

# Prehistoric Oceanic Biological Variation: Sigatoka, Lapita and Polynesia

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## Introduction

One of the most important issues to emerge within the field of Pacific prehistory for the period 3,500 to 2,000 BP is whether or not the Lapita phenomenon can be characterised as a bio-cultural complex, a social unit demarcated from others by distinctive linguistic, biological and material culture traits (Kirch 1988; Spriggs 1989; Terrell 1988, 1989). As pointed out by Gosden (1991), the archaeological markers of Lapita as a 'people' are few, "boiling down to distinctively decorated pottery, shell technologies which are thought to be new, and a particular pattern of coastal settlement" (Gosden 1991:261). The situation is even more tenuous if we approach the issue from a biological perspective. Conclusions derived on the basis of biochemical investigations of contemporary Pacific groups can never hope to define the Lapita 'people' unless ancient DNA technology dramatically improves and we can access extremely large and well preserved skeletal samples. The limited skeletal sample currently available and relevant to the period provides divergent opinions as to the affinities, and indeed, a definition of, the Lapita 'people' (Green 1989; Houghton 1989a; Pietruszewsky 1989a; Turner 1989).

Currently, the total number of individuals represented by Lapita-context skeletons stands at around 15, including adults and a few children. Most of these remains are poorly preserved and offer limited data sets which are often inconsistent across all burials. The application of even simple descriptive statistics to this data set might therefore result in rather meaningless statements about how homogeneous or heterogeneous the sample is, and how it compares to other Pacific populations.

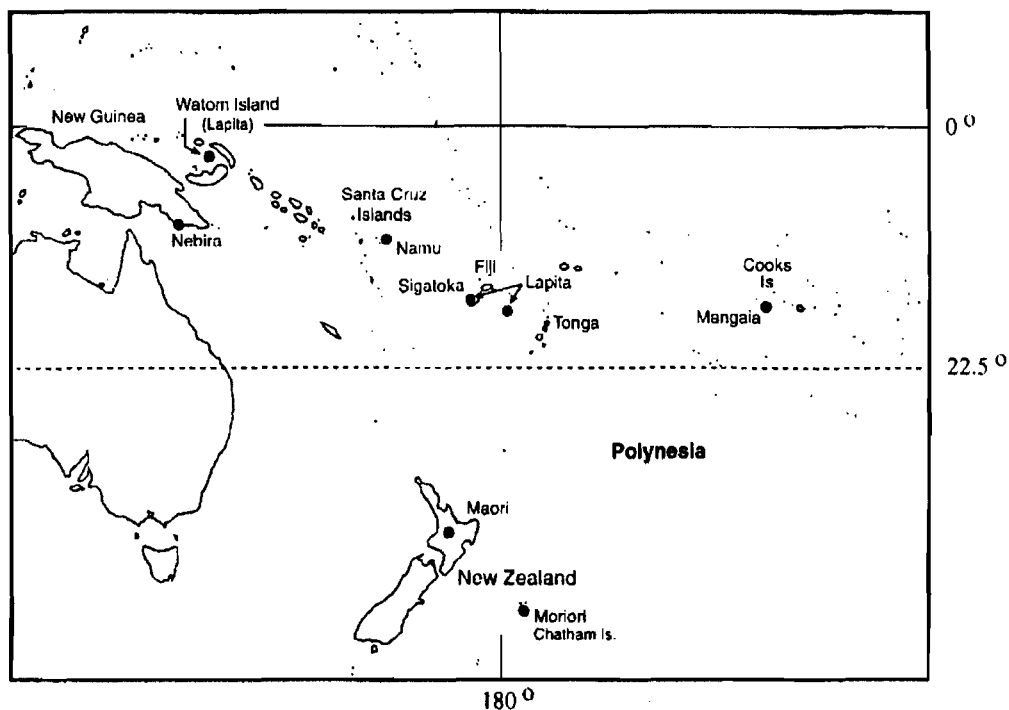


Figure 1  
Western and central Pacific regional locations  
from which the skeletal samples were derived.

It is not our intention in this paper to investigate the potential for distinctive morphometric parameters that define the Lapita “people”. In the total absence of non-Lapita-context skeletal remains from the same period, this is currently an unachievable task. Nor do we wish to comment on the ultimate biological origins of the Lapita “people” although this is also a question of intense interest among Pacific prehistorians. Rather, we are more concerned with biological process and function and what these perspectives have to offer by way of comment on the Lapita phenomenon. Consequently, although we will often refer to the Lapita sample throughout this paper, we wish to make it quite clear that we are simply referring to a sample of individual skeletal remains whose common characteristics are that they derive from clearly defined Lapita ceramic contexts and are of similar antiquity.

As mentioned earlier, there are currently no known human skeletal remains dating to the period 3,500 to 2,000 BP that are not derived from Lapita contexts. There is, however,

a large sample of skeletal remains from Sigatoka, Fiji, that is securely derived from immediate post-Lapita deposits (Best 1989). Therefore, while it might not be possible to biologically define what Lapita is or is not, it might be possible to ask “what happened to the Lapita “people” if we take a little latitude and define the ‘people’ in this case on the basis of archaeological parameters alone.

The aim of this paper is to reassess the Lapita phenomenon in the light of new approaches to the study of Pacific human biology. Before human biology can make a useful contribution to prehistoric interpretation, we must achieve as full an understanding as is possible of the underlying evolutionary, functional and developmental processes that influence the production of regional and temporal skeletal variation. Following on from this general aim, we want to address three specific objectives:

1. How do Lapita skeletons as a group compare to recent prehistoric skeletal samples derived from Near and Remote Oceania?
2. How do the Lapita and Sigatoka samples compare morphometrically with each other and with recent skeletal samples from Fiji and Tonga? What does this have to say about patterns and processes of culture history already described for Western Polynesia?
3. How does the pattern of biological variation derived from this exercise compare with the heat balance and prehistoric oceanic voyaging model developed by Houghton (1990, 1991a, 1991b, 1996)?

Houghton (1989a) has commented on the need for adequate samples from archaeologically-derived and well-dated sites. The Sigatoka sample meets these criteria, and so becomes an important comparative sample in this analysis. It is the only substantial sample that immediately postdates the Lapita period anywhere in the Pacific, and furthermore, a recent prehistoric sample from Fiji is also available which allows an assessment of the degree of local evolution and of the factors, both biological and cultural, that may influence this process.

