KEEPING YOUR TEMPER UNDER CONTROL:
MATERIALS AND THE MANUFACTURE OF PAPUAN POTTERY

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INTRODUCTION

A BASIC assumption of traditional archaeological analysis of pottery has been cultural determinism: that the nature of a pottery vessel is dictated by cultural pressures, so that forms, decorations and functions reflect cultural learning and that classification of these characteristics of pottery corresponds to a cultural classification. In Melanesia, Golson (1971) and Garanger (1971) exemplify this approach to the study of prehistoric pottery, where the analysis is based essentially on vessel forms and decorative styles; and probable functional types. When these variables are appropriately defined this type of data is amenable to statistical analysis.

While the value of such analysis is not in question, it cannot provide any assessment of the potter's (and indirectly the culture's) relationship with his or her environment. The potter is a user of natural materials, and has to know which materials to select and how to use them. Each pottery vessel reflects decisions made about materials and techniques as well as cultural choices, and thus represents a combination of many variables which may be useful in archaeological interpretation.

It can be argued that specific materials and techniques are selected by cultural pressures, especially in the case where potters carry on an hereditary craft unmodified, and that materials can be modified or selected to suit techniques and functional requirements, but such arguments are not valuable unless supported by data delineating the practical limitations of material use — the 'environmental' criteria. If technological constraints can be identified then we move further to understanding why potters have used specific materials and methods, and also why some vessels may be 'superior' to others.

Arnold (1971) has discussed the relationship between the etic approach to the understanding of pottery materials, depending upon: 'the phenomenal distinctions judged appropriate by the community of scientific observers' (Harris, quoted by Arnold, *ibid.*) and considered as: 'cross cultural, external, absolute (measurable directly) and preliminary' (Arnold 1971:22); and the emic approach, which: 'views behaviour in terms of a culturally specific system which

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requires the inclusion of criteria relevant to the internal function of the system' (ibid.) The emic units applicable to a specific culture must be discovered within that culture by determining phenomenal distinctions made by the people involved, and hence for studies in prehistory are recoverable only by observation of etic patterns within artefacts (or through ethnographic analogy). For example, consistent use of specific minerals as pottery temper may be observed in sherds. Technological reasons for use of this mineral can be sought at the etic level; and by implication at the emic level it can be concluded that potters were selectively using this mineral rather than others available as a result of cultural learning.

Arnold's approach was to use an ethnographic study of a specific group of potters, to recover their emic framework; and to then relate this to laboratory studies of materials to establish the etic correlations. This approach had an advantage over more common approaches to prehistoric pottery materials in that it offered the possibility of explaining material use at the etic level and thus deriving soundly based emic hypotheses for some aspects of cultural behaviour. Previous approaches to material use have tended to be descriptive, not attempting to determine why specific materials and processes have been used, but instead merely determining that they have and then using this data to test hypotheses of relationships between cultures such as contact through trade.

Studies of the materials used by potters have not been lacking in archaeology. The pioneering work of Shepard (1971) in the 1930s, using thin sections made from pottery sherds, provided a method which is now very widely used. By noting the type, size and shape of mineral inclusions in the pottery sherds, it is possible to deduce the geological origins of the inclusions, to decide whether they are naturally present or have been added by the potter, and often to then pinpoint the specific location of the source of the pottery materials. This data can then be used to evaluate trade and distribution of pottery. Other analytical techniques such as X-ray fluorescence, neutron activation, and optical spectroscopy, reveal partial chemical compositions of pottery sherds. Comparison of these partial compositions with those of likely source materials can again point to sources, and be used to study trade and distribution patterns. Classic analyses of this type were used to study the distribution of, and differences between, Minoan and Mycanaean pottery (Castling, Richards and Blin-Stoyle, 1963; Millet and Catling 1967).

Applied to the prehistoric context, ethnographic studies may suggest general resource surplus or deficiency relative to population size, and thus account for trading on this basis. In one such ethnographic study, Groves (1960) noted that the Motu of Papua had recurrent food shortages which were overcome by using their plentiful clay resources to produce pots which they traded for food. It is certain that such supply and demand pressures can account at least partially
for prehistoric trade. For some technologies it is possible to account for trade on the basis of demonstrably superior materials; for example, the obsidian trade in Melanesia (Ambrose: in press). Obsidian occurs naturally in very few locations in Melanesia but has been very widely traded, over distances as great as 2500 km from its source.

With pottery, however, etic data allowing recognition of superior materials and techniques is not available. Descriptive studies of materials such as those referred to above do not provide reasons for using specific materials in ceramic technological terms. Why does a potter use one clay or temper as opposed to others which are available? This can only ever be partially answered at the emic level because the reasons for using a specific material are not always technological. A potter may use clay X which he knows to be inferior, because the owner of land on which superior clay Y is found charges too high a price for clay Y, as in the Amphlett Island case referred to by Lauer (1974:143). A potter may use a specific temper not realizing that another material which is easily available would be technologically more desirable. These reasons are not recoverable archaeologically. What are recoverable are patterns of material use at the etic level. If similar specific materials are used by potters widely separated in time and space we can ask: 'what technological advantages do these materials offer when used to make vessels of x function by y technique?'. If answers to this question can be found then we are beginning to understand strategies adopted by the potter in using his material environment. This in turn will provide a better control over the analytical techniques employed by archaeologists dealing with ceramics. For example, it may provide direction for the selection of new typological traits to be analysed. Conversely it may lead to the exclusion of other traits which emerge as culturally meaningless.

The aim of the present study is to provide etic data which will advance some basic principles of material use by potters — more specifically, the paper investigates the theoretical advantages of using calcite as a tempering material for low-fired, unglazed cooking pots, and attempts to determine experimentally whether using seawater with, or adding salt to these calcite bodies has any technical advantage. The study also examines some problems faced in making cooking pots, and strategies of material use which potters can adopt in overcoming these problems.

Theoretical Considerations

Reasons for Tempering

In the Melanesian context it is extremely unlikely that tempering practice is correlated with forming techniques used to make vessels. Two widely used elements of forming technique used in Melanesia are coiling, and paddle-and-anvil. Data reported by Tuckson in fieldwork in Papua New Guinea (Tuckson 1966; Tuckson and May 1975; and pers. comm.) show that some potters
(at Wanigela, Markham Valley, Watut, Lae, Goodenough Island, Bosman, Orokaiva, and possibly other localities) commence forming vessels by coiling and then complete the form using a paddle-and-anvil technique. Thus it cannot be assumed that coiling and paddle-and-anvil techniques are alternative but equivalent forming processes. In reality, coiling is a beginning process, a method of achieving the initial form of a vessel, which is then completed to its final form by another process; whereas the paddle-and-anvil technique is essentially a finishing process, used to complete the form of a vessel which has been given its initial shape by some other technique. Thus it is to be expected that a widely used initial technique and a widely used finishing technique would come together in some localities in Melanesia.

The fact that both techniques are combined in some localities indicates that clay bodies which have appropriate workability for coiling also have appropriate workability for the paddle-and-anvil technique. Thus the reasons for tempering versus not tempering are not correlated with forming techniques alone.

