlow, 1990:241). Growth and development cannot be isolated but must be considered within a complex interrelationship between the skeletal structure, physiological factors, genetic factors, and extraneous environmental factors such as climate.

2.31 Cranial base

The sequence of development and maturity of the cranium is vital in determining facial form (Figure 10.1). The sequential processes of development of aspects of the cranium appear to be controlled by epigenetic regulation. In the head, the cranial base develops first to support the growing brain (Houghton and Kean, 1987). The cranial base is required to be structurally rigid, because the brain stem, blood vessels and cranial nerves exit through the base. The brain stem and nerves are critical to survival. Any bony modification in the cranial base would compromise these systems and an individual's survival.

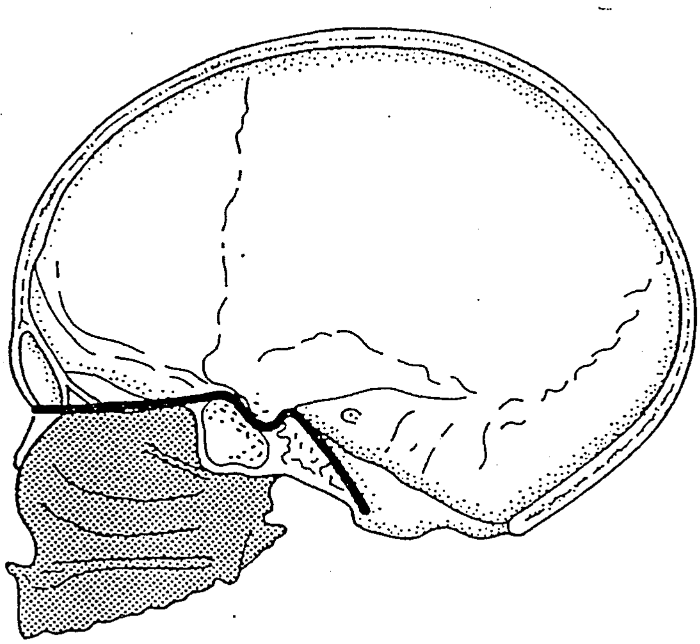
Variations in head form are important. For example, dolichocephalic or brachycephalic head types establish different basicranial templates for facial development. The dimension, flexure and configuration of the basicranium may further influence the anteroposterior placement of the maxilla relative to the mandible (Enlow, 1990). The breadth of the middle cranial fossa establishes the sites for the positioning of the mandibular condyles, which articulate on the glenoid fossa and eminence of the temporal bone of the skull. Therefore, whatever genetic or epigenetic growth control lies within the mandible and ethnomaxillary components, they must necessarily conform to a higher level of predetermination, such as brain location and positioning (Houghton and Kean, 1987).

2.32 Nasal passage

The anterior cranial base provides what has been termed a "median beam" from which the central part of the upper facial skeleton is suspended (Enlow, 1968; Kean and Houghton, 1982).

The micromorphology of the upper facial skeleton is influenced by internal and external factors, primarily through the adaptability of the nasal airway. An increase in the capacity of the passage has been argued to be only possible through vertical development. This is because horizontal enlargement is restricted by neurophysiological and morphological constraints, such as the orbits and nervous system (Kean and Houghton, 1987). However, nasal breadth and height have been shown to vary among populations (Franciscus and Long, 1991). This aspect was considered in Chapter Six. Studies have demonstrated that during maturation the height of the airway is one of the major dimensional changes occurring in the face (Enlow, 1968). During postnatal growth, genetic control increases the height of the nasal capsule concomitant with bony facial developments and the development and eruption of the permanent dentition (O'Higgens and Dryden, 1992). Increases in the height of the nasal passage are in response to oxygen demands. These demands in turn are influenced by the body's (muscle mass) requirements for oxygen (Miyashita and Takahashi, 1971). It follows that differences in oxygen requirements, and therefore nasal height, will occur between males and females.

Figure 10.1
The cranial base indicated by the bold line. The shaded area represents the upper face, the shape of which is influenced by variations in the cranial base angle.



Extrinsic factors influencing the nasal area have been shown to relate to climate, humidity and temperature. However, some studies suggest that it is more valid to consider nasal height and nasal breadth separately, because it appears that they may be influenced by different factors. For example, nasal height is decreases among individuals who live in a warm climate compared to those who live in cold climates (Granville, 1966; Crognier, 1981). Nevertheless, the findings of these studies are consistent with the association between body size and temperature.

2.33 Gonial angle

Developmental changes in nasal height and the expansion of the airway passage influences the positioning and spatial placement of the maxillary dentition. This requires an equal developmental change in the position of the mandible to maintain functional effectiveness of the masticatory system (Zingeser, 1989; Verrela, 1990). As the maxillary dentition moves inferiorly in response to airway enlargement, the occlusal plane and body of the mandible align more horizontally. This reduces the mandibular angle and increases the ramus height (Kean and Houghton, 1987). The development of the pharynx and broadening of the middle cranial fossa requires changes in the mandible, whereby the ramus breadth increases and lengthens vertically. To accommodate these changes, the gonial angle must alter towards a more acute angle to prevent a change in mandibular and maxillary occlusion. However, the biological basis of these changes is not well understood and appears to differ between head types (Enlow, 1990). If bigonial and bicondyle breadths enlarge, an increase in the acuteness of the gonial angle requires that ramal breadth has to expand, and so become more massive to maintain occlusal efficiency. One expression of this in the facial skeletal structure is a reduced gonial angle of the mandible in heavily muscled individuals.

Clinical studies of foetal development have demonstrated that the development of the gonial angle process is under genetic control (Enlow, 1990). However, during post natal life the morphogenesis and maintenance of shape are determined by mechanical influences, primarily by the masseter and medial pterygoid muscles that insert in the gonial angle process (Moss and Simon, 1968).

One argument holds that a reduced gonial angle has very specific functional disadvantages. More energy is required to operate the load arm of the mandible for it to occlude with the maxillary dentition (Houghton, 1978). Therefore, greater muscle mass is needed to provide the extra energy for the power strokes of the mandible during chewing. This extra muscle mass is reflected skeletally on the ramus breath and height, where the muscles associated with moving the mandible insert. This view seems to be heavily dependent on singular functional activity. The causes shaping the gonial angle are likely to be more complex.

Changes in the gonial angle are not always associated with the cranial base angle and masticatory musculature. For example, the gonial angle has been shown to decrease in association with advancing tooth wear (Fishman, 1976; Zingeser, 1989). This association has been discussed in Chapter Six and Seven.

One of the ways in which the biomechanical efficiency of the mandible as a lever may be increased is by broadening bicondyle breadth. This can be achieved in individuals with larger mandibles by increasing the size of the pterygoid muscles. These changes bring the muscle force closer to the load and shifts the ratio of the power to the load arm (Hylander, 1975). Such biomechanical adaptations have been identified in Eskimos (Hylander, 1975) and the Maori (Houghton, 1978).

2.34 Ramal dimensions

The dimensions of the ramus are partially influenced by mechanical demands imposed by the masticatory muscles (Kilaridis, 1989; Enlow, 1990). It is necessary to point out that while masticatory forces have a major influence on ramal dimensions, different ramal locations are influenced by different local developmental, functional, and structural conditions and circumstances (Enlow, 1990). Clinical studies have demonstrated that the removal of the temporalis muscle, which inserts in the coronoid process of the ramus, precipitates changes in the ramus whereby it becomes smaller and changes shape (Avis, 1959; Washburn, 1947). McNamara (1980) observed similar changes in cases where the masseter and pterygoid muscles were lengthened, resulting in a decrease in the ramal breadth and a resorbed antegonial notch. Coronoid height did not vary significantly, presumably because the temporalis muscle retained its influence on the coronoid process.

Expansion of the brain seems to be important in influencing the size and shape of the mandible. Enlow (1990:106) has pointed out that any increase in the ramal breadth "mirrors" the enlargement of the middle crania fossa during growth. This is because the mandible must maintain occlusal efficiency. Therefore, as the sizes of the cranial lobes increase so does the temporal plate that must accommodate this expansion. Thus, bigonial and bicondyle breadths must increase. This means that up to at least adolescence, ramal breadths are partial reflections of the largely genetically controlled growth of the middle crania fossa and mid cerebral lobe expansion.

2.35 Mandible length

The basal bone that forms the mandible body appears to be under primary genetic control (Bjork, 1972). At birth the basal bone is made up of cartilaginous material that is slowly replaced with bone by the third year of life. Clinical studies have demonstrated that development of the bone continues without any mechanical input, but it appears that transplanted mandibles in animal studies tend to have thinner basal regions (Felts, 1961).

Biological development proceeds to maximise biomechanical efficiency. An implication of this development is that the body responds in a way that restricts the length of the mandible to prevent inefficiency and muscular over development, while striving to maintain maximum occlusal efficiency. The size of the dentition and the subsequent skeletal requirements for their support (alveolar bone) are set at an early age. Thus, for a given cranial base morphology, the larger the body mass, the relatively smaller the dentition. This suggests that teeth have a more complex adaptive basis than simply changing nutrition. This aspect has been discussed in Chapter Nine.

2.36 The masticatory system

Skeletally, the masticatory system, comprised of the maxilla and the mandible, is the last system in the face to develop. This is necessary so that it is able to adapt to changes that occur in the nasal passage and cranial base. Inherently, the system is influenced by an array of variables, from the head, the body and the environment (Kean and Houghton, 1987). Underlying this is the cranial base to which the mandible must articulate at the temporal fossae. The central area of the cranial base is determined early in life (as noted previously). The lateral areas of the cranial base (the temporal bone) develop later. Like the mandible, they are influenced by the development of the masticatory muscles. Heavy use of these muscles broadens the area of attachment on the cranial base.

2.37 Bigonial and bicondyle breadths

Ramal and mandible condyle growth rates are partially correlated, but their growth is separate because they develop under different local influences and controls (Enlow, 1990). The cranial base affects the structure, dimensions, angles and placement of the various facial parts. The cranium is the template upon which the face develops (Enlow, 1990).