## ■ Body Form and Mandibular Anatomy

While interpopulation differences in stature and body mass may be influenced by dietary and health differences, a number of studies have shown that body size and form is also influenced by temperature. Typically, populations living in cool climates will be shorter but will weigh more than populations from warm climates (Bergmann 1847; Allen 1877; Roberts 1953, 1978; Newman 1956).

Interestingly, within the context of Pacific Islanders, contemporary Polynesian populations from warm tropical island environments have a characteristically heavy body

mass when compared with cool climate populations, although Polynesians also retain a relatively tall stature (Pawson, 1986; Houghton, 1990, 1991a, 1991b). The heavier Polynesian body mass has been proposed as an adaptive feature to a cool tropical marine environment (Houghton, 1990, 1991a, 1991b).

The mandible is one of the best preserved skeletal elements to have been recovered from Lapita sites. The same is true of the remains excavated from Sigatoka, and it is for this reason that we have focused on this part of the skull and not the cranium. Nevertheless, mandibular dimensions provide a useful source from which head form, facial musculature and the size of the airways can be deduced, anatomical features all central to Houghton's heat balance model (Houghton 1990, 1991a).

The mandibular skeleton has long been one of the skeletal characteristics used to identify 'racial' types (e.g. Flower 1881; Scott 1895; Howells 1973a). More often than not, these studies ignore physiological and environmental variables that are now known to have a considerable influence in determining not only mandibular form, but the morphology of the entire craniofacial skeleton. To understand the factors that underlie facial development, it is important that mandibular skeletal is viewed as an ongoing process that aims to reach and maintain a state of "structural and functional equilibrium" (Enlow 1990:241). This process must be considered within a complex interrelationship between mandibular structure and physiological, genetic, and extraneous environmental factors.

The sequence of development and maturity of the cranium appears to be controlled by epigenetic regulation (Enlow 1990). This process of genetic regulation is vital in determining facial form. The cranial base develops first to support the growing brain. It is required to be structurally rigid, because the brain stem, blood vessels and cranial nerves exit through it. The brain stem and nerves are critical to survival, therefore any bony modification in the cranial base would compromise the function of these systems and consequently an individual's survival (Kean and Houghton 1982; Houghton and Kean 1987).

Differences in basicranial templates allow for variations in head form, such as dolicho-cranic or brachycranic head types. These head types establish patterns for the configuration of the basicranium that may further influence the anteroposterior placement of the maxilla relative to the mandible (Enlow 1990). This is because the positioning of the middle cranial fossa on which the mandible must articulate is dependent upon the location of the basicranium. The biological consequence is that whatever the genetic or epigenetic growth controls that lie within the mandible and ethnomaxillary components, these components must necessarily conform to a higher level of predetermination, such as brain location and positioning (Houghton and Kean 1987).

Changes in nasal height and the concurrent expansion of the airway passage occur in response to increases in oxygen demands made by the development of greater muscle

mass during the growth phases. These changes influence the positioning of the maxillary dentition (Miyashita and Takahashi 1971; O'Higgins and Dryden 1992). Consequently, an equal developmental change in the position of the mandible is required to maintain functional effectiveness of the masticatory system (Zingesser 1989; Varrela 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 ramus height (Kean and Houghton 1982; Houghton and Kean 1987). The development of the pharynx and broadening of the middle cranial fossa necessitates changes in the mandible, whereby the bigonial and bicondylar diameters of the mandible increase and the ramus increases its length and breadth. To accommodate these changes, the gonial angle must alter towards a more acute angle to prevent malocclusion. However, the biological basis of these changes is not well understood and appears to differ between head types (Enlow 1990).

Clinical studies of foetal growth have demonstrated that the development of the gonial region is under genetic control (Enlow 1990). However, during postnatal life the morphogenesis and maintenance of shape are determined by mechanical influences, primarily by the masseter and medial pterygoid muscles that attach in this region at the gonial angle (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 in an increased ramus breadth and height, where the muscles associated with moving the mandible attach. This view seems to be heavily dependent on singular functional activity, however, and the forces shaping the gonial angle are likely to be more complex. Variation in the gonial angle is not always correlated with the cranial base angle and masticatory musculature. Changes in the occlusal surface of teeth and tooth loss have also been shown to cause a reduction in the acuteness of the gonial angle (Fishman 1976; Zingesser 1989).

The biomechanical disadvantage of an acute gonial angle may be alleviated by increasing bicondylar breadth. This can be achieved in individuals with larger mandibles by increasing the size of the masticatory 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 Maori (Houghton 1978).

Finally, the dimensions of the ramus are partially influenced by mechanical demands imposed by the masticatory muscles (Kiliaridis 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 demon-

Sample	N	Date
Lapita	7	800 -100 BC
Watom	4	500-100 BC
Lakeba	1	800 BC
Natunuku	1	100 BC
Tongatapu	1	800 BC
Sigatoka	17	<i>circa</i> 180 AD
Namu	15	<i>circa</i> 1600 AD
Nebira	11	<i>circa</i> 1600 AD
Tonga	17	<i>circa</i> 1600 AD
Mangaia	13	recent prehistoric
Maori	12	recent prehistoric
Mori	13	recent prehistoric
Fiji	5	recent prehistoric

■ Table 1  
Summary information on the Pacific skeletal samples used in the present study

trated that the removal of any of the muscles associated with moving the mandible precipitates changes in its size and shape (Avis 1959; McNamara 1980; Washburn 1947).

All of this is to say that there is a very close functional relationship between head form in general and the physiological demands of different body forms. The nature of the particular relationship between mandibular shape and body size and shape is elaborated by Houghton (1990, 1991a, 1991b), and is central to the interpretation of our results.

## *Materials*

Twelve samples spanning a reasonably broad sweep of the western and central Pacific are included in the present study (Fig. 1; Table 1). The process of sample selection and inclusion became a tradeoff between the need to sample as much of Near and Remote Oceania as was possible, while including as many biological variables as possible that would be relevant to an assessment of Houghton's heat-balance model. Given the paucity of well-provenanced Pacific skeletal collections which contain anatomically-related cranial and postcranial remains, our choices became quite limited.

Each of the skeletal samples included in the present study is described below. The Lapita sample is a composite derived from remains excavated in both Near (Watom) and Remote Oceania (Lakeba, Natunuku and Tonga). Unless otherwise stated, all of the data recorded from the remains comprising these samples were recorded by one of us (EV). Only adult male data has been included here, for the simple reason that males are much better represented and in larger numbers than are females.