‘Tempering’ as the term is used in archaeological literature, is the mixing of additives (including other clays) with clay to produce a body for pottery making. Properties of a body (mixture of materials used to form vessels) of importance to a potter are: workability, such that on one hand the clay is not too ‘fat’ and sticky, or on the other too lean, tending to crack when pressure is applied to it; shrinkage, the extent to which a clay contracts on drying — if shrinkage is too high uneven drying can lead to cracking of vessels both before and after firing. Note that clay normally shrinks also on firing, but according to Searle and Grimshaw (1959:726) the effect of sand additions on firing shrinkage is negligible at firing temperatures below 800°C; firing behaviour, which often in traditional pottery making where open fires are used implies the ability of the pot to withstand a very rapid heating and cooling cycle; and fired properties, essentially the physical characteristics of the fired fabric which are best suited to the intended function of the vessel. In my experience these four major properties are well known to traditional potters, as best witnessed by the fact that even the most remote and unsophisticated potters of Pakistan today include in their vocabulary words for these properties (Rye and Evans: in press) and have criteria by which variations in the properties can be recognized and, to a lesser extent, controlled. It is unreasonable not to assume that prehistoric potters achieved at least this level of sophistication in ceramic technology. Thus to the potter tempering is seen as a way of modifying the properties of materials to produce known physical results, that is, to vary workability, drying shrinkage, firing behaviour and fired properties. This can be taken as axiomatic for all potters, whereas the particular strategy adopted in specific cases can be considered as the result of the interplay of two determinants: available material resources, and the transmitted knowledge of earlier generations. The procedure adopted in any specific case will not necessarily
be the 'best' ceramic technological answer, but a study of these procedures will give prehistorians an insight into the potters' cultural-material environment.

Firing Traditional Pottery

The processes taking place when pottery is fired may now be reviewed briefly. Changes in apparent porosity, true porosity and bulk density, with temperature, are shown in Figure 1. A recent paper by Hill (1975) provides a more detailed summary of changes in clays as they are dried and fired.

Before a vessel is fired it is completely dried to equilibrium with the

![Graph](image_url)

Figure 1—Effect of increasing temperature on apparent porosity (1), true porosity and bulk density of an hypothetical ceramic body. The second apparent porosity curve (apparent porosity 2) represents changes which are more typical of Papuan pottery bodies used in the present experiments. Appearance of pore structure at various temperatures is shown schematically at the bottom.
surrounding air. If the air is humid a certain quantity of free water (interstitial water) will remain, filling some of the spaces between clay and other mineral particles, but most of these spaces will be filled with air thus giving a certain apparent porosity (volume of interconnected pore spaces). As the vessel is heated (and note that many potters preheat vessels before firing), the remainder of this interstitial water will be driven off. From the temperature at which firing begins there is thus a slight increase in apparent porosity up to the temperatures where decomposition of the clay minerals begins. This decomposition involves loss of the hydroxyl water which forms part of the clay crystalline structure. For individual clay minerals this decomposition occurs over a temperature range; for example kaolinite begins to decompose at about 415°C (Searle and Grimshaw 1959:567) but at this temperature the reaction is very slow; at 550°C there is complete loss of the hydroxyl water in 30 minutes. Temperatures of rapid decomposition for clay minerals are: hydrous mica (illite) 550°C; halloysite 558°C; kaolinite 585°C; montmorillonite 678°C; muscovite mica 856°C (Searle and Grimshaw 1959:567). These temperatures would be expected to vary somewhat according to crystalline modifications and firing conditions.

After this loss of hydroxyl water from the clay minerals, the maximum apparent porosity occurs, and is retained to about 800°C. This summarizes the processes occurring in the firing of most 'primitive' pottery where the maximum temperature ranges between 600°C-900°C. The firing of this type of pottery is usually dependent on the reactions involving loss of the hydroxyl water in the clay minerals, such that a sintered (bonded at grain boundaries by solid state diffusion reactions) mass of amorphous residue is formed from the clay mineral. At ordinary temperatures and pressures this structure is stable, as witnessed by the durability of buried sherds; and the plastic nature of the original clay cannot be regained.

The porosity at this stage is contributed mainly by open and interconnected pores so the ware is permeable to water and other fluids. If the pottery is fired to higher temperatures glass begins to form in the process known as vitrification. Glass can begin to form at very low temperatures (say 700°C) but most commonly vitrification does not begin extensively until about 900°C-950°C. As vitrification becomes extensive the increasing surface tension of the glass allows it to form around some of the open pores, closing them off and thus decreasing apparent porosity. The fabric of the ware becomes more densely packed and thus bulk density increases. If the temperature continues to rise these processes can eventually lead to the almost complete absence of open and interconnected pores, thus giving an apparent porosity close to zero, while the quantity of closed pores has increased proportionately. These closed pores contain gases (for example, CO₂, CO, SO₂, SO₃, air, water vapour, unburned hydrocarbons, and O₂). As the temperatures increase the pressure of these
gases also increase; at the same time the glass is becoming less viscous (more fluid). These two factors combine to cause an expansion in the size of the closed pores, and in extremes large blisters can form on the surface and in the walls of a vessel. This is known as 'bloating' and is characteristic of overfiring in traditional ceramics; it is usually associated with extensive warping and distortion of vessels. In extremes sufficient glass may form for a vessel to 'flow' at high temperatures. For traditional ceramics this would only occur at temperatures over say 1100°C-1200°C, well above the range for vessels fired in an open fire where the temperatures effectively never exceed 950°C-1100°C. So in summary, for traditional ceramics the lowest point at which firing can occur is above the temperature of decomposition of the clay minerals present (generally above about 600°C but dependent on the types of clay minerals present), and overfiring cannot occur in the temperature range achieved in an open fire.

Despite this, many other problems can develop in firing, many of which can result in irreparable damage to a vessel. For example, the interstitial water being driven off at low temperatures (below about 100°C) must be able to escape through open pore and capillary networks. Some fine grained or densely packed clays cannot allow the water to escape quickly enough and steam forms with sufficient pressure to fracture the vessel. Similarly, too rapid heating with some clay mineral types can result in a network of fine cracks, often with 'hexagonal' structure, appearing on the walls and especially the outer surface of vessels. This problem seems to be aggravated when the fabric is very densely packed, such as when the vessel has been formed using a paddle-and-anvil technique. It is very common, for example, on vessels made at Boera, near Port Moresby. Other problems may arise when salts or minerals in the clay expand or decompose very rapidly, creating pressures which cannot be accommodated by the fabric at low temperatures.

Firing temperature can be measured in the ethnographic situation, using simple equipment (thermocouples and pyrometer). For prehistoric sherds various methods of assessing the original firing temperature are available, of which the most accurate is to use a dilatometer to measure thermal expansion (Roberts 1963; Tite 1969). Because of variations in the original firings, many samples from a homogeneous class of sherd need to be tested in order to determine the firing range.

Potters in Papua New Guinea use vegetable fuels for their firing; for example the Mailu Island potters use the ends of coconut midribs (rhachis), which otherwise would be waste material of no value. This use of waste material as fuel may be typical of prehistoric potters also (Matson 1966:152). Considered in relation to other uses of fire (metallurgy, glassmaking, high temperature ceramics) New Guinea firing technology must be considered only at the beginnings of pyrotechnology (Wertime 1973) but in relation to a specific local technology the potters achieve a level of sophistication in their firing
techniques, which provide good control within the narrow limits imposed by their total technology.

Functional Considerations

Two fundamental vessel types in all pottery using cultures are the cooking pot, and the water storage vessel, both vessels serving universal human needs. In contemporary societies where traditional pottery is being replaced by vessels of other materials such as aluminium, plastic and iron, it is usual that these two vessel types are the last to survive (Rye and Evans, in press, as example). There are good reasons for this: a porous water storage pot allows water to slowly permeate to the outer surface and evaporate in hot climates, thus providing pleasantly cool drinking water. Earthenware cooking pots accumulate a deposit of food residues, particularly in the pores, which people often say gives food a better flavour than when prepared in metal vessels (Groves 1960:10). In Papua New Guinea this view is maintained particularly by people who eat sago, and in several areas sago is still prepared in earthenware pots while other cooking is done in aluminium containers. Thus in pottery using societies we see archaeologically non-recoverable reasons for the perpetuation of the use of a specific technology.