The growth of the middle cranial fossa has a displacement effect on the anterior cranial floor, the nasomaxillary complex and the mandible. The mandible is the least affected, but the cranial base remains the template to which the face, and ultimately the mandible, must develop. During early childhood (5 - 6 years) frontal lobe growth and anterior cranial fossa expansion are largely complete. The temporal and middle cranial fossae continue to enlarge for several more years (12- 15 years of age). The size of the middle cranial fossa influences the size of the pharynx. The bigonial breadth bridges the pharynx, and as the space enlarges, the ramus increases to an equivalent extent to maintain the same facial form (Enlow, 1990). Ramal breadths and the middle cranial fossa are direct counter-parts to each other. As the mandible develops in response to cranial changes, it must also change to maintain efficient occlusion with the maxillary arch, otherwise malocclusion will result. In short, the mandible breadth must match the enlargement of the pharyngeal space and the breadth of the middle cranial fossa.

The methods used to analyse these variables have been presented in previous Chapters.

3.0 Results

3.1 Body proportions

3.11 Crural and brachial index

The results of crural and brachial index comparisons are presented in Tables 10.1 and Table 10.2. These results show greater variation among populations in the lower limbs than the upper limbs. This difference may be an indication that lower limbs experience greater environmental selective pressure than upper limbs.

Table 10.1

Crural indices and univariate results of selected Oceanic males compared to Sigatoka males.

Population	Mean	n	sd	*t* statistic	f ratio	Source
Mokapu	82.4	46	0.6	- 0.9	0.2	Snow, 1974
Maori	75.5	11	3.5	3.1 *	0.0	Houghton, nd[c]
Moriori	72.3	3	2.1	3.4 **	0.3	Houghton, nd[c]
Namu	82.4	11	1.9	- 1.6	0.0	Visser, nd
Tepoto	82.8	3	3.6	- 1.0	0.2	Dennison, nd
Pukapuka	84.2	3	0.4	- 1.6	0.9	Yohsida, 1988
Marquesas	84.1	3	0.9	- 1.6	0.2	Pietrusewsky, 1976
Mangaia	81.7	11	2.4	- 1.0	1.3	Katayama, 1986
Tonga	82.4	3	0.5	- 0.9	0.3	Pietrusewsky, 1969
Sigatoka	**80.4**	**11**	**3.9**	----	----	
Fiji	84.7	5	2.0	- 2.4 *	0.1	Weber, 1934
Nebira	84.3	6	0.7	- 1.7	-1.7	Pietrusewsky, 1976
Eriama	84.7	4	2.2	- 1.8	0.3	Visser, nd
Solomon Isl[1]	87.9	29	5.0	—	—	Moseley, 1877
Del Fuego	82.8	5	2.2	- 1.3	0.3	Garson, 1886
Aboriginals[1]	87.6	11	6.4	- 3.2 **	0.4	Abbie, 1951

Significance levels * P ≤ 0.05. ** P ≤ 0.01. 1 Denotes anthropometric measurements.

Sigatoka males have a larger standard deviation compared to most other populations. However, the crural index is within the Polynesian range, and only the Maori and the Moriori have lower indices. The warm climate populations, including the Solomon Islanders, have greater crural indices.

Table 10.2

Brachial indices and univariate results of selected Oceanic males compared to Sigatoka males.

Population	Mean	n	sd	*t* statistic	f ratio	Source
Mokapu	77.7	26	2.2	-1.0	0.0	Snow, 1974
Maori	78.3	27	2.4	-2.3 *	46.9 **	Houghton, nd[c]
Moriori	78.5	16	1.5	-3.0 *	0.0	Houghton, nd[c]
Namu	79.6	4	2.2	-2.1	0.0	Visser, nd
Tonga	77.1	5	2.2	-1.0	19.1 *	Pietrusewsky, 1969
Tepoto	78.0	4	1.9	-1.2	0.0	Dennison, nd
Mangaia	77.3	10	2.5	-1.3	0.0	Katayama, 1986
Marquesas	76.7	4	1.4	-0.6	0.0	Pietrusewsky, 1976
Pukapuka	77.7	3	1.1	-1.1	0.0	Yoshida, 1988
Sigatoka	**75.3**	**5**	**3.6**	----	----	
Lapita	78.6	2	6.7	-0.9	0.0	Visser, nd
Fiji	76.8	4	2.0	-0.8	1.7	Weber, 1934
Nebira	78.3	6	3.8	-1.1	0.0	Pietrusewsky, 1976
Solomon Isl1	79.9	27	7.0	----	----	Moseley, 1877
Del Fuego	83.6	4	6.5	-2.5	0.3	Garson, 1886
Aboriginals[1]	84.5	22	6.6	-4.3*	0.6	Abbie, 1951

Significance levels * P ≤ 0.05. ** P ≤ **0.01. 1 Denotes anthropometric measurements.

The comparative results indicate that the Sigatoka males have the lowest brachial index, although they have a high standard deviation. Only four populations, Namu, Tierra del Fuego, and the warm climate populations, the Aboriginals and the Solomon Islanders, have a greater standard deviation than Sigatoka. Student's *t* tests comparisons between Remote and Near Oceania (excluding recent Fiji and Sigatoka) show that significant differences exist in the brachial index ($t = 11.0$ $p \leq 0.00$) between the two areas. No differences were evident in the crural index. Significant differences in the brachial index were found between Sigatoka and Near Oceania ($t = 4.5$ $p \leq 0.00$) and between Sigatoka and Remote Oceania ($t = 2.7$ $p \leq 0.01$). No differences were found in the crural index, nor were differences in variance found.

3.12 Limb-to-stature ratios

Arm-to-stature ratios are presented in Table 10.3 and leg-to-stature ratios in Table 10.4. A slight cline of declining limb length to stature is evident from Near Oceanic populations to Remote Oceanic populations. The Sigatoka population displays indices that are similar to Remote Oceanic populations.

Table 10.3

Arm-stature ratios and univariate results of selected Oceanic males compared to Sigatoka males.

Provenance	Mean	n	sd	*t* statistic	f ratio	Source
Mokapu	35.1	42	3.3	-1.4	1.5	Snow, 1974
Maori	33.5	27	0.7	-1.6	0.4	Houghton, nd^c
Moriori	33.6	3	0.6	-1.1	1.2	Houghton, nd^c
Namu	37.2	4	5.6	-1.7	0.5	Visser, nd
Tonga	33.1	3	0.4	-0.2	2.4	Pietrusewsky, 1969
Tepoto	33.6	3	0.3	-1.2	2.5	Dennison, nd
Mangaia	31.1	10	0.5	2.8 *	2.5	Katayama, 1986
Marquesas	33.3	3	0.4	-0.5	2.4	Pietrusewsky, 1976
Pukapuka	33.0	3	0.4	-0.1	2.5	Yoshida, 1988
Sigatoka	32.9	5	1.0	----	----	
Lapita	34.2	2	2.4	-1.1	0.0	Visser,nd
Fiji	32.1	4	1.9	0.8	0.0	Weber, 1934
Nebira	32.0	6	2.2	0.8	2.6	Pietrusewsky, 1976
Admiralty Isl^1	31.6	4	1.9	1.3	1.4	Moseley, 1877
Solomon Isl^1	33.4	27	1.0	-1.0	0.2	Guppy, 1886
Del Fuego	32.5	4	1.4	0.6	0.9	Garson, 1886
Aboriginals^1	34.3	22	1.9	-1.6	3.4	Abbie, 1951

Significance levels * $P \leq 0.05$. ** $P \leq$ **0.01. 1 Denotes anthropometric measurements.

The small sample sizes of many of the comparative populations make any interpretation subject to speculation. Nevertheless, there does seem to be very little difference in arm to stature ratios. This lack of difference is also evident when all the Remote and Near Oceanic populations are compared.

Table 10.4
Leg-stature ratios (sitting height) and univariate results of selected Oceanic males compared to Sigatoka males.