### *Watom Island, New Britain*

The incomplete skeletal remains of eight individuals were recovered from site SAC, Watom Island (New Britain) in 1966 and 1985 (Green et al. 1989). The remains were excavated from within securely identified Lapita cultural deposits (Green et al. 1989; Specht 1968) and have been dated to between 2100 and 2500 BP (Green and Anson 1987). The material has previously been described by Houghton (1989a) and Pietrusewsky (1989a). The data used in the present study include observations from Burials 3, 4, 5 and 6.

### *Lakeba, Fiji*

Fragmentary remains of at least two and possibly three individuals dating to the Lapita period were excavated by Best (1977, 1984) from Lakeba in the Lau Islands, Fiji, and described by Houghton (1989b). The Lakeba data used in the present study is derived from casts of the primary inhumation remains excavated from the surface of the cemented grey to orange sand in Trench 28 of site 196 (Best 1984:100). The site from which the skeletal material was recovered is firmly associated with Lapita pottery.

### *Natunuku, Fiji*

The skeletal remains of a single adult male were excavated at Natunuku (VL1/1), on Viti Levu, Fiji (Green 1979). The remains have been described by Pietrusewsky (1985a, 1985b, 1989b). The site contains Lapita pottery in the lower levels (Layers 5 and 6); the remains were excavated from a shallow grave in Layer 5. Originally thought to have dated to between 2100 and 2500 BP (Pietrusewsky 1989b), the age of the burial has recently been revised to circa 2100 BP (Davidson et al. 1990). It is not clear if the skeletal remains are associated with the Lapita culture or a later phase. For the purposes of the present paper, the remains have been included here with other Lapita associated skeletons. The data used here is that presented by Pietrusewsky (1985b).

## *Tongatapu, Tonga*

Skeletal remains representing two individuals were excavated by Poulsen (1987) in association with Lapita pottery at the Pea site (To.1., Tongatapu). These remains have been described by Spennemann (1987), Taylor (1987), and Houghton (1989c). The data included in the present study derive from the main burial alone. Again, these remains were found in firm association with Lapita artefacts.

## *Sigatoka, Fiji*

The Sigatoka dune site is located on the western edge of the Sigatoka river mouth, on the southwest coast of Viti Levu, Fiji. It lies between a low series of foredunes and a major dune system. The foredunes have been subsequently lost by erosion. It is not known when the major dune system first formed, but dune formation continued after first settlement in the area (Best 1989).

The site was excavated in the early 1970s by the Birks (Birks 1973). They recorded three extensive occupation surfaces, but found no human skeletal remains. It was not until over a decade later that the first human remains were recovered approximately 200 meters west of the original occupation site. Nevertheless, the stratigraphy of the burial site was consistent with that described by the Birks.

There are three phases of occupation at the site (Birks 1973). The earliest phase has been dated to 2510±90 BP. Pottery recovered from this level is decorated primarily with notched rims, although some sherds are dentate stamped. These decorative patterns are similar to those observed on Lapita pots from Watom, Tonga and Fiji, although the Sigatoka manufacturing technique is similar to that of red slip pottery recovered from sites on the PNG coast.

Level two has been dated at 1748-1820 BP. Pottery manufacturing techniques and styles differ from those in Level One. Pottery was made using symmetric incising and rim cord decorations. Finger pinching and finger gouging were also used rather than dentate stamping. These changes occurred simultaneously throughout Fiji at this time and are contemporary with pottery change in central Vanuatu (Best 1984). Significantly, obsidian recovered from Lakeba and sourced to northern Vanuatu has been dated to the same period (Best 1984).

A third, undated but more recent level containing fragmented pottery was also identified by the Birks. The pots were undecorated, and the manufacturing technique, a paddle and anvil method, also differed from those of the two earlier levels.



During 1987 and 1988, 63 skeletons were excavated at Sigatoka. These skeletons have been dated to  $1820 \pm 90$  BP, a date contemporary with the Birks' Level Two (Best, 1989; Visser 1994a). The skeletons were buried facing east within a discrete, bounded burial ground.

### *Nebira, Papua New Guinea*

This skeletal population was excavated from the Port Moresby region in Papua New Guinea between 1968 and 1969 (Bulmer 1979). A total of 37 individuals are represented in the collection. The site has been dated to between  $149 \pm 270$  BP and  $760 \pm 80$  BP and (Bulmer 1978 :134), and red slip pottery has been found in association with the burials. The skeletal material has previously been described by Pietrusewsky (1976). Unfortunately, the cranial and postcranial skeletal elements recovered from this site could not be reassociated, and so the mandibular data and the body size data used in the present study must remain as separate data sets.

### *Fiji*

The data comprising this sample is derived from Weber's (1934) published descriptions of skeletal remains which, although locally unprovenanced and undated, are thought to have derived from Fiji's late prehistoric period. The remains were stored in the Museum für Völkerkunde, Leipzig until 1943 when it was destroyed in a war-time bombing raid (Pietrusewsky 1986).

### *Namu, Taumako*

Although Taumako (immediately NE of the Santa Cruz Islands) lies west of the traditional boundary separating Melanesia and Polynesia, its status as one of the Polynesian Outliers (Davidson 1970, 1974; Bayard 1976) allows for an interesting twist to the comparative assessment of 'Polynesian vs Melanesian' human biology. A burial ground at Namu on Taumako, excavated in 1977 and 1978 by Foss Leach and Janet Davidson, dates to between 302 and 470 BP (Whitehead et al. 1986). Over 160 skeletons were recovered from the site, and these have been examined and described by Houghton (1996, n.d.). A selection of these burials was recorded by EV and the data incorporated in the present study.

### *Mangaia, Cook Islands*

The data used to represent this sample were recorded in the field by Nancy Tayles (Dept. of Anatomy and Structural Biology, University of Otago) in 1991 from skeletal remains excavated by Kazumichi Katayama (Dept. of Physical Anthropology, Kyoto University) in the vicinity of Vairorongo, Mangaia. The remains are currently undated but are thought to derive from the late prehistoric to early protohistoric period (Tayles pers. comm. 1996).

### *Tonga*

Davidson (1969) excavated the skeletal remains of 99 incomplete individuals from two burial mounds at Atele on Tongatapu. The remains were subsequently described by Pietruszewsky (1969). Bone material was used to date the remains to post-1350 BP, although this date probably seriously over-estimates the age of the burials (Davidson 1969).

### *Maori, New Zealand*

The Maori data used in the present study was partially obtained from the database compiled by Philip Houghton (Department of Anatomy and Structural Biology, University of Otago). This applies to mass and stature. The rest of the data was recorded directly by EV. This skeletal material comprising the database is undated, but is generally thought to derive from late prehistoric contexts and includes locations from both the North and South Islands.

