NEW ZEALAND ARCHAEOLOGICAL ASSOCIATION

NEW ZEALAND ARCHAEOLOGICAL ASSOCIATION MONOGRAPH 17:
Douglas Sutton (ed.), *Saying So Doesn't Make It So: Essays in Honour of B. Foss Leach*

SAYING SO DOESN'T MAKE IT SO

PAPERS IN HONOUR OF B. FOSS LEACH

Edited by
Douglas G. Sutton

New Zealand Archaeological Association
Monograph 17

Water Absorption Testing of Pacific Pottery

Michiko Intoh

Department of International Cultural Relations, Hokkaido Tokai University, Sapporo, Japan

INTRODUCTION

Many pottery studies in the Pacific to date have been concerned with typological characteristics, particularly decorative features. Although this work has been very successful in revealing historical relationships, there is much more that could be learned about pottery technology. In particular, little is known of the physical properties of pottery in the Pacific region.

With this concern, Foss Leach established a Pacific pottery collection at the Archaeology Laboratory, University of Otago. Samples of about 30 thumb-sized sherds from discrete cultural assemblages were requested and a number of archaeologists responded. A variety of tests were made on these potsherds (see Intoh 1982; Intoh and Leach 1981) and a standard water absorption test was developed. The author has been involved in the pottery project for the past seven years under Foss Leach's supervision. It is appropriate to publish the water absorption study as a tribute to Foss on his departure from Otago University. This paper, which is mainly based on Intoh (1982), describes the method used and summarises the assemblages studied and the initial results obtained.

POROSITY OF POTTERY

Porosity is defined as the ratio of the volume of pore space to the total volume of pottery. Clays are a mixture of grains of many shapes and sizes and in the burning process these are sintered together by partial fusion of the material, although there is no complete melting. It follows that a feature of the fired product will be the existence of innumerable fine spaces and passages of irregular shapes and varying size penetrating it in all directions. These spaces within the body of the material are called pores. Figure 1 shows the various kinds of pores.

The volume of pores is obtained as follows:

$$\begin{aligned} \text{Apparent volume} &= V_a \\ \text{True volume} &= V_t \\ \text{Bulk volume} &= V_b \\ \text{Volume of closed pores} &= V_c = V_a - V_t \end{aligned}$$

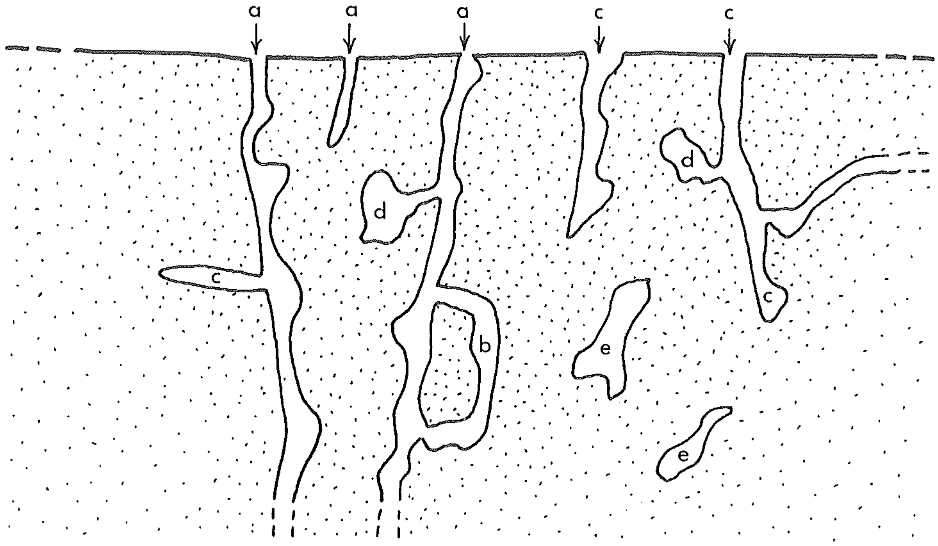

Figure 1: The various kinds of pores (after Butterworth 1948). a. channel pores. b. loop pores. c. blind alley pores. d. pocket pores. e. sealed pores.

$$\text{Volume of open pores} = V_o = V_b - V_a$$
$$\text{Volume of total pores} = V_p = V_c + V_o = V_b - V_t$$

The volume of the pore space and the size and shape of pores affect characteristics of pottery such as density, strength, permeability, and degree of resistance to thermal shock. Generally speaking, as the porosity increases, density and strength of the pottery decrease while permeability and degree of resistance to thermal shock increase (see Shepard 1956: 126). The porosity of the pottery may be described in two ways: True Porosity and Apparent Porosity. True Porosity measures the total pore space and Apparent Porosity expresses the relative volume of the open pores only. There is little difference in the two values in low-fired pottery, which largely lacks sealed pores. Therefore, Apparent Porosity is likely to be a satisfactory measure of the porosity of Oceanic pottery. For this reason, and because of the difficulty of measuring True Porosity, it is recommended that only Apparent Porosity be measured routinely in the analysis of prehistoric pottery.

While a considerable number of porosity studies were included in early works (e.g., Bradfield 1931; Matson 1937; Myers and Earnshaw 1937; Shepard 1936) the most detailed porosity study was done by Matson (1937, 1940) who concluded that

> although porosity studies may give interesting information, they are not useful as objective criteria in ceramic classification or description ... It is conceivable that in detailed studies of pottery from one site, porosity figures might be of importance in demonstrating the differences in firing temperatures. (Matson 1940: 476)

This indicates the proper place of porosity studies. It may be meaningless to compare porosity values between different assemblages because many factors influence porosity. However, an obvious change in porosity range within a specific pottery tradition may be an indication of technological change. This study is an initial attempt to build a data base in order to reconstruct a particular technological aspect of Pacific pottery traditions.

METHOD OF WATER ABSORPTION TEST

There are several methods which could be used to measure the porosity of pottery:

- Immersion method
- Boiling-in-vacuo method
- Boiling-in-air method
- Vacuum method
- Air porosimeter method

The immersion method has been shown to be unreliable. A little of the entrapped air may find its way out in the course of long continued soaking, but the pores will not be filled completely, even after the brick has been immersed for months (Butterworth 1948: 70).

The boiling-in-air method is very time consuming and is not recommended. For example, boiling for three hours in the open air results in the same level of water impregnation as boiling in a vacuum for one hour. Furthermore, boiling in air results in a loss of weight due to rehydration (Butterworth 1948: 981). This problem may also occur in the boiling-in-vacuo method. The vacuum method is widely accepted as the most trustworthy way of determining porosity, although if only a poor vacuum is available, the boiling-in-vacuo method can also be recommended (Butterworth 1948: 979).