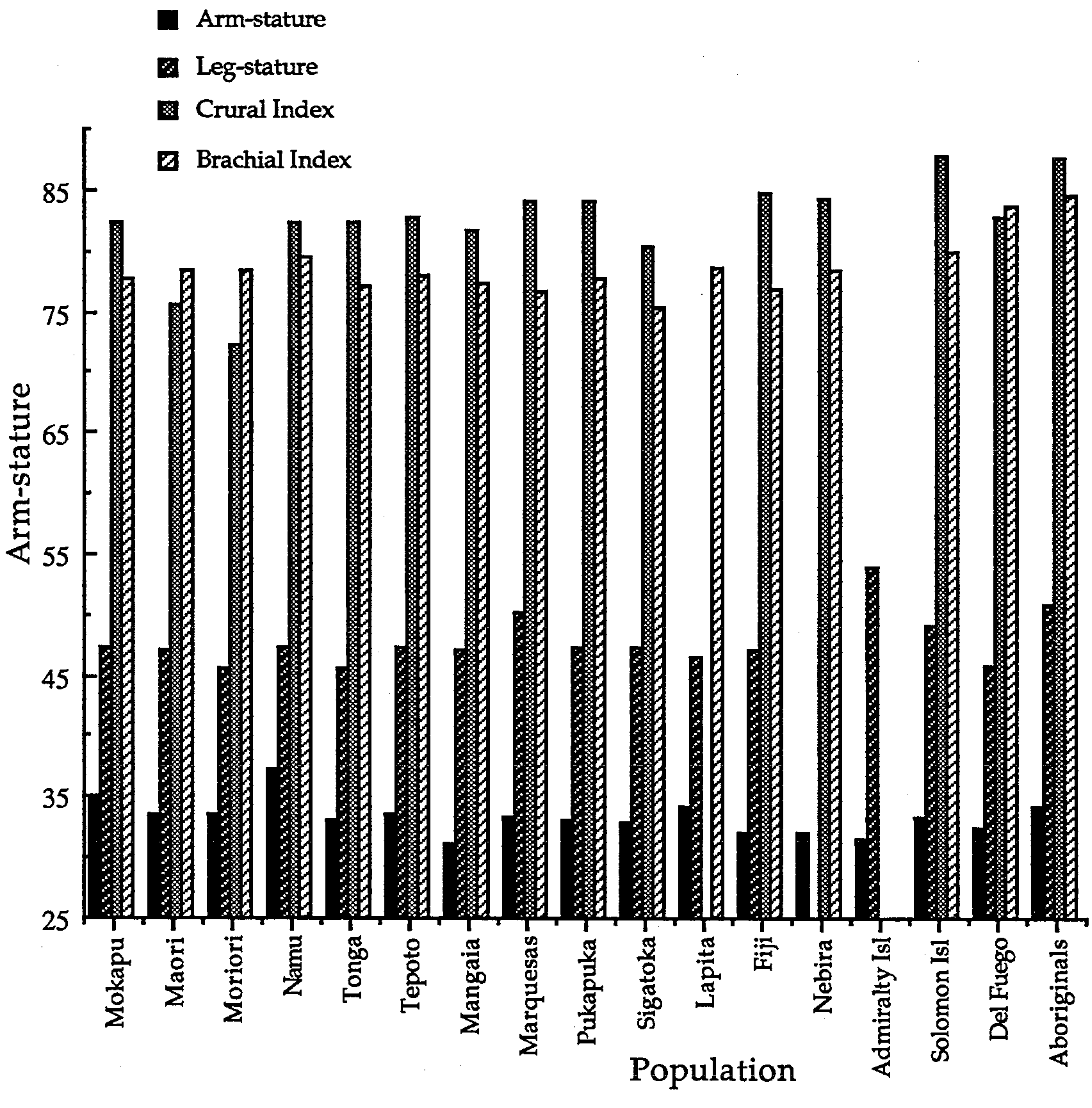
Population	Mean	n	sd	*t* statistic	f ratio	Source
Mokapu	47.4	46	1.8	-0.1	0.3	Snow, 1974
Maori	47.2	5	1.5	0.0	5.0	Houghton, nd[c]
Moriori	45.6	3	0.3	2.7 **	0.5	Houghton, nd[c]
Tepoto	47.3	3	0.6	0.0	4.8	Dennison, nd
Mangaia	45.5	3	1.0	2.6 *	5.2	Katayama, 1986
Namu	47.4	8	0.6	-0.3	6.3 *	Visser,nd
Marquesas	47.2	5	1.5	0.1	2.0	Pietrusewsky, 1976
Pukapuka	50.2	3	0.8	-4.2 **	4.8	Yoshida, 1988
Tonga	47.3	3	0.7	-0.5	4.8	Pietrusewsky, 1976
Sigatoka	**47.3**	**8**	**1.1**	----	----	
Fiji	46.5	5	1.5	1.1	1.4	Weber, 1934
Nebira	47.0	6	2.3	0.3	0.3	Pietrusewsky, 1976
Eriama	----	---	----	----	----	Visser, nd
Admiralty Isl [1]	53.9	5	1.8	-8.4 **	3.7	Moseley, 1877
Solomon Isl [1]	49.0	27	1.1	-3.8 **	0.9	Guppy, 1886
Del Fuego	45.9	5	0.9	2.4 *	0.1	Garson, 1886
Aboriginals[1]	50.8	10	2.0	-4.5 **	3.6	Abbie, 1951

Significance levels * P ≤ 0.05. ** P ≤ **0.01. 1 Denotes anthropometric measurements.

Leg-to-stature ratio comparisons appear to follow a temperature gradient. Warm climate populations from the Solomon Islands, the Australian Aboriginals, the Admiralty Islands, and Pukapuka, group together. All remaining populations, apart from two cold climate populations, Tierra del Fuego and Moriori and Mangaia, cluster in another group. The later two populations have low indices. These trends are significant when the leg-to-stature ratios of Remote Oceanic populations are compared to Near Oceanic populations ($t = 3.4$ $p \leq 0.00$). Similarly, Sigatoka leg-to-stature ratios significantly differ from Near Oceanic populations ($t = 2.1$ $p \leq 0.04$). No significant differences from the mean were found between Sigatoka and Remote Oceanic populations.

Keeping in mind that the comparative sample sizes are small, there are few statistically significant differences in the body proportions of Oceanic populations compared to Sigatoka. However, it is evident from the graph illustrated in Figure 10.2 that the Sigatoka population has body proportions which have greater similarities to populations in Remote Oceania than those in Near Oceania.

Figure 10.2
Body proportions of males from Oceanic populations.



Body proportions of Sigatoka males differ significantly in three of the four body proportion variables when compared with Aboriginals. In particular, Aboriginals have significantly longer legs to body height compared to Sigatoka. Differences with Tierra del Fuego are less marked, although this population has a significantly shorter leg-to-stature ratio than the Sigatoka males. Populations that come from similar environments to Sigatoka, such as Pukapuka and Mangaia, differ significantly from Sigatoka. Namu also varies significantly in the crural index, while there are no significant differences with inland populations.

3.13 Chest circumference and clavicle length

Anthropometric data on chest circumferences from some Oceanic male populations are presented below in Table 10.5.

Table 10.5
Anthropometric measurements of chest circumferences of males from Oceanic populations.

Population	Mean	n.	sd.	Source
Tokalau[1]	102.2	?	----	Lister, 1892
Tonga[1]	91.9	?	----	Lister, 1892
Lau (Fiji)	95.5	74	----	Lourie, 1972
Ontong Java	91.1	145	----	Rhoads, 1987
Lau	91.3	145	----	Rhoads, 1987
Solomon Islands	86.5	18	3.3	Guppy, 1886
Nasioi	83.9	59	----	Rhoads, 1987
Admiralty Islands	83.8	?	----	Mosely, 1877
New Guinea	80.0	20	----	Comrie, 1877

The results of univariate analysis of clavicle lengths of various Oceanic populations compared to the Sigatoka males are presented in Table 10.6

Table 10.6
Clavicle lengths of males from various Oceanic skeletal populations compared to Sigatoka.

Population	Mean	n	sd	*t* statistic	Source
Easter Island	140.0	5	2.6	----	Murrill, 1968
Mokapu	149.0	3	8.3	0.5	Snow, 1974
Maori	151.0	12	8.0	-1.2	Houghton, nd
Moriori	148.2	6	6.8	-0.5	Houghton, nd
Mangaia	151.0	2	—	----	Tayles, nd
Namu	141.0	2	4.2	----	Visser, nd
Marquesas	151.0	3	7.6	-0.8	Pietrusewsky, 1976
Tonga	141.0	9	6.6	0.8	Pietrusewsky, 1969
Sigatoka	**145.0**	**3**	**11.5**	----	
Fiji	137.1	4	5.7	1.2	Weber, 1934
Nebira	130.0	2	2.8	----	Visser, nd
Del Fuego	150.7	3	4.2	0.8	Garson, 1886
Aboriginals	139.5	3	8.7	0.7	Ray, 1959

The anthropometric chest circumference data shows that populations from Remote Oceania tend to have greater chest circumferences than populations from Near Oceania. Clavicle lengths of males also reflect this difference, although the sample sizes for different Oceanic populations are small. Most Polynesians have clavicle lengths that exceed all other populations. The exceptions are the Easter Islanders and Tongans who have shorter clavicle lengths. The average clavicle length of the Sigatoka males is greater than Fijian and Near Oceanic groups, although this difference is based on small sample sizes.

3.2 Crania

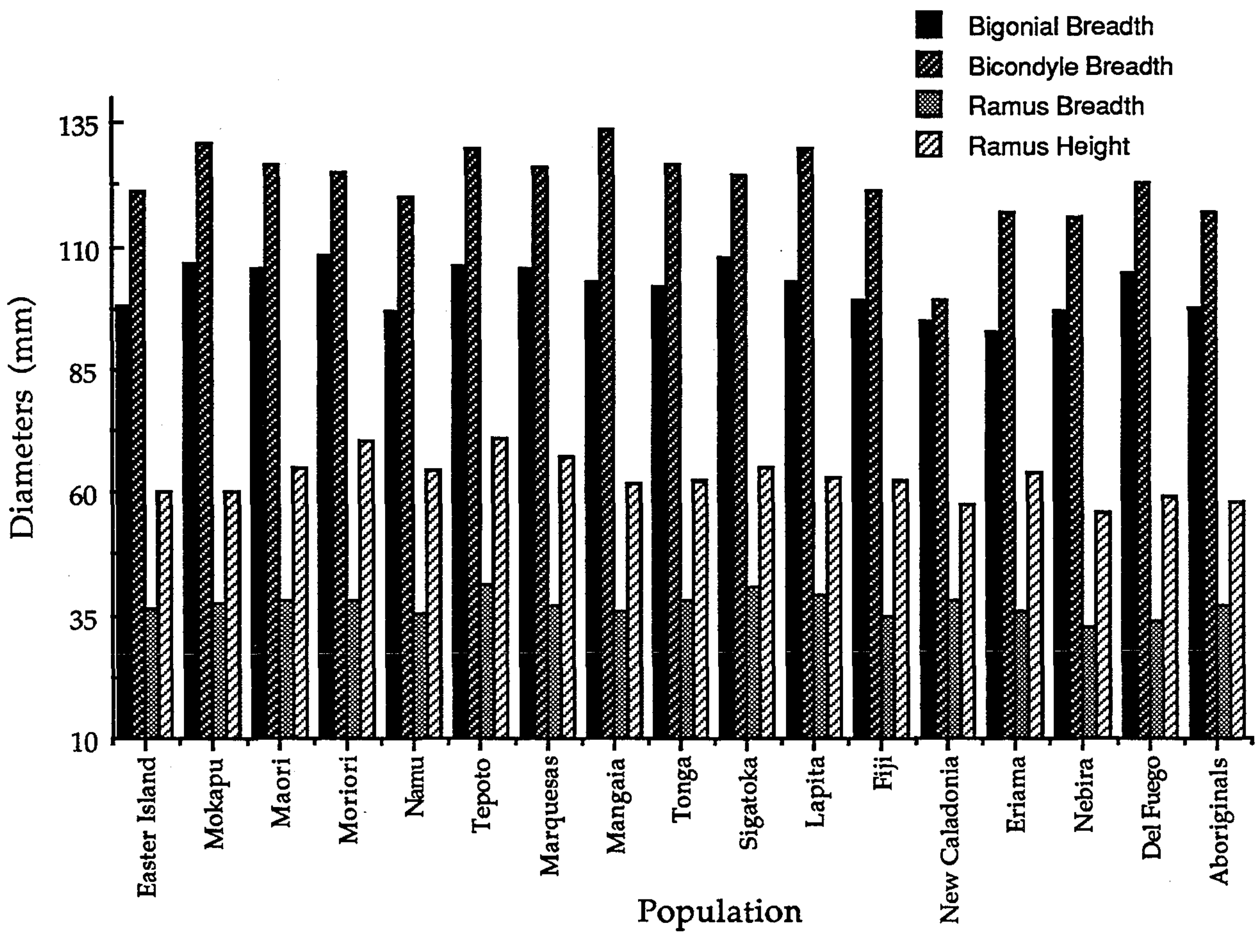
3.21 Nasal and mandible diameters and angles

Nasal and mandible diameters and angles are presented in Appendix 5. The results show that the Sigatoka males have greater similarities to populations in Remote Oceania, Namu and Lapita associated populations than to populations in Near Oceania. Statistically significant differences occur most frequently when Sigatoka is compared to populations from Near Oceania and the climatic control populations (Table 10.7). Within the Polynesian set, the most frequent nasal and mandibular differences with Sigatoka occur with the extreme Polynesian group of Mokapu, the Maori and Easter Islanders.