### *Moriori, Chatham Islands*

The data presented for this sample is derived from sources as already described for the Maori sample. Again, although undated, this material is generally thought to be derived from late prehistoric contexts.

### *Methods*

Six metric variables are used in the present study. Four are mandibular measurements (ramus height and minimum ramus breadth, bigonial breadth and gonial angle) recor-

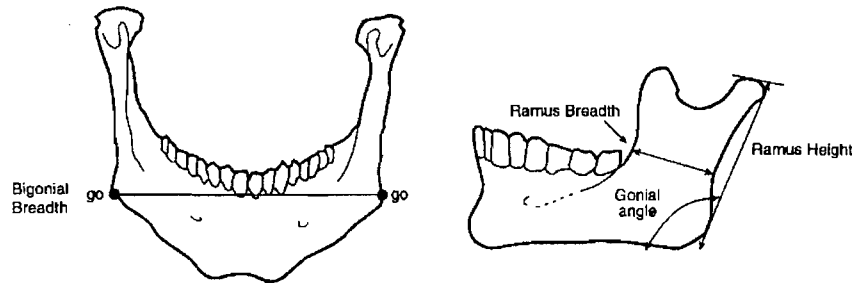


Figure 2  
Illustration of the mandibular measurements.

ded directly from the skeletal remains, and two are estimates of body size (stature and mass) that were calculated using a variety of postcranial measurements not presented here.

The mandibular measurements are defined below and illustrated in Fig. 2.

1. ramus height: direct distance from the highest point on the mandibular condyle to gonion (Buikstra and Ubelaker 1994:72, 78)
2. min. ramus breadth: least breadth of the mandibular ramus measured perpendicular to the height of the ramus (Buikstra and Ubelaker 1994:78)
3. bigonial breadth: direct distance between right and left gonion (Buikstra and Ubelaker 1994:72, 78)
4. gonial angle: angle formed by the inferior border of the corpus and the posterior border of the ramus (Buikstra and Ubelaker 1994:78)

Whenever maximum long-bone length data was available, stature estimates were calculated using the regression equations specifically developed for Polynesians by Houghton *et al.* (1975). Similarly, long-bone breadth data recorded at the ankle, knee, wrist and elbow were used to calculate mass estimates using a modification of the regression equations of Houghton *et al.* (n.d.).

The data were analysed in three stages using a variety of univariate and multivariate statistical procedures. First, all six measurements were assessed for statistically significant patterns of regional variation using standard one-way anovas (analysis of variance tests). F-ratios estimating the degree of within-group to between-group variation were calculated, along with their probability estimates. Equality of variance within each of the anova models was tested using the Levene statistic, and post-hoc multiple comparisons tests using the Scheffé statistic allowed for the assessment of significant differences between regional pairs.

The second stage of the analysis was to produce simple plots contrasting patterns of regional variation across two or more biologically-related variables. Following this protocol, a bivariate plot of stature vs. mass was created, as well as a three-dimensional plot of the three most important mandibular variables (gonial angle, bigonial breadth and ramus breadth). These plots were then assessed for any structure in their patterns of regional variation.

Lastly, the data was analysed in two separate discriminant function analyses, one using all six variables and the other using a variable subset designed to maximise the size of the Lapita sample.

The major purpose of discriminant analysis is to predict group membership on the basis of a variety of predictor variables (Tabachnick and Fidell 1983). The mathematical foundation of this procedure is now well established (Goldstein and Dillon 1978; Lachenbruch and Goldstein 1979). The objective is to weight and linearly combine a series of discriminating variables such that intercorrelation of the variables is considered and the ratio of between-group variance to total variance is maximised. Depending on the number of discriminating variables used or the number of groups under consideration (whichever is the greater), a finite series of orthogonal functions is derived which maximise group separation. The first function is computed so as to account for the majority of variation among the groups. The remaining functions account for the residual variation in a sequentially decreasing order of contribution.

Multivariate statistical techniques allow individuals within a sample to be treated as complete morphological units where the interrelationship between variables is taken into account (Howells 1969). When this observation is combined with the fact that discriminant function analysis allows for the identification of those variables which contribute most to the discriminatory power of the derived functions, it becomes possible to comment on the particular suite of morphological features which contributes most to the pattern of group variation.

Multivariate analysis assumes certain characteristics in the data which, if not satisfied, may have adverse effects when formal significance tests are used to indicate a probability level of the hypothesised group differences (Corruccini 1975; Campbell 1978; Lachenbruch and Goldstein 1979; Tabachnick and Fidell 1983:299-301). Briefly, multivariate techniques must be supplied with meaningful data, large sample-sizes for all groups, complete data for all cases, normally distributed variables, and homogeneity of the covariance matrices.

When dealing with archaeologically-derived human skeletal remains, adequate sampling is always going to be a problem. Basically, we have to deal with what we have. With regard to multivariate normality and variance homogeneity assumptions, Campbell (1978) and Mardia (1971) believe that violation of the latter will have a more detrimental effect than the former. Unfortunately, tests of variance homogeneity are

notoriously sensitive, almost always reject the hypothesis (Cooley and Lohnes 1971), and are of little help in determining when departures from the assumption are damaging (Olson 1974). In the present study, Box's M. (Box 1949) has been used to test for homogeneity of the covariance matrices. Following Tabachnick and Fidell (1983:233), when sample sizes are unequal and Box's M. rejects the homogeneity assumption at  $\leq 0.01$ , the results are cautiously interpreted.

There is a diverse range of ideas prevalent in the biological literature concerning the proper use of multivariate statistics. Criticisms of the applicability of multivariate analysis to morphometrics, based on a slavish adherence to the strict requirements of statistical theory, ignore its equally valid use as a data-analytic procedure designed to ordinate and efficiently describe multivariate observations (Albrecht 1980). This is not to imply that we can completely do away with the need to satisfy underlying assumptions and ignore the statistical significance of the results of any multivariate procedure. In much of statistics, however, the basic problem is making some kind of sense of the numbers, and hypothesis testing may or may not play an integral part in doing this (Campbell 1978). In essence, it becomes a matter of balancing the need for correct application of the multivariate model with a desire to explore the data for structure and meaning. As Robinson (1967) so eloquently says, "the statistical techniques do not