Another quite different method of measuring porosity takes advantage of the relation between the pressure and volume of a gas, usually air. The specimen is tested dry and no wetting is necessary. Quite a variety of instruments have been devised to work on this principle. They all measure, not the volume of the pores, but the net volume of the material enclosing the pores, conventionally known as the Apparent Volume. Since the overall volume (Bulk Volume) is easy to measure, the volume of the pores can be worked out by simple subtraction (Bulk Volume minus Apparent Volume). One method is to use an air porosimeter (Butterworth 1948). These air expansion methods of measuring porosity have some attractive features, but there are still problems that need to be clarified by further experimental work. This method of measurement also needs greater skill and more refined apparatus than water absorption methods. For these reasons, the method is not widely recommended by ceramic testing laboratories, although it is possible it may be increasingly adopted in future (Grimshaw 1971: 421–4). Considering the often poor condition of low fired Pacific potsherds, the vacuum method is most suitable for measuring the porosity of Oceanic pottery.

The equipment used for the Water Absorption test was: a Qualtrex analytical oven (set at 110 ° C); a glass desiccator containing silica gel; a vacuum chamber which can be evacuated down to 100 Torr; and a Sartorious top loading digital balance with a precision of 0.001 g. The following three weight measurements are required for each sherd; the Dry Weight (W_d), the Wet Weight (W_w) and the Weight Submerged (W_s) in water. Using these measurements, Water Absorption, Bulk Density, Specific Gravity and Apparent Porosity can be calculated. The formulae are given below.

A sample of 30 sherds from each assemblage is desirable, to give an indication of variation within the assemblage. Some sherds of Oceanic pottery have been found to disintegrate during vacuum impregnation. The size should be at least about 3 by 3 cm. Smaller pieces will result in unacceptable errors in measuring the Wet Weight (see below). Pottery from one assemblage is measured during one experimental series to prevent any accidental admixture with other assemblages. It is advisable to prepare several standard ceramic pieces and have them tested at a ceramic laboratory using their routine method of water absorption test. One of the standard sherds should be examined with each assemblage to test the accuracy of results at every point in the procedure.

Firstly, the sherds are cleaned with compressed air and placed in the Qualtrex analytical oven for one night to obtain the Dry Weight (W_d). They are then placed in the desiccator under vacuum for a few hours to cool down in a dry atmosphere. When cool the sherds are taken out of the desiccator and weighed immediately on the digital balance. Since these dried sherds quickly absorb moisture from the air, only three sherds are taken out of the desiccator at a time. This method of measuring the Dry Weight yields very accurate and repeatable results; the possible error is only $\pm 0.1\%$.

Soon after the Dry Weight is obtained, the following steps are taken to obtain the suspended weight, while the sherds are sufficiently dry. They are put in a clean dry 5 litre beaker. If they are fairly large, it is preferable to divide them into two groups and measure each group separately. Otherwise, the sherds near the bottom can be crushed by the weight of the upper sherds when they are saturated in water under vacuum. The beaker is then placed in the vacuum chamber, and a plastic hose (which is connected to the inside of the chamber) inserted in the beaker. The end of the hose should be a little higher than the upper level of the sherds to prevent contact with any bubbles when water is let into the beaker. After the door is shut, the vacuum chamber is evacuated slowly until a vacuum of 250 Torr has been reached. It is important to pull the vacuum slowly otherwise the sherds can break up. Also, it is necessary to leave the chamber in this condition for about 20 minutes to release the air contained within the sherds gradually. The vacuum pump is turned on again and freshly boiled, cold, distilled water is then admitted to the beaker from outside the chamber by means of another hose connected with the first via a valve through the chamber wall. It was found that the water should be admitted slowly, otherwise many air bubbles appear from the sherds which can cause severe damage to them. In the early stage of the project, quick evacuation or rapid addition of water caused several sherds to disintegrate completely.

The water valve is turned off when the water is a few centimetres above the sherds. When the pressure reaches 150 Torr, the vacuum pump is turned off. Lower pressures can cause some sherds to break up. The sherds are left to soak thoroughly for one hour. If this final stage is omitted, 1 or 2% less by weight can be obtained for the Standard sherds, in both the recorded Suspended Weight and Wet Weight. After one hour, if no further bubbles are observed, the vacuum is released and the sherds are left under water at atmospheric pressure overnight. This allows further water penetration. At this stage, most of the open pores are filled with water.

The Suspended Weight (W_s) can now be measured. Each sherd is put on a wire cage suspended in a 5 litre beaker of distilled water, to which a few drops of a preparatory wetting agent (Triton) have been added to lower the surface tension. The wire cage is attached to the underside hook of the digital balance through a vibration free bench. The balance is adjusted to zero with the wire immersed in the water. The meter reading is done after the movement of water has ceased. Sherds are placed quickly in a tray filled with distilled water after the measurement of Suspended Weight. The possible error is ±0.9% for this Suspended Weight.

The next stage is to obtain the Wet Weight (W_w) following detachment of the wire cage. Excess surface water is carefully wiped off each sherd with a damp sponge cloth. The sherd is then weighed on the digital balance before too much evaporation takes place. Since archaeological sherds have rough surfaces, particularly in cross section, wiping must be done carefully to remove water from hollows. A large potential error is introduced at this stage. It is always likely to be positive rather than negative, and is adjudged to be up to 0.5%. Grinding of broken sherd sections is recommended if the specimen is not too valuable. In this case, the possible error will be smaller.

The three weights have now been obtained. However, as Matson (1940: 470–1) observed, there is a possibility that some sherds will lose a fraction of their original Dry Weight after they have been soaked in water because of loss of soluble salts initially present in them and derived from the archaeological site. This suggests that it is preferable to determine the Dry Weight after saturation. Therefore, the sherds are dried slowly overnight in a drying room at 28 ° C, and then for a further 24 hours in the Qualtrex oven at 110 ° C.

Most of the sherds show a loss of weight between these two dry weight measurements. This is not only due to loss of soluble salts, but also because of a small degree of damage during the saturation process.

