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# Gardening at the Edge: Documenting the Limits of Tropical Polynesian Kumara Horticulture in Southern New Zealand

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Kumara (*Ipomoea batatas*), a major food source for Maori, was brought to New Zealand from tropical Eastern Polynesia ~700 years ago. Maori successfully adapted their cultivation techniques to grow kumara in New Zealand's cooler, seasonal climate, although most kumara cultivation was limited to the warmer North Island, with cultivation becoming more marginal southward. Banks Peninsula area is considered to be the southernmost limit for kumara gardening. The Okuora Farm archeological site on the southern side of Banks Peninsula has five pits that appear to be of the raised-rim type used for over winter storage of kumara tubers. We conducted a preliminary investigation into the nature of the pits and surrounding 1 km<sup>2</sup> area using nondestructive techniques in accordance with Maori designation of food storage sites as *tapu*. Ground penetrating radar (GPR) investigation of two of the pits revealed subsurface disturbances consistent with postholes and drains, typical of raised rim kumara storage pits. Soil modification typical of kumara gardening was identified on a 1 ha area on a warm north-northwest facing hillside. Several large borrow pits were identified as the likely source of the gravel added to the modified soil, possibly to retain heat and moisture. A plant phytolith study of soil samples identified several that appear to be from kumara. The combination of results strongly suggests this site was one of the southernmost Maori kumara gardening sites yet identified in New Zealand. © 2004 Wiley Periodicals, Inc.

## INTRODUCTION

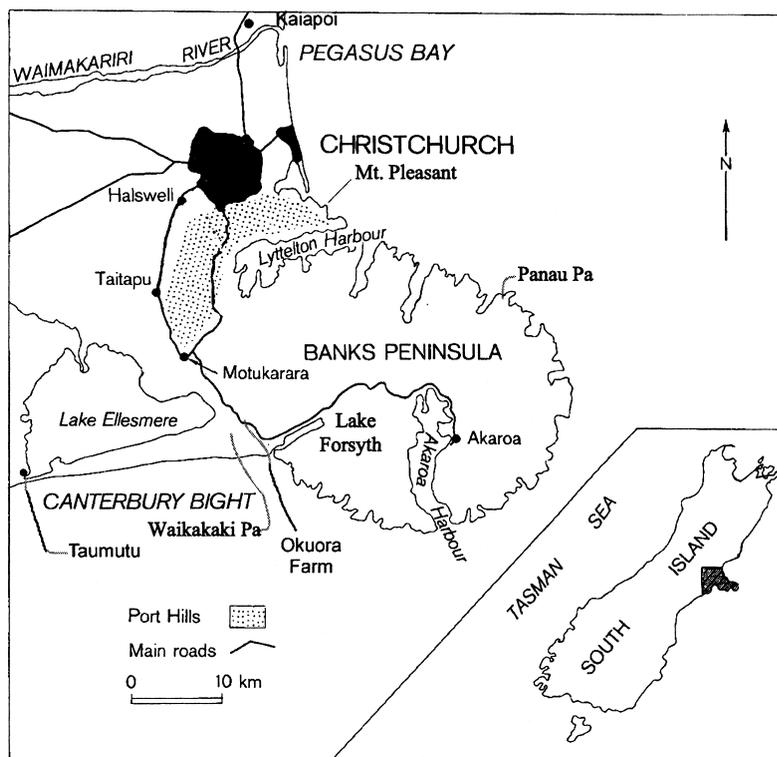
The early Maori seafarers, who arrived in New Zealand from Eastern Polynesia near the end of the 13th century A.D., brought plants and other material from their tropical home that were needed for the successful colonization (Davidson, 1987; Anderson, 1991; Higham et al, 1999; Holdaway and Jacomb, 2000). These included kumara (*Ipomoea batatas*), yam (*Dioscorea* sp.), taro (*Colocasia esculanta*), gourd (Family Cucurbitaceae), paper mulberry (*Broussonetia terminalis*), banana (*Musa* sp.), breadfruit (*Artocarpus communis*), tropical cabbage tree (*Cordyline terminalis*), and coconuts (*Cocos nucifera*) (Best, 1925). The cooler, seasonal temperate climate of New Zealand meant that many of these crops failed to thrive, or, as in the case of coconuts, bananas, and breadfruit, did not grow at all. Taro, paper mulberry, and yam growing were restricted to the warmer North Island.

Maori horticulture probably started soon after New Zealand's settlement (Leach, 1987) and the earliest recorded gardening sites in New Zealand are found at the Clarence River mouth in Marlborough and along the Wairarapa coast, both <sup>14</sup>C dated to before A.D. 1300 (Leach and Leach, 1979; Trotter and McCulloch, 1997). The largest pre-European Maori gardening sites are on the North Island, including the Auckland Isthmus and the Waikato regions, both of which have 2000 ha of former horticultural sites (Taylor, 1958; Sullivan, 1972). An 80 ha gardening site and associated settlements occupied the coastal region at Palliser Bay, Wairarapa, with well-developed horticultural techniques being carried out from ca. A.D. 1400 (Leach and Leach, 1979; Goff and McFadgen, 2001). Early European accounts of New Zealand report large areas being used for horticulture, and Captain Cook observed large plantations along the east coast of the North Island being used to grow kumara, yam, and taro in the 18th century (Best, 1925).

The tropical sweet potato *Ipomoea batatas*, known as kumara by the New Zealand Maori, was important in two ways. First, it provided a source of food that was high in nutritive value (Coleman, 1972), and, second, it was a spiritual and physical connection to the Maori ancestral homeland, Hawaiki (Yen, 1961). The cooler, more seasonal temperate climate of New Zealand was quite different from the tropical conditions in which kumara were grown in Polynesia (Yen, 1961). As a result, Maori had to modify their horticultural techniques to enable the tropical kumara plant to grow 1000 km further south than it was grown anywhere else in the world (Yen, 1961).

Maori adapted their horticultural techniques in several ways. They selected areas with suitable microclimates as gardening sites, generally coastal with north-facing slopes that received more solar energy than other sites. Gravel and sand were added to garden soils, presumably to trap heat, producing "made" or plaggen soils (McFadgen, 1980a). Plaggen soils were often associated with excavation pits, termed borrow pits, that were the source of the gravel. Low stone walls or earth lines were built, possibly as plot boundaries (Leach, 1984), possibly to channel cold air away from the garden site (Trotter and McCulloch, 1997), or possibly to trap heat for planting (McFadgen, 1980b; Jacomb, 2000). Maori also developed methods of storing seed kumara over winter in underground storage pits (Yen, 1961).

Most researchers suggest that Banks Peninsula, on the East Coast of the South Island, was the marginal southernmost limit of kumara cultivation in New Zealand (Figure 1; Leach, 1987; Challis, 1995; Anderson, 1998; Trotter and McCulloch, 1999). Maori oral tradition records that kumara were grown in the Banks Peninsula area in the pre-European period (Beattie, 1990; Trotter and McCulloch, 1999), and several archeological sites display features associated with kumara gardening. Harrowfield (1969) described earth lines at seven sites on Banks Peninsula that appear to have been used by Maori for horticulture. One of these, Panau at Long Lookout Point on the north side of Banks Peninsula, has 5 ha of stone and earth lines and modified soil identified on a north-facing slope, but no associated kumara storage pits (Worrall, 1993; Jacomb, 2000). Two other sites, Kaiapoi on the coast north of Banks Peninsula (Walton, 1985) and Taumutu on the coast south of the Peninsula



**Figure 1.** Map of the Banks Peninsula region with locations mentioned in the text (after Griffiths, 1973b).

(Trotter and McCulloch, 1999), have been identified as possible kumara gardening sites based on the presence of borrow pits and modified soils, but lack other features associated with kumara gardening.

We investigated a possible pre-European Maori gardening site, the Okuora Farm site, on the southernmost side of Banks Peninsula (Figure 1). The site is on a north-facing slope with several pits on the crest and slopes that were identified as probable raised-rim kumara storage pits used to store kumara tubers over winter (NZAA Site Recording Scheme, Challis, 1995), one of only two sites identified on Banks Peninsula as having possible storage pits.

Modern Maori culture forms an active presence in New Zealand culture, and researchers must incorporate Maori cultural concerns into their research design. Certain kinds of sites must be treated with greater respect and circumspection and cannot be excavated. Such sites include burial sites (e.g., Nobes, 1999), sites where people have died in battle, and sites where food was or is stored. Thus, the possible kumara storage pits, which were part of this study, could not be excavated without causing offence to local *iwi* (tribes).

As a result, our preliminary investigation used non-destructive techniques on the pits and surrounding gardening slope. The investigation techniques included surveying, noninvasive ground-penetrating radar (GPR) on the pits, description of soil stratigraphy, and examination of plant phytoliths in order to determine whether Okuora Farm was a Maori kumara gardening site, one of the southernmost to be documented and the southernmost site with over-wintering kumara storage pits.

## **STUDY AREA**

The Banks Peninsula region is considered by many to be the southernmost limit for kumara horticulture (Leach, 1987; Challis, 1995; Anderson, 1998; Trotter and McCulloch, 1999). It is also the southernmost limit for a large number of other warmer climate plants, such as Nikau palms, suggesting that the microclimate is warmer and wetter (Wilson, 1992). There are several sites around Banks Peninsula with modified soils and stone rows (Panau, Kaiapoi, Taumutu, Goughs Bay, and Duckfoots Bay), but only two have possible kumara storage pits; Okuora Farm is one of those sites (Figure 1; Challis, 1995; Jacomb, 2000). The rich natural resources of the southern Banks Peninsula area allowed Maori to diversify and kumara gardening was only one of many sources of food. As a result, the area was one of strategic importance.

## **Settlement History**

In the Canterbury area, Maori occupation sites were concentrated along the coastline, where food resources were most abundant and the climate most benign. Banks Peninsula in particular, with its large number of bays, provided a wide array of marine resources, and a correspondingly large number of Maori archaeological sites are situated around its shores (Challis, 1995). Three main tribal groups have inhabited the Banks Peninsula and Canterbury areas in the last seven hundred years: the Waitaha, Ngati Mamoe, and Ngai Tahu. Radiocarbon dating of moa-hunting sites suggests that the first people occupied the area in the 1300s (Challis, 1995), with the Ngati Mamoe migrating from the Wellington region in the late 1500s (Anderson, 1998). Ngai Tahu then superseded the Ngati Mamoe and settled in the South Island in the early 1700s (Ogilvie, 1994).