Variable	Nebira			Namu			Fiji L			apita			Sigatoka			Tonga		
	n	mn	sd	n	mn	sd	n	mn	sd	n	mn	sd	n	mn	sd	n	mn	sd
ramus height	11	56.2	3.14	7	66.0	4.77	5	62.8	1.92	4	62.7	4.41	15	65.3	5.00	13	61.9	6.91
ramus breadth	11	32.5	3.74	9	33.6	4.00	5	35.8	2.68	6	39.8	6.09	17	40.9	2.92	13	37.5	3.57
bigonial breadth	6	98.5	6.00	9	95.7	4.76	5	98.0	3.61	6	103.7	4.23	14	107.5	10.3	12	100.8	8.91
gonial angle	10	121.9	3.40	13	114.5	6.72	5	120.1	3.68	2	105.0	17.0	17	116.9	5.30	12	109.1	4.60
stature	8	1659	32.8	8	1770	34.5	5	1692	50.5	7	1736	35.5	12	1739	30.4	10	1723	35.0
mass	7	69.1	3.55	8	75.1	3.99	5	63.9	6.50	5	72.5	6.74	10	70.0	6.97	5	77.6	2.74

Variable	Mangaia			Maori			Moriiori		
	n	mn	sd	n	mn	sd	n	mn	sd
ramus height	10	62.0	4.08	12	61.9	4.78	12	68.8	7.22
ramus breadth	10	35.7	2.75	12	37.9	2.61	13	36.7	2.72
bigonial breadth	10	102.97	6.7	12	106.1	6.88	13	106.5	8.55
gonial angle	0	—	—	12	114.9	6.13	13	115.0	6.44
stature	12	1729	46.3	12	1702	28.9	7	1687	16.1
mass	0	—	—	12	71.1	3.41	7	73.5	5.51

Table 2  
Descriptive statistics for the Pacific regional samples. All length measurements recorded in mm, angles in degrees, mass in kg.

themselves have biological judgment and are no substitute for biological insight" (cited in Corruccini 1975:1). All statistical analyses were performed using SPSS v. 6.1 for the Macintosh.

## Results

Descriptive statistics including sample sizes, means and standard deviations for all six variables for each of the nine Pacific regional samples is provided in Table 2. Clearly, there are problems in the total data set, with incomplete records for some individuals and extremely small sample sizes in many instances.

The anova results are presented in Table 3. All six variables show significant F values at  $\leq .01$ , while a lack of significance in any of the Levene's test results indicates equivalent degrees of variance across the samples for each variable.

The multiple comparisons results (Table 3) indicate that for ramus height, Nebira has a significantly ( $\leq .05$ ) lower mean value (56.2) than the Sigatoka (65.3) or Moriori (68.8) samples. The ramus breadth results show Nebira and Namu at the lower end of the scale, significantly different from the Lapita and Sigatoka samples. The gonial angle analysis excludes the Lapita sample due to its small size (2 cases), and indicates a signi-

ramus height	4.938**	1.276	Nebira	Sigatoka, Moriori
ramus breadth	7.240***	1.967	Nebira	Lapita, Sigatoka
			Namu	Sigatoka
bigonial breadth	2.816**	1.912		
gonial angle	5.843***	1.542	Tonga	Nebira, Fiji, Sigatoka (ex Lapita & Mangaia)
stature	7.237***	1.561	Nebira	Namu, Lapita, Sigatoka, Mangaia
			Namu	Maori, Moriori
mass	3.717**	1.020	Fiji	Tonga (ex Mangaia)

\* p < .05  
 \*\* p < .01  
 \*\*\* p < .001

Table 3  
 F. levene's multiple comparisons.

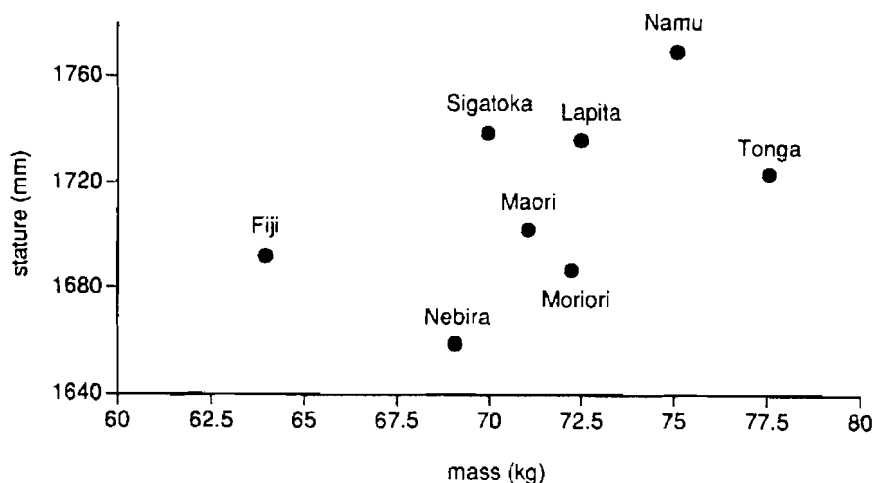


Figure 3  
Plot of stature versus mass using regional mean values for selected Pacific samples.

ficant difference between the closed angle described for Tonga (109°) versus the more open angles of Nebira (122°), Fiji (120°) and Sigatoka (117°). Although bigonial breadth shows a significant F ratio, indicating variation across all of the regional means, no two regional pairs were significant at  $\leq 0.05$ .

The multiple comparisons test results for stature (Table 3) clearly separates the low mean value for Nebira from Namu, Lapita, Sigatoka and Mangaia. Interestingly, Namu is also significantly taller than the Maori and Moriori samples. Tonga and Fiji are the only two samples to show significant differences in mass.

Summarising the anova results, all variables show significant mean differences across the total range of Pacific samples used in this study. With regard to the pattern of significant pairwise regional differences, people from Nebira in the west are differentiated by their smaller ramus values, open gonial angles and

lower statures, while the Sigatoka people in the east possess mandibular rami of greater height and breadth in conjunction with more acute gonial angles and taller statures.

A bivariate plot of stature versus mass using the regional means (Fig. 3) reveals a general west to east trend of increasing body size. Essentially, as stature increases, so does mass. Namu is identified as a geographic outlier in terms of this west to east trend, and Tonga occupies a somewhat intermediate position, combining medium stature with greatest mass. The Maori and Moriori occupy approximate positions within the plot, as do Lapita and Sigatoka. Of note is the degree of divergence in body size between the recent prehistoric Fijians and Sigatoka.

