

## Micronesians, Asians, Thais and Relations: A Craniofacial and Odontometric Perspective

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**Abstract**—Mesial-distal and buccal-lingual dental measurements and seventeen craniofacial measurements were made on specimens from some twenty groups from China, Japan, Southeast Asia, the Philippines, Australia, Melanesia, Polynesia and Micronesia. After the craniofacial measurements had been used to construct Euclidean distance dendrograms, the samples were grouped into three relatively unrelated clusters—Mainland-Asian, Australo-Melanesian and Jōmon-Pacific. The Mainland-Asian cluster included Southeast Asian and Chinese Neolithic and modern samples plus Yayoi and modern Japanese samples. The Australo-Melanesian cluster included Australians and samples from island Melanesia. The Jōmon-Pacific cluster included the Jōmon and Ainu from Japan as well as all the Polynesian and Micronesian samples. Post-Pleistocene dental reduction started earliest and has proceeded furthest in the Jōmon-Pacific cluster, especially its northernmost members. The possibility is proposed that the original source of the Austronesian speakers of the Pacific—the Polynesians and Micronesians—may have been the Japanese and Ryukyu archipelago. An *in situ* transformation of Melanesians into Polynesians is the least likely explanation.

### Introduction

Currently the question of a place of origin for the peoples of Oceania is once again a matter for debate. Although many and differing suggestions have been offered, these boil down to variants of two basic hypotheses. The older of these proposes that the inhabitants of the island Pacific originally stemmed from some former homeland on the Asian continent, reaching their current locations after a series of migrations (Crawfurd 1852, Bellwood 1979, 1986). More recently, the view has been proposed that the Oceanic islanders

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arose by differentiation in Melanesia—whether coastal New Guinea or the adjacent island groups—following which they spread throughout the previously unoccupied islands of the Pacific basin (Green 1967, 1973, 1979, Groube 1971, Houghton 1980, Terrell 1981, 1986).

The main support for the latter view has come from interpretations of linguistic and archaeological data. Whereas some of its defenders have tried to argue that this is not incompatible with the data of human biology (Terrell 1981, 1986), most of those who have actually dealt with the latter dimensions have felt that the time available was insufficient for the *in situ* development of the differences observable between Polynesians and Melanesians (Howells 1973, 1979, Howells & Schwidetzky 1981, Turner & Scott 1977, Turner & Swindler 1978, Turner 1986, Brace & Hinton 1981, Brace *et al* 1989b, Pietrusewsky, this volume). Consequently, biological anthropologists have tended to prefer the older view that those differences must reflect adaptive responses to separate sets of selective forces over a period of time considerably longer than the extent of human habitation in Oceania. Indeed, this is the position we defend in the present paper. It is our intent to show that this “preference” on the part of biological anthropologists is based on more than just educated guesswork (*pace* Terrell 1986: 152). Towards this end, we treat patterns of similarity and difference derived from an assessment of craniofacial and dental dimensions in a series of Oceanic, Asian and adjacent samples.

## Materials and Methods

### SAMPLES USED

Here we recount the names of the populations sampled, the numbers of individuals measured in each, and the addresses of the collections in which they are located. It should be noted that the numbers of individuals refer only to those with complete data for more than a dozen of the measurements listed in Table 1, and for the products of the three measurements used in Table 5. Only these individuals could be used for the multivariate procedure on which our cluster diagrams are based. Many otherwise incomplete specimens, however, had measurable teeth, and we used these for our appraisal of tooth size. This is why the range of N's in Table 2 does not correspond with the numbers of specimens listed below.

Since our previous concerns have been more with the populations of the Asian continent and Japan (Brace, 1978; Brace and Nagai, 1982; Brace *et al.*, 1984; Brace and Vitzthum, 1984), it is inevitable that our efforts have yielded larger samples of these than of the populations of Oceania *per se*. Consequently, our Australian, Melanesian, Micronesian, Philippine, and Polynesian samples may be somewhat less representative of the areas from which they were derived. The conclusions based on them, then, can be regarded as only tentative.

#### Ainu 55 specimens

Hokkaidō 7 specimens  
Anatomy Department II  
Sapporo Medical College  
Sapporo, Japan

Hokkaidō 48 specimens  
University Museum  
University of Tōkyō  
Hongo, Bunkyo-ku  
Tōkyō, Japan

**Australians** 16 specimens

Murray Basin  
 Department of Anatomy  
 Medical School  
 University of Edinburgh  
 Edinburgh, Scotland

**Chinese** 392 specimens

Hebei 40 specimens  
 Yunnan 64 specimens  
 Institute of Vertebrate Paleontology and  
 Paleoanthropology  
 Academia Sinica  
 Beijing  
 People's Republic of China

Neolithic Henan Xi Chang 2 specimens  
 Neolithic Gansu 16 specimens  
 Institute of Vertebrate Paleontology and  
 Paleoanthropology  
 Academia Sinica  
 Beijing  
 People's Republic of China

Sichuan 51 specimens  
 Department of Anatomy  
 Chengdu College of Traditional Chinese Medicine  
 Chengdu, Sichuan  
 People's Republic of China

**Japanese** 271 specimens

Nagasaki 28 specimens  
 Department of Anatomy  
 Nagasaki University School of Medicine  
 Nagasaki, Japan

Tōkyo 113 specimens  
 University Museum  
 University of Tōyko  
 Hongo, Bunkyo-ku  
 Tōkyo, Japan

**Jōmon** 9 specimens

Early Jōmon 1 specimen  
 Middle Jōmon 1 specimen  
 Late Jōmon 4 specimens  
 Department of Anatomy II  
 Sapporo Medical College  
 Sapporo, Japan

**Melanesians** 71 specimens

New Britain, Ralum (Tolai) 60 specimens  
 New Britain, Baining 7 specimens  
 New Ireland 4 specimens  
 von Luschan Collection  
 American Museum of Natural History  
 New York, N.Y.

Hong Kong 45 specimens  
 Department of Oral Anatomy  
 Prince Philip Dental Hospital  
 Hong Kong

Shanghai 174 specimens  
 Anthropology Division  
 Department of Biology  
 Fudan University  
 Shanghai  
 People's Republic of China

Tōhoku 56 specimens  
 Department of Anatomy  
 School of Medicine  
 Tōhoku University  
 Sendai, Japan

Tōkyo, Chiba 74 specimens  
 Department of Anatomy II  
 Sapporo Medical College  
 Sapporo, Japan

Middle Jōmon 1 specimen  
 Late Jōmon 2 specimens  
 Laboratory of Physical Anthropology  
 Faculty of Science  
 Kyōto University  
 Kyōto, Japan

**Micronesians** 55 specimens

Guam 36 specimens  
Bernice P. Bishop Museum  
Honolulu, Hawaii

Yap 5 specimens  
Palau 5 specimens  
Mortlocks 4 specimens  
Carolines 1 specimen  
Chamorro 1 specimen  
Jaluit 1 specimen  
Nauru 1 specimen  
Tari-Tari 1 specimen  
von Luschan Collection  
American Museum of Natural History  
New York, N.Y.