3.22 Mandible musculature. (A reflection of masticatory muscles and body form)

Ramal diameters are comparatively large in the Sigatoka males compared to most other populations (Figure 10.3). Ramal diameters of Near Oceanic males are frequently significantly smaller than Sigatoka males. For example, the differences between Sigatoka and all Near Oceanic populations are very significant ($p \leq 0.00$) in ramal height and breadth. This contrasts with the Remote Oceanic males, the Lapita associated skeletons and Namu. Lapita associated skeletons and Tongans have mandible diameters that are similar to Sigatoka. Tepoto males have larger ramal diameters than Sigatoka. The Moriori have significantly greater ramal height. Significant differences ($p \leq 0.00$) were found when the ramal breadths of Sigatoka males were compared to all Remote Oceanic males. However, no differences were found in ramal heights between those two populations. Statistically significant differences in at least one of the two ramal diameters exist between Sigatoka, Aboriginals and Tierra del Fuego.

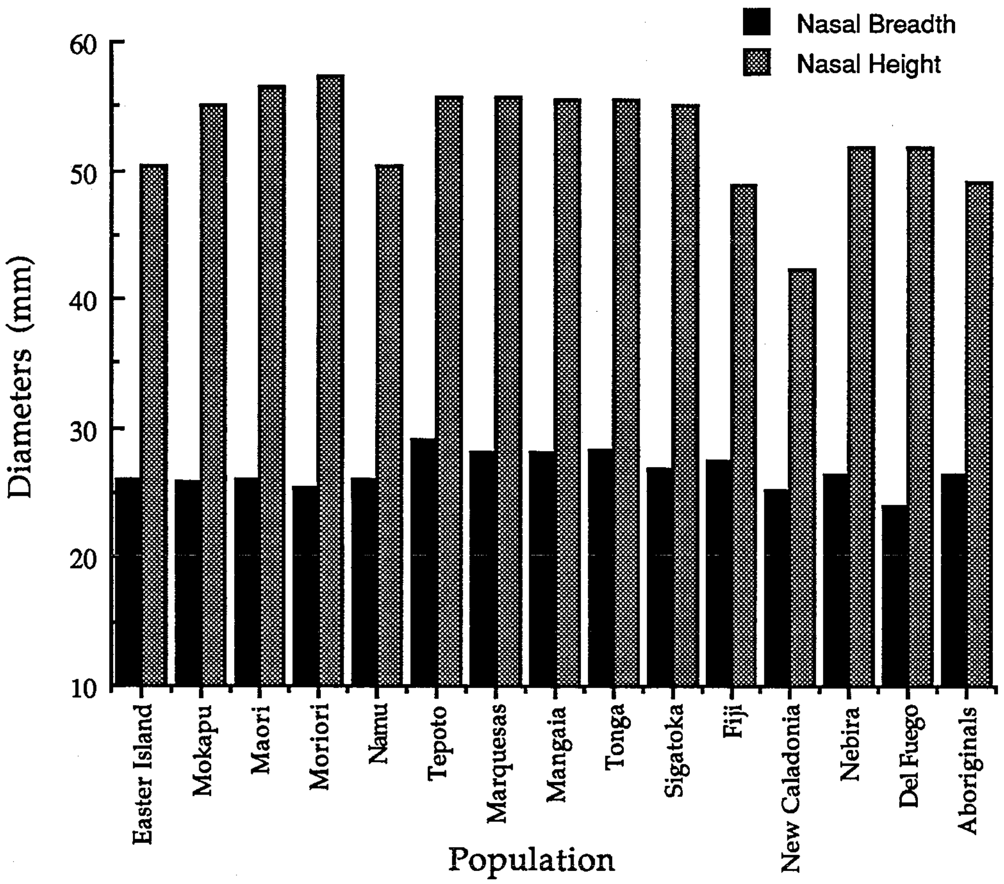
Figure 10.3
Male mandible diameters of Oceanic populations.



3.23 Nasal, bicondyle and bigonial diameters

There are few significant differences in the bigonial ($t = 1.8$ $p \leq 0.08$) or bicondyle diameters ($t = 1.0$ $p \leq 0.30$) between Sigatoka and Remote Oceanic populations, or the Lapita associated skeletons. Differences between Sigatoka and Remote Oceanic populations only exist with Mangaia and Easter Island (Tables 10.7). The males from Namu have smaller diameters than the Sigatoka males. Mean bigonial and bicondyle breadths of the Tierra del Fuegans are the same as Sigatoka, and within the range of the Polynesian groups. In the two Near Oceanic groups, Nebira and Eriama, the bigonial and bicondyle breadths are consistently smaller than either the Sigatoka males or females. In general, both the Remote Oceanic populations and Sigatoka differ very significantly ($p \leq 0.00$) from Near Oceania in the bigonial diameter and in the bicondyle diameter. These differences are also evident in the Aboriginal population. The Sigatoka males have nasal heights similar to all Remote Oceanic populations, apart from Easter Islanders (Table 10.7). Indeed, Student's *t* tests comparing Sigatoka to Remote Oceanic populations show that no significant differences in nasal height exist between the two groups. Populations from Near Oceania and Australia tend to have shorter nasal heights compared to populations from Sigatoka and Remote Oceania (Figure 10.4).

Figure 10.4
Male nasal diameters of Oceanic populations.



These differences are significant, ($t = 3.4$ $p \leq 0.00$) between Remote Oceania and Near Oceania, and significant ($t = 3.1$ $p \leq 0.01$) between Sigatoka and Near Oceania. The level of variation in nasal breadth between all the populations is small compared to nasal breadths of the Sigatoka population. However, nasal breadth tends to be smaller in Near Oceanic populations compared to Polynesians, Lapita associated skeletons and Sigatoka. Only the broad nasal diameters of the Tepoto males diverge from all other populations (Figure 10.4).

3.24 Mandibular form

The mandible of the Sigatoka males tends to be longer than most of the other populations and is most similar to Tongans (Table 10.7). The only significant variation from the Sigatoka population in mandible and corpus lengths was found with Mangaians, who had shorter mandibles. Maori corpus lengths were found to be significantly longer than Sigatoka.

Sigatoka gonial angles are more acute than those found among Near Oceanic populations. These differences are reflected in the statistical analyses that show that significant differences exist in either one or both of these diameters (Table 10.7). The gonial angles of the Sigatoka males are significantly more acute than the Fijian and Nebira angles, and more acute than the Aboriginals. The Maori, Lapita, and Namu males have either one or both gonial angles significantly more acute than Sigatoka.

There are a number of reasons why multivariate statistical analyses will not be applied to the data. The data used in multivariate techniques must meet a number of criteria to be applicable. Corruccini (1975: 14) and Manly (1986) list these criteria which include large sample sizes for all groups and complete data recorded for each specimen. The populations used in this study do not meet these criteria (See Chapter Nine and this chapter). Furthermore, the small sample sizes and the lack of significant differences of variance will have the affect of making the results of multivariate statistics open to misinterpretation (B. Niven, pers comm.). As Campbell has pointed out;

"As in many other applications of statistical techniques to biological problems, there is no substitute for sound advice from an experienced statistical practitioner!" (Campbell, 1978: 202-203).

Table 10.7

Means and univariate analyses of naso-mandibular dimensions of males from Oceanic populations compared to Sigatoka males.

Nasal breadth

Population	Mean	n	sd	*t* statistic	f ratio	Source
Easter Island	26.1	16	1.3	0.7	0.3	Murrill, 1968
Mokapu	25.8	8	1.2	1.1	1.1	Snow, 1974
Maori	26.1	8	1.0	0.8	0.1	Houghton, nd[c]
Moriori	25.4	7	1.9	1.1	1.6	Houghton, nd
Namu	26.1	8	1.7	0.7	0.0	Visser, nd
Tepoto	29.2	4	1.2	-1.6	0.0	Dennison, nd
Marquesas	28.1	5	1.2	-0.0	0.1	Pietrusewsky, 1976
Mangaia	28.1	12	1.3	-1.3	0.1	Katayama, *et al.*, 1988
Tonga	28.3	3	0.6	-0.9	0.1	Pietrusewsky, 1969
Sigatoka	**26.9**	**8**	**2.7**			
Fiji	27.4	8	1.4	0.4	0.7	Weber, 1934
New Caladonia	25.4	4	1.8	1.0	0.0	Waterston, 1908
Nebira	26.4	8	3.3	0.4	1.3	Visser, nd
Del Fuego	23.9	7	2.1	2.4 *	0.5	Garson, 1886
Aboriginals	26.5	8	2.4	0.3	0.6	Duckworth, 1894