In terms of physical properties, water pots and cooking pots are required to have differing properties related strictly to their function. These properties may be briefly summarized:

**Water Pots**

- Thermal shock resistance unnecessary
- High porosity (permeability) with fine pores, for cooling water in hot climates (cold climates low porosity?)
- White or pale colour to reflect heat in hot climates (cooling by evaporation vs heating by conduction).

**Cooking Pots**

- Thermal shock resistance essential
- Coarse pores desirable as one means of achieving thermal shock resistance but permeability to fluids undesirable
- Dark colour or black to retain heat (carbon staining from cooking fires contributes).

Thermal Shock Resistance

Thermal shock resistance is the property which allows a ceramic to withstand repeated cycles of heating and fast cooling without damage such as cracking or spalling. The reasons why cracking due to thermal shock can occur have been summarized by Lawrence (1972:174-5). When a vessel is heated from below, the outside becomes much hotter than the interior, because ceramics are not good thermal conductors compared for example with metals. Since the hot face expands more than the cold, tensile stresses will result on the cold, and when these stresses exceed the tensile strength of the body, a crack will develop on the colder (interior) side.
Three major variables involved in thermal shock resistance which can be controlled by a traditional potter are: porosity — both the extent of porosity, and pore size distribution; mineral inclusions — that is, types of minerals present, the particle size distribution of minerals present, and the quantity of minerals present; thermal expansion — the extent to which the fired clay matrix, and mineral inclusions, expand on heating.

Unfortunately, research on ceramic thermal shock resistance has been focussed on materials fired at much higher temperatures than those used by traditional pottery makers, but we can on theoretical grounds specify the physical properties which could contribute to thermal shock resistance in low fired (below 1000°C) cooking pots, and from this basis go on to examine ways in which the traditional potter could produce a vessel with these properties. Properties which should contribute to thermal shock resistance are:

1. Shape of the vessel. The shape should be such that thermal gradients are minimized, i.e. no sharp changes of direction or carinations, and an even wall thickness. A spherical shape best answers the requirements.

2. Relatively high porosity (at least 10% apparent porosity), with homogeneous distribution of pores around the vessel. The pores should be mostly large. Mellor (quoted Searle and Grimshaw 1959:864) has shown that for a given size or pore space, or volume of air, there is a temperature at which the quantity of heat passing through it by radiation equals that which would be carried by a solid substance occupying the same space (Figure 2). From the graph relating this 'critical temperature' to pore size, we can extrapolate to the assumed temperature achieved in a cooking fire (say about 300°C-500°C) and state that the ideal pore size would be between about 7 and 9 mm. Allowing for the highest conceivable temperatures in a cooking fire, the range of desired pore size could be larger than 5 mm and smaller than 1 cm. Using this size range, pores can be substituted for mineral inclusions with no loss of 'cooking efficiency' for a pot. The large pores, according to Lawrence (1972:181) contribute to thermal shock resistance by preventing crack propogation through the walls of a vessel; if a crack starts it is arrested when it reaches the large pore.

3. Control of mineral inclusions; the mineral inclusions should have thermal expansions very close to that of the fixed clay matrix, and should not have crystal lattice structure changes ('inversions') in the range of heat used for cooking. If these criteria cannot be met the content of mineral inclusions should be as low as possible and their particle sizes should be as small as possible.

How can these criteria be met by the traditional potter? It is obvious that no traditional potter conceptualizes cooking pots in the frame of reference just outlined. I suggest that a prerequisite for controlling the physical properties
is long empirical observation through time, observing that some techniques and materials produce better pots than others, cooking pots which can be used many times before the thermal gremlins take over. So it is necessary to allow long periods of time for a specific group of potters to develop techniques for using specific materials.

Technologically, the traditional potter firstly has available a very simple method of achieving large pores in cooking pots: organic tempering, using material such as chopped grass, straw, seeds etc., which on firing burn out leaving pores of appropriate size. Organic temper has been widely used in prehistory.

![Figure 2—Relation of temperature to pore size at which the quantity of heat passing through the pore by radiation equals that which would be carried by a solid substance occupying the same space. (After Mellor).](image)

Secondly, if using a clay with few mineral inclusions, but which needs some temper to give workability for forming, the potter can use ‘grog’, or crushed fired sherds formed from the same clay as used for vessels. When fired the grog has the same thermal characteristics as the clay matrix. This approach has the advantage that the raw material is readily available, ensures that the grog has been fired to similar temperatures as the vessels, and allows considerable variability in the amount of temper added and the method of its grinding and preparation.
Both these methods, use of organic temper, and use of grog as temper, have been widely used in antiquity as empirical methods of producing thermal shock resistance at the same time as improving the workability of clay. Neither method has been reported in the literature on Melanesian pottery, so obviously other strategies have been adopted.

The third method of controlling thermal shock resistance mentioned above was control of mineral inclusions. The use of grog as temper can in practice be considered in this category, but to extend the discussion it is necessary to examine naturally occurring minerals such as may be used by a traditional potter. For such potters the primary physical variable involved in selection of materials is thermal expansion, which of course is not to suggest that the choice is conceptualized this way by the potters involved.

Data on thermal expansion of many common materials have been published (Skinner, in Clark 1966:78-96). Some of these are summarized in the graph (Figure 3) for temperatures up to 800°C which covers the firing range for much primitive pottery. In order that the graph should be legible some minerals have been deleted, but their expansion characteristics can be summarized: iron oxides are in the same range as CaO; most felspars plot between plagioclase and rutile; hornblende is similar to graphite; augite is similar to calcite. It should be noted that minerals crystallising other than in the cubic system have different expansions along different crystal axes. Calcite is a notable example. When heated it actually displays a contraction perpendicular to the c axis. In order to simplify discussion, however, all values on the graph have been plotted as 'average volume expansions'.

Searle and Grimshaw (1959:717) summarize expansion data for different types of clays which had previously been fired. Overall the range fits into the graph between slightly lower than zircon (at 800°C about 0.8% volume expansion) to around olivine (at 800°C about 2.4% volume expansion), but generally expansion (at 800°C) is in the range 1.5 to 2.0%. A 'typical' expansion value which could be used for the low fired earthenware clays used by traditional potters is included on the graph (Figure 3).

Winkler (1973:47) has summarised thermal expansion of some common rocks. These vary considerably for any one rock type but in general the more basic rocks (basalts, gabbros, diorites etc.) have much lower expansions than the more acidic rocks such as granites; and the sedimentary and low grade metamorphic rocks tend to have a very wide range of expansion within any one rock type.

Overall, the thermal expansion of rocks appears to be lower than would be calculated from the individual minerals from which they are composed, probably indicating that the structure is capable of absorbing some of the stresses during expansion of the individual grains.
The graph showing thermal expansions of minerals (Figure 3) allows some prediction of which minerals would be best suited to use in cooking pots, for thermal shock resistance. Those minerals with the lowest thermal expansions, or thermal expansions closest to the clay in which they are incorporated, would be the most suitable in avoiding stresses within the fabric during repeated heatings and coolings. Thus zircon, plagioclase and other felspars, augite, hornblende — and calcite — appear to be the most suitable minerals. There are other materials which are used in modern heat resistant bodies but they are not accessible to the

Figure 3—Thermal expansion, expressed as volume percent, of some common pottery materials, plotted against temperature.
traditional potter, for example petalite, spodumene, fused silica, cordierite, silliminate and mullite.