**Philippines** 21 specimens

Visayas  
Museum of Anthropology  
University of Michigan  
Ann Arbor, Michigan

**Polynesians** 131 specimens

Easter Islanders 11 specimens  
Maori 25 specimens  
von Luschan Collection  
American Museum of Natural History  
New York, N.Y.

Hawaiians 69 specimens  
Bernice P. Bishop Museum  
Honolulu, Hawaii

Marquesas 26 specimens  
Department of Anthropology  
American Museum of Natural History  
New York, N.Y.

**Thai** 65 specimens

Bangkok 63 specimens  
Department of Anatomy  
Siriraj Hospital  
Mahidol University  
Bangkok, Thailand

Neolithic, Ban Chiang 1 specimen  
Department of Anthropology  
University of Hawaii  
Honolulu, Hawaii, U.S.A.

Neolithic, Ban Nadi 1 specimen  
Museum of Prehistory  
Siriraj Hospital  
Bangkok, Thailand

**Vietnamese** 5 specimens

Musée de l'Homme  
Paris, France

**Yayoi** 21 specimens

Doigahama  
Department of Anatomy  
Medical School  
Kyūshū University  
Fukuoka, Japan

### Craniofacial Measurements

To test whether change through time in a given area is the product of *in situ* modification or of invasion and replacement (or varying degrees of absorption), we collected a series of craniofacial measurements on each of our samples. It was our hope that analysis of these measurements would reveal patterns that could be due only to recency of common ancestry. The logic is similar but not identical to that used in the analysis of genotypes (*cf.* Sibley & Ahlquist 1984, 1986, 1987), *i.e.*, if enough measurements are compared, the degree of similarity in pattern will be proportional to the degree of genetic relationship despite possible differences in aspects of selection. In our case, since we are dealing exclusively with phenotypes, we also have to contend with the possibility that some of the similarities and differences observed may be the result of specific environmentally imposed effects.

The list of the craniofacial measurements used is given in Table 1. In fact we had a list of some two dozen measurements, refined by repeated use of discrimination statistics, which were most effective in separating the populations with which we have been concerned. Two problems have prevented our use of all twenty-four of these. First, we did not discover the importance of some of them until several trial analyses had been performed, after which point it was not always possible to go back to the various collections previously measured to redo the specimens with the expanded list. Second, the often fragmentary state of prehistoric skeletal material has frequently precluded the acquisition of some of our most diagnostic nasofacial measurements.

These are the reasons why we settled on the seventeen measurements listed in Table 1. Most of these are defined in Martin (1928). Measurements 11 and 12 were based on the

Table 1. Craniofacial measurements.

Variable Number	Description
1	Nasal Height (Martin No. 55)
2	Nasal Bone Height (Martin No. 56[2])
3	Nasion Prosthion (Martin No. 48[1])
4	Nasion Basion (Martin No. 5)
5	Basion Prosthion (Martin No. 40)
6	Superior Nasal Bone Width (Martin No. 57[2])
7	Minimum Nasal Bone Width
8	Inferior Nasal Bone Width (Martin No. 57[3])
9	Nasal Breadth (Martin No. 54)
10	Height of Rhinion over measurement number 8
11	IOW Subtense at Nasion (Woo & Morant)
12	MOW Subtense at Rhinion (Woo & Morant)
13	Bizygomatic Width (Martin No. 45)
14	Glabella Opisthocranion (Martin No. 1)
15	Maximum Cranial Breadth (Martin No. 8)
16	Basion Bregma (Martin No. 17)
17	Basion Rhinion

approach taken by Woo & Morant (1932, 1934). Measurements 10, 11 and 12 were made with a "simometer," a kind of coordinate caliper on loan from Professor W. W. Howells. Since our initial impression had been that the elevation of aspects of the nasal skeleton differed among populations that were long-term residents in northern and southern regions, we added measurement 10 to try to test this. Measurement 10 was made by placing the two horizontal arms of the simometer on the points where the right and left lateral nasal sutures meet the piriform aperture, the lowermost point in measurement 2. The vertical arm then was adjusted so that its tip was on rhinion. In fact, as it turns out, this measurement is largely unrelated to the elevation of the nasal skeleton. A short distance between nasion and rhinion coupled with a long naso-maxillary suture, measurement 2, will produce a high reading for measurement 10 even though there is very little elevation of the nasal bones above the adjacent maxilla. We did not discover this until we actually went through a series of collections applying our measurement battery. By the time we figured out what the most useful measurements should have been, it was too late to go back and remeasure everything we had done over the previous six years.

### Tooth Measurements

Mesial-distal and buccal-lingual measurements were made for all the available teeth—maxillary and mandibular, right and left—of all the individuals available in the samples used for the present study. The measurement techniques have been previously discussed in detail (Brace 1979, 1980). Since the right and left antimeres are phenotypic expressions of the same underlying genotype, the best expression of the latter is an average of the two. Individual dimensions for each tooth class were then calculated from the means of the antimeres measurements. To produce a population figure for a given tooth class dimension, the mid-sex mean was used—that is, the sum of the mean male and the mean female dimensions divided by two (Brace *et al.* 1987). In this fashion, mean population figures for the mean mesial-distal and mean buccal-lingual dimensions of each of the sixteen tooth classes were calculated for each sample. The result yielded thirty-two figures for each group considered.

In order to simplify this, cross-sectional areas were produced by taking the product of the mesial-distal and buccal-lingual dimensions for each tooth class. As was the case for the individual mesial-distal and buccal-lingual dimensions, the population figure was considered to be the mid-sex mean of the cross-sectional area for each tooth class.

This still leaves sixteen data points per population. While this is a very effective way of comparing two or three groups at a time, there can be real confusion when the number of groups being compared rises to ten or more. Under the latter circumstances, a crude but effective measure is obtained by the using the summary tooth-size figure, TS. This is simply the sum of the mean cross-sectional areas of all the tooth categories in a single sample (Brace 1978, 1979, 1980). As with the means for individual measurement and cross-sectional areas, the mean TS of a sample is a mid-sex mean.

Table 2 displays the TS figures for the samples used in this study arranged in order of magnitude. Since each TS figure is based on a summary of mean individual tooth cross-sectional areas and since each of them has a different N, there is no way to calculate a variance for the TS figures presented here. As was noted in a previous study (Brace 1980:

Table 2. Summary of tooth size measurements (TS) in mm<sup>2</sup> based on various numbers (N) of tooth samples.