Nasal height

Population	Mean	n	sd	*t* statistic	f ratio	
Easter Island	50.4	16	4.8	2.4 *	0.4	Murrill, 1968
Mokapu	55.0	8	3.5	0.0	1.0	Snow, 1974
Maori	56.5	8	2.8	0.8	6.4	Houghton, nd[c]
Moriori	57.3	6	2.0	-1.4	0.7	Houghton, nd[c]
Namu	50.4	3	3.1	1.6	0.3	Visser, nd
Tepoto	55.6	3	4.2	-0.2	2.1	Dennison, nd
Marquesas	55.7	6	3.3	-0.3	0.5	Pietrusewsky, 1976
Mangaia	55.4	8	7.6	-0.1	3.4	Katayama, *et al.*, 1988
Tonga	55.5	3	5.9	-0.1	0.1	Pietrusewsky, 1969
Sigatoka	**55.1**	**9**	**4.7**	----	----	
Fiji	48.8	8	3.2	3.2 **	5.3	Weber, 1934
New Caladonia	42.4	4	3.8	4.7 **	0.3	Waterston, 1908
Nebira	51.8	4	3.6	1.2	1.9	Visser, nd
Del Fuego	51.7	7	1.5	1.8	1.7	Garson, 1886
Aboriginals	49.1	8	3.1	4.1 **	7.5 **	Duckworth, 1894

Bigonial breadth

Population	Mean	n	sd	*t* statistic	f ratio	Source
Easter Island	98.0	12	5.1	0.9	1.2	Murrill, 1968
Mokapu	106.6	13	7.4	0.4	0.3	Snow, 1974
Maori	105.5	13	5.7	0.7	1.4	Houghton, nd[c]
Moriori	108.0	15	7.2	-0.1	1.4	Houghton, nd[c]
Namu	97.0	13	5.4	3.6 **	0.8	Visser, nd
Tepoto	106.2	6	8.2	0.4	0.1	Dennison, nd
Marquesas	105.4	10	7.2	0.7	6.3	Pietrusewsky, 1976
Mangaia	102.9	10	7.7	1.3	0.5	Katayama, *et al.*, 1988
Tonga	101.8	13	9.4	1.6	2.5	Pietrusewsky, 1969
Sigatoka	**107.8**	**15**	**9.9**	----	----	
Lapita	102.7	5	3.7	1.1	0.6	Pietrusewsky, 1990
Fiji	99.0	13	4.6	2.9 *	1.9	Weber, 1934
New Caladonia	94.7	3	7.0	2.2 *	0.0	Waterston, 1908
Eriama	92.6	4	6.0	2.6 *	0.0	Visser, nd
Nebira	96.7	8	6.1	2.9 *	6.0	Visser, nd
Del Fuego	104.6	5	2.3	0.7	7.2 *	Garson, 1886
Aboriginals	97.5	13	7.7	3.0 *	7.2 *	Duckworth, 1894

Bicondyle Breadth

Population	Mean	n	sd	*t* statistic	f ratio	Source
Easter Island	121.0	12	5.1	0.9	1.2	Murrill, 1968
Mokapu	130.8	12	6.7	2.0	10.3	Snow, 1974
Maori	126.4	12	7.5	0.7	1.4	Houghton, nd[c]
Moriori	125.0	12	5.2	-0.3	0.8	Houghton, nd[c]
Namu	120.3	7	3.8	1.0	0.1	Visser, nd
Tepoto	130.0	2	1.8	-0.9	----	Dennison, nd
Marquesas	126.1	10	6.8	-0.6	16.1	Pietrusewsky, 1976
Mangaia	133.3	10	7.7	1.3	0.5	Katayama, *et al.*, 1988
Tonga	126.5	12	7.0	-0.7	2.2	Pietrusewsky, 1969
Sigatoka	**124.1**	**12**	**9.3**	----	----	
Lapita	129.7	3	13.7	-0.9	0.0	Pietrusewsky, 1990
Fiji	121.2	12	4.7	0.9	0.5	Weber, 1934
New Caladonia	99.0	3	7.7	4.3 **	0.5	Waterston, 1908
Eriama	117.0	2	3.9	1.0	0.0	Visser, nd
Nebira	115.8	12	13.2	1.7	18.5	Pietrusewsky, 1976
Del Fuego	122.8	5	5.5	0.3	0.1	Garson, 1886
Aboriginals	116.9	12	6.3	2.2 *	1.0	Duckworth, 1894

Ramus breadth

Population	Mean	n	sd	*t* statistic	f ratio	Source
Easter Island	36.6	15	3.0	3.7 **	1.3	Murrill, 1968
Mokapu	37.5	14	2.5	3.3 **	0.4	Snow, 1974
Maori	38.0	14	2.5	2.7 *	1.7	Houghton, nd[c]
Moriori	37.9	14	2.3	3.0 *	3.7	Houghton, nd[c]
Namu	35.1	14	4.0	4.3 *	2.4	Visser, nd
Tepoto	41.1	7	3.0	-0.5	14.0	Dennison, nd
Marquesas	37.2	11	4.4	2.5 *	2.7	Pietrusewsky, 1976
Mangaia	35.7	10	2.8	4.6 **	1.1	Katayama, *et al.*, 1988
Tonga	38.1	14	4.1	2.0	1.3	Pietrusewsky, 1969
Sigatoka	**40.6**	**14**	**2.4**	----	----	
Lapita	39.3	5	5.8	0.7	1.7	Pietrusewsky, 1990
Fiji	34.9	12	3.0	5.4 **	0.0	Weber, 1934
New Caladonia	38.3	3	5.8	1.1	0.7	Waterston, 1908
Eriama	36.0	4	4.5	2.8 *	0.0	Visser, nd
Nebira	32.6	7	3.4	7.0 **	0.1	Pietrusewsky, 1976
Del Fuego	34.0	5	2.0	5.4	0.4	Garson, 1886
Aboriginals	37.1	14	3.4	3.1 **	4.0	Duckworth, 1894

Ramus height

Population	Mean	n	sd	*t* statistic	f ratio	
Easter Island	60.4	13	8.9	1.8	0.6	Murrill, 1968
Mokapu	60.0	14	4.8	2.8 **	0.5	Snow, 1974
Maori	65.1	14	10.4	0.1	0.5	Houghton, nd[c]
Moriori	70.6	14	5.1	-2.8	0.0	Houghton, nd[c]
Namu	64.3	9	4.7	0.4	0.0	Visser, nd
Tepoto	70.9	7	4.7	-2.4 *	5.0	Dennison, nd
Marquesas	67.4	10	7.4	-0.8	0.2	Pietrusewsky, 1976
Mangaia	62.0	10	4.1	1.6 *	7.0	Katayama, *et al.*, 1988
Tonga	62.1	14	6.7	1.4	0.5	Pietrusewsky, 1969
Sigatoka	**65.2**	**14**	**5.2**	----	----	
Lapita	62.9	4	4.2	0.8	0.0	Pietrusewsky, 1990
Fiji	62.5	14	4.1	1.5	0.6	Weber, 1934
New Caladonia	57.7	3	7.5	2.1 *	0.0	Waterston, 1908
Eriama	64.0	4	7.0	0.4	0.0	Visser, nd
Nebira	55.9	13	3.1	5.6 **	0.1	Pietrusewsky, 1976
Del Fuego	59.0	5	5.2	2.3	0.0	Garson, 1886
Aboriginals	58.1	14	7.4	2.9 **	1.4	Duckworth, 1894

Mandible Length

Population	Mean	n	sd	*t* statistic	f ratio	Source
Easter Island	97.8	13	6.2	6.4**	0.9	Murrill, 1968
Mokapu	108.6	30	5.6	0.9	1.4	Snow, 1974
Maori	110.0	30	4.8	-0.1	0.1	Houghton, nd[c]
Moriori	110.2	13	6.0	-0.1	0.7	Houghton, nd[c]
Namu	110.3	9	5.9	-0.1	1.4	Visser, nd
Tepoto	107.0	3	6.4	1.5	0.7	Dennison, nd
Marquesas	113.9	10	9.2	-2.0	0.2	Pietrusewsky, 1976
Mangaia	103.1	10	4.4	4.2*	1.7	Katayama, *et al.*, 1988
Tonga	108.4	17	6.4	0.9	6.1	Pietrusewsky, 1969
Sigatoka	**110.0**	**15**	**3.8**	----	----	
Lapita	106.0	3	11.1	1.2	0.0	Pietrusewsky, 1990

Gonial angles

Population	Mean	n	sd	*t* statistic	f ratio	Source
Mokapu	119	30	5.7	-1.0	0.4	Snow, 1974
Maori	112	30	6.7	2.3 *	0.5	Houghton, nd[c]
Moriori	111	16	5.3	3.2 **	1.8	Houghton, nd[c]
Namu	115	13	6.7	1.0	0.0	Visser, nd
Sigatoka	**117**	**17**	**5.3**	----	----	
Lapita	108	3	13.3	0.2	0.0	Visser, nd
Fiji	123	15	7.1	-2.9 **	0.7	Weber, 1934
Eriama	115	4	7.8	0.5	0.0	Visser, nd
Nebira	122	12	2.9	-2.9 **	0.1	Pietrusewsky, 1976
Del Fuego	124	5	6.3	-2.6 *	0.0	Garson, 1886
Aboriginals	120	14	9.7	-1.2	-0.1	Duckworth, 1894

4.0 Discussion

Sigatoka males display "robust" mandibular muscularity. This "robustness" is more keenly expressed than that found among most Polynesian populations, but is similar to the Lapita skeletons. The breadth of the mandibles (bigonial and bicondyle) suggests that the Sigatoka males were brachycephalic. This head form is comparable to Polynesians, but different from populations from Near Oceania, the Aboriginals and the Tierra del Fuegans. The lengths of the Sigatoka mandibles indicate a slightly more prognathic facial profile than most Polynesians, but similar to Tongans. This prognathic profile is much less pronounced than that found in Near Oceanic populations, Aboriginals and Tierra del Fuegans.

The stature and body mass comparisons presented in Chapter Nine, show that populations from Remote Oceania are taller and heavier than populations from Near Oceania, although some comparatively tall and heavy populations are found in littoral environments in Near Oceania. These populations are commonly involved in ocean fishing and canoeing.

One explanation for the larger body sizes and stature between Near and Remote Oceania has been ascribed to the "abundance" of food, particularly protein availability, and health (van Dijk, 1993). Poor health and nutritional deficiencies, particularly during the growth spurt phases, have been shown to retard stature. Furthermore, stature is associated with body weight. Tanner (1988) has shown that the shorter the stature the lower the body weight. Therefore, body mass can be influenced not only by stature, but also by health and nutrition.