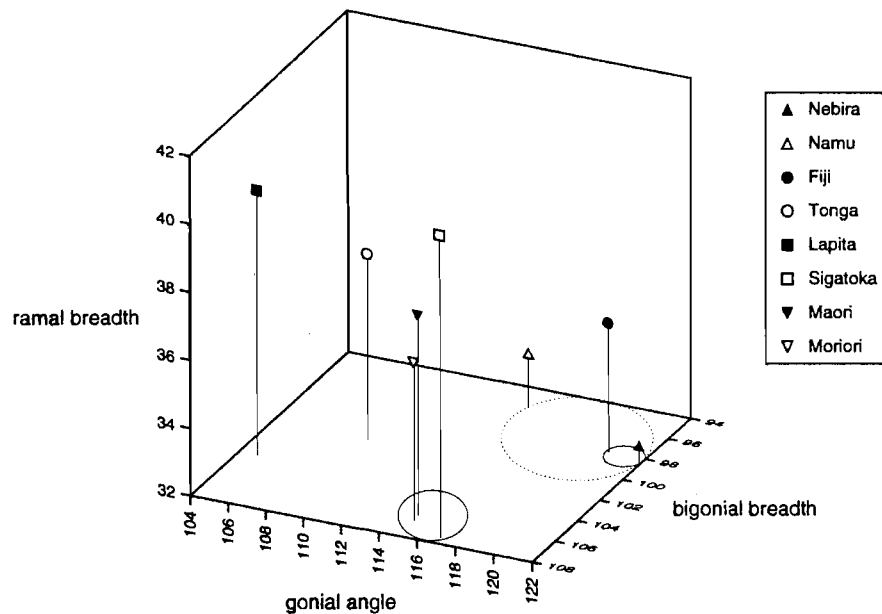


Figure 4  
Three dimensional plot of gonial angle, bigonial breadth and ramus breadth using regional mean values for selected Pacific samples.

A three dimensional plot of the three most important mandibular variable means - gonial angle, bigonial breadth and ramus breadth - is given in Figure. 4. These three variables were selected according to aspects of their developmental and functional anatomy, as described earlier in this paper. Of the four mandibular variables used here, gonial angle is argued to be the most important owing to its close functional relationship with the cranial base angle. Bigonial breadth is argued to be the next most important variable, owing to its developmental relationship with the middle cranial fossa and its mechanical relationship with the gonial angle. Ramus breadth reflects the degree of masticatory musculature and is itself influenced by gonial angle and bigonial breadth.

Of the three planes represented in Fig. 4, the XY plane (gonial angle versus bigonial breadth) is therefore identified as being the most biologically significant. This plane has been used to form the basis of an assessment of geographical patterns of regional variation. Nebira and Fiji cluster tightly together, although these two samples also form a loose association with Namu to create a cluster identified by their open gonial angles and reduced bigonial and ramus breadths. The Sigatoka, Maori and Moriori samples combine to form a second tight cluster, characterised by intermediate gonial angles and



Function	Canonical Eigenvalue	Wilk's % of variance	Correlation	Lambda	chi <sup>2</sup>	p
1	2.5487	60.6	.8475	.0781	82.87	.0000
2	.9686	23.03	.7014	.2771	41.71	.0193
3	.4072	9.68	.5379	.5456	19.70	.2344
4	.1711	4.07	.3823	.7677	8.60	.4758
5	.0835	1.99	.2777	.8991	3.46	.4844
6	.0265	0.63	.1606	.9742	0.850	.3566

Table 4  
Summary statistics for the performance of the discriminant functions produced by a direct entry analysis of all six variables.

ramus breadths and greater bigonial breadths. Tonga stands apart from this latter cluster, mainly by virtue of its lower gonial angle and bigonial breadth, and the Lapita sample is isolated due to its comparatively low gonial angle. It is important to note here that the Lapita sample for gonial angle consists of only two cases and has a standard deviation almost three times the value recorded for the other samples.

The first of the discriminant function analyses was designed to investigate patterns of regional variation using all six variables. Unfortunately, a direct entry discriminant analysis meant that Mangaia and Nebira had to be omitted, owing to the fact that gonial angle and mass were not recorded for Mangaia, and the Nebira mandibular data could not be directly associated with the stature and mass estimates for each individual. The omission of Nebira means that there are no Near Oceanian samples available for comparison.

The lack of complete data sets for many of the individuals used in the present study means that regional sample sizes for this discriminant analysis are severely reduced in most cases (Namu 6; Fiji 5; Lapita 2; Sigatoka 8; Tonga 3; Maori 12; Moriori 4). Furthermore, the number of variables used in the analysis (six) is equal to or exceeds the number of cases in all but two samples, rendering the majority of group covariance matrices singular and so preventing their inclusion within Box's M. test.

Summary statistics for the six discriminant functions resulting from the procedure are given in Table 4.

The first two functions are both significant ( $\leq .05$ ) when assessed using Wilk's lambda, and together account for 83.6 % of the total variance. An interpretation of the variables contributing most to the patterns of group separation for these functions (Table 5) is based on an examination of the across-groups correlation coefficients between the dis-

Variable	Function 1	Function 2					
ramus height			.0485			.3644*	
ramus breadth			.9406***		.0566		
bigonial breadth		.4901***		-.0591			
gonial angle			-.2755			-.4989**	
stature				-.2072			.7462***
mass				-.1781			.5703***

\* p < .05  
 \*\* p < .01  
 \*\*\* p < .001

Table 5

Across-groups correlations between discriminating variables and discriminant functions 1 and 2, direct entry analysis using all six variables.

criminating variables and the discriminant functions themselves, following Howells (1972, 1973b) and Corruccini (1984). The variables most highly correlated with function 1 are ramus breadth and bigonial breadth (both positive). Individual cases or group centroids (multivariate means) scoring positively on function 1 therefore possess mandibles of greater ramus and bigonial breadth. Function 2 correlates positively with stature and mass, and negatively with gonial angle. The two functions are therefore best described as a mandibular function (1) and a body size function (2).

A plot of the group centroid scores on functions 1 and 2 is given in Fig. 5. An obvious feature of this plot is that all but one of the group centroids falls along a line of increasing ramus and bigonial breadth correlated with increasing body size but decreasing gonial angle. Fiji is characterised by its small body size and mandibular breadths in association with a more open gonial angle. In contrast, Lapita is characterised by its greater body size and larger mandibular dimensions, but a more acute gonial angle.

