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THERMODYNAMICS OF EXPERIMENTAL SMALL UMU

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The preference for cooking foodstuffs in the ground with heated stones is of considerable antiquity in New Zealand, and the practice was probably brought here by the earliest voyagers from East Polynesia. The first ethnographic accounts of Polynesian ovens in New Zealand are from the journals of Captains Cook and Furneaux, concerning their respective visits to Queen Charlotte Sound in 1769 and 1773. Cook's surgeon Dr Anderson records the cooking of prepared fernroot in a "great hole dug for that purpose" (Reed and Reed, 1951:250).

As a consequence of the need for further information about the workings of small ovens (larger ones are considered a separate field of inquiry), a series of experimental ovens were constructed (Gillies, 1979). To prevent the experiment from becoming too unwieldy only three types of rock known to occur in small prehistoric <u>umu</u> were chosen. These were basalt, schist and greywacke; selected in two standardised sizes ('large' and 'small'), and used in small ovens of standardised dimensions.

The following problems were considered relevant to the thermodynamics of small ovens.

1. What is the 'life expectancy' of the three different stone types and their two sizes, i.e. how many times could a particular type and size be re-used before significant fracturing might render the stones unusable?
2. What is the qualitative cooking performance of the ovens for such foodstuffs as octopus, kumara (<u>Ipomoea batatas</u>), taro (<u>Colocasia sp.</u>), fish, beef and mutton?
3. Of the two standardised sizes of ovenstone chosen for the experiment, which is the optimum size?

Methods and materials

A site with alluvial soil by the Leith Valley Stream in Dunedin was chosen. Ovens were dug into a single homogeneous soil. These each had a top diameter of 1 m, tapering to a bottom diameter of 0.5 m, and with a depth of 0.5 m. These dimensions were considered representative of the variety of small <u>umu</u> found throughout prehistoric New Zealand (expecially Murihiku). The ovens were freshly dug into grass-covered soil eight hours before each firing. Thermocouples were placed in each oven and they were then covered with roofing iron to afford some protection from the elements. The following morning a fire was kindled in the two fresh ovens, and the recording of internal temperature commenced.

Internal temperatures were recorded by using a thermocouple of 'brightray-magonic' wires slotted through twin-holed ceramic beads, and sheathed in close-fitting stainless steel tubing with a wall thickness of 2 mm. This tube was welded at the hot junction so as to provide a waterproof seal, and to protect the thermocouple from physical shock. Calibrated at the Department of Physics (Otago University), these thermocouples covered a range of 15° - 900° C. They were connected to a low resistance milliameter capable of providing sufficient deflection for the above temperature range (0 - 25 milliamps). The thermocouples were placed so that their tips protruded through the side of each oven to its centre (of diameter and depth). A simple cross-over switch facilitated rapid reading of both thermocouples. Air temperature readings were taken for the cold junctions of each thermocouple so as to provide the necessary correction factor. Readings were recorded on prepared forms and converted to $^{\circ}$C with a calibration curve supplied with the thermocouples. Corrected readings were in most cases graphed for a maximum period of 30 hours.

Two standardised sizes of ovenstones were chosen: an average diameter of 10 cm, and one of 20 cm. In terms of the average mass of these required to fill an oven three-quarters full (leaving room for some hot charcoal), these were 45 kg of the large size and 35 kg of the small size. Three varieties of water-worn rock were selected from localities on the east coast of Otago. These were olivine augite basalt from the Waitati River, Otago (map reference S164,200860); greywacke from the Shag River, Otago (S146,316216); and quartz-feldspathic schist from the lower Taieri River, Otago (S163,928738).

After two ovens were kindled they were slowly filled with coarsely-chopped manuka (Leptospermum scoparium) until each was at least half full. When this was burning properly, a further thin layer of fresh wood was placed over the fire so as to lessen the occurrence of thermal shock to the stones. Layers of stones and wood were then added, ensuring a continual fire through all the stones during their heating. After all the stones had been placed in this manner, the initial visual result was a dense choking outpouring of white smoke, and a definite lack of visible flame. It usually took up to three quarters of an hour before the flames began to appear through the layers of wood and stones, yet the thermocouples indicated that there was sustained burning near the base of the oven during this period. The effect of placing the stones/wood layers on (over the space of about five minutes) was to smother the flames, reduce the oven's oxygen supply (and hence its temperature), and to cause the voids between the inner burning wood to become smaller as the weight of the stones settled everything down.

A total weight of 40 kg of chopped, slightly damp manuka was consumed by each oven. Depending on wind conditions, the burning time for each oven was an average of three hours. After all the wood was consumed the contents (stones/hot charcoal) of the oven were left undisturbed and immediately covered with a thick compressed layer of soaking wet fern fronds. A simple test for food contamination potential was to chew the fern leaves - if they were not excessively bitter then the food would not be contaminated. Flax for example is very bitter and therefore unacceptable. The food was placed in a conical pile on top of this and covered with more wet fern fronds (or clean wet flour sacking). This was then covered with a compacted layer of moist earth (from the digging of the ovens) to an average thickness of 20 cm.