Four main factors attracted Maori to the southern Banks Peninsula area. Nearby Te Waihora (Lake Ellesmere) and Te Wairewa (Lake Forsyth) provided a large amount of resources such as eels and waterfowl for food and flax for building materials (Figure 1; Hemmingsen, 1997). The varied coastline of Banks Peninsula provided types of food resources not available on the coastlines to the north and south (Challis, 1995). The forested areas provided additional resources of food such as bird life and material for making shelters, weapons, and fishing equipment, as well as natural medicines. The Wairewa area also controlled the strategic north-south coastal route between North Canterbury and settlements further to the south since the ground immediately inland was very swampy and difficult to cross, forcing the trade routes along the coast or farther inland.

Te Waihora dominates the area just south of Banks Peninsula, and there are many Maori sites along its shores, particularly where these are adjacent to the hills (Figure 1). It is a ca. 400 km<sup>2</sup> brackish- to fresh-water lake impounded behind the Kaitorete Barrier. Kaitorete Barrier was formed in the last 6 Ka as mixed sand and gravel sediment was transported northwards by longshore currents in the Canterbury Bight, first forming a spit, and then a beach-barrier complex (Kirk, 1994; Hemmingsen, 1997; Holmes, 1998). Currently, the level of Te Waihora is artificially maintained at 1.13 m above mean sea level (amsl) by dredging open the gravel barrier at the south end of the lake (Hemmingsen, 1997). In pre-European times, Maori maintained the lake at higher levels of up to 5.5 m amsl, but periodically opened an outlet channel at Taumutu for eeling or when the lake level threatened their communities (Figure 1; Hemmingsen, 1997).

The many Maori archaeological sites in the Birdlings Flat area on the south side of Banks Peninsula testify to its importance to Maori. However, apart from reconnaissance description of many of these sites, there has only been limited archaeological work carried out in the area (Jacomb, 1994). The types of archaeological sites range from a large number of ovens on Kaitorete Barrier, undefended settlements, pits, rock shelters, and fortified pa (Challis, 1995). The largest site in the Birdlings Flat area is the Waikakahi undefended settlement, which covers a three-hectare area on top of old beach ridges beside Te Waihora (Figure 1). The Okuora Farm archaeological site is on the southern slopes of Banks Peninsula, near the shore of Te Waihora, only 1 km from the large Waikakahi settlement.

### **Climate**

New Zealand has a cool temperate climate with distinct seasons. Kumara needs temperatures of >15°C for five continuous months for successful germination and a reasonable crop of tubers (Yen, 1961; Coleman, 1972). The climate of the North Island fits these criteria, but the east coast of the South Island is marginal for successful kumara growth, with the southern limit occurring in the vicinity of Banks Peninsula.

The climate of Banks Peninsula is wetter and warmer than the adjacent Canterbury Plains, providing a regional microclimate more suitable for kumara horticulture (Jayet, 1986). The peninsula receives 800 mm/yr of rainfall, compared to the about 500 mm/yr that the Canterbury Plains receive, although with greater temporal variations; Banks Peninsula receives 20% less rain in spring and summer and 30% more rain in the winter months (Ryan, 1987). The higher winter rainfall is due to the Peninsula's greater exposure to southwesterly storms that bring rain, especially in the winter. The higher elevation of the peninsula also produces an orographic effect, increasing the precipitation as storms are forced to rise over the higher landmass (Ryan, 1987).

Young kumara plants are very susceptible to frost damage early in their growing season. Therefore, kumara gardens are sited close to the sea in a warmer microclimate. Kumara gardening sites identified at Palliser Bay (Leach and Leach, 1979),

Clarence River mouth (Trotter and McCulloch, 1997), and Banks Peninsula sites (Challis, 1995) are all close to the sea and have a low occurrence of frosts.

Degree-days are a method of calculating the number of critically warm days so that growing seasons for agricultural crops can be estimated (Turner and Fitzharris, 1986; e.g., Worrall, 1993). A degree-day is a measurement of the thermally weighted time required for a crop to reach maturity. If the minimum heat requirement for growth is not maintained then harvesting may be delayed and risks of frost increase.

Degree-days are calculated as

$$D = \sum N(T - B)/M,$$

where  $D$  is degree days,  $N$  is the number of days in the growing season,  $T$  is temperature in Celsius,  $B$  is the minimum temperature required for plant growth, and  $M$  is the mean average daily temperature (Turner and Fitzharris, 1986).

Mean average daily temperatures are calculated as

$$M = (T_{\max} + T_{\min})/2,$$

where  $T_{\max}$  is the daily maximum temperature and  $T_{\min}$  is the daily minimum temperature.

Mean monthly temperatures are 1.5°C higher on Banks Peninsula than on the adjacent Canterbury Plains, providing a microclimate that allows kumara gardening at its southernmost limit. Minimum temperatures in particular are much higher, an important factor for kumara growth, and do not have the large range of extremes experienced on the adjacent plains (Jayet, 1986). The warmer mean temperature may be the result of two factors: the presence of the sea around the Peninsula that moderates the temperature and the effects of the topography on katabatic drainage off the Southern Alps (Jayet, 1986). On the plains, cold katabatic air drains down from the mountains towards the sea at night, reducing temperatures. The hills of Banks Peninsula block the passage of this cooler air, effectively insulating the area and lifting it above the cold (Jayet, 1986).

Banks Peninsula also has a lower incidence of frosts and in some years, is frost free (Ryan, 1987). Frost is defined in two ways: (1) ground frost, which occurs when the temperature at the ground reaches  $-1.0^{\circ}\text{C}$ , and (2) air frost, which occurs when the air temperature reaches the same temperature. Ground frosts occur before air frosts. Frost occurrence is linked to topography, with flatter, low-lying areas tending to frost more than hilly areas (Kingham, 1969). Higher wind speeds caused by air channeling down valleys also tend to keep the hilly areas frost free (Jayet, 1986). The Mount Pleasant recording station on the north side of Banks Peninsula (Figure 1) receives only 12 ground frosts per year on average, whereas nearby low-lying sites receive 70–110 ground frost days per year. Air frosts occur even less often on Mount Pleasant, with a mean frequency of 0.4 days per year (Ryan, 1987). The Onawe recording station near Akaroa on the southern side of Banks Peninsula

(Figure 1) records a similar frost occurrence rate with only 3.3 air frosts recorded per year and an air frost-free season of 245 days compared to the 132-day season Christchurch experiences (Ryan, 1987). The ca. 1100 degree-days above 10°C calculated for Onawe indicate that it receives the highest number of critically warm growing days of the Canterbury area, approaching the values recorded for the Wellington region (Ryan, 1987).

## **OKUORA FARM ARCHAEOLOGICAL SITE**

### **Site Survey**

The Okuora Farm archeological site is located on the lower hills of southern Banks Peninsula where they abruptly meet the shoreline of Te Waihora (Figure 1). The hills surround the relatively flat lying, 1.6 km wide, southwest facing Okuora Valley opening out onto the old Te Waihora lakeshore. The owner of the property, Mr. Reg McIntosh, aged 84 at the time of the research and with an excellent knowledge of the European and Maori history of the area, said the pits on the farm, including the large pit at the base of the hill, had been there as long as his family had owned the farm (since the 19th century). He added that the Wairewa Runanga (local Maori community) has an acknowledged association with the site and had inspected the pits on the hill on several occasions.

### *Survey Methods*

The general topography and geomorphic features of the site were first collated from existing topographic maps. Then a series of air photos from the 1940s to the 1980s were examined for indications of archaeological features, specifically those associated with possible Maori horticultural activity at Okuora Farm.

A detailed topographic survey of the site (Figure 2) was conducted using a Total Station, comprising a Wild Electronic Theodolite (Model T-1000) and Electronic Distomat (Model DI-1000) in conjunction with optical reflecting prisms. The 3-D survey data was stored digitally on a Wild GRE-4 data terminal-data logger. The survey was fixed to the known position of Trig D by taking sightings from three survey stations. The position of the pits and other features was surveyed to a <1 cm level of accuracy. The positions of geomorphic features such as beach ridges and relict shoreline platforms were also recorded.

### *Survey Results*

The hills surrounding the Okuora Valley reach a height of 120 m amsl and have the typical geomorphic features found on Banks Peninsula: a long, low-angled spur with steeper slopes on the spur's margins (Figure 2). The tip of the spur on the eastern side of the valley contains the possible kumara pits that are the focus of this study. The Devil's Knob (99 m high) is at the end of a long spur that extends southwest from the high central Mount Herbert-Sinclair-Fitzgerald ridge. The southeastern and southern sides of the Devil's Knob are bounded by steep, 50-m-high