Sample	TS	Mean N	Range of N
Australia, Murray Basin	1429	185	(148-209)
New Britain	1355	41	(14-67)
Guam	1311	70	(38-88)
Philippines, Visayas	1288	109	(53-201)
Easter Island	1256	12	(1-23)
New Ireland	1245	8	(3-21)
China, Neolithic	1236	152	(57-278)
Yayoi, Doigahama	1232	9	(3-18)
Japanese	1229	212	(130-294)
China, North	1223	97	(42-136)
Thai, Neolithic	1222	46	(30-61)
Thai	1222	27	(23-31)
Jōmon, Early	1211	6	(5-12)
Marquesas	1204	35	(29-41)
China, South	1187	209	(58-447)
Hawaii	1176	42	(33-50)
Vietnam	1169	9	(2-21)
Jōmon, Middle	1152	17	(7-28)
Maori	1135	61	(42-79)
Jōmon, Late	1134	49	(17-76)
Ainu	1083	20	(7-44)

144), which included the analysis of complete individuals where such variance figures could be calculated, "a summary tooth-size difference of 50 mm<sup>2</sup> between groups compared is probably meaningful, and a difference of 100 mm<sup>2</sup> or more almost certainly has some basic biological meaning."

#### ANALYSIS

Previous work (Brace 1967, 1978, 1979) has supported the view that human dental dimensions underwent a clearcut reduction in the late and post-Pleistocene. In addition, it is apparent that the observed reductions followed the adoption of non-dental food processing procedures, and that the rate of reduction effectively doubled after the acquisition of pottery (Brace 1977, Brace *et al.* 1987). One would expect, then, that the relative differences in tooth size among the various peoples of the world today would be roughly proportional to the differences in the length of time that the peoples in question have used pottery and its predecessors as important parts of their food-processing technology (Brace 1988). Certainly within a continuing population, we would expect that the more recent representatives should have smaller teeth than their ancestors of several thousand years ago, and, by and large, this expectation is fulfilled (Brace & Vitzthum 1984, Brace *et al.* 1984, Brace *et al.* 1987). Simple tooth measurements, however, cannot demonstrate an ancestral-descendant relationship. For such purposes, a separate and independent set of variables is necessary. The analysis of dental morphology works splendidly in this regard as Turner

has shown elegantly and often (Turner 1976, 1983, 1985, 1986, and this volume, Turner & Hanihara 1977).

For our purposes, however, we have chosen the technique successfully used elsewhere to elucidate the relationships between various Japanese samples past and present (Brace *et al.* 1989a). This involved the selection of a non-dental battery of craniofacial measurements which was subjected to separate statistical treatment. It is gratifying to note that this produces a picture that is largely in agreement with the work of Turner mentioned above as well as with that of Howells (1973, 1979, 1986, Howells & Schwidetzky 1981) and with the non-metric and metric distance studies of Pietruszewsky (1970, 1971, 1984, and this volume).

In order to deal with the matter of relative proportion, or "shape," of the craniofacial features with which we are concerned, some kind of proportional transformation would be desirable to minimize the effects of major size differences when comparing diverse populations. Recently, Howells (1986) has proposed the use of the C-score statistic to accomplish this, and we have employed this in analyzing the variables presented in Table 1. C-scores are similar to ratios in that they both are measures of relative size. The advantage of a C-score over a simple ratio is that the C-score reflects the relative size of a given feature in comparison to the size of all the other traits appraised in that individual, while a ratio can only reflect relative size in comparison with a single referent. The calculation of C-scores is described below.

C-scores are calculated as the difference between the Z-score of a single measurement for a given individual and the mean Z-score of that individual for all the measurements used in the analysis. The first step in this procedure is to standardize individual unweighted measurements by converting them into sex-specific Z-scores where each Z-score represents the number of standard deviation units by which the value in question departs from the grand mean of all the samples used in a given analysis. This can be represented as:

$$Z_{i,j} = \frac{(X_{i,j} - \bar{X}_i)}{\sigma_i} \quad (1)$$

where:  $i$  = number of the measurement (*e.g.* 1 . . . 17)

$j$  = number of the individual

$X_{i,j}$  = value of measurement "i" for individual "j"

$\bar{X}_i$  = overall sex-specific average value for measurement "i"

and  $\sigma_i$  = overall sex-specific standard deviation for measurement "i"

After this transformation each variable has been converted into an expression of the number of standard deviations by which that variable differs from the overall mean, a value that may be positive or negative. For instance, a very large individual might have a value of 3.5 for cranial length. This individual's cranial length is 3.5 standard deviations from the mean cranial length for all populations considered in the analysis. The next step is to determine which variables are particularly large. To do this, the Z-score for each

variable for each individual is compared to the individual's mean Z-score for all variables. The mean Z-score of an individual is calculated as follows:

$$\bar{Z}_j = \frac{\sum Z_{i,j}}{N} \quad (2)$$

where:  $\bar{Z}_j$  = the average Z-score for all the variables for individual "j",  
and N = the number of variables used (*e.g.* 17 if all are represented).

These values are used to compute the C-score, as follows:

$$C_{i,j} = Z_{i,j} - \bar{Z}_j \quad (3)$$

The C-scores were then used as the basis for constructing dendrograms representing the relationships of the various groups sampled. Actually, we made a great many trial dendrograms. Initially we used the untransformed data. Subsequently we repeated these trials using Z-scores, and finally we settled on the use of C-scores as defined above. We also made trials without the use of frequently missing variables in an attempt to maximize our sample sizes. In the final analysis, however, we used an approach that maximized discrimination even though it had the effect of reducing our sample sizes to a slight extent. This seems to have produced the most reliable results where reliability is determined by the consistency with which samples known to be related are put into the same cluster after the addition or subtraction of other samples in the course of constructing our various trial dendrograms.

The dendrograms we have produced are hierarchical trees based on calculations of Euclidean distance, a procedure that produces results similar to those achieved by Ossenberg (1986) and by Dodo & Ishida (1987) using Mean Measures of Distance of nonmetric cranial variables. The logic is discussed in Sneath & Sokal (1973), and the computation procedure is the one specified in Fox & Guire (1976). This is a multivariate procedure requiring that values for all of the variables used in the analysis be present in each specimen. And because of the problem of artificially maximizing common variance that occurs when regression procedures are used to estimate missing data, we avoided the use of any kind of interpolation to fill in missing variables. This is why the N for many of our samples is as small as it is, especially for the often-fragmentary prehistoric groups.

