

FOOD PRODUCTION, ENVIRONMENT, AND CULTURE IN THE TROPICAL  
PACIFIC: EVIDENCE FOR PREHISTORIC AND HISTORIC PLANT CULTIVATION  
IN POHNPEI, FEDERATED STATES OF MICRONESIA

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## DISSERTATION ABSTRACT

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Title: Food Production, Environment, and Culture in the Tropical Pacific: Evidence for Prehistoric and Historic Plant Cultivation in Pohnpei, Federated States of Micronesia

Food production, or the cultivation and processing of edible materials, is closely linked to both the physical environment and human social systems. This is especially true on the islands of Remote Oceania, where cultivation of plants introduced with colonization has always been a key component of survival. This project centers on the production systems of an island in the west central Pacific: Pohnpei, Micronesia. It addresses the fundamental question of how food production is related to changes in social and physical environments and also addresses the optimum ways to archaeologically study plant remains in tropical oceanic environments with poor preservation. In order to examine these questions, this project looks at human-environment interrelationships using historical ecology.

A multi-pronged approach was used in this research. Archaeological survey was used to identify prehistoric and historic features on the landscape and to map the distribution of food production activities. Excavation of selected archaeological features, including breadfruit fermentation pits, yam enclosures, and cooking features, was conducted to examine formation patterns. Paleoethnobotanical analysis included collection and analysis of flotation samples for carbonized plant macroremain analysis

and sediment samples for phytolith analysis. Finally, because a reference collection is key to all paleoethnobotanical research, plant specimens from multiple Pacific locations were collected and processed for phytolith reference.

Botanical data show that phytolith analysis is very useful in the Pacific region, as many economically important taxa produce phytoliths. However, because of differential silica uptake, it should be used in conjunction with other methods. Archaeological phytolith analysis of the garden landscape shows disturbance caused by pigs, which were introduced historically, a change from the prehistoric phytolith record, which shows no major shifts. Combined analysis of plant macroremains and phytoliths from secure archaeological contexts shows the use of banana leaves in breadfruit cooking in the historic period, highlighting the importance of multi-method paleoethnobotanical study. These data point towards an anthropogenic environment and stable agricultural system that was present in late prehistoric Pohnpei. Major changes occurred in the historic period, although production of plant foods that were important for centuries continues to flourish today.

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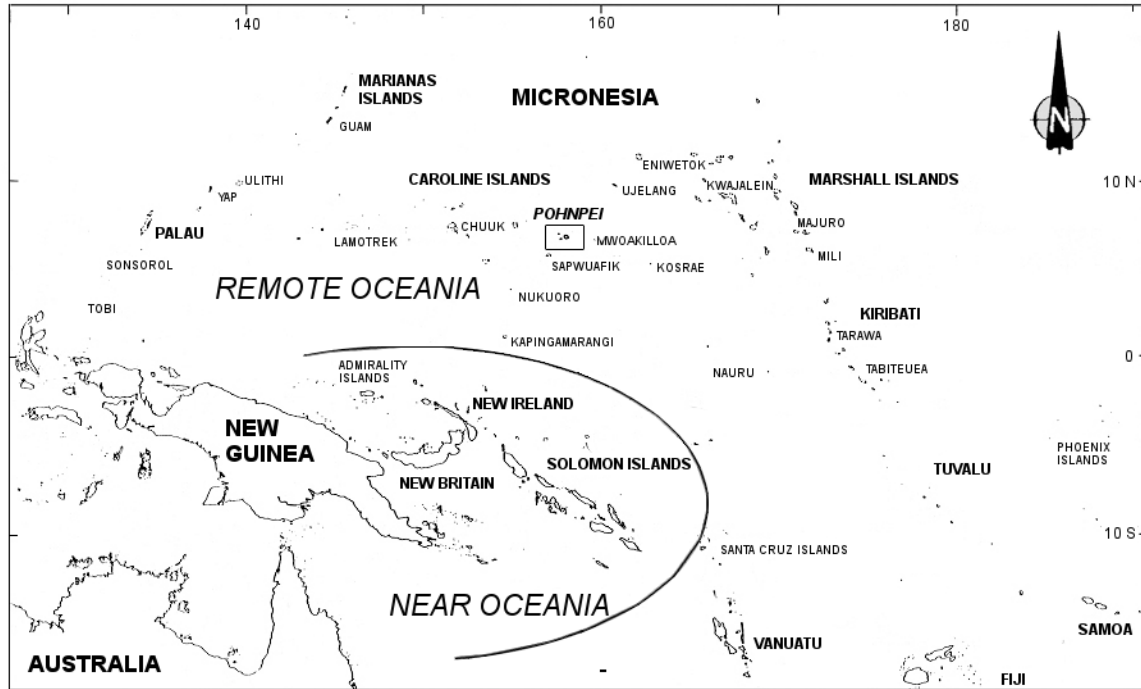
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# CHAPTER I