In the Melanesian setting, there is only one reference in the literature to potters using different body compositions for different functional vessel types, at Kaiwat in the Sepik (Kaufmann 1972:131). Traditional potters in other parts of the world have also followed this practice, for example in the Swat Valley of Pakistan (Rye and Evans, in press) and in Ticul, Yucatan (Arnold 1971), where the potters specifically use calcite temper for cooking ware and other tempers for ware not used in cooking. Considering the number of publications on Melanesian pottery making it is safe to state that almost all Melanesian potters each use one body composition only and produce all their vessel types from this. Thus we cannot look at the properties required in a cooking pot in isolation, but must take into account the varying properties required for other vessel types.

All of the data on mineralogy of Melanesian prehistoric pottery presently available stems from studies of excavated or surface collected sherds by the use of thin sections. Dickinson and Shutler (1968) have summarized the geological background to the availability of tempering materials in Oceania. Specific temper combinations can be related to quite specific source localities. This approach has been mentioned above; location of sources for materials leads to statements about trading and contacts between peoples. Other studies in the Pacific using mineralogical data for these purposes have been provided by Dickinson and Shutler (1969, 1971, 1974); Key (1968, 1973); Specht (1969, 1972); and Dickinson (1971, 1973).

Ethnographic observations on tempering materials have been made by Glover (1968), Groves (1960), Tuckson (1966, 1975), Ellen and Glover (1974), and Lauer (1974). The ethnographic accounts tend to be much less specific about the mineralogy of tempering materials or inclusions in sherds than the specialist petrologist's studies. However, it is notable in all the published accounts of ceramic petrography that minerals with low thermal expansions (cf. Figure 3) are very commonly the most frequent inclusion in sherds. Calcite, in the form of shell from beach sand, is very common as the major inclusion; other minerals such as plagioclase, hornblende, rutile and zircon also commonly occur as major inclusions: whereas quartz, which from Figure 3 can be seen to be undesirable because of its relatively high thermal expansion as well as its crystalline inversion at 573°C, is much less frequently the most common inclusion. A detailed study of the frequency of occurrence of minerals with low thermal expansion in Melanesian sherds is beyond the scope of this paper, but some postulates can be made. Firstly, when the potters are using only one material to make a range of vessels which include cooking pots, then the desirable mineralogy required for those cooking pots would be much more limited than for other vessel types, and it can be predicted that over a period of time the clay body would be adjusted to give the best thermal shock resistance characteristics. Secondly, in order to
make vessels suitable for other purposes, post-firing techniques could be used, such as applying an organic coating to decrease the permeability of vessels intended for fluided storage. The use of organic coatings has been referred to in ethnographic literature, and Groves (1960:17) quotes informants from Boera:

'When) the job of firing is entirely finished, (the potter) returns her pots to a cool place. After that, cooking pots (uro) and dishes (nau) are left without further attention, but the potter gives water vessels (hodu) further treatment. She takes the leaves of plants and rubs the water vessels (with them). She rubs them with (the leaves of) different plants: pawpaw leaves, the leaves of trees, and the leaves of kasipolo (Passiflora); and then the job is finished. The reason for this rubbing is that the water will not leak out'.

The informants go on to describe further procedures to ensure that the water vessels do not leak. The use of red mangrove bark dye is also mentioned, but it is specifically noted that the dye is used only as a decoration and has no functional purpose. This statement by informants including one of the better known Boera potters, tends very strongly to support the suggestion that the body is compounded to give suitable physical properties for cooking pots, and for other purposes vessels are either also suitable or are modified subsequent to firing. Hopefully ethnographers will examine questions such as this in future studies, at other Melanesian locations.

Some vessels, such as those used to store dry foods, would not require any special physical properties other than those necessary to survive the making and firing. Unfortunately mineralogical studies of Melanesian sherds to this point have not made the correlation between mineralogy and vessel function, so it is not possible to determine from the literature whether all cooking pots are made from low expansion materials, but the frequency of mention of these materials supports my postulate that raw materials are blended primarily for cooking pots and that other vessel types are modified after firing.

Thirdly, it is not inevitable that because some materials offer advantages over others all potters would use them preferentially. Some potters may not have the background of time and empirical observation with a limited set of materials, which would allow selection of those technologically most suitable. And in rare cases, the most suitable materials simply may not be available, and inferior materials would be used, or the people would import vessels from other areas where more suitable materials were available. It is of course possible to predict from theoretical considerations what materials give the most appropriate properties for various vessel types, particularly cooking pots. Such data has not been, but could be, used to evaluate whether the potters of one area had a trading advantage over those of another area on the basis of superior raw materials and knowledge of their use.

In order to determine whether thermal shock resistance is indeed correlated with thermal expansions of minerals occurring in their fabric, a comparison of
test pieces made from a single clay, but incorporating different non-plastic and organic tempers will be included in experimental studies yet to be completed.

Use of Calcite and Shell

It is obvious that calcite in one form or another has been very widely used as a tempering material for pottery bodies. Groups as diverse as some Indians of the US, coastal potters of Melanesia and Bronze Age potters of Palestine have used shell or crushed crystalline calcite as temper. In studying Late Bronze Age pottery from Tell Ta'annek, in Occupied Jordan, the writer noted that most sherds of cooking pots contained calcite temper. A modern cooking pot maker in Yabad village, near Tell Ta'annek, uses crushed crystalline calcite to temper clay for cooking pots; she explained that despite the difficulty of obtaining this material it is used in preference to many other more readily available materials (including limestone) because cooking pots tempered with calcite lasted much longer in use.

The armchair explanation for the use of calcite or shell as temper would be simply that it is readily available, especially where coastal people or peoples who eat shellfoods are involved, and the argument could be improved by noting the ease of crushing shell as against other much harder materials. But, in view of its widespread use and its apparent advantage as a tempering material for cooking pots, it is reasonable to ask what special advantages it may have as a pottery raw material.

Technologically, the first reaction to this question is that potters could not select a worse material. When heated, CaCO$_3$ decomposes in the reversible reaction: CaCO$_3$ $\rightleftharpoons$ CaO + CO$_2$. According to Rigby (1953:128) this reaction can begin at temperatures as low as 620°C, and the reaction becomes very rapid at higher temperatures, around 900°C. This temperature range is of course very much within the range of temperatures to which primitive pottery is fired.

When pottery is fired within the range of decomposition temperatures of CaCO$_3$, and allowed to cool, CaO can be present in significant amounts in the fabric of the ware. This CaO will readily combine with water vapour in the air, or with water if the vessel is wetted, in the reaction: CaO + H$_2$O $\rightarrow$ Ca(OH)$_2$. This reaction is the basis of the setting of lime mortars. Unfortunately for pottery makers, there is a very considerable difference in the volume occupied by CaO and Ca(OH)$_2$, the latter occupying a much larger volume. Thus the crystallization of calcium hydroxide can create considerable pressures$^1$ which under

$^1$Winkler (1973:119-125), in discussing the causes of damage to natural stone in buildings, notes crystallization pressure and hydration pressure of salts as a major causative factor. Winkler does not give data for Ca(OH)$_2$ formation but notes that the main variables affecting hydration pressure are relative humidity, temperature, and the volume change before/after hydration. Variables in crystallization pressure are temperature, degree of super-saturation of the solvent, and molecular volume of the salt. The extent of pressure can be instanced by NaCl which can exert pressures as high as 2190 atmospheres at 50°C.
suitable conditions will completely fracture the fabric of a vessel, in extremes reducing it to a pile of fine grains.