The regional sample distribution illustrated in Figure 5 may be described as approximating a west to east geographic arrangement. Namu, however, is distinguished by virtue of its narrow mandibular breadths in association with larger body size. The Maori and Moriori samples occupy almost identical positions within the distribution. As was observed in the three dimensional mandibular plot (Fig. 4), the recent Fijian sample is well separated from Sigatoka, and the Lapita sample occupies a somewhat isolated position. It is important to note that in the discriminant analysis results just described, both Tonga and Lapita are represented by very small sample sizes (three and two respectively). In an attempt to increase the size of the Lapita sample, a second discriminant analysis was performed using a reduced number of variables, selected in such a way so as to maximise the number of Lapita individuals with a full data set. In this analysis, the variables

Function	Eigenvalue	% of Variance	Correlation	Lambda	chi <sup>2</sup>	p
1	1.1198	72.5	.7268	.3236	63.74	.0000
2	.3212	20.8	.4931	.6860	21.29	.0463
3	.1033	6.7	.3060	.9064	5.55	.3520

Table 6

Summary statistics for the performance of the discriminant functions produced by a direct entry analysis using ramus breadth, bigonial breadth and stature.

indicated as being the most important contributors to variation on the basis of the previous analysis - ramus breadth, bigonial breadth and stature - were used. This variable reduction procedure also means that Mangaia can now be included in the analysis. Summary statistics for the three discriminant functions resulting from this second analysis are given in Table 6. The first two functions are both significant ( $\leq .05$ ) when assessed using Wilk's lambda (function 2 only marginally so), and together these two functions account for 93.3 % of the total variance. A reduction in the number of variables included in the analysis means that group sample sizes have increased. All of the group covariance matrices are now non-singular, permitting the calculation of Box's M. (64.58). This value is not significant ( $p = .1906$ ) and indicates homogeneity of the covariance matrices. The across-groups correlation results (Table 7) indicate that all three variables contribute significantly to the pattern of group separation on function 1 (ramus breadth and bigonial breadth positively, stature negatively), while stature and ramus breadth correlate significantly with function 2 (both positively, stature more so than ramus breadth). The two functions are again best described as a mandibular function (1) and a body-size function (2).

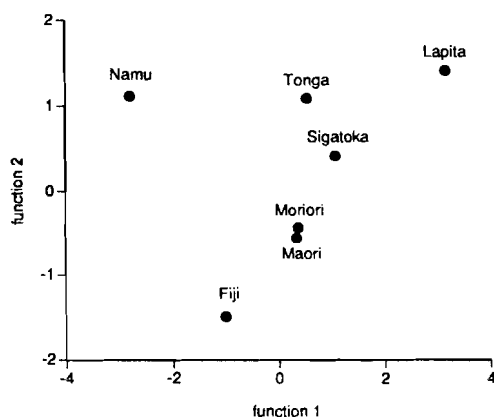


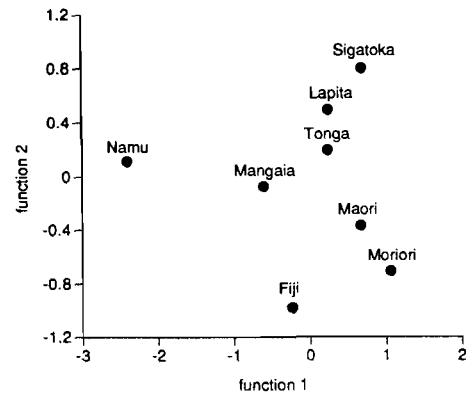
Figure 5

Plot of regional group centroids on the first two discriminant functions, direct entry analysis using six variables.

Variable	Function 1	Function 2
ramus breadth	.7564***	.5324***
bigonial breadth	.5872***	.1737
stature	-.5214***	.8056***

\* p < .05  
 \*\* p < .01  
 \*\*\* p < .001

**Table 7**  
 Across-groups correlations between discriminating variables and discriminant functions 1 and 2, direct entry analysis using ramus breadth, bigonial breadth and stature.



**Figure 6**  
 Plot of regional group centroids on the first two discriminant functions, direct entry analysis using ramus breadth, bigonial breadth and stature.

A plot of the group centroid scores on functions 1 and 2 for this second analysis is given in Figure 6. The clear trend of increasing body size correlated with increasing mandibular breadths identified in the previous analysis (Fig. 5) is missing here, although the omission of mass and gonial angle will have undoubtedly influenced this result. Namu continues to be isolated from the other samples. The Maori and Moriori samples again occupy very similar positions within the distribution, but appear to be separated from Tonga and Mangaia. Fiji and Sigatoka remain quite separate from each other. Lapita, however, no longer stands out as an outlier and appears to cluster with Sigatoka and Tonga. In general, the overall distribution of these Pacific samples appears to reflect their geographic relationships rather neatly, especially with regard to longitude.

## Discussion

Houghton's heat-balance model (1990, 1991a, 1991b, 1996) is now well established in the biological literature dealing with the Pacific and will not be reviewed in detail here. The model is essentially based on the observation that increases in body size in cold climate populations are accompanied by changes in anatomy and physiology which are

focused on the need to maintain greater body mass while reducing surface area. This adaptation results in an improved ability to maintain core body temperature in a cold and/or wet environment. If we accept that the tropical oceanic environment is cold and wet with the potential for high windchill factors (Houghton 1990, 1991a), then the seemingly misplaced tall and muscular Polynesian physique is explained as a successful adaptation to long distance voyaging across a selectively hostile environment. This is in contrast to the short and comparatively slender people of tropical environments further west whose maritime experiences are restricted to the coastal margin (Houghton 1991b).

Larger bodies have greater oxygen demands. In many large-bodied, cold-climate populations, the maintenance of an adequate oxygen supply is facilitated by an enlargement of the airway passages. There is evidence that one of the craniofacial correlates of an increase in respiratory airway size is an increase in the cranial base angle (Kean and Houghton 1982; Houghton and Kean 1987). Returning to the developmental and anatomical considerations discussed earlier in this paper, the cranial base angle acts as a template upon which the form of the entire facial skeleton depends. People with large cranial base angles and large airways consequently tend to have greater upper facial heights, reduced degrees of alveolar prognathism and a mandibular morphology which combines a taller and broader ramus, greater bigonial breadth, a more acute gonial angle, and the absence of an antegonial notch (rocker jaw) (Houghton 1978). In fact, all of these features describe the exact craniofacial anatomy of most recent Polynesians.

Our results show that most of the post-400 BP and recent prehistoric Polynesian samples match the body size and mandibular characteristics just described - tall, heavy, bigonially wide with broad mandibular rami and closed gonial angles. This is certainly the case for Tonga, Mangaia, Maori and Moriori, especially when these samples are compared with Nebira, the only Near Oceanian sample available to us. In this respect, the Polynesian morphological pattern identified on the basis of these results is consistent with the body form described by Houghton.