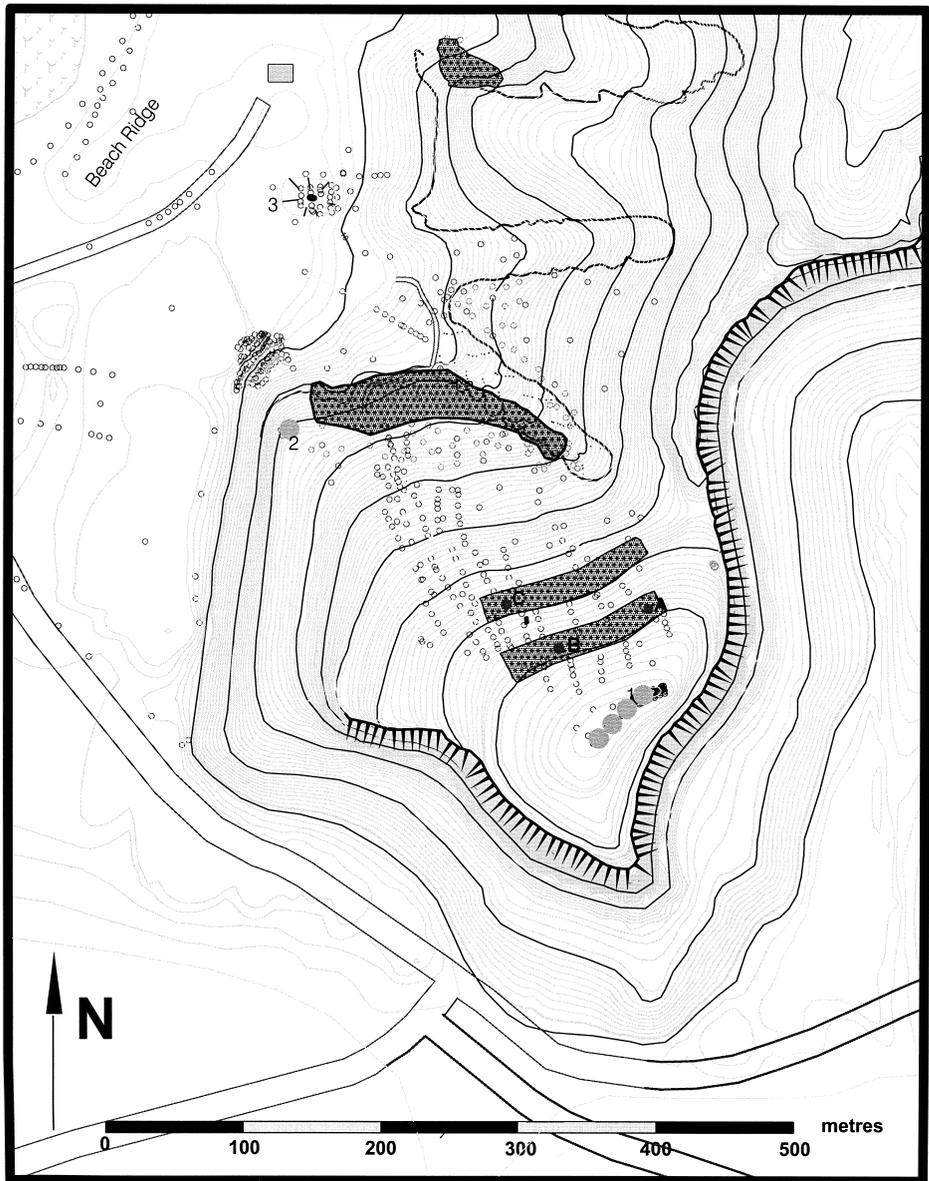
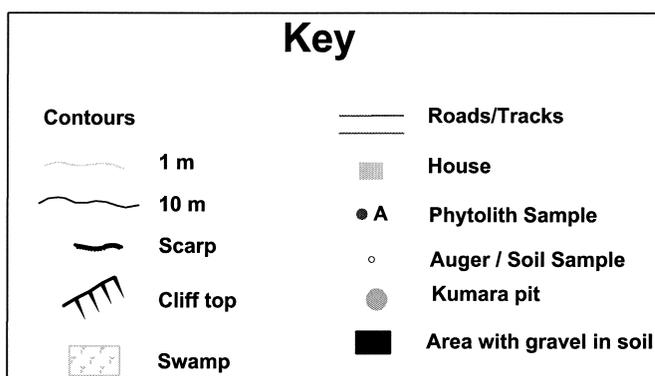


Figure 2a. Surveyed map of the Okuora Farm site showing archaeological features and sample sites.



**Figure 2b.** Key for surveyed map.

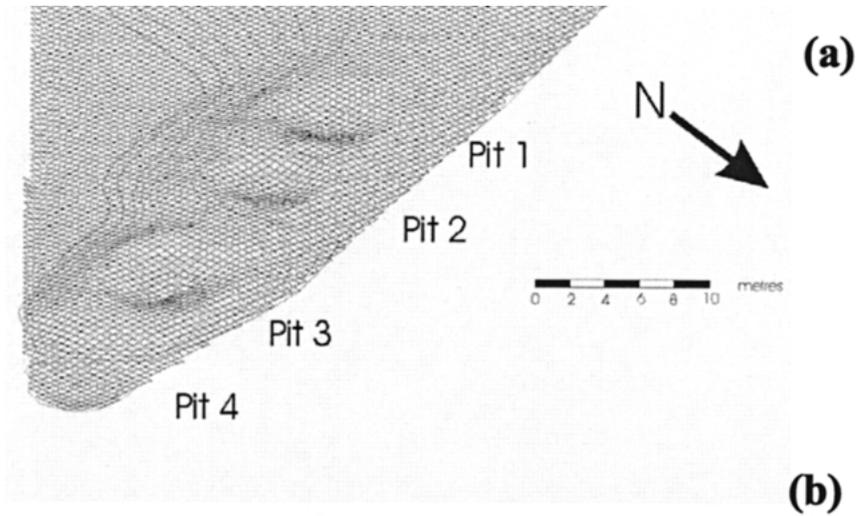
cliffs, with talus slopes rising 20 m above the base of the cliffs (Figure 2). These cliffs, along with a sea stack off the end of Devil's Knob, are relict shoreline features from when the sea level was higher 120 Ka B.P. (Shulmeister et al., 1999). The caves in these cliffs contain a Maori burial ground called Marokuraiti (Taylor, 1952). The north-facing side of the Devils Knob has a slope angle of between 15° and 25°, with steeper slope angles of up to 35° at the base of the hill. Four rectangular pits, identified as possible kumara storage pits (Challis, 1995), occur on the crest of this slope with another two occurring partway down (Figure 2).

The pits at Okuora Farm show up clearly on the air photos including the earliest photo series produced at the start of World War II. There are six pits at the site, five of which were identified as associated with kumara tuber storage and another one as a possible borrow pit (Challis, 1995). The possible storage pits include a line of four rectangular pits on the crest of the Devil's Knob at an altitude of 90 m amsl with dimensions of 3.5 × 3 × 0.4 m (Figures 2a, 2b, and 3a). The fifth pit, on the lower slope at 30 m amsl, is larger than the other four, with dimensions of 5 × 2.5 × 0.7 m (Figure 3b). The possible borrow pit occurs at the base of the hill in a beach ridge at 7 m amsl. It is a 40 × 29 × 1.4 m rectangular feature (Figure 2).

The Okuora Valley is situated at the margin of the old Te Waihora lakebed, an old beach ridge of which runs across the property at the mouth of the valley (Figure 2). The top surface of the beach ridge is mainly bare gravel with a sparse covering of vegetation. The sediment in the beach ridge is composed of feldsarenite (Torlesse greywacke) clasts that range in size from granule to medium pebbles. Several other pits that have the appearance of borrow pits occur on the beach ridge, although their definitive identification as such is complicated by the wave-washed swash-cusp morphology of the beach ridge.

### Site Selection

Careful site selection with respect to solar angle of incidence, proximity to the sea, and shelter from winds can create a microclimate favorable for kumara hor-



**Figure 3.** (a) Rendered 3D model from survey data of the four pits on the crest of the Devils Knob. (b) Photograph of the large pit located on the lower hillside at 30 m amsl.

ticulture. The Okuora Farm site shows signs of careful attention to slope orientation in particular.

### *Background*

One of the adaptations the Maori made to grow kumara in marginal southern areas was the selection of north-northwest facing slopes of hills with slope angles of 7–20° as growing sites (Brailsford, 1981; Trotter and McCulloch, 1997). The siting of gardens on a north-facing hillside increases the amount of incidental solar energy the ground surface receives, as calculated by the Lambert equation:

$$I_c = I_{co} \cos \beta,$$

where  $I_c$  is incident photo flux density or solar energy measured in nm,  $I_{co}$  is photo flux energy perpendicular to incident solar energy, and  $\beta$  is the angle between  $I_c$  and a line perpendicular to the ground surface (Figure 4; Tang, 1997).

An increase of angle  $\beta$  causes a proportional drop in energy reaching a surface. Applying this equation to a north-northwest facing 20° slope decreases angle  $\beta$ , thereby increasing the solar energy reaching the surface. This made the best use of the available sunlight, effectively increasing the length of the growing season.

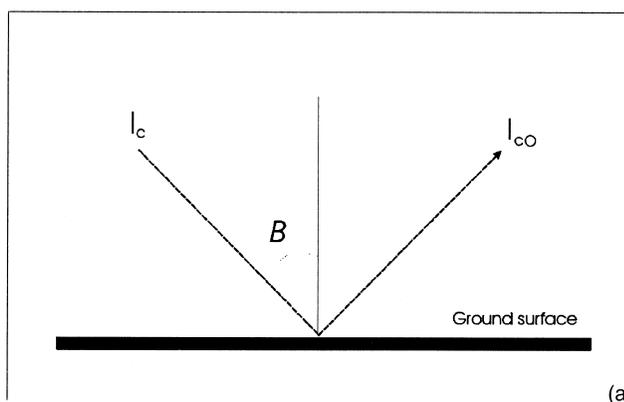
### *Microclimate of the Study Area*

The Wairewa area, on the south side of Banks Peninsula where Okuora Farm is located, has its own microclimate. Strong northeasterly winds originating in Pegasus Bay rise over the Mount Fitzgerald-Sinclair-Hilltop ridge and are funneled down the Wairewa Valley (Figure 1). The wind strength progressively increases, becoming very strong by the Te Wairewa (Lake Forsyth) outlet. During the summer field season of 1999–2000, a strong La Niña pattern affected New Zealand's weather, producing strong northeasterly winds along the east coast of the South Island. Strong northeasterly winds occurred in the Wairewa Valley, and the top of the Devil's Knob was particularly exposed to this wind. However, down-slope from the Devil's Knob in the Okuora Valley, winds dropped off considerably, suggesting this area was more sheltered.

The slopes on the north side of Devil's Knob, where modified soils were found, are north-northwest facing and have slope angles of between 22° and 30°. The optimum slope angle and orientation for receiving the maximum amount of solar energy available at latitude 43°S during the warm growing season months of October to March is between 20° and 30° and is north facing (Reed, 1998). Thus the slopes at Okuora farm are orientated to receive maximum solar energy, and modified soils were found only on the most favorably oriented slopes.

### **Soil Modification**

Soil modification involving the addition of gravel is an indication of kumara gardening at a site. The natural soils of the lowland parts of the Wairewa region are



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Month	Sun Altitude	Surface perpendicular to solar angle
Jan	67	23
Feb	58	32
Mar	47	43
Apr	35	55
May	27	63
Jun	24	66
Jul	27	63
Aug	35	55
Sept	47	43
Oct	59	31
Nov	67	23
Dec	70	20

**Figure 4.** (a) Schematic of Lambert equation diagram of solar angle of incidence  $I_c = I_{co} \cos \beta$ , where  $I_c$  is incident photo flux density or solar energy measured in nm,  $I_{co}$  is photo flux energy perpendicular to incident solar energy, and  $\beta$  is the angle between  $I_c$  and a line perpendicular to the ground surface. (b) Table of solar altitude and angle of a surface that will receive the maximum solar energy for 43°S.

described as yellow-grey earths or pallic soils, and are primarily derived from the underlying loess or basaltic bedrock forming the hills of Banks Peninsula (Griffiths, 1973b). The silt-rich loess was deposited during the last glacial period, and the loess unit is <1 m to 5 m thick in the Wairewa area. Griffiths (1973a) reported a

radiocarbon age of  $17,450 \pm 2070$  yr B.P. determined on bulk organic carbon from a paleosol developed in the upper part of loess unit at a locality elsewhere on Banks Peninsula. The surface soil is described as a generally dark greyish-brown, friable, sandy, or silty loam with a weakly to moderately developed nut structure. This commonly overlies an olive-brown, silty loam that has weakly developed nut structure or is massive, and has strong brown mottling with iron and manganese concretions (Griffiths, 1973b). The soils on the hill slopes at the Okuora Farm site were examined to determine whether or not soil modification, i.e., addition of gravel, had taken place.