Before constructing each dendrogram, the program evaluated the importance of each variable by a stepwise linear multiple discriminant procedure. The variable with the greatest power of discrimination was used first. Subsequent variables were then added in order of importance until it was determined that the contribution to reliability had a *p* value  $\leq 0.05$ . Since this procedure is done automatically each time a dendrogram is constructed, there is always the possibility that dendrograms with different samples will have been built with the use of slightly differing sets of variables. Indeed, this is the case for the two dendrograms we give here, namely Figures 1 and 2. For example, the first six variables in order of importance that contributed to the dendrogram illustrated in Figure 1 were 15, 16, 7, 17, 5 and 13. Obviously cranial width and height were of particular im-

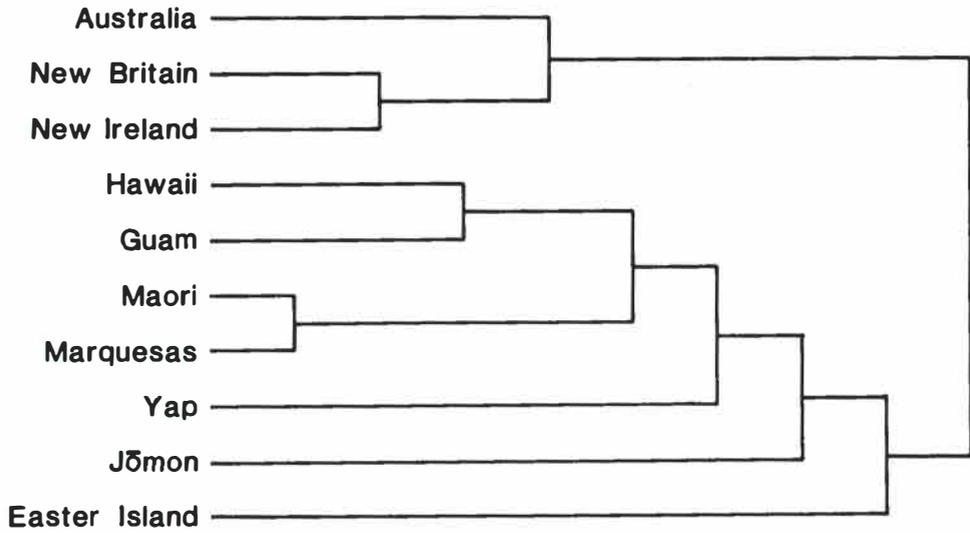


Figure 1. Dendrogram showing the Euclidean distance relationships of 10 Oceanic samples based on the same craniofacial variables used to construct the  $D^2$  figures in Table 5.

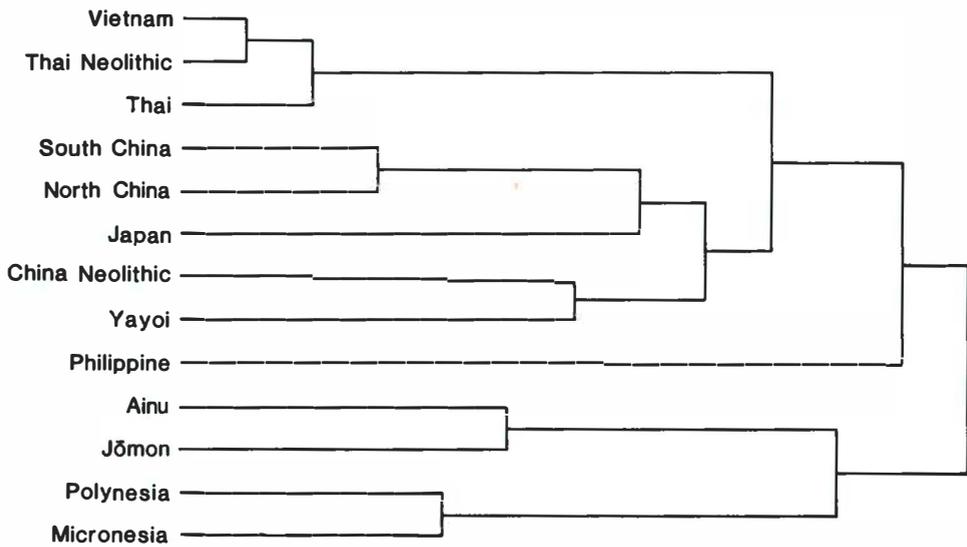


Figure 2. Dendrogram showing the Euclidean distance relationships of 9 Asian and 3 Oceanic samples based on the same craniofacial variables used to construct the  $D^2$  figures in Table 6.

portance in discriminating between the members of this set of samples. The first six variables that contributed to the construction of the dendrogram in Figure 2 were, in order of importance, 17, 2, 1, 3, 11 and 12. Here it is evident that relative amounts of nasal elongation and projection were of particular importance. The lists of variables in the order that they were used in the construction of Figures 1 and 2, plus the F-Statistics and significance values, are shown in Tables 3 and 4.

Table 3. Sequence of entry of variables used to produce Figure 1.

Variable Number	Variable Name	F-Statistic	Significance
15	Maximum Cranial Breadth	37.075	0.0000
16	Basion Bregma	10.122	0.0000
7	Minimum Nasal Bone Width	8.846	0.0000
17	Basion Rhinion	8.861	0.0000
5	Basion Prosthion	9.637	0.0000
13	Bizygomatic	6.910	0.0000
14	Glabella Opisthocranion	4.983	0.0000
12	MOW Subtense at Rhinion	3.912	0.0001
8	Inferior Nasal Bone Width	3.394	0.0006
11	IOW Subtense at Nasion	2.816	0.0036
1	Nasal Height	2.593	0.0071
4	Nasion Basion	2.475	0.0101
9	Nasal Breadth	2.073	0.0325

Table 4. Sequence of entry of variables used to produce Figure 2.

Variable Number	Variable Name	F-Statistic	Significance
17	Basion Rhinion	48.478	0.0000
2	Nasal Bone Height	18.437	0.0000
1	Nasal Height	15.402	0.0000
3	Nasion Prosthion	13.804	0.0000
11	IOW Subtense at Nasion	10.084	0.0000
12	MOW Subtense at Rhinion	9.560	0.0000
9	Nasal Breadth	8.213	0.0000
8	Inferior Nasal Bone Width	7.863	0.0000
14	Glabella Opisthocranion	8.185	0.0000
13	Bizygomatic	4.256	0.0000
6	Superior Nasal Bone Width	4.904	0.0000
15	Maximum Cranial Breadth	4.420	0.0000
4	Nasion Basion	3.455	0.0001
5	Basion Prosthion	3.175	0.0002
16	Basion Bregma	2.914	0.0006
10	Height of Rhinion over 8	2.574	0.0023

After constructing our dendrograms, we used the same samples and the same variables to construct matrices of Mahalanobis Distance ( $D^2$ ) figures (Fox & Guire 1976). The  $D^2$  figures comparing each of the groups used in Figures 1 and 2 are shown in Tables 5 and 6. We considered the possibility of using the  $D^2$  figures to construct our branching diagrams since Mahalanobis Distances compensate for the correlation between variables by calculating covariance matrices and incorporating this variance into expressions of distance. We did not use  $D^2$  figures for two reasons. The first of these is practical. At the moment, no algorithm is readily available that can use the information inherent in  $D^2$  figures to construct dendrograms. To use  $D^2$  in proper fashion to create cluster diagrams, the matrix has to be inverted after each incorporation step and this is prohibitively expensive for more than just a few such steps. The second is theoretical. Although  $D^2$  is a robust and useful technique, doubts have been expressed about the multivariate normality of the sample dispersion matrices in most multivariate taxonomic studies (Sneath & Sokal 1973). The fact that the statistic is widely regarded as useful prompts us to provide these values for comparison. In essence, the  $D^2$  figures in Tables 5 and 6 corroborate the Euclidean distance values of which Figures 1 and 2 are visual representations.