According to Searle and Grimshaw (1959:522, 538), the decomposition of CaCO$_3$ when heated proceeds until the vapour pressure of CO$_2$ reaches a critical value, then stops at equilibrium. The reaction will start again if a current of air flushes the CO$_2$. If CO$_2$ is removed as fast as it is formed the decomposition will be complete, but if the CO$_2$ pressure is allowed to exceed the critical limit then the reaction will reverse and CaCO$_3$ will form again. Thus it is obvious that the extent and distribution of open pores in a pottery body and the supply of moving air, during the firing, will have a large influence on the decomposition rate of CaCO$_3$, this influence being less at the lower temperatures (say around 650°C), and becoming more significant at higher temperatures (around 900°C).

Despite the apparent dangers of using CaCO$_3$ as a tempering material in low fired bodies, it has been extensively and successfully used. One question is: under what conditions can CaCO$_3$ be used in low fired pottery bodies without post-firing damage by CaO hydration? Secondly: what advantages does CaCO$_3$ temper have for cooking pots over other potentially usable materials, or more specifically, does the use of calcite or shell give cooking pots better thermal shock resistance than would the use of alternative materials? Experimental work reported below has focussed on the first question; experiments designed to answer the second are not yet complete.

Use of Saltwater

Data collected by Tuckson (pers. comm.) show that some Melanesian potters wet their clay with freshwater, whereas others use saltwater. Some potters have very strong preferences for the type of water used; for example the potters of Boera, near Port Moresby who use saltwater ‘reported that pots will crack if freshwater even splashes on the clay or pots’ (Tuckson, pers. comm. 1975). Conversely, at Tubetube Island, in the Engineer Group, potters ‘stressed that it must not be saltwater, and firmly stopped one of us touching a piece of clay after having washed our hands in the sea. They said that the pots would break if saltwater touched the clay or the pots’. At Kwaraiwa Island, in the same group, ‘the women always wash their hands in freshwater before starting in case there is any saltwater on them . . . they say that pots will break if saltwater is used’. Clearly, the choice of salt or freshwater is not merely a matter of ready availability of one type of water and scarcity of the other.

Matson (1971:66-7) has referred to the use of saltwater by potters in Mesopotamia and other countries in the Middle East; and I have observed that some traditional Arab potters add ground salt to their clay body, as do potters in some areas of Pakistan (Rye and Evans, in press). Arnold (1971:29-30)
notes the use of calcite temper for cooking ware, and mentions strong preferences by the potters for clay which ‘tastes’ salty. These salty clays contain significant amounts of the chloride ion so the salt is probably NaCl. Pakistani and Arab potters I have interviewed have claimed two benefits from adding salt to the clay: firstly, that water storage vessels made from this type of body keep the water cooler; and secondly that the colour of vessels is better. My observations are that salt certainly has an influence on the fired colour of bodies. A red earthenware body will fire to a relatively constant red colour between temperatures of about 600° and 1000°C, when freshwater has been used. With salt added, the body will fire to roughly the same colour at 600°-700°C, but as the firing temperature increases the colour progressively changes to yellow or white at 800°-900°C, and becomes a light green and then darker olive green between 1000° and 1100°C. Given the contention that vessels made from this material keep water cooler, it may be that lighter coloured vessels reflect heat better than darker ones although the effect must be marginal. It must be noted that because of uneven temperature distribution in the type of kilns used to fire earthenware in the Middle East the full range of colours may be produced in any single firing, and thus it is at the least misleading to classify sherds of such pottery on the basis of colour alone. Considering the wide range of temperatures in a bonfire open firing, the same comment may apply to prehistoric Melanesian sherds where seawater has been used.

As with the use of calcite and shell for pottery making, an initial reaction to the fact that potters in Melanesia use seawater to wet their clay is that it appears to be a most unsuitable material. Modern ceramic practice is to avoid the use of clays or water containing soluble salts, for several reasons. Firstly, any salts remaining after firing tend to form a scum on the surface of the ware; which is thought to detract from the appearance of a pot, and may also prevent successful glazing. It may not be a problem where cooking pots are concerned, for aesthetically the exterior surface will become blackened from cooking anyway. Perhaps the only question is whether the salt coating on the interior is soluble or not, and if so whether it improves the taste of the food.

The second, more important reason for avoiding soluble salts is their effect on the workability of the clay in the plastic state. Clays in suspension in water (i.e. slips) may be viewed as a colloidal suspension, as the size of individual crystals of the clay minerals is very small (roughly two microns or less). The individual crystals have a capacity to absorb anions and cations which will cause attractions and repulsions of the crystals according to their relative charges. Attraction causes the slip to ‘thicken’, giving the property known as flocculation. Repulsion causes deflocculation or relative ‘thinning’ of the clay slip. A practical assessment of the state of the slip can be gained from its pH; if less than 7, the slip is acidic and tends toward flocculation,
KEEPING YOUR TEMPER UNDER CONTROL

whereas a pH greater than 7 indicates deflocculation. A flocculated slip requires more water than a deflocculated slip to give the same viscosity, and thus tends to have a longer 'plastic range' (the interval between the sticky point-liquid limit, with maximum water for working, and the stiff point—i.e. plastic limit—with minimum water for working). In summary, the workability of a clay body can be altered strongly by varying the degree of its flocculation or deflocculation, as a slip. Seawater could be expected to deflocculate the mixture, creating poorer working properties in the plastic state than would a flocculated mixture.

Despite this, some Melanesian potters are using seawater to wet their clay. So it can be asked: what are the relative merits of using freshwater and seawater with the materials and techniques used by Melanesian potters?

Initially, a link between the use of two 'unsuitable' materials has been suggested indirectly, in the work of Arnold (1971:37), in that the Ticul potters only use 'salty' clay with calcite temper for cooking pots, but do not use these clays when calcite temper is not used. Laird and Worcester (1956) provide a direct correlation. A clay used for brick making in England contained shelly limestone, which caused 'blowouts' or lime spalling in bricks fired to 1050°C. Laird and Worcester found that this problem disappeared when additions of NaCl were made to the clay before forming bricks. Additions of 0.3% NaCl were sufficient to counter the effects of 5% of limestone in the clay; for 10% limestone 0.5% NaCl was effective. Thus there is direct evidence that saltwater could assist in preventing lime spalling when calcite or shell was used in a low temperature body. Thus experiments were designed to verify this with Papuan pottery materials, and also to determine the variation in effects with these materials.

EXPERIMENTAL INVESTIGATIONS

Method

A combined experiment investigated the effect of firing temperature on bodies containing varying amounts of beach sand temper (containing shell and coral) and of the characteristics of fired bodies which had been prepared with seawater or freshwater. Materials collected by the writer from three locations on the south Papuan coast were used. Clay, and beach sand used as temper at Boera were collected by two Boera potters, in my presence. The Boera potters make a range of vessel types from the one mixture but as noted above (quote from Groves 1960:17) this produces fired properties suited primarily to cooking pots and other vessels are treated subsequent to firing to give properties appropriate to other functions. Clay from Mailu Island (Irwin 1974; Saville 1926; Malinowski 1915) was collected by a Mailu potter accompanied by me; the Mailu potters do not use temper but a sample of beach sand was also collected on Mailu. The Mailu potters make only cooking pots.
A clay sample was collected from the nearest point on the mainland to Motupore Island, and a sample of beach sand collected on the island itself. In addition, samples of seawater were collected in all three locations.