Results and conclusions

Sources of error. In the matter of the sources of experimental error there were several problems. The presence or absence of wind appeared to alter the rate at which the manuka burned. High winds sometimes shortened the burning time for an oven by up to three-quarters of an hour and may have caused slightly higher internal temperatures.

The void pattern between the burning manuka and stones probably caused variations in the burning rate as the stones and wood settled down into the oven. The thermocouples recorded temperatures from the charcoal-filled interstices of the stones. While this probably did not result in a significant difference for the reading of small sized stones, the large stones (at least until they heated up, were probably cooler than the actual temperature recorded. The manuka used was slightly but consistantly damp. Higher temperatures and faster burning rates might have been reached with dry wood.

The higher collective surface area of the small stones may have had some unforseen effect (though buffered to a certain degree by the hot charcoal), and cooking times were not as standardised as they should have been. The difference in collective stone mass (large vs small) needed to fill each oven may also have affected this.

1. What is the life expectancy of the three stone types and two sizes? Figure 1A shows a much smaller percentage of shattered stones for each successive firing of the small sizes than the large sizes (Figure 1B). Table 1 gives the probable upper limit to the number of re-firings the stone types and sizes could be subjected to before 50% fracturing was reached.

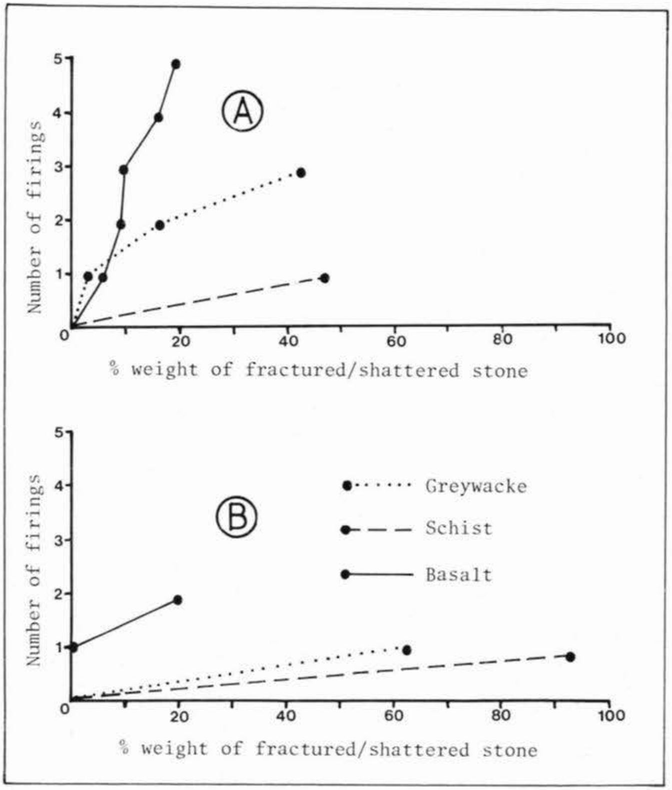

FIGURE 1. The percentage of fractured/shattered stones of the three rock types, for successive firings of small (A) and large (B) sizes. For each successive firing, the entire original volume of ovenstones (including broken pieces) were included.

Rock Type	Number of re-firings before 50% fracture	
	Large Size (diameter=20cm)	Small Size (diameter=10cm)
BASALT	5	10
GREYWACKE	2	4
SCHIST	0	0

TABLE 1. Extrapolated 'life expectancy' of ovenstones.

Because whole stones seemed generally to give better performance (especially in terms of re-use) 50% fracture roughly approximates the limits of ovenstone efficiency in retaining oven heat and resistance to thermal shock. Very different results could be expected if ovens were made as umu konau, where the stones are heated in one pit and then transferred to another cold one for cooking (Best, 1923).

The ovenstones were subjected to a pre- and post-fired lithological analysis (Gillies, 1979:13, 40). The only major change observed for their temperature ranges (15° - 850°C) was in the schist. Here some of the iron oxides present were burnt off making the rock more friable. This rock proved the least satisfactory for this type of oven. Basalt or any other dense (and preferably semi-spherical) igneous rock would seem to be the best choice, and could be re-used a number of times. It is also noted here however, that almost any type of rock could be used in an ember-oven at least once.

2. What is the qualitative cooking performance of the ovens? Starchy food usually took about three hours to cook. The octopus generally required about four hours to be properly cooked. Beef and mutton usually required about three hours, but fish took the least time of all and was placed in the coolest part of the oven (at the top of the conical food pile). Steam was the cooking agent in these ovens, and the temperature (as verified by the thermocouples) usually stabilised within the food zone at 100°C. No higher steam temperatures than this were recorded. This was to be expected for these small ovens of

limited duration, where pressure (and hence superheated steam) was absent. Sutton's (1971) manometer readings of zero pressure in some of his earlier experimental ovens of similar dimensions also substantiated this. The rise in temperature in the food zone occurred between 30 minutes to one hour after the food was covered. These ovens would cook up to 10 kg of food in about four hours. Quantities larger than this often took up to seven hours to cook. This manner of 'food steaming' is similar to that observed by Best (1923), which he calls tao kai.