Finally, to give some idea of the comparative magnitude of the metric phenomena with which we were dealing, we attempted to show how tooth size varies when corrections are made for differences in body bulk. Since our data came almost exclusively from cranial collections, we had to rely on the fact that, within a species, brain size has a close allometric relationship to body size (Jerison 1973, Martin 1983, Riska & Atchley 1985, Smith 1989). The three major cranial dimensions provide a remarkable accurate estimate of cranial capacity—itsself the best measure of brain size—when used in conjunction with carefully worked out constants (Hooke 1926, Pearson 1926). As the term “constant” implies, the only information concerning differences in cranial capacity comes from the cranial measures themselves. This is why we ignored these constants in our comparison.

We calculated the product of the three major cranial dimensions—Length, Width and Height—as represented in variables 14, 15 and 16. These are ranked in their order of

Table 5. Craniofacial  $D^2$  figures for 10 oceanic samples using variables 1, 4, 5, 7–9, 11–17.

Sample	Population									
	S. Aust.	New Brit.	New Ire.	Hawaii	Guam	Maori	Marque	Yap	Jōmon	East Is.
S. Aust.	—									
New Brit.	5.18	—								
New Ire.	10.38	4.25	—							
Hawaii	23.02	15.10	17.82	—						
Guam	20.23	13.80	19.82	5.56	—					
Maori	11.87	10.67	16.06	4.89	8.78	—				
Marquesas	12.16	8.61	13.27	5.18	8.86	2.17	—			
Yap	17.01	8.30	11.49	5.72	4.71	6.43	6.18	—		
Jōmon	22.53	14.17	24.14	8.54	12.80	11.12	12.43	12.42	—	
Easter Is.	15.97	11.99	16.37	11.02	14.21	9.04	11.16	15.29	16.05	—

Table 6. Craniofacial D<sup>2</sup> figures for 9 Asian and 3 Oceanic samples using variables 1–6, 8–17.

Sample	Population												
	Vietnam	Thai Neol.	Thai	S. China	N. China	Japan	Chn. Neol.	Yayoi	Phili.	Ainu	Jōmon	Polyn.	Micro.
Vietnam	—												
Thai Neol.	8.90	—											
Thai Mod.	3.42	11.70	—										
S. China	6.19	10.12	4.15	—									
N. China	10.17	14.81	8.54	2.29	—								
Japan	5.92	14.11	4.99	2.55	2.79	—							
China Neol.	5.81	8.82	8.06	4.56	4.56	4.86	—						
Yayoi	8.30	13.39	6.89	4.05	5.76	4.44	4.55	—					
Philippines	9.34	18.22	6.93	9.91	17.62	13.34	14.22	12.35	—				
Ainu	13.03	28.98	13.14	11.13	12.68	6.91	13.68	9.52	17.45	—			
Jōmon	14.20	32.32	14.00	13.08	16.11	9.22	18.18	11.23	18.23	2.75	—		
Polynesia	8.93	24.08	6.38	6.27	8.14	3.99	10.58	9.32	10.48	4.31	7.67	—	
Micronesia	7.63	18.33	6.38	5.63	9.70	5.04	9.35	8.55	6.94	8.39	10.61	4.16	—

Table 7. Cranial size (CS) as a product of length  $\times$  width  $\times$  height and in proportion to tooth size (TS).

Sample	CS	TS/CS
Jōmon	3,550	0.33
Polynesia	3,534	0.34
Ainu	3,498	0.31
Micronesia	3,438	0.37
Thai, Neolithic	3,427	0.36
China, Neolithic	3,369	0.37
China, North	3,276	0.37
Japan	3,275	0.38
Yayoi	3,275	0.38
Vietnam	3,236	0.36
China, South	3,207	0.37
Thai	3,198	0.38
Australia, Murray Basin	3,171	0.45
Philippines, Visayas	3,142	0.41
New Britain	3,038	0.45
New Ireland	2,945	0.42

magnitude in Table 7. Although this approach may be tantamount to treating human beings as “block-heads,” it is the only comparative figure we have to represent relative body bulk. Tooth size in proportion to this approximation to body bulk is represented in the last column of Table 7, where CS represents cranial size as a product of Length  $\times$  Width  $\times$  Height, and tooth size is TS as defined above.

### Results and Discussion

As can be seen in Figure 1, the various “Oceanic” samples form two essentially unrelated clusters. The two samples from island Melanesia—New Britain and New Ireland—join the sample of Murray Basin Australian aborigines in a single clearly-related cluster. The various Polynesian and Micronesian samples make up a separate cluster to which is added the Jōmon of prehistoric Japan.

And if the samples from New Britain, Micronesia and Jōmon Japan are broken down into their constituents, even with sample sizes of 1 for those so noted in our list of samples, there is no change in the essential dichotomy—the Australo-Melanesian cluster remains intact and so does the cluster that includes all of the far islands of Oceania. What we have called our “Jōmon-Pacific” cluster includes only Austronesian-speaking groups in Oceania, while many of our “Australo-Melanesian” cluster members are non-Austronesian speakers. Of course, one can object that the people of Ralum (Tolai) in New Britain and most of the people of New Ireland actually speak Austronesian languages, and that we have no way of knowing what was spoken by the Jōmon of Japan. Naturally, there is nothing in the craniofacial configuration of a given cluster that predisposes its members to speak a particular language. Still, if the common possession of a particular configuration of physical features is an indication of a long-term shared history, the same thing is also true for lan-

guages that can be called "related." It is no surprise, then, that peoples with a long common history not only tend to have a set of physical features in common but also tend to speak related languages. In any case, our clusters present essentially the same picture as the ones produced by Howells (1973, especially Figure 3, page 46) and Pietrusewsky from more extensive samples of the same major areas of the Pacific (Pietrusewsky, in press), and this leads us to agree with their conclusions as well.

In slight contrast to Pietrusewsky's results, we do not get such clear-cut distinctions between Micronesians and Polynesians, but we cannot yet determine whether this is because our Micronesian sample sizes, except for Guam, were so small or because we used C-scores. When we combine the available Polynesians and Micronesians into respectively named samples and compare them with other Asian groups, as in Figure 2, they fall into very much the same pattern. In this run we added the Ainu sample and, as can be seen, it tied in with the Jōmon in the Jōmon-Pacific cluster.