ABSORPTION (%)

The amount of pore space per unit of Dry Weight, expressed as a percentage, is known as Absorption. It can only be used for comparative purposes when the Bulk Specific Gravity of the series is known, since the porosity is calculated as the product of the percent Absorption and the Bulk Specific Gravity (Matson 1937: 108).

$$\text{Water Absorption (\%)} = \frac{W_w - W_d}{W_d} \times 100 \pm 0.8 \qquad (= 2.7\% \text{ error})$$

DENSITY

In ceramic work, the terms True, Apparent, and Bulk Density are used and the relationships between them are as follows.

$$\begin{aligned} \text{Bulk volume} &= V_b \\ \text{Apparent volume} &= V_a \\ \text{True volume} &= V_t \\ \text{Bulk density} &= d_b \\ \text{Apparent density} &= d_a \\ \text{True density} &= d_t \\ \text{Dry weight} &= W_D \end{aligned}$$

Defined:

$$\text{Bulk volume } V_b = V_o + V_c + V_t = \frac{W_D}{d_b}$$

$$\text{Apparent volume } V_a = V_c + V_t = \frac{W_D}{d_a}$$

$$\text{Bulk density } d_b = \frac{W_D}{V_b}$$

$$\text{Apparent density } d_a = \frac{W_D}{W_D - S} = \frac{W_D}{V_t}$$

$$\text{True density } d_t = \frac{W_D}{V_t}$$

$$\text{Volume of closed pores } V_c = \frac{W_D}{d_a} - \frac{W_D}{d_t}$$

Since it is difficult to obtain the True Volume of a solid, only Bulk Density was calculated for this study. Bulk Density is the ratio of the Bulk Volume of a body, which includes all closed and open pores, to an equal volume of water. This property of ceramic bodies is affected inversely by porosity: that is, the more porous a body, the less it will weigh per unit of bulk Volume.

$$\text{Bulk Density (g/cc)} = \frac{W_D}{W_w - W_s} \pm 0.03 \qquad (= 1.9\% \text{ error})$$

SPECIFIC GRAVITY

There are three kinds of specific gravity which can be calculated. The Apparent Specific Gravity is the ratio of the Apparent Volume (which excludes open pores, but includes closed pores), to an equal volume of water. It may be obtained by the following calculation:

$$\text{Apparent Specific Gravity} = \frac{W_D}{W_D - W_s} \pm 0.05 \qquad (= 1.9\% \text{ error})$$

The Bulk Specific Gravity is also known as Bulk Density (see above). The True Specific Gravity is the specific gravity of the solid substance of which the material is composed and is exclusive of all open or closed pores. It is necessary to crush the material to a fine powder and measure the volume with the Picometer to obtain the True Specific Gravity. Only Apparent Specific Gravity was calculated in this study.

POROSITY (%)

There are two kinds of porosity: True Porosity and Apparent Porosity. The Apparent Porosity is the relation between the volume or weight of the mass of an article and the volume or weight of the water absorbed when it is immersed. As the volume of the sealed pores is difficult to determine the True Porosity of a material is seldom considered and the term 'porosity' usually refers to the Apparent Porosity only. The following is the calculation to obtain the Apparent Porosity:

$$\text{Apparent Porosity (\%)} = \frac{W_w - W_D}{W_w - W_s} \times 100 \pm 2.00 \qquad (4.4\% \text{ error})$$

POTTERY ASSEMBLAGES EXAMINED

ASSEMBLAGE 1: REEF ISLAND LAPITA WARE [$N = 29$]

Three sites on the Main Reef Islands in the Santa Cruz Group were excavated by Green in 1970. Pottery from these sites belongs to the Lapita pottery tradition. The oldest radiocarbon date for these sites is 2955 ± 95 B.P.[1]

Roughly one third of the excavated sherds were decorated. The decorative system has been analysed by Donovan (1973). Most of the pottery was manufactured within the Main Reef Islands, while a few exotic tempered sherds are thought to derive from the nearby Santa Cruz Group (Green 1976: 261).

A grab sample of 23 plain sherds was selected from the materials excavated from Layer I of the Nenumbo site on the island of Ngangaua. It is reasonable to assume that the material sampled constitutes a single cultural assemblage.

ASSEMBLAGE 2: BANKS ISLANDS WARE [$N = 33$]

In 1973 Ward carried out excavations in the Banks Islands which are situated between Santa Cruz and Vanuatu (Ward 1979). A major excavation was conducted on Pakea Islet and produced a considerable number of potsherds. Despite a relatively small proportion of decorated pottery (6%), there is a wide range of vessel, rim and lip forms. These sherds are considered to be related to the Mangaasi style pottery from Central Vanuatu in terms of inclusions, construction and finishing techniques and other observations concerning firing and manufacturing condition. The time range of the major occupation (layer L3b) is 2005–2380 B.P. However, this pottery appears up to the present ground surface.

A grab sample of 22 sherds excavated from Pakea Islet and 12 sherds collected from the surface of other islets (two each from Mota, Mota Lava, Gaua and Vanua Lava and four from Rowa) were used for the present study. In view of the range of circumstances of finding these various sherds, we cannot be confident that they represent a single cultural assemblage.

ASSEMBLAGE 3–4: TAUMAKO

An assemblage of pottery was excavated by Leach and Davidson on the Polynesian Outlier of Taumako in the eastern Solomon Islands in 1977–78. Apart from one or two sherds, it appears that this entire assemblage dates between 1950–2950 B.P.

This pottery belongs to an essentially plain ware tradition, although there are rare examples of both dentate stamped and incised decoration. The cultural affinities of the assemblage are still the subject of study, but it may be considered similar to material from other Polynesian outliers such as Anuta. Petrographic study of the assemblage has shown there to be about equal proportions of sherds with andesitic temper and pyroxenic temper. Both these temper types are indigenous to Taumako. A few late sherds have exotic temper and were clearly brought into the island group. These were not included in the present study. This petrological division of the pottery is a convenient basis for distinguishing two sub-assemblages as follows:

- Assemblage 3: Taumako Andesitic ware [$N = 31$]

[1] All radiocarbon dates in this paper refer to the old half life without secular correction.

- Assemblage 4: Taumako Pyroxenic ware [$N = 18$]

ASSEMBLAGE 5–7: NATUNUKU

A sherd-rich site at Natunuku on the north-west coast of Viti Levu, Fiji, was excavated by Shaw in 1966. The excavated sherds are classified mainly into three types—Dentate Stamped and Plain Lapita Ware, Paddle Impressed Ware, and the Incised and Plain Late Ware. The oldest radiocarbon date for the Lapita horizon is 3240±100 B.P. Petrographical analysis revealed two distinct temper types, one certainly indigenous and one possibly foreign (Dickinson 1971).

Three sub-assemblages are as follows; each can probably be considered a discrete cultural assemblage.

- Assemblage 5: Natunuku Lapita Ware [$N = 24$]
- Assemblage 6: Natunuku Paddle Impressed Ware [$N = 4$]
- Assemblage 7: Natunuku Late Incised Ware [$N = 20$]

ASSEMBLAGE 8: SIGATOKA PADDLE IMPRESSED WARE [$N = 11$]

Birks and Birks excavated the Sigatoka Dune Site on south-east Viti Levu in 1965–66 (Birks 1973). Pottery belonging to both the Lapita and an Impressed ware tradition was recovered. The date for the former tradition is about 2450 B.P., while 2050 B.P. is a date for the latter. Only sherds of the Paddle Impressed tradition were available for study. Six rim sherds and five base sherds were selected. Some of these sherds may belong to a single pot.