Improperly cooked food sometimes resulted if the wet ferns (the steam reservoir) and food were placed on at an internal temperature of 500°C. Properly cooked food always resulted if the food was placed on at an internal temperature of 600°C. This probably resulted in a faster rise in temperature in the food zone. Why this should ensure better cooking is not clear. Perhaps it was something to do with the effect of 'surprising' the food with rapid generation of steam.

3. What is the optimum ovenstone size? As shown in Figure 1 the best overall performance obtained was with the small size stones. These seem to have allowed more oven heat retention during cooking, thereby ensuring a high generation of steam within the ovens. The small stones allowed a more even heat distribution within the oven during all phases of its heating and cooling. They were also much less prone to fracturing than the larger stones, giving them greater re-use potential. The charcoal left undisturbed within the oven probably had a marked effect as well. With the smaller stone sizes there was probably a more evenly distributed volume of hot charcoal creating a buffering effect against fracture and heat dissipation.

Further observations. An interesting effect of leaving the charcoal embers in with the ovenstones was the phenomenon of re-ignition. If the food was removed after about 3-4 hours the internal temperature was usually high enough (150°C) to cause the hot charcoal to re-ignite after being exposed to the fresh air. This effect can be seen in Figure 2 where one re-ignition temperature of 800°C was reached. After 3-4 hours of re-burnings most ovens were hot enough to cook a further small quantity of food (fresh wet ferns would be needed).

After the complete cycle of firing, cooking, re-exposure and re-ignition was over, the ovens (used only once in all cases) had the following appearence. Ovens which had re-ignited had a light brown coloration imparted to their upper walls (quite different from their pre-fired brown). In the bottom layer the stones were covered with a fine white ash. In the ovens which did not

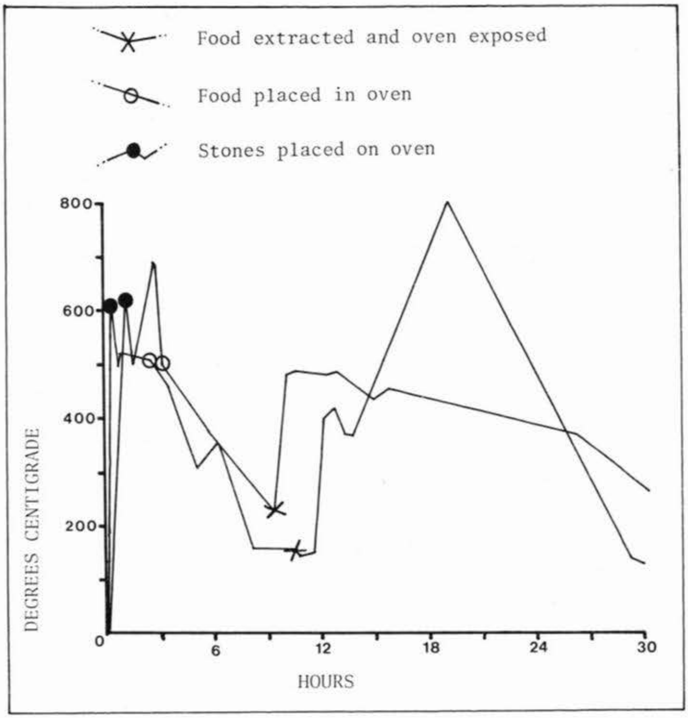

FIGURE 2. Two examples of the temperature records of internal oven heat. Both these ovens re-ignited on exposure, following long periods of cooking.

re-ignite after exposure, a large volume of charcoal remained. Otherwise their coloration was the same as the others. One of these ovens which did not re-ignite (with the stones subsequently removed) was cross-sectioned two years later. A band of charcoal extended along the basal oven surface, and the oven was partially filled with grass-covered topsoil (although there was no slumping of the walls).

Despite the lack of steam pressure in the cooking zone of these small ovens, food temperatures of 133°C (using the same thermocouples) have been recorded by Fankhauser (1982:133, 134) in much larger experimental ovens. This suggests that superheated steam did play a significant role in the thermodynamics of large <u>umu</u> over cooking periods of one to two days. Re-ignition also occurred in this large oven when exposed after two days (Fankhauser, 1982:133).

For those who would try their hand at these small <u>hangi</u>, the above experimental method is quick and easy. A point will be reached, usually two to three hours, when the oven is full of semi-burnt wood and stones. From this point the internal temperature will drop no matter how much more wood is added to the top. Move fast to place and cover the wet ferns and food when the fuel is finished. Try placing the food beforehand in small flat circular baskets of wire netting. This will make for ease of extraction and will minimise burnt fingers. For larger quantities of food required, simply increase both the size of the oven along with the amounts of fuel and ovenstones (don't use stones that are very large). Even the toughest of meats (goat, octopus, paua, etc.) will be steamed tender by these <u>umu</u>. The taste of the cooked food will not be contaminated as long as non-bitter wet ferns/greens are used (don't use sacks), and there are no large lumps of unburnt wood on top of the oven before it is covered.

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