Also in slight contrast to Pietrusewsky's results, we did not get much indication of a residual affiliation of the Jōmon-Pacific samples with anything on the Asian mainland. Admittedly, the ties indicated in Pietrusewsky's dendrogram are at such a distance that one might suggest that they are shown simply because the nature of the algorithm dictates that the computer has to end up by drawing such a connection. We suspect that there is little biological meaning inherent in that picture. In any case, we tried another run into which we put all the samples we used. The computer of course had to tie them together at the end, but it kept the Jōmon-Pacific and Mainland-Asian clusters separate until the next-to-last step. Then in its very last operation, it drew its line connecting the Australo-Melanesian cluster.

What we did get, however, was a very convincing link of Polynesians and Micronesians to the Ainu and the prehistoric Jōmon in Japan (see Figures 1 and 2). Twenty years ago, Yamaguchi calculated  $D^2$  values showing the tie between the Ainu and the Maori of New Zealand (Yamaguchi 1967). Our Figure 2 suggests that this was no fluke. It also reinforces the interpretation that the Ainu are simply the modern descendants of the prehistoric Jōmon, a view first clearly articulated by Koganei (1903, 1927, 1937) whose assessment of craniofacial morphology has subsequently been amply reaffirmed by studies of dental morphology (Turner 1976, Turner & Hanihara 1979), dental metrics (Brace & Nagai 1982), and craniometric and morphological multivariate studies (Howells 1966, 1986, Yamaguchi 1982, Dodo 1986, Ossenberg 1986). A fuller consideration of this matter is the subject of a separate treatment (Brace *et al.* 1989, Brace & Hunt 1990; Brace *et al.* 1989b).

However we treat the variables, whether using transformed data or not, the Jōmon and the Ainu always fall in the Jōmon-Pacific cluster while the Yayoi and the modern Japanese fall in the Mainland-Asian cluster with the north and south Chinese, the Thai and the Vietnamese, and the Neolithic of China and Thailand. The sample from Visayas in the Philippines (Guthe 1927) is less firmly anchored. When we made clusters that maximized for N rather than for discrimination, it flipped into the Jōmon-Pacific cluster although the tie was just as remote and weak as the association with the Mainland-Asian cluster visible in Figure 2.

Actually, in the course of this work, we stumbled across a bit of methodological understanding that would not otherwise have occurred to us. That is, when one increases

the number of variables used for testing, the relationships and differences between the groups being compared are more accurately depicted even if the N of each group is less than would be the case if a smaller set of variables were used. It would appear that a similar methodological issue is behind the differences in interpretation visible in the various groups concentrating on the analysis of mitochondrial DNA (Cann *et al.* 1987, and discussed in Lewin 1987, Cann 1988), and it is even more obvious when the issue is the comparison of nuclear DNA (Sibley & Ahlquist 1984, 1987, Nei 1987). Again, the logic behind what approach works best at the morphological level is very similar to that which applies at the molecular level. The vast bulk of DNA is not transcribed (Ohno 1970, 1972, Britten 1986, Loomis & Gilpin 1987). Nucleotide sequence similarities in different organisms will provide a measure of relatedness, and the more the restriction fragments sampled the better the estimate of relationships. In morphometric assessment, the addition of further adaptively insignificant dimensions improves our ability to assess population relationships and distinctions (Brace *et al.* 1989a, Brace *et al.* 1989b, Brace & Hunt 1990). This almost certainly is why Pietrusewsky gets a closer approximation to the linguistic and cultural dimensions of Oceania in his dendrograms than we do in ours (Pietrusewsky, this volume).

If the interpretations that emerge from Figures 1 and 2 (and Tables 5 and 6) are obvious and easy to make, what can we say about the matter of tooth size on the basis of the data in Table 2? First of all, of the only three groups with a TS of over 1300 mm<sup>2</sup>, two of these are found in the Australo-Melanesian craniofacial cluster depicted in Figure 1, namely, the New Britain sample and Australian aborigines proper. The remaining member of the Australo-Melanesian cluster, the New Ireland sample, has a TS of 1245 mm<sup>2</sup> which is exceeded only by the Guam, Easter Island and Philippine samples when the rest of the list is scanned. It is a matter of record that Australian aborigines have the largest teeth to be found among the living human populations of the world (Brace 1980, Brace & Ryan 1980), and it would seem that those populations that can be associated with Australo-Melanesian form on the basis of craniofacial metrics also tend to have large teeth.

Now the mere details of nasofacial dimensions share little common variance with tooth size *per se*, and since it is these details that are particularly important in the construction of the clusters visible in Figures 1 and 2, it is obvious that the simple fact of being ranked in the Australo-Melanesian cluster does not by itself ensure the possession of large teeth. Rather, the possession of large teeth by those Melanesian groups that are assigned to the Australo-Melanesian cluster must be the result of circumstances in the recent past stressing the adaptive value of large tooth size. We would argue that this suggests a later arrival of the selective-force-altering aspects of food-preparing technology in the part of the world inhabited by the ancestors of the Australo-Melanesians than was the case for peoples whose ancestors were shaped by conditions farther north where food-preparation technology and consequent dental reduction had a much greater antiquity (Brace 1977, 1978, 1979, 1988, Brace *et al.* 1987, Brace *et al.* in press).

Only one member of the Jōmon-Pacific cluster, Guam, has a TS figure of over 1300 mm<sup>2</sup>. No member of the Mainland-Asian cluster has TS of 1300 mm<sup>2</sup> or more, and we have to look back to the Neolithic to find measurements that approach or exceed this figure (Brace & Vitzthum 1984). Back in the Mesolithic, all mainland Asian groups exceed 1300 mm<sup>2</sup> although the southern Mesolithic samples clearly had larger teeth than their northern contemporaries. Dental reduction obviously began in the north long before the invention

of pottery, and we have argued that, both genetically and in terms of selective force alteration, the north was the source of the reductions that subsequently spread south and out into Oceania (Brace & Hinton 1981, Brace *et al.* 1987, Brace *et al.* in press).

The oldest member of the Jōmon-Pacific cluster is our Early Jōmon sample at a date of roughly 5000 B.C. (Pearson 1986: 219; Tsukuda 1986: 39). It is interesting to note that, starting at this date, tooth reduction in Jōmon Japan extending up to the modern Ainu has a regression slope of  $-0.015 \text{ mm}^2/\text{yr}$ . This is a rate of approximately 1% per thousand years which is exactly the same as the Mesolithic-to-Neolithic-to-modern rate for Europe, the Middle East, China and Southeast Asia (Brace *et al.* 1987, Brace *et al.* 1989).