However, consistent differences in stature and body mass between Near and Remote Oceania can not be ascribed to the availability of food or the state of health. It has also been noted that littoral Near Oceanic populations have larger statures, greater body mass and shorter limb proportions to stature, compared to inland populations (Guppy, 1886; Friedlaender, 1987[a]; Houghton, 1991[a], 1991[b]). Similarly, significant differences or marked contrasts exist in these variables between Remote and Near Oceanic populations, and between Sigatoka and Near Oceania, but not between Sigatoka and Remote Oceania. Changes in limb to body proportions are not associated with interrupted growth spurts. These differences are suggested to reflect an adaptation to different environmental conditions (Houghton, 1991[a], 1991[b]).

Large stature, accompanied by heavy body mass and short limb extremities, reduces the body surface area. This has the affect of limiting the amount of body heat lost. This body form is an adaptation to a cool marine environment. Houghton (1990, 1991[a], 1991[b]) argues that this body form has evolved in Polynesians as a response to the selective demands placed on ancestral Polynesians during their development of ocean going sailing and exploration of Remote Oceania (see Chapter Two). Briefly then, individuals with low body mass, short stature and long limbs to body size would have had a lower survival rate during prolonged canoe sailing in a cool marine environment compared to heavier individuals with short limbs to stature.

Comparisons of the Sigatoka population with other Oceanic populations show that the Sigatoka people exhibit a body type that is most similar to populations from Remote Oceania. This body type is one that is argued to reflect adaptation to a cool marine environment. Stature and body mass are often significantly greater than Near Oceanic populations. Furthermore, the results of the leg-to-stature comparisons reflect that the Sigatoka people had experienced similar selective forces to that of Remote Oceanic populations, that is, a cool environment. The same selective forces do not seem to have operated on populations from Near Oceania or Aboriginals because there tends to be many significant differences between them. Only the cold climate population from Tierra del Fuego has similarities to Sigatoka and Remote Oceanic populations. The Sigatoka body indices tended to be most similar to Remote Oceanic populations, Tierra del Fuegans and in most cases Fijians. Only the crural index of Fijians differs significantly from the Sigatoka males. The general similarity between these populations tends to suggest adaptability to similar environments.

One finding of this study is that lower limbs appear to experience greater variability than upper limbs. This may be an indication that the lower limbs experience greater susceptibility to environmental selective pressures than upper limbs. A number of studies that have focused on nutritional improvements have found that as diet improves, the length of the legs also increases relative to the arms (Eveleth and Tanner, 1976; van Dijk, 1993). Improved nutrition has been shown to increase limb length. However, without evidence suggesting that nutrition was better in Sigatoka and Remote Oceania compared to Near Oceania and more recent Fiji, it is more probable that the theory of climate gradients and the operation of the biological rules identified by Bergmann (1847) and Allen (1877), are important factors contributing to differences in lower limb lengths in Oceanic populations.

Anthropometric chest measurements and skeletal clavicle length measurements show a trend of increasing upper body breadth from Near Oceania to Remote Oceania. The Sigatoka population is intermediate within this trend. Although the number of Sigatoka clavicles measured is small, there are enough to suggest that clavicle lengths, as indicators of chest diameter, are a response providing increased respiratory capacity compared to Near Oceanic populations. Physical activities such as digging and canoe paddling cannot influence the variation of chest or clavicle measurements between populations, unless these activities occur before the end of growth. Remote Oceanic populations tend to have longer clavicle lengths compared to Near Oceanic populations. Generally, broad chests and long clavicles fit with the large trunk - cold climate rule.

It has been shown that the Sigatoka people have larger body sizes compared to Near Oceanic populations. One principle of a larger body is that it requires a greater oxygen supply. Demands for greater oxygen requirements are reflected in the nasal and mandibular skeleton. The nasal and mandibular skeleton of the Sigatoka males reflect not only the greater oxygen demands of the body, but also greater musculature compared to Near Oceanic populations. The expression of greater musculature is also evident in mandibular diameters, particularly at the site of the masseter and temporalis muscle insertions.

In comparing the climate control populations, it is evident that the Tierra del Fuegans and the Moriori have longer clavicles than Aboriginals. This is indicative of a larger chest diameter in these populations compared to Aboriginals. This feature may be an adaptive response to living in a cool climate, in an effort to minimise core body temperature loss. Within Oceania, most Polynesian populations have greater clavicle lengths than Sigatoka. Sigatoka and Tonga have longer clavicles than Near Oceanic populations, including Fiji. This east-west difference is reflected in anthropometric data collected on chest circumferences in Oceanic populations. The inference is that the greater the clavicle length, the greater the chest circumference and therefore the greater the ability to retain core body heat.

Chapter Eleven
Synthesis and conclusion

1.1 Objectives

This chapter synthesizes the information discussed in previous chapters into an integrated understanding of the Sigatoka people. The main objective of this study has been to evaluate the degree of success the Sigatoka people had in adapting to their environment nearly 2000 years ago.

Four main approaches have been used to evaluate the adaptive process. Chapters Three to Six assessed the Sigatoka skeletal and dental material to ascertain life span, health, pathology and degree of sexual dimorphism. Chapter Seven then focused on the biological differences in burial arrangements and social organisation within the burial ground. These biological differences provide some understanding of certain cultural factors that may have contributed to the population's adaptation. Chapters Eight and Nine compared the affinity of the Sigatoka people with other Pacific populations. Chapter Ten examined selective factors that may have affected the body forms of different Oceanic populations and considered how these relate to the Sigatoka population.

1.2 Sigatoka life span, health, pathology and sex differences as indicators of an adaptive response

The mean age at death and life expectancies of the Sigatoka skeletons have been calculated to be around 28 to 30 years of age (Chapter Three). In order for the population to maintain viable replacement growth rates, average life span is estimated to have been around 40 years of age. However, a disparity in length of life estimates that arises because of an over representation of young adults in the burial ground has to be taken into account.

This estimate of longer average life span is supported by skeletal evidence that consistently showed that the population was healthy (Chapter Four). The Sigatoka people, and males in particular, often attained taller stature and heavier body mass compared with other Pacific populations. Taller stature suggests that growth disruptions were minimal and diet was more than adequate to maintain bone development during the growth episodes and for the population to attain a comparatively heavy body mass during adult life. Additionally, there is no evidence that infectious diseases were present, and the low levels of skeletal pathologies lend further support to the conclusion that the Sigatoka people were healthy, within a prehistoric context. A healthy population suggests that the Sigatoka people were able to exploit their physical environment to adequately meet their dietary needs.

Dental analysis, however, indicates that health was compromised in some individuals. The presence of enamel hypoplasia suggests that growth was disrupted during infancy and early childhood. One explanation of why enamel hypoplasia was present in some individuals is that those individuals had a greater susceptibility to childhood illnesses. If food shortages had occurred, there would have been a higher incidence of enamel hypoplasia. However, it is possible that individuals with marked enamel hypoplasia were of lower social status and consequently may have had reduced access to food than other individuals in the community.

Age-associated degeneration of the teeth and bone rapidly increased among individuals over the age of 30 years. The prevalence of dental caries rapidly increases in the over 30 year age group. In many cases caries are interproximal. This suggests a diet high in its carbohydrate and sugar content and an inability of the salivary and dental structures to inhibit decay. Such a diet is indicative of cultivated crops. Similarly, age-related increases in the prevalence of osteoarthritic degeneration were found in the vertebral column. Bony degeneration in these areas can be associated with heavy work, such as carry, lifting and bending. Degenerative changes in bone not only suggest a pathological response, but also an attempt to accommodate stress forces acting on the joints.

Some sex-specific pathologies are very likely to have occurred as a result of cultural activities. Among males, degeneration of the temporomandibular joint (TMJ) was caused by repetitive forceful assymetrical chewing. It is argued in Chapter Five that this chewing was to process kava. Degeneration of the TMJ would have lead to discomfort and difficulties in chewing food, but was unlikely to have been associated with secondary pathological factors that affected health. In some females the consequences of cultural activities may have been deleterious to health. A non-dietary form of tooth wear in some anterior teeth exposed the dental pulp chamber to infection. Infection frequently resulted in bony alveolar abscessing. The effects of multi-abscessing in the alveoli of some females probably increased their susceptibility to secondary infections and early death.

There is a low prevalence of pathological instances in the population, particularly an apparent lack of infectious disease, and evidence of good health (fertility, stature, body mass). The lack of disease and the absence of extreme selective forces enabled the Sigatoka population to attain a body size closer to their genetic potential, for which their ancestors had been selected.

A low level of sexual dimorphism in teeth suggests their sizes were not related to mandible or body size. Rather, it is suggested that natural selection has favoured small teeth. In this case, selection may have favoured people with smaller teeth because they were less likely to experience interproximal caries and associated abscessing. However, the significantly larger body size and muscularity in males compared to females indicates adaptability to an environment within which a population experienced limited physical and cultural stress in accordance with the theory held by a number of authorities (Stini, 1975, 1985; Tobias, 1975; Relethford and Hodges, 1985) presented in Chapter Six. Alternatively, sex differentiation may have allowed males to have better access to food compared to females, and this may have contributed to the significantly larger male body sizes.

1.3 Internal burial differentiation and social organisation

Archaeological evidence presented by Best (1989) in the form of grave goods, burial location, and the size of the burial mound indicated that burial arrangements reflected a social hierarchy. Skeletal analyses confirm this finding. The oldest, tallest, and heaviest males were buried at the highest point and under the largest coral mound in the burial ground. This group of males differed significantly from other males, and it is argued that males may have been socially stratified into two tiers, a high ranking older group, and all other males. Under this social arrangement higher ranking males probably had preferential access to community resources such as food.

There is additional evidence of social stratification. A small group of females who tended to be buried on the outer perimeter of the burial ground had a greater incidence of marked enamel hypoplasia. It is suggested that within a family unit, female children may have had less access to food. Reduced access to food is linked to a greater probability of ill-health and subsequent growth disruptions in childhood. The fact that these females were buried on the perimeter of the burial ground indicates that they held a lower social status during life compared to males and females buried within the main perimeter of the burial ground and who displayed no or only slight evidence of enamel hypoplasia.