### *Background*

As noted earlier, gravel and sand were often added to kumara garden soils. Early descriptions of Maori kumara growing techniques discussed the choosing of sandy or gravel soils, or the addition of this material to soils (Wakefield, 1845; Walsh, 1902). Shortland (1854) recorded "for they (Maori) even employed the method of forming an artificial soil by mixing sand with the natural soil in order to make it light and porous, and so render it more suitable to the growth of sweet potato." These early ethnological accounts were good descriptions of the practice, but the exact reason why material was added was not recorded (Walton, 1982). Some consider the most important reason for applying gravel and sand to garden soil was to improve moisture content and soil drainage (Taylor, 1958; Challis, 1976). However, there is some consensus among contemporary archaeologists and ethnologists that the addition of gravel and sand to soils were both to lighten the soil and to increase the soil temperature (Jones, 1994; Trotter and McCulloch, 1997).

There are many regions in the country where modified soils occur, including large areas of the Auckland, Waikato, and Wellington regions (Taylor, 1958; Sullivan, 1972; McFadgen, 1980a). In the South Island, 400 ha of modified soils have been described in the Nelson area (Challis, 1976, 1978), while in Canterbury there are several areas of these soils. Ten hectares of modified soils have been described at Kaiapoi just north of Banks Peninsula (Walton, 1985) and at Woodend north of Kaiapoi (Trotter, 1982).

### *Soil-Sampling Methods*

The methods used to sample the soils at the Okuora Farm site are as follows. First, outcrops with good exposures of soil and parent materials (loess and basalt) were described. In areas on hill slopes with poor or no exposures, an auger was used to collect 1-inch-diameter cores in order to examine the soil stratigraphy (Figure 2). Soil samples were collected from the upper 150 mm of soils and passed through a 1 phi-mesh sieve. If gravel clasts were present, they were described and retained for later measurement and weighing. Surface soil samples were collected at random locations on the hillside at the site and were sieved for gravel. Auguring and digging disturb *tapu* sites such as the kumara storage pits, and, therefore, were limited to non-*tapu* sites on the slopes.

*Results of the Soil Investigation*

The following description of the soils and stratigraphy is based on a series of cores taken on the slopes of Devil's Knob, up the gully at the base of the Knob, around the base of the slope, and on the adjacent flats (Figure 2). Below an elevation of 17 m amsl, there is usually a thin soil developed in fine-grained beach sediment overlying beach gravel. The fine-grained sediment above the beach gravel is 100–300 mm thick. The unit of beach gravel overlies late Pleistocene loess.

The deposition of the beach gravel at the base of the cliffs and in the Okuora Valley probably occurred about 6000 yr B.P., following eustatic sea level rise that flooded the Waihora interfan area, leading to the development of a lake (Figure 2; Griffiths, 1973a). Most Te Waihora beach ridges occur at 11 m amsl, but the large fetch and the strong northwest and southwest winds could have produced large waves at the east end of the lake (Hemmingsen, 1997), depositing the beach ridge that terminates at 17 m amsl along the base of the hill.

Above 17 m amsl, the surface soil is developed in loess overlying basalt. The surface soil has a 200–250 mm-thick A horizon above a 250–500 mm-thick B horizon. Unweathered loess (C horizon) occurs below a depth of 500 mm, and basalt bedrock is 0.75–1.5 m below the land surface.

This showed a general pattern of an organic horizon down to 200–250 mm, an organic-clay mixture from 250–500 mm, and then entirely loess from 500 mm downward. The basal basalt bedrock lay between 0.75 and 1.5 m deep.

Gravel was found in the surface soil in four different areas (Figure 2), well above the nearest source of gravel, the beach ridge at the base of the hill. The locations of the gravelly areas are of particular significance. Each is located on a north-facing slope, with a solar incidence angle of between 22° and 30°. Three of the four areas are next to one or more of the kumara storage pits and, most importantly all four are in places 11–90 m above the beach ridge, where no natural processes can explain the presence of the gravel.

Along the south side of the gully running up from the farm track, greywacke and quartz pebbles were recorded on the surface of the soil. The side of the valley where the clasts were found was north facing, at a height of 25–50 m amsl, and had a slope angle of 25–35°. Clasts were collected and analyzed. The grain size was dominantly 2.5  $\phi$ ; 27% of the clasts were quartz with the rest composed of greywacke.

Further up the hill on the north-facing slope just below the pits (73–90 m), relatively large amounts of greywacke clasts were recorded on the soil surface (Figure 2). The clasts were found in two main areas running across the face of the hill that had a slope angle of 20–23° and faced north-northwest (Figure 2). The first area was 73–80 m amsl and had an area of 125 m  $\times$  18.5 m (2312 m<sup>2</sup>); 37.15 g of gravel were collected from a sample. The next area was further up the slope 84–90 m amsl. It had an area of 25  $\times$  120 m (3000 m<sup>2</sup>), and a sample yielded 56.57 g of gravel. The grain-size distribution and composition of the two gravel samples were very similar to the beach ridge sediments.

At two locations on the hill, moa gastroliths were found in the loess. The gastroliths are medium-sized, well-rounded quartz pebbles with semipolished surfaces. Gastroliths are relatively common finds in areas that moa previously inhabited (Worthy, 1993). Moas would ingest pebbles, which would be held in the crop and used to assist the digestion process.

### *Gravel Analysis*

Gravel in the topsoil on the north-facing slopes above 23 m amsl, particularly the gravel found near the top of the Devil's Knob at 73–90 m amsl, indicates modified soils (Figure 2). The total area of the hill in which gravel was found in the soil was ca. 10,000 m<sup>2</sup>. Augering in the gully at the base of the hill revealed that the beach ridge reached a height of 17 m amsl and was covered by 100–300 m of fine-grained beach deposits. The comparison of grain size and composition between the four gravel samples collected from above 23 m amsl on different areas of the hill and the two samples from the beach ridge suggests the gravel is from the same source.

The possible mechanisms for gravel deposition on the hillside include beach gravel from higher sea levels, beach gravel from higher lake levels, transport by glaciers or glacial outwash, aeolian transport, gastrolith excretion by moa, or the addition of gravel to the soil by humans, either Maori or European farmers.

Higher sea levels around Banks Peninsula occurred during the Quaternary (Schulmeister et al., 1999). However, for the last 100,000 years, the sea level around Banks Peninsula has been well below its present elevation, except around 6000 yr B.P. when it was 1 m higher than present (Suggate, 1968). Since the gravels first appear on the surface at an elevation of 23 m amsl, it is highly unlikely that higher sea level was responsible for depositing them at that landscape position.

Likewise, former lake levels were not high enough to explain the presence of gravel in the topsoil on the hill slope above 23 m amsl. Typical lacustrine beach ridges at Te Waihora reach a height of only 11 m amsl (e.g., Speight Ridge to the west of Okuora Farm; Hemmingsen, 1997). Beach gravel at an elevation of 17 m amsl at Okuora Farm may be explained by the large fetch of the lake with respect to north and southwesterly winds and the channeling of waves into Okuora Valley and the smaller gully at the base of the hill.

The gravel at Okuora Farm cannot be attributed to glacial processes; Banks Peninsula was never covered by glaciers (Wilson, 1992). Likewise, the hills are too high for glacial outwash to occur on the slopes; outwash is restricted to the low-lying Canterbury Plains.

Aeolian transport (rolling) of small pebble and granule-sized clasts from the beach terrace at the base of the hill a short distance up onto the lower hillside may be possible. However, aeolian transport of gravel to an elevation of 90 m amsl is highly improbable.

The excavation of moa bones at the site (MacIntosh, personal communication, 2000) and the discovery of moa crop stones on the hillside may explain the presence of some gravel in the soil. However, the limited distribution of the gravel on the

hill is a quandary. An area of about 40,000 m<sup>2</sup> was surveyed, yet gravel was only found in some of the north-facing slopes. Hence, the deposition of this gravel by moa is very unlikely.

Having ruled out natural processes, humans become the most likely agents for transporting the gravel up onto the hillside. The owner of the property stated that he or his relatives, who have worked the land since the 19th century, when the area was first settled by Europeans, were not responsible for depositing the gravel on the hillside. Despite this assertion, it is possible that gravel was placed on the vehicle track that runs from the base of the gully at 12 m amsl up onto the hill to 35 m amsl (Figure 2). However, this still does not explain the presence of the gravel further up the hill at 73–90 amsl, nor the gravel found along the side of the gully up to 50 m amsl, and on the slope above the farmhouse.

Hence, it is likely that the Maori were responsible for adding gravel to the soil as a method of increasing the yield of the crop grown at this site. The addition of sand or gravel to the soil is strongly associated with Maori kumara horticulture (Challis, 1976).

### **Borrow Pits**

Modified soils are often accompanied by pits, termed borrow pits, from which the gravel was extracted to add to the garden soils. In the South Island, borrow pits are associated with the 400 ha of modified soils in the Nelson area (Challis, 1976, 1978). In Canterbury, eight borrow pits, the largest measuring 40 × 15 m, have been described at Kaiapoi just north of Banks Peninsula (Walton, 1985) and at Woodend (Trotter, 1982). Taumutu, south of Te Waihora, is the site of 40 such pits in a marine beach ridge, with soil modification apparent nearby (Trotter and McCulloch, 1999).

#### *Analysis of Suspected Borrow Pits*

Sediment samples were collected from the edge of the suspected borrow pit at the base of the hill. These samples were sieved to determine the grain-size distribution of the gravel. Also, the shape and composition of the gravel was analyzed.