The morphological similarity of the Maori and Moriori samples identified here is not surprising, given their close geographic and temporal relationship. What is interesting, however, is the fact that in the two discriminant analyses described earlier, these two temperate Polynesian samples are slightly separated from their tropical Polynesian counterparts. The Maori and Moriori stature estimates are amongst the lowest of the samples presented here, but their mass estimates fall within the middle of the total range (Table 2). Following Bergmann's rule, this squat body form is to be expected in populations inhabiting a cooler climate.

Taumako, on which Namu is located, is classed as a Polynesian Outlier, one of the islands lying within Melanesia or Micronesia whose population speaks a Polynesian language and who shows other Polynesian affinities. Despite this label, Outlier populations also share a variety of archaeological, biological and cultural similarities with their

Melanesian and Micronesian neighbours (Irwin 1992:183). It is not surprising, therefore, that the Namu sample lies in a somewhat isolated position in the mixed variable discriminant analyses, quite separate from the Polynesians. When body size alone is considered (Fig. 3), Namu is isolated by its much greater mean stature, although mass estimates place it within a general Polynesian range. Namu also occupies a somewhat marginal position in the three dimensional mandibular plot (Fig. 4), although in this case it appears to form a loose association with Nebira and Fiji. Namu's inconsistent behaviour throughout the variety of analyses presented here may well be a reflection of its Outlier status, and may indicate an initial Polynesian phenotype overlaid by later 'Melanesian' contacts.

The recent prehistoric Fijian sample tends to occupy a fringe position in relation to most of the other samples (Figs. 3, 4, 5 and 6). It is distinguished by its comparatively small body size in conjunction with narrow bigonial breadth and a more open gonial angle. In these respects it is distinctly non-Polynesian, although it approaches the Maori and Moriori stature averages, a feature noted by Houghton on the basis of anthropometric data (Houghton 1991a:52, Table 1). Also of interest in this respect is the repeated observation of morphological dissimilarity between the recent Fijian sample and Sigatoka, both samples deriving from the same island but separated in time by at least 1,500 years.

These observations concerning the distinctive nature of the recent Fijian sample may be explained in one of three ways: a considerable degree of localised evolution over the last 1,500 years has occurred within Fiji (either by selection or drift); there was substantial gene flow into Fiji from non-Polynesian sources after 1820 BP; or there was a combination of both local evolutionary factors and gene flow. While some aspects of the recent Fijian phenotype may have been influenced by localised selection pressures not experienced elsewhere in the central Pacific, it is unlikely that these would have been sufficient to alter body form to the extent that differentiates Fiji and Sigatoka in the present study, especially with regard to the mandible. Furthermore, there is botanical (Lebot 1991; Visser 1994b), archaeological (Green 1963a, 1963b; Frost 1979; Hunt 1980, 1987) and biological (Gabel 1958; Ward 1967; Pietruszewsky 1984, 1990, 1994; Serjeantson 1989; Kirk 1989) evidence supporting the idea of Fijian admixture with populations from the west, probably from Vanuatu. It would appear, therefore, that gene flow is the likely source of the morphological changes within Fiji identified here.

We will now turn our focus to the Lapita and Sigatoka samples. The statistical data presented in Tables 2 and 3 indicate that although the Lapita sample comprises individuals from a number of sites scattered across Near and Remote Oceania, there are no significant differences in mean values between it and the more recent Polynesian samples for any of the variables used in this study. The same is true for the Sigatoka people. The morphological pattern identified for these two samples on the basis of the regional distribution presented in Figure. 6 clearly locates them within a general suite of Polynesian samples, characterised by large body size and large, broad mandibles with

closed gonial angles. This morphological pattern is quite different from the one described here for Nebira and other, more recent Near Oceanian populations (Houghton, 1990, 1991a).

More importantly, the Sigatoka, Lapita and recent prehistoric Tongan groups form a distinct morphological cluster within this general Polynesian distribution (Fig. 6). Despite the fact that these groups span more than 2,500 years and over 3,000 km of ocean, they show a degree of morphological similarity that approximates the level identified for the Maori and Moriori, who share a much closer geographical and temporal relationship.

One way of explaining this ancestrally widespread but locally longstanding morphological pattern is with reference to the archaeological record. The original 'Lapita' colonisers of the western and central Pacific appear to have possessed a phenotype which was already well adapted to long distance voyaging through an often cold and wet oceanic environment. They were tall and heavy, with a distinctive craniofacial form that was reflected in their mandibular morphology. Based on the ceramic evidence, these 'people' were settled in Fiji, Tonga and Samoa by 3,000 BP (Kirch and Weisler 1994:291). The morphological similarities described here between Sigatoka and Tonga suggests the maintenance of a close biological affiliation between the two island groups during the early prehistory of the region, at least up to 1,800 BP. The existence of prehistoric interaction networks in West Polynesia is now well documented (Kirch and Weisler 1994:299), and it appears that, for once, the biological and archaeological data are mutually supportive.

Lastly, the clear separation of the recent Fijian and Tongan samples in the present study is explained by a possible diminution in the amount of biological contact between these two areas over the last 1,500 years, in conjunction with the evidence for gene flow into Fiji from western sources discussed earlier.

## ■ Conclusion

The following points have emerged from the preceding analyses:

1. There are both longitudinal and latitudinal clines in general body form and size across Remote Oceania, that conform to the predictions of Bergmann's and Allen's rules and Houghton's model. The 'Lapita people' possessed a body form similar to recent Polynesians, lending support to the archaeological model of Lapita people as Polynesian ancestors.
2. A similarity in body form and size exists between the temporally separate people from Tonga and the people from Sigatoka and 'Lapita'. In contrast, the recent Fijian

population is different from not only the Tongans, but also the Sigatoka and Lapita people. This distinction suggests that there was an initial close biological affinity between Tonga and Fiji (and Lapita), but this relationship began to diminish sometime after 1800 BP. Evidence of more recent Fijian contacts with people from the western Pacific is provided by the clear separation of the recent Fijian sample from Sigatoka in the first instance, and more generally from all Polynesians.

3. The skeletally based comparison of the Lapita and Sigatoka samples reveals little or no significant differences in body form or size. This is an example of biological similarities transcending material culture differences. What, then, is the biological definition of Lapita? Bio-skeletally, the Sigatoka people could simply be described as Lapita people without flashy decorated pots!

#### Acknowledgments

We would like to thank the Lounsberry Foundation for funding the archaeological excavation at Sigatoka in 1987-88.

Robbie McPhee did the artwork for Figures 1 and 2.

Helpful comments on earlier drafts were provided by members of the Otago University Functional Anatomy/Biological Anthropology Working Group, although the opinions expressed in this paper are entirely our own.

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