ASSEMBLAGE 9–14: YANUCA

A large collection of pottery was excavated by Birks and Birks in 1966 from the floor of a rock shelter on Yanuca Island, south-east Viti Levu. This pottery has been classified into three major groups according to decorative method and age. Dentate Stamped Lapita Ware and the associated Plain Ware were found in the earliest period, the estimated age for which is 3100 B.P. The middle period consists of Paddle Impressed Ware and an associated Plain Ware. The Paddle Impressed Ware is further divided into two types based on differences of the design on the paddle—cross hatch and parallel rib. The age for the middle period has been estimated to be 2000–1000 B.P. Only plain sherds from the late period were found, and the age is about 600–200 B.P. The decorative system at this site has been studied by Hunt (1980). Petrographic analysis has shown that the pottery is indigenous (Dickinson 1971: 113).

A grab sample of 98 sherds was selected from these assemblages. They have been classified into the following 6 sub-assemblages according to the criteria mentioned above.

- Assemblage 9: Yanuca Early Lapita Decorated Ware [$N = 15$]
- Assemblage 10: Yanuca Early Plain Ware [$N = 28$]
- Assemblage 11: Yanuca Middle Period Carved-Paddle Impressed (Parallel-rib) Ware [$N = 15$]

- Aemblage 12: Yanuca Middle Period Carved-Paddle Impressed (Cross-hatch) Ware [$N = 15$]
- Assemblage 13: Yanuca Middle Period Plain Ware [$N = 15$]
- Assemblage 14: Yanuca Late Plain Ware [$N = 10$]

Clearly, some of these assemblage distinctions may not denote discrete cultural status. In particular, the plain and decorated sherds could belong to identical pots. It may be advisable to group these assemblages into three: early, middle and late.

ASSEMBLAGE 15–17: LAKEBA

An assemblage of pottery was excavated on Lakeba Island in the Lau Islands, Fiji, by Best and Rogers in 1975–76 (Best 1977). The excavation of a rock-shelter demonstrated a sequence of three major ceramic styles on the island. The early assemblage belongs to the Lapita pottery tradition and has yielded dates ranging from 3000 to 2600 B.P. The Paddle Impressed Ware followed, and has been dated from about 1750 to 1900 B.P. The Late Plain Ware, which has a different mineral content, has been dated between 940 and 600 B.P. Various kinds of analyses on the pottery assemblage have been undertaken by Best, who has since refined the pottery sequence (Best 1984).

Initial petrographic analysis suggested that the sand tempers are indigenous to Lakeba or the Lau group as a whole (Dickinson 1978). A grab sample of 50 sherds was separated (by Best) into three groups according to his initial analysis as follows:

- Assemblage 15: Lakeba Lapita Ware [$N = 30$]
- Assemblage 16: Lakeba Paddle Impressed Ware [$N = 4$]
- Assemblage 17: Lakeba Late Plain Ware [$N = 16$]

Assemblage 16 was so small that it had to be combined with Assemblage 17 in the present study. The combined assemblage must be regarded as mixed.

ASSEMBLAGE 18: MULIFANUA LAPITA WARE [$N = 28$]

A number of potsherds were collected from the Ferry Berth Site at Mulifanua, Upolu, Western Samoa. This site, about 110 m offshore in the lagoon, is submerged under sea water. The sherds were discovered during dredging for the ferry berth.

Pottery from Mulifanua belongs to the Lapita pottery tradition and has been dated to 1000 ± 80 B.P. About 8% of the sherds are decorated (dentate stamped, incised and applique) and have been described by Green (1974). Petrographic study reveals that these sherds are indigenous to Samoa (Dickinson 1974). A grab sample of 28 sherds was selected for the present study, and forms a discrete cultural assemblage.

ASSEMBLAGE 19: VAILELE THICK COARSE WARE [$N = 20$]

The Vailele site in northern Upolu was excavated by Green in 1963–64. The excavated sherds belong to the Polynesian Plain Ware tradition and have been classified into two types—Thin Fine Ware and Thick Coarse Ware, the same as those at the Sasoa'a site.

Radiocarbon dates for this pottery are about 1850 B.P. These sherds are indigenous to Samoa, according to petrographic analysis (Dickinson 1969).

A grab sample of 20 sherds of the Thick Coarse Ware was selected for analysis, and is a tight cultural unit for study.

ASSEMBLAGE 20–21: SASOA'A

A considerable number of pottery sherds were excavated from Sasoa'a, eastern Upolu, by Green in 1967. The two same types of pottery as Vailele were found—Thin Fine Ware and Thick Coarse Ware. The Thin Fine Ware is older than Thick Coarse ware although there is a chronological overlap between the two. The radiocarbon dates suggest that this pottery dates to just before the Christian Era. Two sub-assemblages are as follows:

- Assemblage 20: Sasoa'a Thin Fine Ware [$N = 30$]
- Assemblage 21: Sasoa'a Thick Coarse Ware [$N = 28$]

ASSEMBLAGE 22–23: MARIANA ISLANDS

Takayama carried out surveys and excavations on Rota Island, one of the least disturbed islands in the Marianas, in 1970–71, 1971–72 and 1975. The excavated potsherds from the Muchon site (M-13), situated on the north end of Rota, were classified into two types by the excavator: Marianas Red Ware and Marianas Plain Ware. The date for the earlier type, Marianas Red, was 2590 ± 85 B.P. and for the later type, Marianas Plain, about 1260 ± 80 B.P. (Takayama and Intoh 1976: 21). Petrographic study has revealed that these sherds are indigenous to the Mariana Islands (Dickinson 1977). Two sub-assemblages are as follows:

- Assemblage 22: Marianas Red Ware [$N = 17$]
- Assemblage 23: Marianas Plain Ware [$N = 30$]

ASSEMBLAGE 24–26: YAP ISLAND

The Pemrang site in southern Yap, first excavated by Gifford, was re-excavated by Takayama in 1980 (Takayama 1982a). Three chronological types of pottery were excavated, although considerable overlap was observed. The earliest type, Calcareous Sand Tempered pottery (CST pottery), is characterised by the use of a calcareous sand temper. The earliest date associated with this type of pottery is about 2300 B.P. (Takayama 1982b). The middle type is called Yap Plain pottery and was found mainly between CST pottery and the late type, Laminated pottery, which appeared around 500 B.P. and persisted into the ethnographic period. Plain pottery does not contain calcareous sand and has a loose textured sherd wall. On the other hand, Laminated pottery has very hard walls and shows distinctive lamination in the wall section. No decoration was found on any of the three types. Three sub-assemblages are based on the above classification as follows[2].