The grain-size analysis of the gravel taken from the edge of the possible borrow pit in the beach ridge (Figure 2) showed the deposit is dominated by the  $-2.5 \phi$  clast size. Two modal populations are present, one from  $-2.5 \phi$  to  $-1.0 \phi$ , which is moderately well sorted, and the other finer mode is from  $-1.0 \phi$  to  $1.5 \phi$ , which is poorly sorted. A characteristic feature of this deposit is an absence of clasts of less than  $2.25 \phi$ . The clasts are discoid to spheroid, and all the clasts were well rounded. Counting of 204 grains showed 95% are grey feldsparite (greywacke); the remainder are white or yellow quartz.

Gravel collected from the hillside soils has a similar grain-size distribution and composition compared to the gravel in the suspected borrow pit in the beach ridge at the base of the slope. The comparison of grain size and composition between

the four gravel samples collected at elevations greater than 23 m on different areas of the hill and the two samples from the beach ridge indicates the gravel is from the same source. This suggests gravel was excavated from the borrow pit by Maori in pre-European times and spread on the north-facing kumara gardens at Okuora Farm. The size of the inferred borrow pit in the beach terrace is  $40 \times 29 \times 1.4$  m, which has similar dimensions to borrow pits described at Kaiapoi (Walton, 1985). The volume of gravel removed from the borrow pit at Okuora farm was about 990 m<sup>3</sup>, an amount large enough to supply all of the gravel on the hill slope and more.

### **Stone or Earth Rows**

The construction of stone or earth rows is often associated with kumara gardens. Early descriptions of Maori kumara gardens discuss low stone walls built through and around gardens, which were originally interpreted as paths and garden plot dividers (Earle, 1909) or windbreaks (Best, 1925).

An 80 ha coastal gardening site in the Palliser Bay area has numerous stone walls on it (Leach and Leach, 1979). Several walls are up to 200 m long and 1–2 m wide and are interpreted as kumara garden plot dividers, demarcating family garden plots (Leach, 1984).

Others have suggested that stone walls or rows at kumara garden sites served a different purpose: as a way of warming the soil and providing shelter from the wind for the young kumara plants (Miticalf, 1970; McFadgen, 1980b). Stone walls found at the Clarence River mouth were originally described as plot markers, but more recent work suggests the walls may have assisted in the down-slope removal of cold air from the kumara gardens, producing a warmer micro-climate and more viable growing conditions (Trotter and McCulloch, 1997). In addition, investigations at Panau on Banks Peninsula show that a greater depth of soil disturbance occurs within the stone and earth rows, suggesting kumara were grown along the stone rows, possibly for warmth (Jacomb, 2000).

It may be that all theories are partially correct, and stone walls and rows served multiple purposes: sheltering the kumara plants from the wind, trapping heat and warming the soil, as well as serving as plot dividers. Whatever their purpose, they can be identified as being associated with kumara horticulture.

An interesting aspect of the Okuora Farm archeological site is the apparent lack of earth or stone lines, which have been an identifying feature at other Banks Peninsula Maori kumara gardening sites including Panau, Goughs, and Duckfoots bays (Crossland, 1996; Jacomb, 2000). However, with the exception of a possible storage pit at Island Bay, a site with stone and earth rows, none of these gardening sites on Banks Peninsula has associated storage pits (Jacomb, 2000). The visibility of stone lines can depend on the time of the year, with spring often being the best time to see them as new grass growth tends to highlight them (Brailsford, 1981; Jones, 1994). Thus they may be present, but not visible, at the Okuora Farm site. Alternatively, the technology used at the site may not have involved stone or earth rows, or the site was used for too short a time to develop stone rows.

## Plant Phytoliths

Phytoliths (*Gr.* plant stones) are particles of hydrated silica that are found in higher order plants. Plants absorb silica in a soluble state from groundwater and then deposit it in intra- and extracellular locations within the plant. Phytoliths form in the leaves and twigs of higher plants and when plants die and decay the phytoliths accumulate in the topsoil (Piperino, 1988). Different genera of plants produce distinctively different phytoliths, which allows classification of plant genera based on phytolith morphology. Phytoliths can be extracted from sediments and compared with those from extant species to develop an interpretation of the paleoecological landscape of an area.

Researchers have recently extracted phytoliths from extant kumara plants (Figure 5a) and compared them to phytoliths extracted from soil samples taken from stone rows on kumara gardens in Northland (Horrocks et al., 2000; Carter, 2001), the first time this technique has been applied to kumara. We sampled the topsoil at the Okuora Farm site near the pits and possible cultivation sites and extracted phytoliths to look for evidence of the former natural and cultivated vegetation at this site (Figure 2).

### *Background*

Humans have had a large impact on the Peninsula since the first arrival of Polynesians. By 500 years ago, fires originally set by Maori had destroyed one-third of the forest cover (McGlone, 1983). Maori cleared the forest to capture birds and to produce areas suitable for horticulture; some of this cleared land was colonized by tussocks and other grasses (Wilson, 1992). When Europeans settled on the peninsula in the 1840s, they felled most of the remaining forest, and the dominant vegetation became grasses used for pasture. The modern vegetation of the Peninsula is 74% grazed pasture, with old growth and second growth forest making up only 1% (Wilson, 1992).

Before human colonization of the area, podocarp and beech hardwood forest covered most of Banks Peninsula (Wilson, 1992). Several warm-temperate species such as Nikau palm (*Rhopalostylis sapida*), Kawakawa (*Macropiper excelsum*), Akeake (*Dodonaea viscosa*), and Titoki (*Alectryon excelsum*) occur at their southernmost range in the more sheltered areas on the Peninsula.

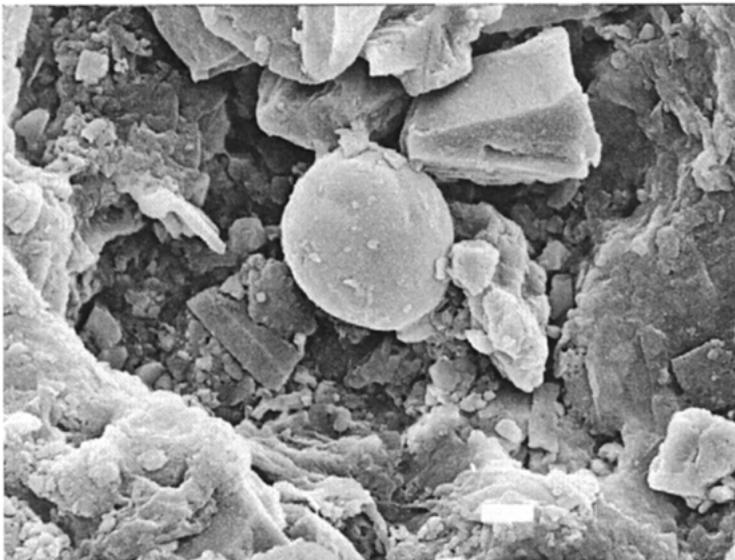
### *Methods of Phytolith Analysis*

A preliminary limited phytolith survey was undertaken at the Okuora Farm site. Three 500 g soil samples were collected from the top 10 cm of the soil at three locations on the hillside at elevations of 73–90 m amsl in areas where gravel was present in the soil (Figure 2). Thus, the locations were chosen from an area that would be most likely used for growing kumara. Soils were not sampled from the pits themselves as they are *tapu*. This did not severely limit the value of the survey, however, because kumara pits were only used to store kumara tubers, not whole plants. Phytoliths are derived from the leaves and twigs in plants, not from the

(a)



(b)



**Figure 5.** (a) SEM image of a kumara phytolith from an extant plant (photo courtesy of J.A. Carter). (b) SEM image of a smooth spherical phytolith extracted from a made soil sample from Okuora Farm. Note the strong similarities to the morphology of phytoliths from extant kumara (scale bar = 3 μm).

tubers, so it was much more likely that phytoliths would be found in the gardening soil than in storage pit soil.

Two 5 g samples were taken from each of the three soil samples for phytolith extraction. The method used for phytolith extraction was based on the technique described by Rovner (1971) and involves washing the soil sample in a variety of solutions (sodium hexametaphosphate, hydrogen peroxide, mixed potassium chlorate and nitric acid, and distilled water), pipetting, and centrifuging. This left the silica fraction of the soil sample that contained the phytoliths. One subsample from each sample was then wet mounted on a glass slide using a gel composed of gelatin, glycerin, and phenol, covered with a glass slip, and heated to solidify the gel sample mix (Swanson, 1985). The slide was then examined under a transmitted light microscope confirming the presence of numerous phytoliths.

Because phytoliths are about 10  $\mu\text{m}$  in diameter, we examined them using the scanning electron microscope (SEM). Samples were first placed on a cover slip, dried, coated with carbon, and examined with the SEM, a Leica S-440. This process had some limitations because dissolved matter in the liquid crystallized on the slip, obscuring the phytoliths in the sample. To avoid the problem, an extra filtering stage was used to remove dissolved material from the samples. The second batch of samples was coated with a gold-palladium mixture, mounted on double-sided carbon tabs and then examined with the SEM, producing excellent images.

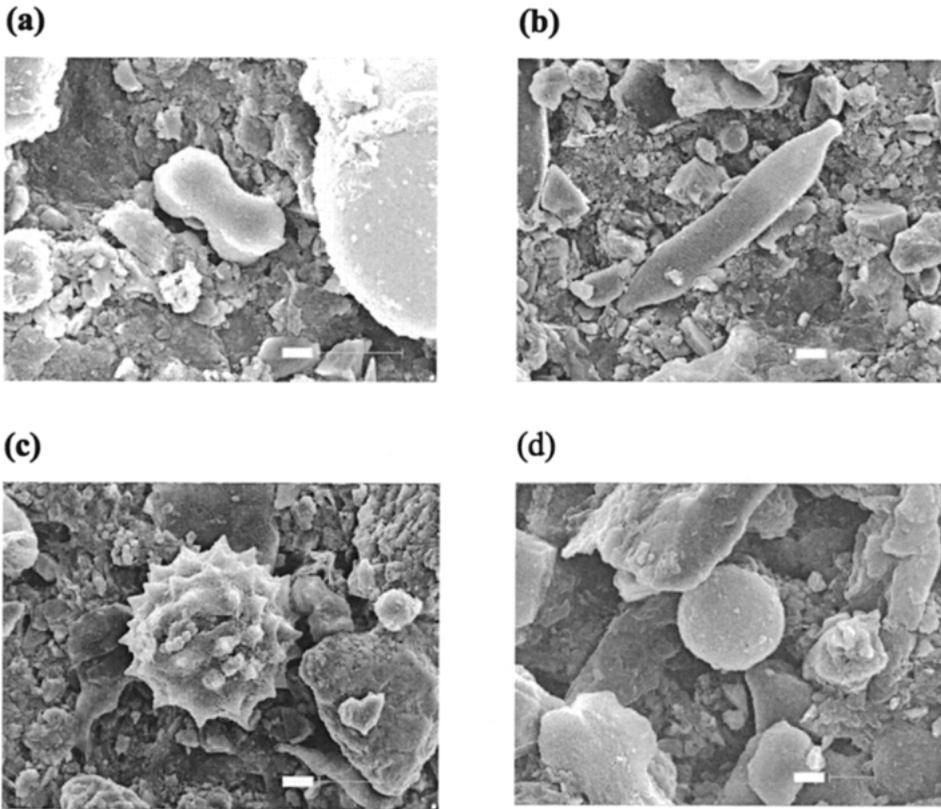
### *Results of Phytolith Analysis*

A basic morphological classification system has been developed (Twiss et al., 1969; Kondo and Sase, 1986) for New Zealand phytoliths (Kondo et al., 1994) that divides phytoliths into three categories based on plant type: Gramineaceous (grasses), ferns, and trees. Within each category, there are further subdivisions based on the different morphologies. The morphological types that were observed in Okuora Farm soil samples are described below.