Even at this rate, which is the fastest one demonstrable in human evolution, it would take more than 15,000 years to evolve a Maori out of a Melanesian like those now found in New Britain. But the early Jōmon of 7,000 years ago already fall in the cluster with Polynesians and Micronesians. So, if the claim is to be made that this configuration took place as a result of transformation of a Melanesian population *in situ*, then we have to entertain the unlikely possibility that it had to have begun some 30,000 years ago or more. Subsequently there would have to have been a migration to Japan from Melanesia at least 11,000 years ago to account for the continuous Jōmon sequence that yields people who resemble modern Polynesians and Micronesians starting at least 7,000 years ago and continuing up to and including the modern Ainu. The evidence for the dramatic *in situ* dental reduction in Jōmon Japan, of course, is just what we would expect given the selective force relaxation that should follow from the use of pottery in food preparation (Brace & Mahler 1971, Brace 1977, 1978, 1988, Brace *et al.* 1987). Since the Jōmon pottery-making tradition has a legitimate claim to being the oldest such in the world (Ikawa-Smith 1986), it is no surprise to find such clearcut evidence for dental reduction among just those peoples who were the long-term beneficiaries of that tradition.

The Ainu not only have the smallest teeth in the Jōmon-Pacific cluster, they have the smallest teeth of all the modern populations of Asia and Oceania, past or present. This is one of the main reasons we regard it as possible that the origins of dental reduction in the whole area under consideration were northern in the first place (Brace *et al.* in press) and that there may be a significant northern component in the Oceanic members of our Jōmon-Pacific cluster. As was previously noted, it is not beyond the bounds of possibility that the hypothetical Austronesian homeland was in the region that included the Japanese and Ryukyu archipelago (Brace & Nagai 1982, Brace *et al.* 1989).

This does not deny the possible link between the Jōmon and Sundaland people suggested by Turner (1986), but it would turn it around and run the movement southward starting at the end of the Pleistocene. Even so, to derive the modern Ainu TS from something the size of the Mesolithic Javanese or Southeast Asian condition (Brace and Vitzthum 1984) would require a reduction of more than 20% within the last 5,000 to 10,000 years or less, and this is at least twice as fast as the most rapid rate ever documented in any of the places in the world where data are available for testing.

We will leave the problem of dealing with Austronesian linguistics to others (*e.g.*, the various views in Capell 1962, 1971, Dyen 1971, Pou & Jenner 1975, Shutler & Marck 1975, Pawley & Green 1975, 1984, Egloff 1979, and Terrell 1986), noting in passing that there is such clearcut evidence for an Austronesian contribution to Japanese (Miller 1971, 1974, 1980, Aikens & Higuchi 1982) that some have claimed with varying degrees of

conviction that there is an Austronesian substratum underlying the Altaic superposition (Ohno 1971, Murayama 1972, 1976, Chew 1978).

If, then, the Oceanic components of our Jōmon-Pacific cluster really can be regarded as relatively recent arrivals from the north, and if they embarked on their push eastwards into the island Pacific via the north coast of New Guinea and/or adjacent island Melanesia (Wurm 1983), they could be expected to have encountered the people who had already been living there during the Pleistocene—namely the ancestors of those who now make up our Australo-Melanesian cluster (Brace & Hinton 1981, Kramer 1989). In the course of that encounter, interbreeding certainly had to have taken place. We suggest that this may well be why the samples in our Jōmon-Pacific cluster which are geographically closest to the area of encounter tend to have the largest teeth among the various components of this cluster.

Conversely, the samples in the Australo-Melanesian cluster which were most affected by the encounter tend to have the smallest teeth of its various components. It is possible that this is why the Guam TS is over 1300 mm<sup>2</sup> and the New Ireland TS is 1245 mm<sup>2</sup>. The Austronesian impact on New Ireland is obvious in that, with a single exception, the languages are legitimately Austronesian (Capell 1962).

Finally, although we do not have postcranial information for the individuals from whom our odontometric and craniofacial data were collected, we have reason to believe that the New Ireland peoples were physically very small (Howells 1973). Our cranio-metric data include gross length, width and height measurements for the crania of all of our groups, and the product of those three variables (numbers 14, 15, and 16 in Table 1) is roughly proportional to endocranial volume in human beings. In turn, there is some reason to consider that this has a close allometric relation to body bulk in modern human groups (Jerison 1973, Martin 1983, Riska & Atchley 1985, Smith 1989). With this in mind, and realizing that our products reflect external measurements and not the internal dimensions of the brain itself—furthermore, they produce a figure that assumes a cubic shape and not a sphere—we calculated the products of those three variables for all of the samples we used. The results can be seen in Table 5. The range runs from a maximum of 3,550 cc for the Jōmon down to 2,945 cc for New Ireland (these figures represent mid-sex means as described above for the calculation of TS). The combined Micronesian figure is 3,438 cc which, curiously enough, is the smallest figure for the groups in the Jōmon-Pacific cluster. Of course, correlation between tooth size and cranial size is not high, ranging from an *r* value of 0.12 for the Ainu to 0.54 for Hong Kong Chinese (and neither is significantly different from zero) (Brace *et al.* 1987). Still, it is just possible that small body size may be part of the reason why tooth size in New Ireland is at the bottom end of the Melanesian range of variation (Brace & Hinton 1981) and also the smallest among the members of our Australo-Melanesian cluster. The proportion of tooth size (TS) to cranial size (CS) in New Ireland, however, is closer to that of the other members of the Australo-Melanesian cluster than it is to the average member of any other cluster (see Table 7).

### Conclusions

Where the north-to-south transect of Asia and adjacent Oceania is measured from Japan to Australia, it is clear that the late and post-Pleistocene onset of human dental re-

duction began earliest and has had its greatest impact in the northern sector (Brace *et al.* in press). On the Asian continent itself, the smallest teeth are to be found in southeast China and adjacent Vietnam. The smallest teeth of all, however, are those of the Ainu of northern Japan. The largest teeth are to be found in the Murray River Basin in southeastern Australia although this condition is approached in New Guinea and the large islands of Melanesia.