- Assemblage 24: Yap Calcareous Sand Tempered Ware [$N = 65$]
- Assemblage 25: Yap Plain Ware [$N = 41$]

[2]The classification of Yapese potsherds in Intoh (1982) was not adequate. They were reclassified in this study and some additional data were included.

- Assemblage 26: Yap Laminated Ware [$N = 30$]

ASSEMBLAGE 27: NGULU ISLAND [$N = 30$]

Ngulu, an atoll situated between Yap and Belau, was investigated by Intoh and Takayama in 1980 (Intoh 1981). Two excavated areas produced a number of sherds. These potsherds are believed to have been imported from nearby high islands, such as Yap and Belau. This is supported by petrographic analysis (Dickinson 1981). This sample must therefore be considered to be a mixed assemblage. The oldest radiocarbon date is 1760 ± 75 B.P.

ASSEMBLAGE 28: BELAU PLAIN WARE [$N = 30$]

A general survey and some test excavations on the Belau islands were undertaken by Takayama and others in 1977–78 (Takayama 1979, Takayama *et al.* 1980). Pottery from Belau is not easily subdivided into distinct categories. Most of the sherds from Belau are plain, although there are a few decorated pieces. As the material available for the present study was mainly from surface collections, the age is not known.

A grab sample of 30 sherds from Belau was selected for this study; this includes 18 from Alptaciel Island, 9 excavated sherds from Kayangel atoll, and 2 from Angaur Island. Although the majority are from surface collections, they may all belong to a single cultural assemblage.

ASSEMBLAGE 29: FEFAN ISLAND CALCAREOUS WARE [$N = 22$]

Pottery was excavated on Fefan island in the Truk group by Shutler and others in 1977 (Shutler *et al.* 1984). These sherds were first discovered during dredging. Although no definite stratigraphy was observed, a radiocarbon date of 2020 ± 85 B.P. was obtained. Petrographic analysis has revealed that these sherds were manufactured in the Truk Islands (Dickinson 1984). A grab sample of 22 sherds were selected. Most of these were obtained as a surface collection from the beach but four were excavated from the TKFE site. There is every reason to believe that they constitute a distinct cultural assemblage.

ASSEMBLAGE 30: NAN MADOL PLAIN WARE [$N = 29$]

The Nan Madol site on Ponape was surveyed and considerable pottery was obtained by Athens in 1979 (Athens 1980). Most of the sherds are plain except for a few rim sherds which have some indentations. The dates for these sherds range from about 750 to 550 B.P.

RESULTS AND DISCUSSION

The results of Percentage Water Absorption are highly correlated with Apparent Porosity ($r = 0.98$). This is predictable, because they are after all very similar characteristics. Bulk Density however, shows up different features of pottery than the results for Apparent Porosity. Considerable differences were observed in the South Pacific assemblages, while relatively similar ranges were obtained for the North Pacific assemblages. It is hard to detect any systematic tendencies amongst the southern assemblages.

An analytical description of porosity values obtained in the Water Absorption test is given below. Because this is a pilot study of physical properties of Pacific pottery, the description is specific rather than general.

The porosity of Pacific pottery ranges fairly widely and is quite distinctive (Appendix 1). A comparison of the porosity range of Pacific potteries with ancient ceramics from several other parts of the world is given in Figure 2. It can be seen that the upper values of Pacific pottery are higher than those of even the porous pottery of American Indians (the so called 'Biscuit Ware' of Shepard 1956); but even the highest Pacific figures are lower than those of the Armant Ware in Egypt. The overall range of Pacific potteries is very broad, comparable to that of Japanese Jomon pottery.

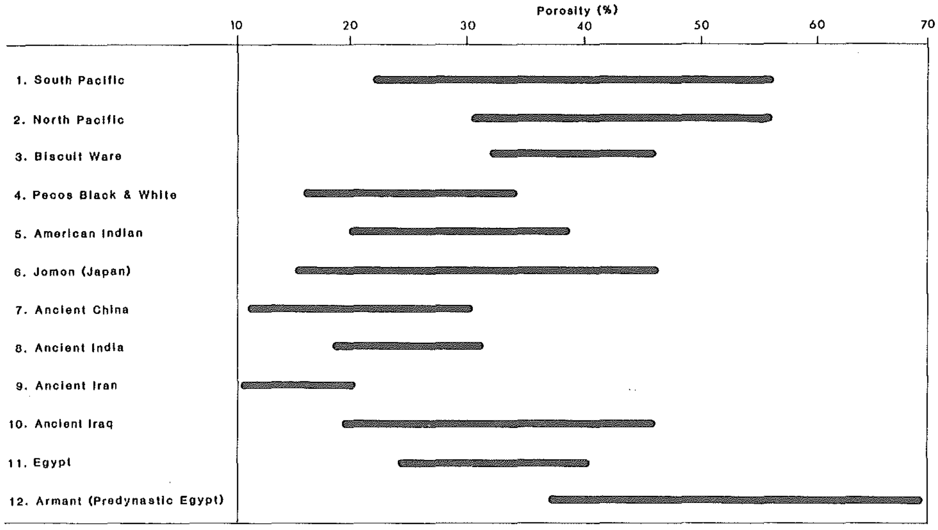

Figure 2: Porosity ranges of various pottery assemblages. Data for 3, 4 from Shepard (1956: 128); 5, 10, 11 from Matson (1940: 472); 6, 7 from Eto (1963: 33); 8 from Rawat (1975: 27); 9 from Hammond (1971: 16); 12 from Matson (1940: 475).

Amongst southern potteries, the upper values of the Lapita sherds from the Reef Islands show the highest porosity; however, the other Lapita assemblages such as Yanuca, Natunuku, Lakeba, and Mulifanua are not as high as the Reef Islands material (see Figure 3 for the results). Even the Sasoa'a Thin Fine Ware shows a higher value than that of these other Lapita assemblages. It must be noted that Sasoa'a Thin Fine Ware and Thick Coarse Ware have very different porosity values. Sasoa'a Thick Coarse Ware is much lower than Thin Fine Ware, probably because of the mixture of large grains used as temper. This is a clear indication that pottery tempered with fine grains is more porous than coarse grained pottery.

The six assemblages from Yanuca show very similar ranges for each period. The Early Lapita assemblages have wider porosity ranges as well as lower overall values than the later periods. Hardly any difference can be observed between the Middle and Late Period material. One extremely low porosity measurement was obtained for a sherd from the late assemblage of Lakeba. The result, 9%, was incredibly low. The measurements were repeated twice with near identical results. This piece of pottery was identified by Best as an imported sherd (Best 1982, pers. comm.). A dotted line beyond the rest of the range for this assemblage is therefore used for this sherd in Figure 3.