Only two of the nine different classes differentiated in the gramineaceous group were observed in the samples. One class of phytolith observed was the dumbbell- and cross-shaped phytoliths of the *Panicoid* phytoliths that originate from the epidermal cells of *Panicoideae* grasses (Figure 6a). *Festucoid* phytoliths were also observed (Figure 6b). These come from the epidermal cells of the Pooideae and Arundinoideae, which include most native and exotic pasture grasses in New Zealand (Kondo et al., 1994). They have a distinctive trough or boat-shaped form (Parry and Smithson, 1964).

Fern phytoliths were seen under the transmitted light microscope, showing their presence, but none with the SEM. All originate within the vascular system, for example, in tracheid tissue from the phloem and xylem and the epidermal cells in leaves.

Three of the 10 classes of phytoliths from trees were found. The spiky star-like shape of the *spherical spinulose* class of phytoliths were seen in the SEM (Figure 6c). These originate from specialized leaf cells and are found in the *Palmae* and



**Figure 6.** (a) SEM image of panicoid phytolith extracted from soil sample at Okuora Farm. (b) SEM image of a festucoid phytolith. (c) SEM image of smooth verrucose phytolith extracted. (d) SEM image of spherical spinulose phytolith. (Scale bar = 5  $\mu\text{m}$ .)

*Bromeliaceae* families. This class is found in the native Nikau palm, where they are less than 10  $\mu\text{m}$  in diameter. *Spherical verrucose* phytoliths were also observed (Figure 6d). They have a spherical shape but with rough surface ornamentation, are approximately 5–20  $\mu\text{m}$  in diameter, and originate in the epidermis of leaves and the ray cells of twigs and wood. They are commonly found in *Nothofagus* species, except for the silver beech. The observed *spherical smooth* class of phytoliths also originate in the epidermis of leaves and the ray cells of twigs and wood. They are small (2–20  $\mu\text{m}$ ) and are often almost perfectly spherical. They have a smooth surface sometimes with indentations and may have a stipelike attachment point. They have been found in Beech, Kamahi, Rata, and Pohutukawa, all of which grew on Banks Peninsula in the past (Wilson, 1992).

Phytoliths isolated from extant kumara also have *spherical smooth* morphology, are approximately 5  $\mu\text{m}$  in diameter, have a stalk attachment point, and have an

identifiable series of indentations on the surface that appear to be unique to kumara phytoliths (Figure 5a; Carter, personal communication, 2000, 2001). We observed spherical smooth phytoliths with a series of dimples on the surface and tentatively identified them as kumara phytoliths because of their close similarity with modern extant kumara phytoliths (Carter, 2001).

#### *Interpretation of Phytolith Data*

The range of phytoliths found in the samples roughly fits with the ecological history of the area (Wilson, 1992). There were many *panicoid* and *festucoid* phytoliths in the samples. This is expected considering the modern grasses growing at the site consisting of exotic pasture grasses such as rye (*Lolium perenne* and *L. multiflorum*) and browntop (*Agrostis capillaris*).

There were also numerous spherical phytoliths, suggesting a forest may have once existed at the Okuora Farm site. Several very distinctive spherical spinulose phytoliths commonly produced by Nikau palms were observed in the samples. Nikau palms are now present at several locations on Banks Peninsula, which is their southern growth limit, and would have been present in and on the forest margins in the past. Although phytoliths are easily transported by the wind and have been found in ocean cores 500 km from shore, a large proportion of phytoliths enter the soil and not the air (Piperino, 1988). At the Okuora Farm site, the forest group of phytoliths were very delicate and were easily damaged by the X-ray detector beam; their lack of damage suggests they were not transported a great distance from living position.

Several phytoliths from the soil samples taken from hill slope areas with added gravel had strong similarities to phytoliths extracted from ashed extant kumara plants (Figure 5; Carter, 2001). The phytoliths extracted from ashed *Rekamaroa* (variety) kumara leaves imaged were small ( $<5 \mu\text{m}$ ), spherical in shape with a very smooth surface, distinctive indentations, and were attached by a stalk to other silica material (Figure 5a). The phytoliths extracted in this study were also of a very similar size ( $<5 \mu\text{m}$ ), had a smooth surface, distinctive indentations, and were attached at the top by a stalk (Figure 5b). These similarities suggest that these phytoliths are from kumara grown at the site.

#### **Kumara Storage**

We examined the pits at the Okuora Farm site using nondestructive, noninvasive techniques to determine the structure of the pits since earlier archaeological reconnaissance mapping had identified them as probable kumara storage pits (Challis, 1995) and therefore *tapu*. We compared pit structure to known Maori kumara storage pit structures to test the validity of the interpretation as kumara storage pits.

#### *Background*

Kumara growing methods in the tropical Pacific islands included propagation from cuttings planted directly into the ground (Handy, 1940). In nontropical New

Zealand, Maori planted seed kumara tubers into the ground to enhance the strike rate, a practice that appears to have been used only by Maori (Yen, 1961).

The direct planting method requires viable seed kumara tubers stored from the previous season's crop. Kumara tubers are very sensitive to damage by cold temperatures and low humidity, and to successfully store kumara tubers a temperature of 13–17°C and a relative humidity of 75–80% are needed (Coleman, 1972). In New Zealand, these conditions occur all year round in the North Island only, whereas conditions in the South Island are much harsher. Maori developed the use of underground storage pits to preserve the living kumara tubers over the winter period, an approach that has been attributed to the Maori only (Yen, 1961). In the rest of Polynesia, the only use of pits appears to be for fermenting breadfruit.

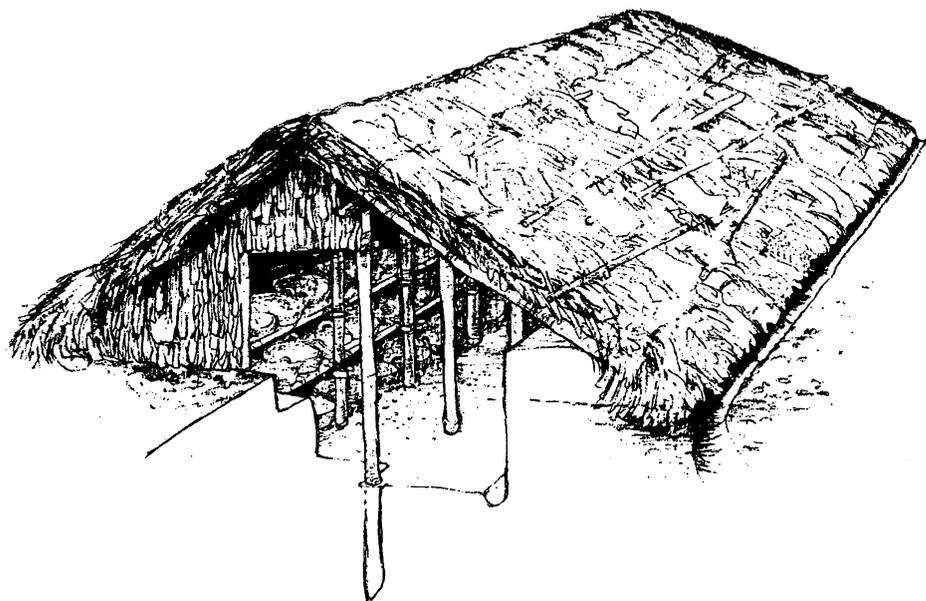
Kumara storage pits are typically sited in the most freely draining soil, which is normally at the tops of hills or on ridges (Davidson, 1987). The value that kumara had to Maori often meant the pits were positioned within a defended *pa* (village or settlement), which were also sited on topographic high points. There are various designs of kumara storage pits, which are subdivided into four different types (Best, 1974):

1. Caves, in most cases artificial, with a front entrance
2. Rectangular excavation in a hillside or on the brow of a terrace, well roofed with earthen walls and a front entrance
3. Excavated pits, entered through a covered hole on top with earthen walls and roof
4. Rectangular excavation of semi-subterranean pits on level land, securely roofed.

Most of these pits conform to the pattern of an underground storage area with a roof made of either plant material or soil. A variation of the last type is the *rua tahuhu*, or the raised rim storage pit, which is found in east coast regions from the Bay of Plenty in the North Island to the east coast of the South Island (Davidson, 1987). This type of pit occurs at Maori garden sites in Palliser Bay and has been dated there at ca. A.D. 1500 (Leach and Leach, 1979).

The design of raised rim kumara storage pits included an excavated rectangular pit with a raised rim edge and roof of plant material built over the top of it (Figure 7; Best, 1974). The size of these pits varied from 2 × 1 m up to 9 × 6 m, with a typical length to breadth ratio of 3:1 or 4:1. The depths of these pits varied from <30 cm to over 1 m (Davidson, 1987). The pitched roof covering raised rim pits was supported by a central row of posts running longitudinally along the pit with some pits having up to two to three central rows of poles (Figure 7). Floor drains were another feature of some storage pits, with either a sump in the bottom of the pit or a drain running out through a wall used to remove excess water and capture cold air.