The Sigatoka people also seemed to have practiced a division of labour between the sexes. This is evidenced by greater male robusticity in the right clavicle and humerus as discussed in Chapter Six. Greater right sided robusticity may be associated with males paddling canoes and digging gardens or clay for pottery production. In addition, there is also evidence suggesting that there was a division of specialist tasks among females. For example, one set of females have non-dietary tooth wear patterns on the anterior dentition that is not found in other females. This aspect was discussed in Chapter Seven.

1.4 Adaptation to the environment

The skeletal material indicates that the Sigatoka people were relatively tall and muscular, and had broad chests. It is argued that this body form and consequent physiological requirements partially influenced the shape of the craniofacial skeleton. In the Sigatoka population, the size and shape of the mandible and bony nasal aperture is consistent with large body muscle mass, and the requirements for higher levels of oxygen compared to smaller individuals. The bicondyle and bigonial breadths of the mandible partially reflect this requirement. These characteristics may have evolved as a response to a pharyngeal expansion to accommodate an increased need for oxygen associated with more muscle tissue. These biological developments require a set of simultaneous cranial adaptations discussed in Chapter Ten.

The skeletal morphological characteristics displayed by the Sigatoka people can be accounted for by the operation of selective pressures. In this argument, natural selection is based on the proposition that the populations ancestral to the Sigatoka people experienced selective pressures to adapt to a cool marine environment. A number of studies have shown that the effect of even a low wind-chill factor in a tropical marine environment is sufficient to induce body heat loss (Beckmann and Reeves, 1966; Siple, 1968; Frisancho, 1979; Houghton, 1991). To successfully colonise the dispersed islands of Remote Oceania meant that the selective pressures of a cool marine environment were greater than that experienced in the previous millennium experienced by populations ancestral to the Sigatoka people in Near Oceania. For colonisation to be possible, both adaptability (phenotypic plasticity) and adaptation (changes in genotype) of the pre-Sigatoka body form was necessary. These biological changes are seen as a consequence of the process and demands of obtaining the technology and knowledge required for ocean sailing (Houghton, 1990, 1991^{a}, 1991^{b}). This theory has been outlined in Chapter Two and detailed in Chapter Ten. Examples of adaptation in the Sigatoka population relate to changes in naso-mandibular dimensions. The mandibular gonial angle suggests changes in the cranial base angle (Kean and Houghton, 1982). These changes are also associated with broader mandibular and nasal diameters. Ultimately these changes are linked to greater body mass, particularly in the form of greater muscularity (Houghton, 1994). The continued expression of these traits in the Sigatoka population and Remote Oceanic populations that have been adapted to a cool marine environment indicates a change in genotype. Conversely, similarity in limb proportions between Sigatoka and Near Oceanic populations and most of the Remote Oceanic population in tropical areas and differences with those populations in cooler areas indicate that limb proportions are a reflection of adaptability.

An associated selective mechanism may have had a cultural basis. In traditional Oceanic societies, large body size and obesity have been perceived as a mark of prestige and high social ranking. This perception may be associated with prehistoric colonisation. The way in which this mechanism may have operated is that the largest people were chosen to colonise new islands. Repeated selection of the large individuals from each subsequent population can rapidly alter the expression of their genotype, and hence the phenotype of descendant populations from the parent population.

1.5 Comparisons with Sigatoka

Facial form and body form of the Sigatoka people exhibits similarities to most Polynesian populations available for comparative study, and Lapita associated skeletons. Populations to the west of Fiji and recent Fijians tend to vary from the Sigatoka people. The form of the Sigatoka mandible indicates that the population had broad, round crania. Other aspects of body shape suggest additional associations to Remote Oceanic populations. The Sigatoka people have lower limb proportions and a body form (stature and mass) similar to Lapita associated skeletons, most Polynesians, and similarities with the population from Tierra del Fuego. Such a body form is an indication of an adaptation to cool environments. The similarities that the Sigatoka people have with Polynesians and Lapita associated skeletons implies that in the past, common ancestral groups experienced similar selective forces.

The likely biological association that the Sigatoka population has with the later Polynesian populations is complex. Tooth size and form have been argued to be under greater genetic control than bone (See Chapters Six and Nine). Results have shown that the Sigatoka people have smaller molar teeth than any other population, but their size has greater similarity to Polynesians compared with populations to the west of Fiji. However, morphological tooth traits were expressed in frequencies that differ from all comparative populations. The different expression of these traits may be a reflection of influences by successive episodes of low level contact with the west.

It seems that the presence of low frequencies of Polynesian nucleic DNA markers indicate "Melanesian" influences in the genotype of contemporary Fijians. Archaeological evidence has been used to suggest that from 1100 AD there was additional influence within Fiji from the west, perhaps Vanuatu. At this time sufficient numbers of people may have arrived to introduce new material culture and biological traits. This change seems to be evident in the skeletal material. Skeletal comparisons between the Sigatoka population and later Fijians indicate significant differences in both body form and craniofacial form. These differences seem to be too great to have been solely the result of regional adaptive changes. An explanation could be that later intrusive contact provided a source of new genetic material within Fiji. Certainly, archaeological evidence discussed in Chapter Two provides evidence of contact, not only with Tonga and Samoa but also Vanuatu.

Low level contact with Fiji from Tonga, Samoa and Vanuatu probably predates as well as postdates the period of the Sigatoka people. It also seems likely both on the basis of archaeological evidence such as adzes and fortifications (Best, 1984) and genetic material, particularly in the frequency of the mtDNA 9 bp deletion (Serjeantson and Hill, 1989), that there was repeated contact with Tongan and Samoan populations (Best, 1984; Geraghty, 1987; Poulsen, 1987). From time to time these contacts introduced new culture, ideas, and perhaps added to the gene pool. Within Fiji, minimal contact between regions served to slow the flow of ideas and genes. Reduced regional contact and the flow of new people in coastal areas effectively allowed some regional biological divergence to occur (Ward, 1967; Hunt, 1987).

If the Sigatoka population is representative of a descendant group who had been living in Fiji for the past millennium (1000 BC to 180 AD), the diversity of some mandibular measurements suggest that it is possible that the Polynesians are genetically derived from the early occupants of Fiji. Unfortunately, comparative skeletal information from Near Oceania is sparse, which makes any conclusion open to question. Studies have shown that New Guinea and the Solomon Islands in particular, and to a lesser extent Vanuatu, have diverse population groups, not only culturally and linguistically, but biologically (Friedlaender, 1987[a]).

1.6 Conclusion

The selective forces that operated to evolve the body form of the Sigatoka people, and ultimately their genotype, acted not only on them but on their ancestors who settled Fiji. The large skeletal dimensions of the Sigatoka people illustrate a muscular physique. This physique and the associated body form suggest an adaptation to a cool marine environment. Differences in skeletal and dental traits within the Sigatoka population suggest that they were genotypically more diverse than would be expected in a small and isolated population. This may reflect the possibility that the settlement of Fiji did not occur in a single colonisation event and that biological (and cultural) contact, particularly from the west, (Vanuatu), continued at a rate which allowed biological diversity to be maintained.

The adaptive success of the Sigatoka people may be assessed by a number of factors. The most important is evidence that the population was growing. That evidence not only indicates that the population was likely to have been increasing, but also there is no evidence of infectious diseases, and comparatively few signs of pathology. Moreover, many individuals attained stature and body mass weights that are unusually high in neolithic communities. Thus, the available evidence presents a picture of a population which biologically and culturally successfully exploited their environment.

Historical and contemporary Fiji has been regarded as a cultural and biological intermediary between the western and eastern Pacific. Yet, the Sigatoka skeletons do not seemingly reflect skeletal characteristics that illustrate the intermediate status of later Fijians. Rather, they are somewhat skeletally distinct from the later Fijian population, and their skeletal biology aligns more closely with Polynesian populations to the east. This distinction was maintained even as contact with the west continued as evidenced by botanical and archaeological finds. Furthermore, a reasonably close skeletal affinity appears to exist between the scattered Lapita associated skeletons and the Sigatoka people. On this basis it is tempting to state, within the limits of this study, that the Sigatoka people represent a pre-Polynesian population that descended from the Lapita associated skeletons.

To improve our understanding of the human biological history of Fiji, and the affinity that Fijians have with people from Vanuatu and Polynesians in particular, requires more skeletal samples. The Sigatoka Dune site still contains invaluable skeletal and archaeological information. The stratigraphic sequence, as noted above, is divided into three temporal episodes. If the information from each of these strata was available, it may be possible to show a sequence of human biological change that matches the Fijian archaeological record. For this reason, monitoring and recovery of eroded skeletal material and further excavation in the dunes may have great potential.

Appendices

and

References

Appendix One

Mt DNA analysis of Sigatoka bone.

Samples of cortical bone from five individuals were submitted to Erika Hagelberg and John Clegg of the Institute of Molecular Medicine, Oxford, England for mtDNA analysis, and specifically to attempt to identify 9 bp mtDNA deletion, which is highly characteristic of contemporary Polynesian populations. The method of amplification and DNA sequencing is outlined in Hagelberg and Clegg (1993).

Upon excavation, the bone intended for future chemical analysis was not treated with the paraloid, B72, but it is possible that low levels of spray drift onto the bone did occur. The bone samples were in a very brittle and weathered state. The bone sent for analysis had been handled in the field by at least two individuals during excavation and once in the laboratory before being submitted to Hagelberg and Clegg for analysis.

The results are presented in Table 1. No region V (9 bp mtDNA deletion) was found.

Table 1.
The results of PCR analyses

Sample	PCR Results	
Sigatoka 3	+ (?)	one round of PCR
Sigatoka 3	+	one round of PCR
Sigatoka 4	+ (?)	two rounds of PCR
Sigatoka 5	-	one round of PCR
Sigatoka 6	++	two rounds of PCR

A number of other bone samples from different Oceanic populations of varying antiquity were submitted to Hagelberg and Clegg for analysis and the findings have subsequently been published Hagelberg and Clegg (1993). These findings are presented in Table 2 below.

Table 2.
Skeletal Pacific populations from which mtDNA has been extracted.