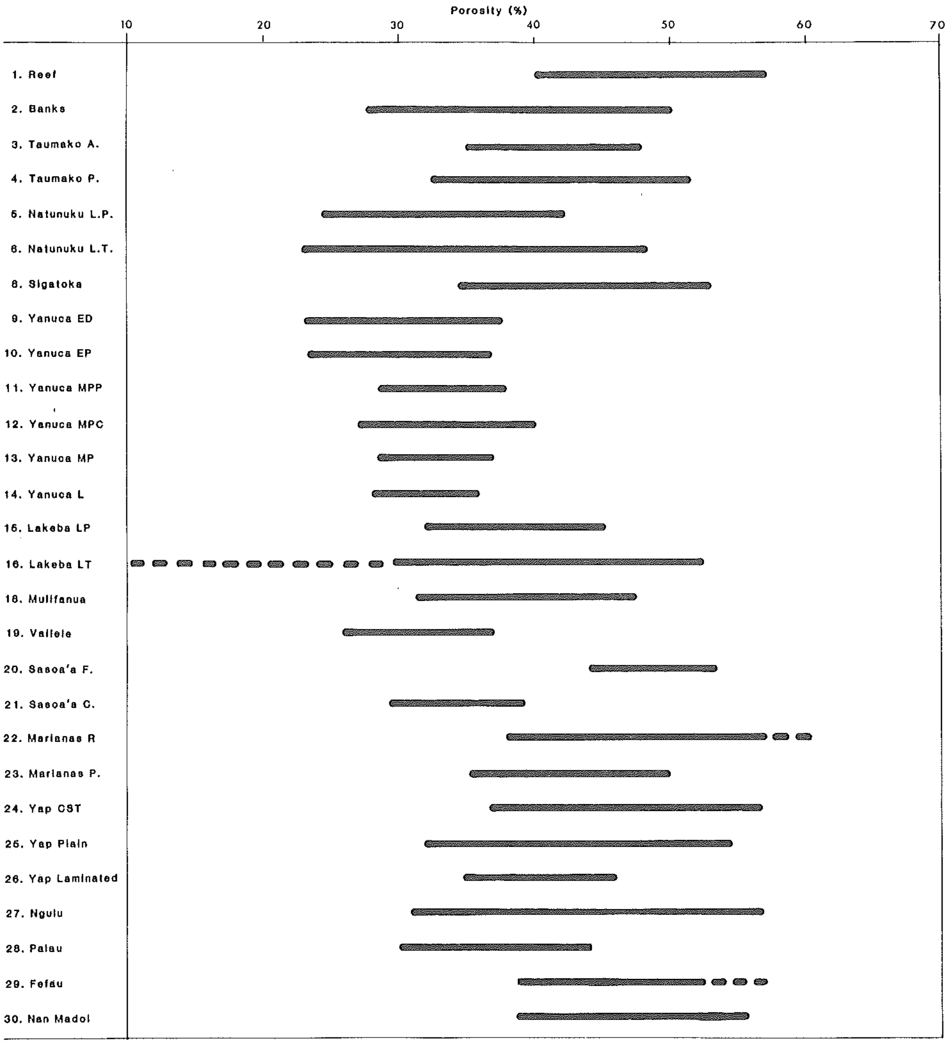

Figure 3: Porosity ranges for assemblages of Pacific Island pottery. See the text for discussion of the very low results for one sherd from Lakeba indicated by the dashed line. In each assemblage, the mean value is indicated by the vertical line. Results for Fefan Island and Marianas Red are believed to be low (see text). This is shown by dashed lines.

In the North Pacific, Marianas Red Ware has the highest overall porosity values, and Yap CST Ware and Yap Plain Ware also have high porosity values. On the whole, most of the North Pacific potteries have a higher porosity variation than the South Pacific assemblages.

The range of variation of the mixed assemblage from Ngulu is very wide and encompasses the range of material from both Belau and Yap. The porosity of the Fefan Island assemblage may be a little low, because the friable sherds (which might have had higher porosity) were not examined.

It was not possible to investigate the range of porosity which might be found within individual pots, but this is something which should be explored in future. Ethno-archaeological data suggest that the highest temperature is achieved at the base part of the pot (for example, see Irwin 1977: 230–62). If the pottery was fired near the temperature at which clay begins vitrification, then the higher temperature around the base might result in a lower porosity there than in other parts of the same pot.

Change in porosity values provides significant information on technological development in tempering, shaping and firing. For example, the use of material which burns out in firing can control the porosity of the pottery. Also, the porosity of the pottery fired in a higher firing temperature tends to be smaller than that of the pottery fired in a lower firing. Examining the porosity value of archaeological potsherds is therefore important in the study of prehistoric pottery technology (e.g., Intoh 1987, n.d.). It is hoped that the method of water absorption test described in this study will become standard in future studies of Pacific pottery.

APPENDIX 1
APPARENT PORORITY RESULTS OF THE PACIFIC POTTERY ASSEMBLAGES

Assemblage 1: Reef Islands Lapita

N	=	29
Mean	=	45.746 ± 0.754
Standard Deviation	=	4.062 ± 0.533
Coefficient of Variation	=	8.880 ± 1.166

Assemblage 2: Banks Islands Ware, Vanuatu

N	=	33
Mean	=	38.395 ± 1.087
Standard Deviation	=	6.247 ± 0.769
Coefficient of Variation	=	16.270 ± 2.003

Assemblage 3: Taumako Andesitic Ware, Solomons

N	=	31
Mean	=	40.084 ± 0.525
Standard Deviation	=	2.922 ± 0.371
Coefficient of Variation	=	7.290 ± 0.926

Assemblage 4: Taumako Pyroxenic Ware, Solomons

N	=	18
Mean	=	38.484 ± 1.092
Standard Deviation	=	4.632 ± 0.772
Coefficient of Variation	=	12.037 ± 2.006

Assemblage 5: Natunuku Lapita Ware, Fiji

N	=	24
Mean	=	34.456 ± 0.876
Standard Deviation	=	4.290 ± 0.619
Coefficient of Variation	=	12.451 ± 1.797

Assemblage 6: Natunuku Paddle Impressed Ware (4) and
Assemblage 7: Natunuku Late Incised Ware (20)

N	=	24
Mean	=	29.054 ± 0.947
Standard Deviation	=	4.637 ± 0.669
Coefficient of Variation	=	15.960 ± 2.304

Assemblage 8: Sigatoka Paddle Impressed Ware, Fiji

N	=	11
Mean	=	38.600 ± 1.630
Standard Deviation	=	5.405 ± 1.152
Coefficient of Variation	=	14.003 ± 2.985

Assemblage 9: Yanuca Early Lapita Decorated Ware, Fiji

N	=	15
Mean	=	29.098 ± 1.147
Standard Deviation	=	4.441 ± 0.811
Coefficient of Variation	=	15.261 ± 2.78