Individual kumara storage pits may have been used for only a few years and then abandoned (Davidson, 1987). The large number of pits and the evidence from archaeological excavations points to repeated filling in of old pits and building of



Note. From 1000 Yrs of Gardening in New Zealand, by H. Leach, 1984, Wellington, New Zealand: A.H. Reed. Copyright 1984 by A.H. Reed. Reprinted with permission.

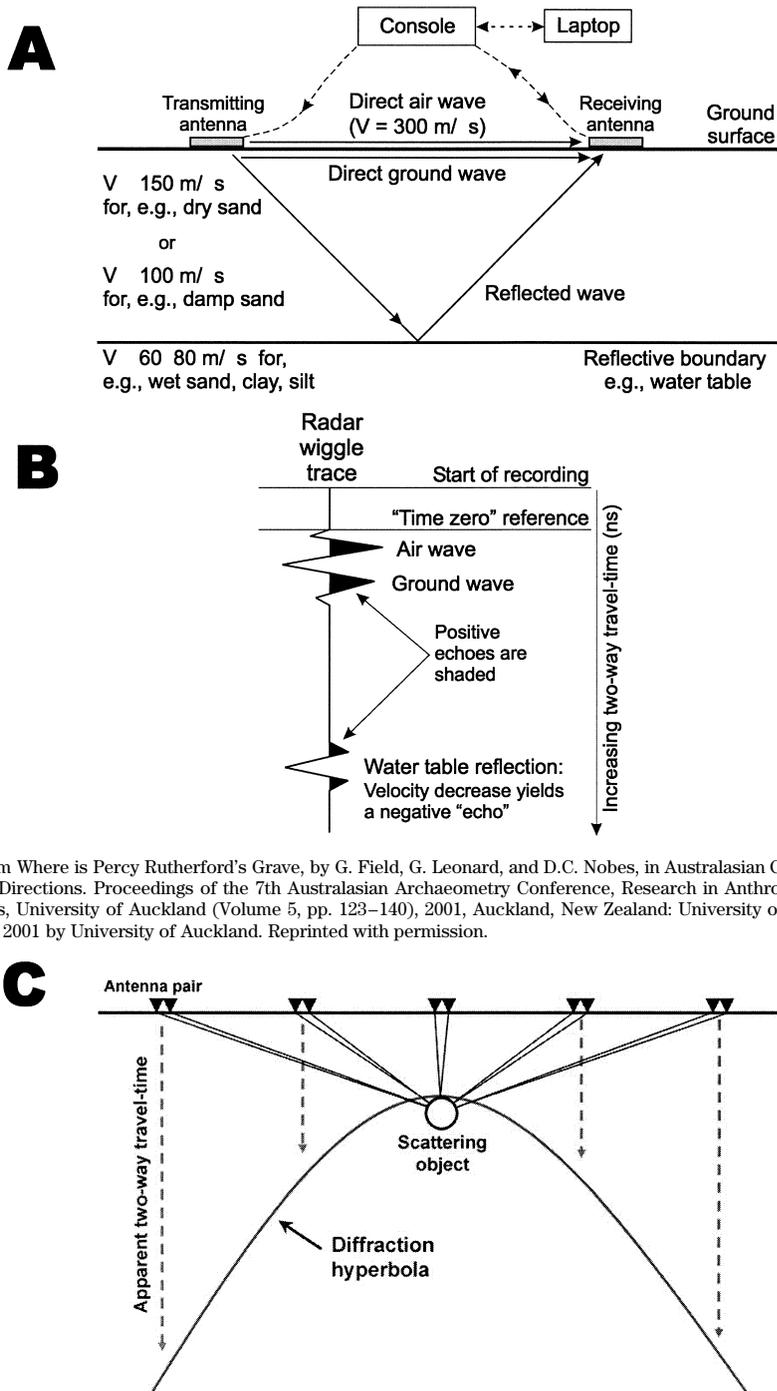
**Figure 7.** A rectangular raised-rim kumara storage pit protected by a thatched roof supported by a central row of posts. An internal drain runs along the bottom of the pit.

new ones, possibly due to fungal infection. It has been suggested that the infection of an old pit and the limited life span of its roof may have required the building of new pits on a regular basis (Davidson, 1987).

### *Geophysical Analysis*

We used near-surface geophysical methods to examine the pits because these methods can be used on culturally sensitive sites such as burial grounds or other *tapu* areas (Nobes, 1999). In this study, geophysical survey techniques allowed nondestructive investigation of subsurface features associated with the pits, which, as food storage sites, are considered *tapu* by Maori and cannot be excavated without further justification. Ground-penetrating radar (GPR) was used at the Okuora site to delineate the subsurface features of two of the possible kumara pits situated near the top of the Devil's Knob (Figures 2 and 3a).

The basic principles of ground-penetrating radar (GPR) are well covered elsewhere (e.g., Davis and Annan, 1989) and will only be summarized here (Figure 8a). The GPR transmitting antenna sends out a pulse of high-frequency electromagnetic (EM) energy, and the GPR receiving antenna records the "echo" reflected from subsurface discontinuities and boundaries (Davis and Annan, 1989). The radar echo response is measured as a function of the two-way travel-time (TWT), a proxy for depth. Positive and negative echoes reflect increases or decreases in subsurface



Note. From *Where is Percy Rutherford's Grave*, by G. Field, G. Leonard, and D.C. Nobes, in *Australasian Connections and New Directions*. Proceedings of the 7th Australasian Archaeometry Conference, Research in Anthropology and Linguistics, University of Auckland (Volume 5, pp. 123–140), 2001, Auckland, New Zealand: University of Auckland. Copyright 2001 by University of Auckland. Reprinted with permission.

**Figure 8.** (a) Schematic representation of GPR survey configuration in cross-section. (b) Schematic representation of a single shaded GPR wiggle trace. (c) Discrete small features can generate GPR diffractions. The diffraction shape depends on the subsurface velocity above the scattering object. Migration of the profile involves collapsing the diffraction curves into a point.

velocity at discontinuities or boundaries. Each individual radar record of positive and negative echoes, presented as a shaded wiggle trace (Figure 8b), is plotted alongside other traces to yield a radar profile. The radar profile can also be plotted as a gridded grey-scale or color plot of radar echo signal strength as a function of position and TWT.

The GPR response is affected by the electrical properties of the subsurface material, which also control subsurface velocities for EM energy. For example, only a few percent change in the subsurface water content will generate a radar reflection (Theimer et al., 1994). If the ground is electrically conductive, then the GPR signal will be severely attenuated and the radar reflections reduced in amplitude or lost completely. The degree of attenuation is also dependent on the GPR antenna frequency; thus choosing the correct frequency for the site is part of the survey design process. As shallow features were of greatest interest, a 200 MHz frequency antenna was used with a pulser voltage of 400. Higher frequency antennas can yield more data, but at the expense of clarity (Nobes, 1999).

GPR surveys work best on flat-lying to slightly tilted continuous layers such as soil horizons. In order to obtain a reasonable GPR response from a discrete object, it must lie beneath, or very near, the radar antennas and must be larger than one-quarter of the radar wavelength (Figure 8c; e.g., Davis and Annan, 1989; Theimer et al., 1994). The ability to detect objects of a defined size will vary with the moisture content of the ground and the frequency of the radar signal. At the surface, this is calculated as

$$R = V/4f,$$

where  $R$  is resolution,  $V$  is the radar velocity in the ground, and  $f$  is the characteristic frequency of the radar signal. There is a fundamental tradeoff between the size of an object that can be detected and the depth of penetration for the GPR profile; archeological surveys generally require high resolution but only shallow penetration.

The GPR data require processing before they can be used for analysis. A series of corrections are applied to the raw data. The first correction, "dewow," removes a low-frequency "wow" that is due to the electrical saturation of the antennas with time. The air wave arrives first, and provides a "time zero" reference (Figure 8b). The "first pick" and "first shift" corrections are applied to align the air wave across the radar profile.

Raw GPR profiles are plotted as if all reflectors are flat-lying, which is often not the case. Migration is thus a process whereby diffractions from discrete objects are collapsed to points and dipping reflectors are corrected for the degree of dip (Figure 8c). The radar data are then migrated using a standard  $f$ - $k$  migration program included in the pulseEKKO software used here. The radar data can also be corrected for variation in topography along the survey line, if required.

In order to convert the TWT of a given echo to absolute depth, the average velocity of the radar signal from the ground surface down to the reflective horizon

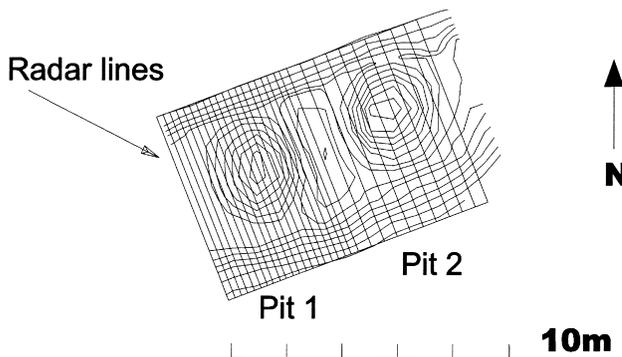
or feature must be determined. This depends on the dielectric material properties, and any amount of water can greatly reduce the radar velocity. The velocity can be determined either by carrying out a specifically dedicated GPR survey or by analyzing the shape of diffractions scattered from discrete subsurface objects as described above (Figure 8c).

If enough GPR profiles are acquired, they can be collected together into a three-dimensional (3D) data cube, which can then be manipulated in a visualization program. Two such data cubes can be constructed: one that uses the raw data with just rudimentary processing to identify any diffraction; and another that uses migrated data to look at the continuity of reflectors at given travel-times. Raw data are not as reliable for viewing TWT “time slices” because diffractions spread and distort the GPR time record.

### *Geophysical Survey Design and Results*

We performed a volumetric EM conductivity reconnaissance survey first, since such a survey can indicate potential problems and guide the choice of the GPR antenna frequency (Theimer et al., 1994). The results indicated that the GPR signal would suffer little attenuation due to electrical conduction losses and that the only concern would be scattering losses, which are minimal for shallow depths.