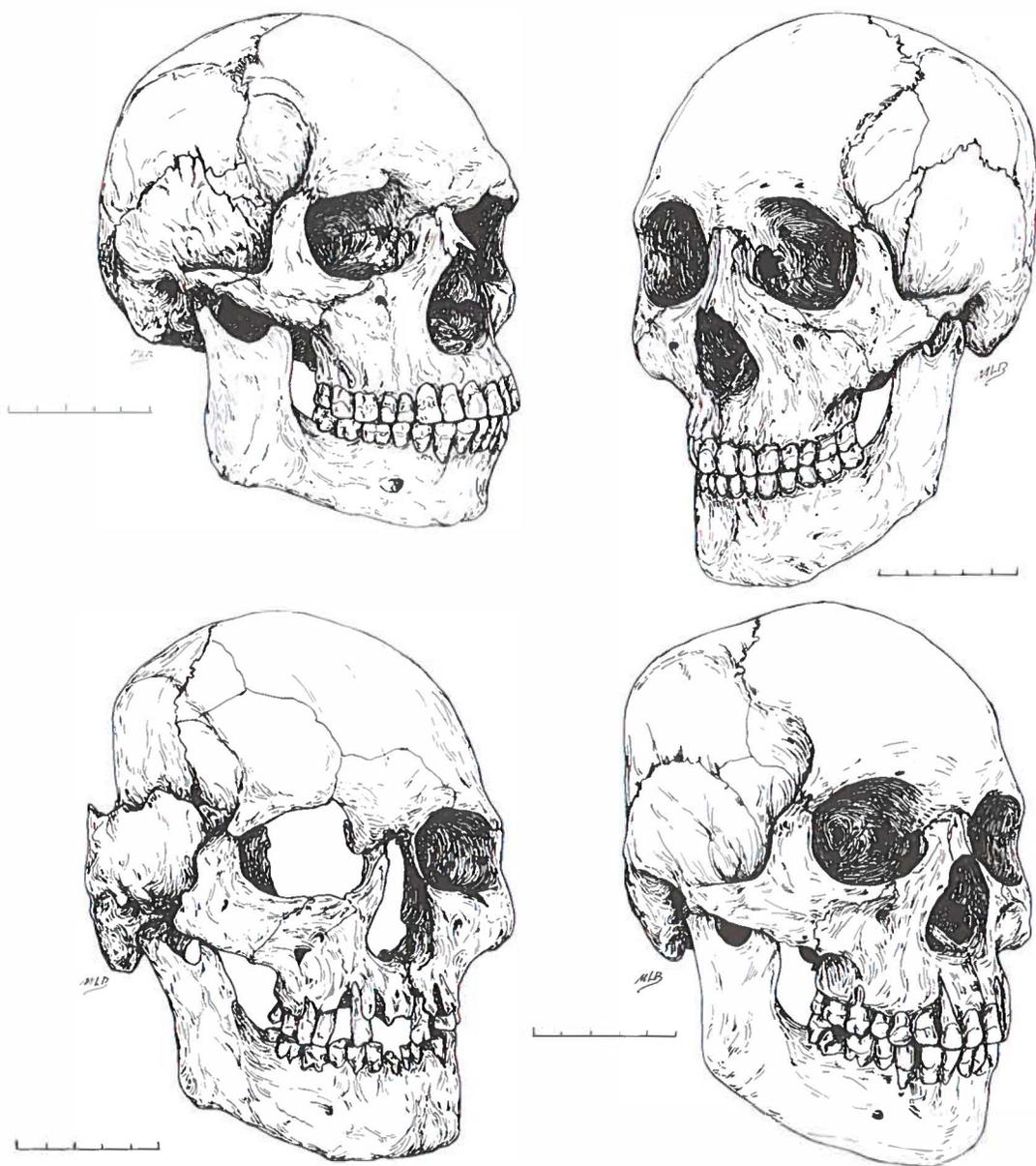
A separate test of biological relationships and distinctions was made by applying a battery of seventeen craniofacial measurements to some twenty samples representing Asia and Oceania. Euclidean distance dendrograms were constructed, and these revealed that the human populations can be seen to congregate in three relatively unrelated clusters—Australo-Melanesian, Mainland-Asian, and Jōmon Pacific.

Members of the Australo-Melanesian cluster (Fig. 3) tend to have a total tooth size measure (TS) of over 1300 mm<sup>2</sup> except at the northeastern edge of the area in which such groups can be identified—namely island Melanesia. Where an impact coming originally from the north and west is indicated by the presence of Austronesian languages, tooth size is reduced somewhat below the 1300 mm<sup>2</sup> level. Part of the reason for this smaller size may also be due to the fact that body size in general is the smallest of the entire area tested.

The Mainland-Asian cluster includes those people ranging from Thailand to northern China (Fig. 4) as well as their Neolithic predecessors in both the south and the north. It also includes the Yayoi people who classically have been associated with the first appearance of intensive rice agriculture in Japan as well as the modern Japanese of Honshu and Kyūshū. Among the modern representatives of this cluster, the maximum amount of tooth size reduction is to be seen in southern China and adjacent southeast Asia, where there is reason to suspect that mainland Asian agriculture and pottery-associated food-preparation traditions have their greatest antiquity (Brace 1978, Brace *et al.* 1984, Brace *et al.* in press).

Members of the Jōmon-Pacific cluster include Micronesians, Polynesians, and the Jōmon and Ainu of Japan (Figs 5, 6). The northernmost members of this group, namely the Jōmon and Ainu, show the maximum degree of dental reduction right in the region where a pottery-assisted food-preparation tradition and its consequent selective force relaxation has an antiquity equal to or greater than anywhere else in the world (Brace & Nagai 1982, Brace *et al.* 1987). It is also clear that the Jōmon inhabitants of Japan were in place and thriving long before the first of their demonstrable relatives began their forays out into the islands of the Pacific, and it is just possible that the archipelago that includes Japan and the Ryukyus was the original source for the peoples who carried Austronesian languages out to where they were spoken today. The members of this cluster with the least apparent amount of dental reduction, either relative or absolute, are those for whom there have been hints of a Melanesian connection. It is just possible that the slightly larger tooth size of the Micronesians may indicate that they have absorbed something from the Australo-Melanesians to their immediate south, although their craniofacial proportions firmly ally them with the Jōmon-Pacific cluster.

In conclusion, the small size of many of the samples used in this paper and the great distances over which they are scattered do not permit us to offer anything more than tentative suggestions. The one that we feel is worth further consideration, however, is the real-



Figures 3–6. Representative skulls from different groups. Figure 3. (upper left) Australian Aboriginal male from Central Australia, No. XXIX D46 (1382) of the W. Ramsay Smith Collection, Department of Anatomy, Edinburgh University Medical School. Drawn with the permission of Professor G. J. Romanes. Figure 4. (upper right) A Chinese male from Guangdong (Canton), No. T74 275 in the Department of Oral Anatomy, Prince Philip Dental Hospital, Hong Kong. Drawn with the permission of Professor Nina Jablonski. Figure 5. (lower left) A Middle Jōmon male, No. 668B from the Ōta site, Hiroshima Prefecture, in the Laboratory of Physical Anthropology, Kyōto University. Drawn with the permission of Professor Jiro Ikeda. Figure 6. (lower right) A Micronesian male from Guam, No. 601 in the Hornbostel Collection at the B. P. Bishop Museum, Honolulu. Drawn with the permission of Dr. Yoshihiko Sinoto. Scales = 5 cm.

ization that prehistoric Japan may well have played a far more important role in the peopling of the Pacific than generally has been realized. We suspect that a proper comparative assessment of the Jōmon of Japan and their modern descendants, the Ainu, is not only essential to understanding the genesis of modern Japan, but it may well hold one of the keys to understanding the peopling of Polynesia and Micronesia as well.

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