Assemblage 10: Yanuca Early Plain Ware, Fiji

N	=	28
Mean	=	30.811 ± 0.591
Standard Deviation	=	3.129 ± 0.418
Coefficient of Variation	=	10.155 ± 1.357

Assemblage 11: Yanuca Middle Period Carved-Paddle
Impressed (Parallel-Rib), Fiji

N	=	15
Mean	=	32.463 ± 0.837
Standard Deviation	=	3.243 ± 0.592
Coefficient of Variation	=	9.990 ± 1.824

Assemblage 12: Yanuca Middle Period Carved-Paddle
Impressed (Cross-Hatch), Fiji

N	=	15
Mean	=	32.506 ± 0.754
Standard Deviation	=	2.922 ± 0.533
Coefficient of Variation	=	8.988 ± 1.641

Assemblage 13: Yanuca Middle Period Plain Ware, Fiji

N	=	15
Mean	=	32.558 ± 0.627
Standard Deviation	=	2.427 ± 0.443
Coefficient of Variation	=	7.453 ± 1.361

Assemblage 14: Yanuca Late Plain Ware, Fiji

N	=	10
Mean	=	32.081 ± 1.072
Standard Deviation	=	3.390 ± 0.758
Coefficient of Variation	=	10.569 ± 2.363

Assemblage 15: Lakeba Lapita Ware, Fiji

N	=	30
Mean	=	37.066 ± 0.597
Standard Deviation	=	3.271 ± 0.422
Coefficient of Variation	=	8.826 ± 1.139

Assemblage 16: Lakeba Paddle Impresed Ware, Fiji
Assemblage 17: Lakeba Late Plain Ware, Fiji

N	=	20
Mean	=	34.077 ± 1.677
Standard Deviation	=	7.498 ± 1.186
Coefficient of Variation	=	22.004 ± 3.479

Assemblage 18: Mulifanua Lapita Ware, Samoa

N	=	28
Mean	=	37.435 ± 0.847
Standard Deviation	=	4.483 ± 0.599
Coefficient of Variation	=	11.976 ± 1.600

Assemblage 19: Vailele Thick Coarse Ware, Samoa

N	=	20
Mean	=	32.215 ± 0.589
Standard Deviation	=	2.635 ± 0.417
Coefficient of Variation	=	8.179 ± 1.293

Assemblage 20: Sasoa'a Thin Fine Ware, Samoa

N	=	30
Mean	=	48.809 ± 0.302
Standard Deviation	=	1.657 ± 0.214
Coefficient of Variation	=	3.394 ± 0.438

Assemblage 21: Sasoa'a Thick Coarse Ware, Samoa

N	=	28
Mean	=	34.934 ± 0.492
Standard Deviation	=	2.603 ± 0.348
Coefficient of Variation	=	7.452 ± 0.996

Assemblage 22: Marianas Red Ware, Mochong, Rota

N	=	17
Mean	=	48.456 ± 1.311
Standard Deviation	=	5.407 ± 0.927
Coefficient of Variation	=	11.160 ± 1.914

Assemblage 23: Marianas Plain Ware, Mochong, Rota

N	=	30
Mean	=	42.509 ± 0.682
Standard Deviation	=	3.736 ± 0.482
Coefficient of Variation	=	8.789 ± 1.135

Assemblage 24: CST Ware, Pemrang, Yap

N	=	65
Mean	=	48.232 ± 0.385
Standard Deviation	=	3.103 ± 0.272
Coefficient of Variation	=	6.433 ± 0.564

Assemblage 25: Yapese Plain Ware, Pemrang, Yap

N	=	52
Mean	=	44.272 ± 0.600
Standard Deviation	=	4.327 ± 0.424
Coefficient of Variation	=	9.774 ± 0.958

Assemblage 26: Laminated Ware, Pemrang, Yap

N	=	29
Mean	=	40.129 ± 0.595
Standard Deviation	=	3.202 ± 0.420
Coefficient of Variation	=	7.980 ± 1.048

Assemblage 27: Ngulu Island Ware

N	=	30
Mean	=	43.531 ± 1.237
Standard Deviation	=	6.774 ± 0.874
Coefficient of Variation	=	15.561 ± 2.009

Assemblage 28: Palau Plain Ware

N	=	30
Mean	=	38.696 ± 0.619
Standard Deviation	=	3.389 ± 0.437
Coefficient of Variation	=	8.757 ± 1.130

Assemblage 29: Fefan Island Calcareous Ware, Truk

N	=	22
Mean	=	45.443 ± 0.719
Standard Deviation	=	3.373 ± 0.509
Coefficient of Variation	=	7.423 ± 1.119

Assemblage 30: Nan Madol Plain Ware, Ponape

N	=	29
Mean	=	46.597 ± 0.815
Standard Deviation	=	4.391 ± 0.577
Coefficient of Variation	=	9.424 ± 1.237

ACKNOWLEDGEMENTS

I would like to express my sincere appreciation to Foss for his enthusiastic guidance and the discussions I had with him throughout my postgraduate study at Otago. What I have learned from him is beyond archaeology. He opened the door to the world of 'archaeological science'. The new world was full of unfamiliar technological terms which annoyed me at first. This world was, however, soon recognised as attractive and significant. I will make sure I do the same for my students in Japan. I am also indebted to Janet Davidson who has been helpful in many ways. Her constructive comments and skilled editorship have always been provided whenever needed and improved my writing. I look forward to their continuing active involvement in Pacific archaeology.

Many archaeologists provided valuable potsherds for the research. Appreciation goes to Roger Green, Janet Davidson, Graeme Ward, Foss Leach, Elizabeth Hinds (nee Shaw), Lawrence Birks, Simon Best, Jun Takayama, Yosihiko Sinoto and Steve Athens.

REFERENCES

Athens, J. S. 1980. Pottery from Nan Madol, Ponape, Eastern Caroline Islands. *Journal of the Polynesian Society* 89: 95–99.

Best, S. 1977. Archaeological investigations on Lakeba, Lau group, Fiji. *New Zealand Archaeological Association Newsletter* 20: 28–38.

Best, S. 1984. Lakeba: the prehistory of a Fijian island. Ph.d. dissertation, Anthropology Department, University of Auckland.

Birks, L. 1973. Archaeological excavations at Sigatoka dune site, Fiji. *Bulletin of the Fiji Museum* 1.

Bradfield, W. 1931. *Cameron Creek Village, a site in the Mompres area in Great Country, New Mexico.* Santa Fe, The School of American Research.

Butterworth, B. 1948. *Bricks and Modern Research.* London, Crosby Lockwood and Son.