The two pits at the southwest end of the line of four on the hillcrest were chosen for detailed GPR surveys (Figure 9). These two pits were the ones situated in the flattest area, allowing ease of handling of the GPR unit and less data processing since topographic corrections would not be necessary, as well as being the ones with the fewest thistles in them. A  $7 \times 11$  m grid was laid out over the pits and survey lines were closely spaced in order to create a 3-D data cube and to increase the chance of delineating subsurface disturbances (Figure 9). Thirty-one survey lines were run perpendicular to the longitudinal strike of the pits. Spacing between each radar sample was 0.1 m; hence, 70 recordings were made for each line. The spacing between each radar line varied between 0.25 m for lines 0–20 (pit 1) and



**Figure 9.** Diagram of GPR survey lines over two pits.

0.5 m for lines 20–30 (pit 2). A Sensors and Software pulseEKKO 100 GPR system and associated software were used to collect the data.

We next analyzed diffractions in order to determine the average velocity structure for the site. We obtained one clear diffraction, yielding a velocity of the order of 120 m/ $\mu$ s (0.12 m/ns). This result is consistent with GPR velocities obtained elsewhere on Banks Peninsula of 70–110 m/ $\mu$ s (Crossland, 1996; Jones, 1997). The velocity of 100–120 m/ $\mu$ s was used to convert TWT to depth, giving a depth of approximately 2.0 m at the TWT time value of 40 ns. The velocity of 100–120 m/ $\mu$ s was also used to migrate the GPR profiles.

A velocity of 100–120 m/ $\mu$ s is typical of partially saturated to unsaturated sand. The minimum resolvable lateral dimension is about 15 cm using a 200 MHz antenna for completely dry soils and about 7 cm for completely saturated soils. Given the moderate soil moisture content at the Okuora Farm site at the time of surveying, the expected resolution was about 12 cm at the ground surface, gradually degrading with depth.

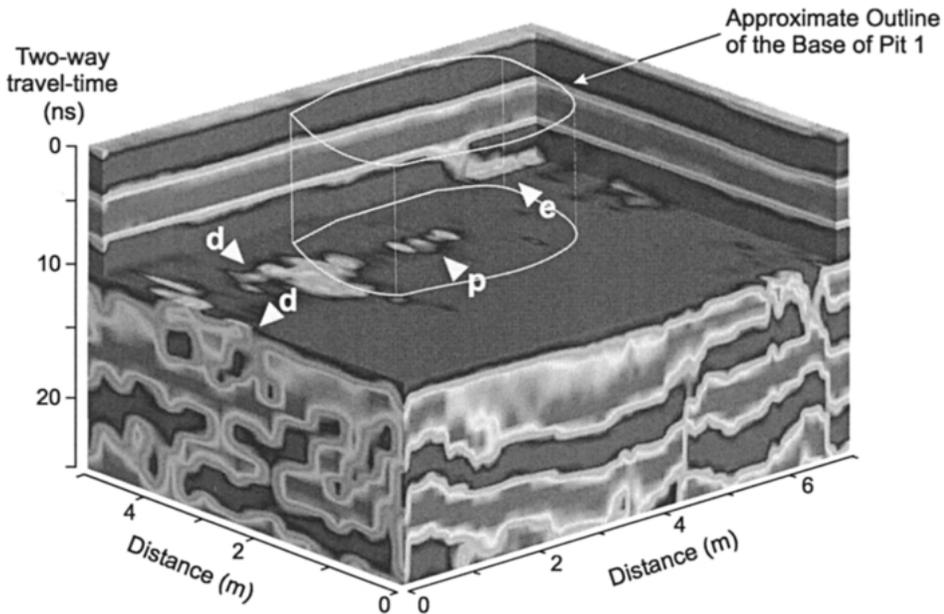
The radar data were then exported into an EKKO 3D Slicer, which joins the radar lines together to form a three-dimensional “cube.” A data cube was constructed for each pit, and the airwaves on the top of the profiles were removed so that the top surface of the cubes represents the ground surface (Figure 10). TWT is a proxy for depth. Thus, a TWT of 20 ns on the vertical axis of the cube equates to an approximate depth of 1 m.

The 3D cube produced some excellent images of the subsurface physical properties of the pits. The results for the two pits are similar, so we present one here in detail (Figure 10). There are noticeable changes in the physical properties in pit 1 at TWT of 5, 15, and 20 ns that likely correspond with the changes in subsurface lithologies seen in the hill slope soil augering.

The time slices down through the radar profiles show subsurface disturbances within the limits of pit 1 in addition to the layers observed (Figure 10). At time slices 12–15, there are some physical disturbances in the central area of the pit (Figure 10, the white arrow labeled “p”) and a strong feature appears in the north-west corner of the pit intermittently between time slices 7 to 15 (Figure 10, the white arrow labeled “d”). There are also variations in the southwest corner (Figure 10, the white arrow labeled “e”) that appear to be associated with the edges of the pits. Deeper changes in the GPR response can be seen on the outer faces of the data cube, suggestive of prior modification and infilling of the pit.

### *Interpretation of Geophysical Data*

Raised-rim kumara storage pits typically have a row or rows of posts down the central axis supporting a roof structure (Figure 7; Davidson, 1987). Some of the disturbances seen on the time slices from the pits occur in the central area of the pits, and at fairly regular spacing (Figure 10, the white arrow labeled “p”), which suggests these features may have been postholes used to support the roof over the pits. The other features of interest are the disturbances in physical properties be-



**Figure 10.** GPR data cube for Pit 1 as viewed from the west. The cube has been sliced at a TWT time of 12 ns showing a strong disturbance in the northwest corner of the pit (white arrows labeled “d”) in the likely position of a drain for raised rim kumara pits. Possible posthole remnants are also present in the central part of the pit (also highlighted by a white arrow, labeled “p”). Variations that occur at and are likely associated with what were the edges of the pit are also apparent in the southwest corner (top right, white arrow, labeled “e”). Older disturbances occur on the eastern and northern edges of the data cube.

tween time slice 10 and 15 in the northwest corner of each pit (Figure 10, highlighted, labeled “d”). Using the estimated travel velocity of 0.1m/ns, these features correspond to depths of 0.5–0.75 m, which correspond to the range of depths at which drains could be expected. Drains were typically located in sidewalls or corners at the base of the storage pit to allow water to drain (Best, 1974). The disturbances seen in the GPR profiles combined with the general design and linear arrangement (Figure 3) of the pits and their location at the top of a hill (Figure 2) strongly suggests they are raised-rim kumara storage pits used for over wintering. Some of the deeper features noted in the GPR response are also consistent with modification of the pits over time (Davidson, 1987).

## CONCLUSIONS

While any single line of evidence presented in this study does not conclusively prove there was kumara cultivation at the Okuora Farm site, together the results are consistent with kumara gardening. We believe our study documents one of the southernmost sites for kumara cultivation in New Zealand. The strongest evidence

for Maori kumara horticulture at the Okuora Farm site is the occurrence of the pits at the top of the hill. Their geometry suggests they were raised-rim kumara storage pits. The GPR stratigraphy showed some changes in the subsurface physical properties that correlate well with physical disturbances from postholes, drains or a sump, supporting the interpretation that the features are kumara storage pits. The posts would have supported a roof structure, and the drains and sumps would have removed water from the pits. The siting of the pits on the top of the hill, which is likely to be the driest, best-draining soil, is a typical landscape position for kumara pits (Davidson, 1987) and is consistent with their identification as kumara storage pits.

Although an alternative function of these pits could have been *umu ti* (cooking pits for ti [*cordyline australis*]) or some type of house, these functions can be discounted because of the pit locations (for the latter) and pit morphology (for both). The top of a hill is an unlikely place for a series of cooking pits due to the effort that would have been required to haul food and fuel up the slope. Some studies have presented the idea of pit-type houses (Brailsford, 1981), but this has largely been dismissed (Davidson, 1987). Again, the location is too exposed and the pits are too small for a house. Thus, the identification of these pits as having the structure of raised-rim kumara pits strongly suggests that kumara were stored at this site over winter and then grown nearby during the summer and autumn months.

The presence of gravel in the soil on the slopes also strongly suggests that kumara gardening took place at the site, as Maori adding sand or gravel to the soil is strongly associated with kumara horticulture (Challis, 1976). Gravel was found on the north-northwest facing slopes in four areas above 23 m amsl. This is well above the level of natural beach deposition in the area, and all the possible natural mechanisms that could be responsible for its presence in the soil were eliminated, leaving the Maori as the most likely agents for contributing gravel to the slopes.

The association of made soil with a possible borrow pit in the old beach strand also strongly suggests Maori were responsible for the addition of gravel to the soil. The gravel on the hill slopes is of a similar grain size and composition to that found in the beach deposits. The area of the hill slope that had gravel in the soil was about 10,000 m<sup>2</sup>. In an experiment, Worrall (1993) applied a ca. 30-mm-thick layer of gravel to a soil. Applying such a layer of gravel to the areas found with gravel at the Okuora Farm site would require 311 m<sup>3</sup> of gravel, which is one-third the volume of the gravel removed from the borrow pit.

It is important to note that Banks Peninsula has a milder climate than the adjacent Canterbury Plains, and the Okuora Farm site appears to be in a sheltered area with its own microclimate. The slopes where the gravel was found in the soil are north-northwest facing and receive the maximum possible amount of solar energy during the summer and autumn months. These conditions are very favorable for kumara.

Also, several phytoliths found in soil samples taken from made soils near the top of the hill were similar to phytoliths in extant kumara plants. They were the same

shape and size, and had the characteristic smooth surface with indentations and connecting stalk that is associated with these phytoliths.

Taken together, the association of storage pits, borrow pits, and modified soil on north-northwest-facing slopes, combined with the phytolith results, are a strong indication that kumara were once grown on the hillside at the Okuora Farm site. However, the question of exactly when the soil modification and kumara cultivation took place is not easy to answer. The use of raised-rim kumara storage pits appears to have started ca. A.D. 1500 in the eastern and southern regions of the North Island (Leach and Leach, 1979; Davidson, 1987). The Ngati Mamoe and Ngai Tahu tribes are thought to have arrived in Canterbury in the late 16th century and early 18th century, respectively (Anderson, 1998). Both of these groups came from, or had strong associations with, the Wellington and East Coast districts of the North Island, suggesting these tribes may be responsible for the kumara cultivation at the Okuora Farm site. This interpretation is further supported by the proximity of four sites attributed to Ngati Mamoe and Ngai Tahu to the Okuora Farm site. The large Waikakahi site, originally occupied by Ngati Mamoe, is less than 1 km to the southwest of Okuora Farm on the other side of the main road to Akaroa (Challis, 1995). These factors suggest that kumara was brought to the Okuora Farm site by Ngati Mamoe or Ngai Tahu some time after the late fifteenth century.

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