Populations	Age	9 bp deletion
Watom	550 -150 BC	-
Watom	"	-
Watom	"	-
Watom	"	-
Taplins	150 BC	-
Sigatoka	180 AD	-
Sigatoka	"	-
Natunuku	0 ? AD	-
To'aga,Samoa	550 BC	-
Pea site, Tonga	750 - 650 BC	-
Tonga	1650 AD	+
New Zealand	1250 - 1650 AD	+
New Zealand	"	+
Waihora, Chatham Islands	1550 AD	+
Waihora, Chatham Islands	"	+
Makatea, Society Islands	Pre-European	+
Barbers Point, Hawai'i	1450 - 1650 AD	+
Kualoa Park, Hawai'i	Pre-European	+
Kosrae, Caroline Islands	1750 AD	+
Yap	1650 AD	-
Afetna, Marianas	1550 AD	-

The lack of a mtDNA 9 bp deletion marker has been interpreted to indicate a mainly "Melanesian" colonisation of central Oceania, (Hagelberg and Clegg, 1993). However, one of the problems associated with extracting DNA sequences from very old bone appears to be the break down of the organic structure of bone and the increasing fragmentation and decay of DNA. Certainly in the samples analysed by Hagelberg and Clegg the lack of the 9 bp deletion in samples older than 700 years may be attributable to this decay process. In fairness, Hagelberg and Clegg pointed out this possibility. However, they favour the view that the earliest inhabitants of Fiji, Samoa and Tonga may have been "Melanesians", and only later did Polynesian characteristics develop. This argument holds that the Lapita culture and people were indigenous to "Melanesia" but are not related to Polynesians.

It is my contention that this view cannot be supported by the DNA information obtained from the skeletal material. It seems highly likely that the DNA from the older samples was very degraded. In consequence, Hagelberg and Clegg appear to base their assumption on linguistic differentiations, Austronesian versus non-Austronesian languages, while ignoring the accumulating data demonstrating artefact similarities between Lapita sites and later Polynesian sites, as well as associations between Lapita associated skeletons and Polynesians. The skeletal analysis of the Sigatoka skeletons has shown that a greater association with Lapita and Polynesian skeletons exists, compared to skeletons from populations from "Melanesia".

Appendix Two
The Sigatoka 1991 material

In 1991 two groups of skeletal remains were found to be eroding from the Sigatoka sand dunes. One group was approximately 210 meters west of the burial ground excavated by Best (1989), and close to the area excavated by the Birks. The other group of skeletons were located approximately 770 meters west of Best's excavation, and approximately 220 meters west of the Birks' excavations (Crosby, 1991).

The skeletons were badly degraded, so that little information could be obtained from them. Laboratory analysis identified the skeletal remains of seven individuals. The individual results of the variables used to compare this population with the Sigatoka skeletons excavated in 1987 and 1988, are presented in the Tables below.

Table 1.
Age, sex and mandibular measurements of the 1991 Sigatoka skeletons.

Name	Age	Sex	Bigonial Length	Gonial Length	Mandible Length	L Ramus Height	L.Ramus Breadth	Mandible Angle	Mandible Physical Angle
91.a.1	26 ± 3	♀					31.6	120	109
91.b.1	29 ± 4	♀		83.5			36.5		
91.c.1	16 ±1	♂		75.5	110	57.9	36.5	123	111
91.d.1	23 ± 2	♀	76.6		108	59.0	39.7	111	102
91.e.2	40 ± 5	♀					34.8		
91.f. 2	27 ± 5	♀							
91.g.2	0 ± 0	?							

Stature and body mass estimates are presented in Table 2. Long bone lengths and the diameters of the weight bearing joints are also given. Stature estimates are based on stature formulae for Polynesians (Houghton *et al.*, 1975). Body mass estimates are based on the regression formulae used for the Sigatoka people, which were derived from Maori data (Houghton, in press).

Table 2.

Femoral platymeria and estimates of stature and body mass.

Name	Stature	Body Mass	Femoral platymeria
91.a.1			74.5
91.b.1			69.2
91.c.1			79.8
91.d.1		50.3	73.3
91.e.2	1683.9	61.0	
91.f..2	1669.4	55.2	73.3

Long bone lengths and the diameters of the weight bearing joints are presented in Table 3. Estimates of body mass and stature based on individual diameters and bone length are also given.

Table 3

Mass bearing diameters and long bone lengths and their body mass and stature estimates.

		Diameter	Body Mass			Length	Stature
91.d.1	Right Ankle	59.0	50.28	91.e.2	Right Radius	257	1683.9
91.e.2	Right Ankle	64.4	58.65	91.f.2.	Right Humerus	312	1635.6
	Left Ankle	64.7	59.68		Right Ulna	260	1634.8
91.f.2	Right Elbow	53.6	54.04		Left Ulna	260	1641.7
	Left Elbow	53.2	55.96		Right Radius	234	1627.0
	Right Wrist	44.7	56.25		Left Radius	234	1631.5
	Left Wrist	44.5	56.78		Right femur	436	1658.8
	Right Knee	71.5	54.58		Left Femur	442	1668.0
	Left Knee	70.8	53.33		Right Tibia	365	1600.3
	Right Ankle	59.4	50.90		Left Tibia	362	1669.4
	Left Ankle	58.5	48.96				

Appendix Three

Age at Death

Estimated age of death of the individuals in the Sigatoka burial ground.

Males	
B1a	28 ± 3
B1b	40 ± 3
B1c	22 ± 2
B1/1	27 ± 3
B4c	33 ± 3
B5c	30 ± 5
B6b	32 ± 4
B8a	32 ± 4
B10a	47 ± 4
B10b	45 ± 5
B10c	39 ± 4
B13a	19 ± 1
B14	29 ± 4
B17b	25 ± 3
B19	27 ± 3
B20	29 ± 3
B21b	15 ± 1
F.C. Skull	30 ± 7

Females	
B2a	31 ± 4
B2b	31 ± 4
B2c	28 ± 2
B3a	27 ± 3
B3d	32 ± 4
B4a	34 ± 3
B4b	28 ± 3
B5d	18 ± 2
B6a	32 ± 4
B9a	35 ± 4
B13b	24 ± 2
B13/1	37 ± 4
B16	23 ± 2
B17a	28 ± 4
B17c	40 ± 4
B18a	35 ± 3
B21a	46 ± 5
B21c	23 ± 2
B23a	24 ± 2
B24	26 ± 4
B25	26 ± 3
B28	42 ± 5
E1	25 ± 3
E2a	31 ± 3
W2	30 ± 4
W3	21 ± 4
W4	26 ± 4

Children	
B3c	3.8 ± 1.0
B5a	5.0 ± 1.0
B9b	6.5 ± 1.0
B11	11.0 ± 1.0
B15	4.5 ± 0.5
B17/1	12.0 ± 2.0
B18b	0.0 ± 0.0
B23b	2.0 ± 0.3
B26	3.5 ± 1.0
B27	0.0 ± 0.0
E2b	8.0 ± 2.0

Appendix Four
Skeletal Dimensions

Table 1.
Adult male mandible diameters (mm) and angles.

Burial	Bigonial Length	Bicondyle Length	Gonial Length	Mandible Length	Ramus Height		Ramus Height		Mandible Angle	Mandible physical Angle
					Right	Left	Right	Left		
1a	115	129	91.9	107	69.9	67.0	40.3	39.3	112.0	99.0
1b	111	134	81.5	114	66.3	67.2	38.6	38.6	120.0	113.0
1c		139	67.0	110		70.2		46.0	124.0	102.0
1/1	101	123	79.0	107	61.0	60.8	40.4	40.2	118.0	105.0
4c	116		89.0	111	71.5	72.5	42.6	42.3	111.0	101.0
5c			69.0		74.8					
6b	108		80.0	110	63.5	63.5	38.6		122.0	111.0
8a	108	116	87.3	115	56.5	58.0	41.6	42.2	126.0	107.0
10a	114	114	90.6	117		72.3	44.2	41.0	111.0	101.0
10b	119	125	84.5	110	64.3	62.6	36.9	38.9	120.0	110.0
10c	112	133	90.0	112	72.7	73.0	42.0	43.3	106.0	93.0
17a	104	122	75.7	102	59.5	59.1	36.1	36.5	121.0	111.0
17b	85	109	86.5	107	60.0	60.0	40.0	42.5	115.0	102.0
13a	99	119	84.0	113	60.6	62.3	41.2	40.4	114.0	103.0
19	121	142	85.0	107	64.5	64.7	37.3	39.3	112.0	93.0
20	93	123	84.0	109	65.6		36.8	37.6	118.5	107.0
21b							37.0		120.0	114.5
W2										

Table 2.

Adult female mandible diameters (mm) and angles.

Burial Physical	Bigonial	Bicondyle	Gonial	Mandible	Ramus height		Ramus Breadth		Mandible	Mandibl
	Breadth	Breadth	Length	Length	Right	Left	Right	Left	Angle	Angle
2a	106		81.0			59.0	39.3	38.7	119.0	108
2b	85		72.2				38.9		120.0	114
2c	105		95.0					37.2	118.0	103
3b			84.0		56.6		34.3	34.8	119.0	103
3d	95		78.0				39.7		105.5	95
4a	103	114	83.0	107	64.1	64.0	40.1	41.1	110.5	101
4b	109		83.0				38.8	39.3	122.5	111
5d							39.0		112.0	
6a	103	111	90.7		60.3	60.0	45.5	44.0	113.0	104
9a	91		78.0	108	64.5	64.0	34.9	34.0	114.5	103
13b	107	136	95.0	109		68.0	38.2	39.5	111.0	103
13/1	96		79.5		57.2	60.	37.0	37.0	127.3	114
14	103	119	74.5	98	61.6	62.0	37.8	37.0	119.5	111
16	83		90.5	110	65.1		41.4	43.8	110.0	101
17c	93		81.0	98	55.5		38.1		110.0	104
18a	102	110	74.8	104	53.5	53.0	35.0	34.4	126.5	112
21a	97		83.0			55.0		38.4	117.0	104
21c	96		82.9	117			37.0	36.6	111.0	101
23a	99	120	73.8	108		53.0	35.4	34.6	129.0	113
24	88	115	79.0	97	56.7	57.0	40.6	40.8	111.0	100
25	102	122	84.0	107	70.5	71.0	39.2	39.8	111.0	97
28	92									
E1										
E2a								38.0		
W4							37.5		123.0	

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