Two parallel series of bodies were made up, one series wetted with freshwater (Canberra tapwater) and the other wetted with seawater from the appropriate locality. In each series, mixtures varying at 5% intervals from 60% clay and 40% sand, to 100% clay were prepared. The clay and sand for each mix were weighed dry, mixed thoroughly, and then wetted with just sufficient water to give best workability without becoming sticky. A sample of each mix was then thoroughly kneaded, rolled out to a coil, which was flattened to give a test bar about 15 cms long. Workability of the mix was assessed by my judgment (as a potter of 14 year experience) during the forming of these test bars. The bars were marked with fine lines 10 cms apart, and when the bars had dried shrinkage was measured from the distance separating the two lines. The bars were then cut into small briquettes, each about 2.5 cms square by 1 cm thick. The briquettes were then fired in a small furnace. The firings were done at five different temperatures: 650°, 750°, 850°, 950°, and 1050°C. These were selected to cover the total range of firing temperatures as indicated in the first few reports of such measurements in Melanesia, where firing temperature and rate have been measured on Goodenough and the Amphletts by Lauer (1972, 1974) and on Mailu Island by Irwin (pers. comm.). In the present experiments firing technique was as follows: the furnace was heated to 650°C and held at this temperature. Samples to be fired at that temperature were then placed in the furnace, with tongs, left for 15 minutes,

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2 This site has been excavated by Jim Allen (Allen, pers. comm.) and the data are now being prepared for publication. Motupore Island is in Bootless Inlet, some 15 km east of Port Moresby.

3 A sample of clay was obtained from the mainland near Motupore Island. Time was not available to begin a complete survey of clay deposits in the local area, so only the most promising area was investigated; this was a small valley, several hundred metres long, at the closest point of the mainland to the island. Only one sample was taken, from the centre of a relatively flat area halfway up the valley. The sample was taken from between 0.5 and 1 metre below the surface, rejecting the upper half metre which contained many roots and decomposing organic material. If more time had been available other samples would have been taken in this valley, in order to study the variation within the clay deposit. The sample consisted of black, plastic clay, naturally containing sufficient moisture to enable it to be worked as dug. It took me half an hour to travel from Motupore Island, collect about 25 kg of clay, and return to Motupore in an outboard engine boat, so the total time for collecting 25-50 kilos of clay, travelling in a small canoe, would take no more than one hour.

Later laboratory studies comparing thin sections of sherds excavated at Motupore by Allen with fired clay/sand sample mixes showed that in many cases the two were very similar, which suggests that samples of materials collected by the writer were almost certainly from a source used by prehistoric occupants of Motupore Island. That some sherds from the site appear dissimilar in mineralogical composition may indicate a) that some pots may have been imported from elsewhere; b) that Motupore potters exploited different clay courses; or c) that the variation in the known clay deposit has not been sufficiently delineated.

If the second possibility is correct it may mean that a correlation exists between different clays, and vessel functions. This is currently being tested.
and then removed and allowed to cool on an asbestos cement pad. The furnace was then raised to 750°C, the firings conducted, and so on. All firings were for 15 minutes only, this very rapid time being selected as relatively normal for Melanesian firings. An initial trial using Boera clay bodies had shown that the final results for samples fired for 15 minutes were the same as for samples fired over a period of four hours, raising the temperature from 20°C to the selected temperature in that time.

When all samples were fired they were laid out on a bench and left for a period of two months. Initially the appearance of the test pieces was noted every day, but afterwards only once a week until the change in test pieces had clearly been completed.

**Results**

**Unfired properties of materials**

The workability of different temper/clay mixes was assessed while preparing the samples, and is indicated on the graphs (Figures 4, 5, 6) as an unshaded area showing the limits within which bodies are workable. For example the Boera clay tended to be sticky and difficult to work with less than about 15% of sand added; and with more than about 30% by weight added sand it was also very difficult to work, becoming short (tending to crack easily when pressure was applied). The Motupore materials also displayed workability limits at both ends of the sand/clay range, requiring more than about 15% of sand but less than about 35% of sand to be added, for suitable workability. The Mailu materials on the other hand showed no minimum limit, but only a maximum; the clay could be worked quite easily with no sand added, but with more than about 30% of sand added it became short and difficult to work, cracking easily when deformed.

There was no noticeable variation in these limits when saltwater was used to wet the clay instead of freshwater, apart from a very slight tendency for the bodies to be more sticky. This tendency was not distinct enough to cause variations in the workability limits as stated.

The effects on drying shrinkage of varying sand/clay proportions, and of using saltwater as opposed to fresh, are outlined in Table 1.

Predictably, increasing the additions of sand to each clay causes a decrease in shrinkage, the effect being greatest for the Mailu clay. Using seawater instead of freshwater had different effects on each clay/sand series. Seawater and freshwater both produced similar shrinkages for all Mailu bodies. For the Boera and Motupore series, seawater produced slightly higher shrinkages than freshwater, but the differences were not much larger than likely errors in measurement.

All samples were allowed to dry from best working condition by being
placed on an open bench, free from draughts, and no drying cracks or other faults appeared on any sample briquettes.

**Table 1**
*Drying Shrinkage for Varying Sand/Clay Mixtures, Showing Values for Mixtures Wetted with Seawater and Freshwater.*

<table>
<thead>
<tr>
<th>Mailu mixture</th>
<th>Boera mixture</th>
<th>Motupore mixture</th>
<th>Percent clay in mixture Sand content = (100 - n)%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh Water</td>
<td>Sea Water</td>
<td>Fresh Water</td>
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<td>6½</td>
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<td>8½</td>
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</tbody>
</table>

* Shrinkage expressed as linear percentages, on drying from condition of best workability to room temperature equilibrium.

**Firing samples**

It was anticipated that some problems might arise due to the very rapid heating and cooling cycles used in experimental firings. Only one sample, however, suffered damage in the firing-cooling cycle; the Motupore clay, with no sand added but where seawater had been used. During heating to each of the five temperatures this clay 'exploded', and the briquettes were badly damaged. The problem disappeared in the samples with no sand, but where freshwater had been used; and did not occur in the seawater samples to which sand had been added, even as little as 5% of sand allowing the samples to fire without damage.

**Post-firing results from samples**

The results of post-firing damage to sample briquettes are summarized in the three graphs (Figures 4, 5, 6,) which plot initial firing temperature of briquettes against the sand/clay content of the briquettes. After the briquettes were removed from the furnace and allowed to cool, they were laid out on a bench and left undisturbed for two months. During this time many of the briquettes suffered damage from the hydration of CaO (resulting from decomposition of CaCO₃ during firing), forming Ca(OH)₂ which has a larger volume.
than CaO. The pressure caused by this hydration reaction (involving water vapour in the atmosphere) caused many of the briquettes to fracture, or in extreme instances to crumble entirely to a pile of loose grains. The graphs show which samples suffered this damage and which survived with no obvious damage. The plate (Plate 1) shows the appearance of briquettes made from Mailu materials, two months after firing.

The Motupore samples, as noted, suffered some damage during firing for the combination 100% clay wetted with seawater. Apart from this sample only three others which had been initially wetted with seawater suffered post-firing damage. Body mixtures with 60% clay/40% sand were damaged after...
firing to 950°C and 1050°C. The body mixture with 65% clay/35% sand suffered damage after firing to 1050°C. So when seawater was initially used to wet the clay, post-firing damage due to CaO hydration was limited to only the high sand/high temperature combinations.

![Diagram](image)

**Figure 5**—Effect of firing to various temperatures on mixtures of Boera clay and beach sand, wetted with either seawater or freshwater. Non-workable mixtures are, indicated by shaded areas.