Dickinson, W. R. 1969. Temper sands in prehistoric potsherds from Vailele and Falefa, Upolu. *In* R. C. Green and J. M. Davidson (eds), Archaeology in Western Samoa, Volume 1, pp. 271–3. *Bulletin of the Auckland Institute and Museum* 6.

Dickinson, W. R. 1971. Petrography of some sand tempers in prehistoric pottery from Viti Levu, Fiji. *Fiji Museum Records* 1: 107–21.

Dickinson, W. R. 1974. Temper sands in sherds from Mulifanua and comparison with similar tempers at Vailele and Sasoa'a (Falefa). *In* R. C. Green and J. M. Davidson (eds), Archaeology in Western Samoa, Volume 2, pp. 179–80. *Bulletin of the Auckland Institute and Museum* 7.

Dickinson, W. R. 1977. Tempers in sherds from Rota in the Marianas. Petrographic Report, WRD-67.

Dickinson, W. R. 1978. Sand tempers in sherds from Lakeba. Petrographic Report, WRD-72.

Dickinson, W. R. 1981. Temper sands from prehistoric sherds excavated at Pemrang site on Yap and from nearby Ngulu Atoll. Petrographic Report, WRD-79.

Dickinson, W. R. 1984. Indigenous and exotic sand tempers in prehistoric potsherds from the Central Caroline Islands. *In* Y. H. Sinoto (ed.), Caroline Islands archaeology: investigations on Fefan, Faraulep, Woleai, and Lamotrek, pp. 131–5. *Pacific Anthropological Records* 35.

Donovan, L. J. 1973. A study of the decorative system of the Lapita potters in the Reef and Sand Cruz Islands. M.A. thesis, Department of Anthropology, University of Auckland.

Eto, M. 1963. Firing temperature of Jomon pottery. *Journal of the Anthropological Society of Nippon* 71: 23–51. (In Japanese with English Summary).

Green, R. C. 1974. Pottery from the lagoon at Mulifanua, Upolu. *In* R. C. Green and J. M. Davidson (eds), Archaeology in Western Samoa, Volume 2, pp. 170–5. *Bulletin of the Auckland Institute and Museum* 7.

Green, R. C. 1976. Lapita sites in the Santa Cruz group. *In* R. C. Green and M. Cresswell (eds), Southeast Solomon Islands cultural history, pp. 245–65. *Royal Society of New Zealand Bulletin* 11.

Grimshaw, R. W. 1971. *The chemistry, physics of clays and other ceramic materials.* New York, Wiley-Interscience.

Hammond, P. C. 1971. Ceramic technology of South West Asia, Syrio-Palestine: Iron IIb, Hebron. *Science and Archaeology* 5: 11–21.

Hunt, T. L. 1980. Towards Fiji's past: archaeological research on southwestern Viti Levu. M.A. thesis, Department of Anthropology, University of Auckland.

Intoh, M. 1981. Reconnaissance archaeological research on Ngulu Atoll in the Western Caroline Islands. *Asian Perspectives* 24: 69–80.

Intoh, M. 1982. The physical analysis of Pacific pottery. M.A. thesis, Department of Anthropology, University of Otago.

Intoh, M. 1987. Environment and technological adaptation. A case study of Yapese ceramic change. Paper presented at Micronesian Archaeology Conference, Guam.

Intoh, M. n.d. Changing prehistoric Yapese pottery technology: a case study of adaptive transformation. Ph.d. dissertation, Anthropology Department, University of Otago.

Intoh, M. and Leach, F. 1981. Physical analysis of Kapingamarangi pottery. *In* F. Leach and G. Ward, *Archaeology of Kapingamarangi Atoll*, pp. 136–7. Dunedin, privately published by B. F. Leach.

Irwin, G. J. 1977. The emergence of Mailu as a central place in the prehistory of Coastal Papua. Ph.d. dissertation, Australian National University.

Matson, F. R. Jr. 1937. Pottery. Appendix A. *In* E. F. Greenman, The Young site. *Occasional contributions from the museum of anthropology of the University of Michigan* 6: 99–124.

Matson, F. R. Jr. 1940. Porosity studies of ancient pottery. *Papers of the Michigan Academy of Science, Arts and Letters* XXVI: 469–77.

Myers, O. H. and C. A. Earnshaw 1937. A Saharan culture. Chapter XVII. *In* Sir R. Mond, and O. H. Myers, Cemeteries of Armant I. *Memoirs of the Egyptian Exploration Society* 42.

Rawat, N. W. 1975. Porosity studies of ancient Indian pottery excavated at Kausambi. *Chemical Era* 11: 26–8.

Shepard, A. O. 1936. The technology of Pecos Pottery. *In* A. V. Kidder and A. O. Shepard, *The Pottery of Pecos II*. Papers of the Philips Academy Southwestern Expedition, 7. New Haven, Yale University Press.

Shepard, A. O. 1956. *Ceramics for the archaeologist*. Carnegie Institution of Washington, Publication 609, Washington D.C.

Shutler, R. Jr., Y. H. Sinoto and J. Takayama, 1984. Preliminary excavations of Fefan Island sites, Truk Islands. *In* Y. H. Sinoto (ed.), Caroline Islands archaeology: investigations on Fefan, Faraulep, Woleai, and Lamotrek, pp. 1–64. *Pacific Anthropological Records* 35.

Sinoto, Y. H. (ed.) 1984. Caroline Islands archaeology: investigations on Fefan, Faraulep, Woleai, and Lamotrek. *Pacific Anthropological Records* 35.

Takayama, J. 1979. Archaeological investigation of PAAT-2 in the Palaus. An interim report. *In* H. Kusakabe (ed.), *Report. Cultural anthropological research on the folk culture in the Western Caroline Islands of Micronesia in 1977*. Committee for Micronesian Research, Tokyo University of Foreign Studies.

Takayama, J. 1982a. A brief report on archaeological investigations of the southern part of Yap Island and nearby Ngulu atoll. *In* M. Aoyagi (ed.), *Islanders and their outside world*, pp. 77–114. Tokyo, St. Paul's University.

Takayama, J. 1982b. Archaeological research in Micronesia during the past decade. *Bulletin of Indo-Pacific Archaeology Association* 3: 95–114.

Takayama, J. and M. Intoh 1976. Archaeological excavation of Latte site (M-13), Rota, in the Marianas. *Reports of Pacific Archaeological Survey* 4. Sapporo, Tokai University.

Takayama, J., M. Intoh and H. Takasugi 1980. The brief archaeological survey on Kayangel and Angaur in the Palaus. *Reports of Pacific Archaeological Survey* VII.

Ward, G. K. 1979. Prehistoric settlement and economy in a tropical small island environment: the Banks Islands, insular Melanesia. Ph.d. dissertation, Australian National University.