The samples which had initially been wetted with freshwater were dramatically different. All samples in this group except those fired to 650°C, and one low-sand (5% mixture fired to 1050°C) were damaged by Ca(OH)₂ hydration to an extent where it was obvious that the combinations could not be used for any vessel manufacture. The differences can be summarised briefly by stating that most clay-sand mixtures wetted with seawater could be fired safely to most of the temperatures used in the experiment, whereas almost
Plate 1—Mailu materials, clay and beach sand mixtures. Appearance of Mailu briquettes two months after experimental firing.  
F = originally wetted with fresh water;  
S = originally wetted with seawater.
none of the mixtures wetted with freshwater were usable over most of the temperature range.

In general similar results were obtained with the Boera materials, but high temperature-high sand combinations were damaged over a broader range than for the Motupore materials, for briquettes which had initially been wetted with seawater. All freshwater samples except those with less than 30% sand and fired to 650°C suffered calcium oxide hydration damage. For the Boera materials, in summary, clay-sand mixes wetted with seawater could be successfully fired to a more limited temperature range than for the Motupore materials, and mixes wetted with freshwater were unusable at all except the lowest temperatures used in the experimental firings.
The striking differences between bodies wetted with seawater, and those with freshwater for the Boera and Motupore materials, were not so evident with the Mailu materials, but damage from CaO hydration was still spread over a wider clay/sand-temperature range for freshwater use than for seawater. Mailu clay without addition of sand could be wetted with either sea or freshwater and fired to any temperature up to about 900°C without subsequent damage, but small additions of sand to the clay lowered the safe maximum firing temperature of the body rapidly when freshwater was used; whereas up to 20% of sand could be added to the clay where seawater was used and the body fired as high as 950°C without subsequent CaO hydration damage.

The Mailu materials did display one characteristic not shown by either Boera or Motupore materials, and that is that where seawater was used, with lower sand additions (less than 15%), the bodies were overfired and bloated (see introductory discussion of firing, above) when fired to 1050°C. Thus there is a segment (top left of graph) of unusable material-firing temperature combinations with the Mailu materials which did not appear with materials from the other two locations.

Another variable which is indicated on the graphs, but not mentioned in preceding discussion, is the CaCO₃ content of the bodies, plotted on the abscissa against body composition. The amount of CaCO₃, which can be assumed to be wholly present as shell and coral fragments, was determined for each clay and sand sample by treating a known quantity of each material with dilute HCl until reaction ceased, then filtering, drying and weighing the insoluble portion and calculating the weight loss percentage as CaCO₃. Despite the inadequacies of this method, the results are accurate enough to show that amount by weight CaCO₃ present in bodies cannot be used to predict post-firing damage by CaCO₃ hydration at any given temperature. Obviously from the results the quantity of CaCO₃ is not the only variable determining whether or not a given composition is usable at a given temperature. For example take from each graph a body mixture containing approximately 15% CaCO₃ (the respective composition being: Mailu clay 95%, Mailu beach sand 5%; Boera clay 60%, Boera beach sand 40%, Motupore clay 85%, Motupore beach sand 15%). It is obvious from observing the behaviour of these compositions at various temperatures that they behave quite differently, and that therefore other variables are also determining the extent of post-firing damage.

It is suggested that one of these variables is the size range of shell or other CaCO₃ fragments in the pottery and that this is more important than percentage content in determining whether or not post-firing damage will occur. This was indicated clearly by one Boera briquette which contained a reasonably large (about 0.6 cm diameter) coral fragment. The briquette remained essentially undamaged after firing except for the area around the coral fragment which was damaged by its obvious increase in size. Significantly, I had previously
observed that the 'grit' removed by Boera potters when preparing the clay (cf. Groves 1960:15) was entirely composed of larger coral and shell fragments and the potters confirmed that they removed these because they cause damage to the vessels if allowed to remain in the clay.

The physical mechanisms by which seawater use inhibits post-firing damage are somewhat speculative at this point, and for the prehistorian it may be enough to realize the existence of the effect without understanding the mechanisms. Several mechanisms may be operating together. Firstly the presence of salt may cause increased vitrification during firing, due to the presence of fluxes — mainly Na and K. Some eutectics (low fusion points) with these fluxes occur at relatively low temperatures, for example the Na-A1-Si eutectic at 732°C and the K-A1-Si eutectic at 695°C. Increasing vitrification would produce a stronger fabric more able to resist the pressures created by CaO hydration pressure. It would also seal off some of the capillary networks of fine pores, restricting post-firing access of water to the CaO. This effect would be greatest at the surface of the vessel, because of the higher concentration of salts there before firing. As the newly formed vessel dried, salts in solution would be carried to the surface and then deposited as the water evaporated. Archaeologically, this vitrified 'skin' could be confused with a slip by an observer.

The postulated increased vitrification when seawater is used definitely occurs with the Mailu clay, which was distinctly overfired at higher temperatures used in the experiments where seawater was used, but not with freshwater. Some of the briquettes of Mailu clay (Figure 6) of high temperature/high sand content combination were bloated. During the rapid heating the exterior was raised to temperatures where partial fusion (vitrification) occurred, sealing exterior pores. Carbonaceous materials in the centre decomposed, liberating gas which could not escape, and thus the glass formed blisters in a process analogous to glassblowing.

Implications of the experimental results

Even from the very limited sample represented by the three sets of materials used in this investigation it is obvious that the materials behave quite differently before, during, and after firing. The results give a background for predicting how these materials could be used by potters, and for the Boera and Mailu materials where we also have ethnographic evidence to show how materials are used, they allow understanding of the techniques practised.

From both the potter's and user's point of view, it is evident that with all three clays there is a very sound technological reason for using seawater when beach sand temper containing shell is added. The firing range is extended for all tempered mixtures. Both the Boera clay and the Motupore
clay are not workable without a temper addition, so the firing behaviour of untempered clay with or without seawater is of rather academic interest. But in the case of the Mailu clay, where workability without temper is quite good and which the traditional potter uses untempered, it is interesting to note that within the temperature range achievable in an open fire it makes no difference to post-firing damage whether seawater or freshwater is used with the untempered clay. Further experimentation may reveal other advantages stemming from the use of one type of water as against another, but at this stage I have not discovered any distinction. Thus it can be suggested that there is no technological advantage to the Mailu potters in using saltwater, and that the reason they use salt as opposed to fresh is simply that freshwater is difficult to obtain whereas seawater is plentiful and close at hand.

The result of firing Motupore clay wetted with seawater but with no temper added was that the clay ‘exploded’ during the rapid heating. This suggests that when dry this clay was more densely packed than any of the other materials used in the experiments, and could not accommodate the pressure caused by rapid expansion of the salt present (see Figure 3). Thus we see a case where, if the clay had been workable without temper additions, potters would have developed a strong preference for using freshwater to wet the clay. Effectively, the experiment indicates that there are cases where using seawater to wet the clay is the only workable method; where either seawater or freshwater can be used (Mailu clay); and where only freshwater could be used. Thus the preference for either seawater or freshwater noted by Tuckson (pers. comm., see above) appears likely to be based on sound technical principles determined by empirical observation. It is a small step to imagine that over time the original reasons for preferring one technique or another could be lost through disuse of the unworkable alternative, but that rituals could be developed in order to perpetuate the successful approach.

The experiment shows quite clearly that when beach sand containing shell (and, by implication, any other calcite or CaCO₃ materials) is used as a pottery temper, there is a definite advantage in using seawater to wet the clay. The successful firing temperature range is significantly extended and post-firing damage due to CaO hydration is much less likely to occur. The ‘safe’ range for any clay-temper combination must be determined for that specific combination. Further experimental work could enable prediction of safe/unsafe temper contents and firing temperature combinations but at this stage it is necessary to test the variables in each case. The use of salt as an additive to pottery bodies in Pakistan (Rye and Evans, in press) in the Middle East, and in other areas is certainly aimed at achieving the same technical advantage where calcareous clays or tempers are used. In general, where calcareous clays or tempers are used, the beneficial advantage of salt could be obtained from: a) using seawater to wet clay; b) using clays naturally
containing soluble salts; c) using tempers naturally containing soluble salts; d) adding crystalline salt to the plastic clay.

The maximum addition of crystalline salt to plastic clay I have observed ethnographically was at Hebron (Occupied Jordan), where 5% of salt was used. The work of Laird and Worcester (1956) indicates that much lower total salt contents — less than 1% — are sufficient to counteract lime spalling. However, in addition to inhibiting lime spalling by salt addition, potters may also be aiming at specific colours for either aesthetic or functional reasons.

The use of salt additions, in any form, to calcareous clays, has a long tradition in the Middle East — the earliest example known to me being a Middle Bronze Age (ca. 1600 BC) chalice from Tell Ta‘annek, in Occupied Jordan but earlier examples may well exist. The antiquity of seawater use in Melanesian pottery has not been investigated, but pottery excavated on Motupore Island shows evidence (based on criteria outlined below) of seawater use with beach sand-tempered pottery dating back at least 700-800 years.

Assuming that the amount of water required to bring clay to working plastic condition varies between 20 and 30% of dry clay weight and that seawater contains 3 to 5% total salts, the effective salt addition to Boera and Mailu materials by present day potters would vary between about 0.5% to 1.2%. These additions are slightly higher than the minimum salt as NaCl additions (0.3 to 0.5%) recommended by Laird and Worcester (1956).

The objection raised above to using seawater to wet clays, that it would cause deflocculation and resulting decreased workability of the body does not apply to the Boera or Mailu potters. Trials with the Motupore materials also show no decrease in workability by using seawater instead of fresh. The reasons for this are firstly that the clay is never in suspension, water only being added to dry or semi-dry clays, and only just enough water to bring the clay to workable condition is used. Hence the anion or cation exchanges which would occur in a clay suspension (slip) take place only to a very limited extent. Secondly, the three Papuan clays used in this experiment have a significant content of organic materials, evident from the black colour of the raw clays which disappears on firing. This organic content, very finely distributed, would act as a 'protective colloid' (Searle and Grimshaw 1959:447) in any potential anion or cation exchange situation, tending the clay towards acidity (flocculation) and producing desirable working properties.

Significantly, potters in Pakistan who add salt to clays with a significant calcite content also only wet clays sufficiently to bring them to plastic condition and do not prepare clays in slip form at any stage (Rye and Evans, in press). Traditional Arab potters, according to my observations, only add salt to clay which has already been prepared to plastic condition. Thus the disadvantages which could occur through using seawater or salt in clay bodies are overcome
by selecting an appropriate method of body preparation which avoids having the clay in slip form (suspension) at any stage.

The use of seawater or other form of salt addition to prehistoric pottery can be recognized generally from the appearance of the sherds; it is most difficult to recognize when sherds have been fired to lower temperatures (600-700°C), as the appearance of the sherd is a uniform reddish colour when red firing clays have been used with either salt or freshwater. The presence of shell temper or calcite in sherds is a signal that salt may have been used. Sherds of this reddish appearance may be refired to temperatures between 800° and 1000°C, and then the criteria for originally higher-fired sherds would apply. For these, the presence of pits, often cubic in form, and with a yellowish rim, is characteristic on the outer surface of the ware. Because temperatures vary considerably in an open fire, vessels fired this way show a range of colours due to the colour-temperature relationship noted above. This colour range is displayed on present day Mailu Island and Boera pottery. If standards could be established by firing appropriate mixtures of materials to a range of temperatures this colour-temperature relationship could be used for prehistoric sherds as a crude estimator of original firing temperature ranges of the sherds.

If thin sections are made from pottery containing salt, further evidence of salt use can be obtained. Cubic voids, pseudomorphs of the original salt crystals formed when the vessel dried, can be seen in the fabric; yellowish rims around these voids are common. Occasionally also, a thin layer of crystals appears on the surface, presumably the result of the reaction of salt carried to the surface in solution and deposited as the vessel dried, with the clay matrix. This layer is not to be confused with a clay slip; in fact it is extremely unlikely that a slip would be used on a salt-containing body which is 'self-slipped' with this crystalline layer, so the only problem is to distinguish one from the other.

It can also be noted that problems occurred more with samples fired to higher temperatures (950°-1050°C), even where seawater was used to wet the clay, than at lower temperatures. Technically, then, it is detrimental to fire to higher temperatures when using these materials. Thus any tendency for techniques to move towards higher firing would be discouraged by seeing the results of occasional high firings. The gradual move to higher firing temperatures in other parts of the world would not occur at least in the three areas considered in the present study unless there was experimentation with different raw materials. Perhaps an explanation such as this may account for the complete absence of kilns in Melanesia.

If we accept at this point that theoretically, calcite is a beneficial temper for cooking pots, then it is safe to predict from the present experiments that seawater would have been used with most of the prehistoric calcite-bearing
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Sherds from Melanesia. It is worth noting that any excavated sherd represents a successful combination of materials and firing techniques. Since many of the present experimental briquettes ended up as a small pile of grains we must assume that unsuccessful Melanesian experiments met the same fate, and thus these unsuccessful experiments leave no archaeological record. Thus, in the past when an area has been newly settled and potters were attempting to adapt their techniques to a new set of materials an absence of pottery in the sequence could be due to unsuccessful experimentation rather than the absence of pottery making.

For prehistorians, the experiment has obvious implications in the discussion of migrations or settlements of people in new locations. Providing shell temper is used either before or after the move, it is quite invalid to make any statements about continuity of techniques used in other locations, without first determining whether or not it is possible to interchange tempering practices, material use (especially mineralogy) patterns and firing techniques between the areas concerned. There is certainly no reason to suggest that forms of vessels, and decoration, would not be continued unchanged; but not if those vessels were destined to disintegrate a month or so after they were made.

Hopefully this paper has established that the Mailu and Boera potters of today, and the Motupore potters of prehistory, are not using ‘primitive’ techniques. In reality they have learned a complex set of technical procedures which enable them to negotiate their way through many potential pitfalls in order to produce ware which is eminently well suited to both their resources and their needs. We see an adaptation of a very sophisticated order operating; an adaptation which the Papuan potters, unbeknown to themselves share with other people widely separated in time and space. By implication it can be suggested that if one looks at any ‘primitive’ pottery technology in detail, it will be found that, given time for empirical observation and development, the total procedures of any potter will be found to be a set of quite complex answers to an array of technical problems imposed by resources, skills, and needs. The potential interpretive value of any excavated sherd is drastically limited by observing only decoration and shape; prehistoric potters were problem solvers as well as artists.

Conclusions

Theoretical considerations yet untested experimentally suggest that calcite is a technologically desirable tempering material for cooking pots. Experiments with Melanesian pottery materials from three locations show that where beach sand containing shell is used as a temper, there are distinct advantages in using seawater to wet the clay, instead of freshwater. Salt (primarily NaCl) added in other forms would have the same effect of preventing post-firing damage to vessels caused by hydration of CaO in the fabric. The three experimental
materials behaved differently from one another, but each showed clay/temper and firing temperature combination limits outside which potters could not work successfully. The experiments showed also that one of the three clays tested cannot be fired successfully if seawater is used; by implication this applies to some clays elsewhere. These technical variables should be taken into account with site-specific materials before any discussion of movement or transmission of prehistoric pottery techniques can be considered valid. Similar experiments with site-specific materials should enable prediction of techniques which potters would have to adopt in using calcite or shell-bearing materials at any particular site.

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