## INTRODUCTION

The question of how people obtain, prepare, and use food is one of the most important lines of inquiry in anthropology. Given how essential food is for our biological survival, the ways that we culturally define and obtain it plays a huge role in shaping the world that we inhabit. Through studying subsistence system development, we can come to a better understanding of how production interacts with social and environmental variables. Thus, this study is ultimately about the relationship between food production strategies, social systems, and local environments.

Within the context of the Pacific Islands (Figure 1.1), food production using domesticated plants has always been a key component to survival on the islands of Remote Oceania. This region, consisting of eastern Melanesia, Micronesia, and Polynesia, was not settled until the latter part of the Austronesian expansion, approximately 3500-3000 BP. This occurred through Lapita colonization of eastern Melanesia (Anderson 2002; Denham et al. 2012; Sheppard 2011) and the settlement of western Micronesia by related groups (Carson and Switzerland 2013; Clark 2004; Clark et al. 2006; Fitzpatrick 2003). Because of the small size of these Remote Oceanic islands and relative lack of natural resources compared to continental environments, the initial colonizers of these islands brought plants and animals with them, creating “transported landscapes” (Anderson 1952; Kirch 1997) in their new locations. Thus, while food production (and foraging) systems necessarily play a crucial role in cultural change anywhere, they are perhaps even more essential to understanding social origins and adaptations in Remote Oceania.



*Figure 1.1. The islands of the western Pacific Ocean showing location of Pohnpei, Federated States of Micronesia. Modified from original map created by W.S. Ayres.*

In this project, I investigate prehistoric food production systems in Eastern Micronesia, with a focus on Pohnpei. In previous archaeological studies, Ayres and Haun (1985, 1990) and Haun (1984) reconstructed the process of agricultural intensification and its relationship to population and social complexity on the island. This project expands on previous work by surveying archaeologically significant areas of Pohnpei and investigating the presence and frequency of certain plants and their use in the past through paleoethnobotanical analysis.

Here, I address as a central question the relationship of food production to variables that can be measured as components of the social and natural environments in islands. Food production as a process invariably alters and is altered by the social and physical environment of humans. However, these relationships differ from place to place

depending on myriad factors including (but not limited to) local and regional ecology and climate, intensity of human occupation, specific crops introduced, agricultural techniques, and social organization.

There are many ways in which archaeologists can study food production and consumption. Archaeological features on the landscape, such as fields, gardens, terraces, storage pits, or granaries can provide valuable evidence for the practice and spatial organization of food production. Tools used in tilling fields, storing surplus, or preparing foods for consumption are useful for determining the types of agriculture or culinary activity in which people were engaged. Direct plant and animal remains provide specific detail on the types of species exploited as well as further information on the nature of cultivation, husbandry, domestication, and consumption. This includes macro- and microscopic plant remains, macro- and microscopic faunal materials, and other types of residual tissue. Finally, ethnographic data from contemporary or historic situations can provide important supplemental information for understanding how different types of agricultural systems work dynamically. While ethnographic data must be applied cautiously to the interpretation of archaeological data, because food production systems change through time, they are nevertheless an important method of understanding food production systems in action and provide models for interpreting archaeological evidence.

The data available to study food production depend on: a) the type of food production systems used; and b) the taphonomic processes affecting preservation of archaeological sites, artifacts, and ecofacts. Systematic archaeological and paleoethnobotanical research on food production systems began in the Near East, a

temperate setting in which cereal grains were heavily used, and it is from this temperate, cereal grain-based system that models for the development of agriculture emerged (e.g., Braidwood 1972,1973; Childe 1936; Harlan 1955). However, in the tropical Pacific Islands, where agroforestry, swidden cultivation, and gardens are common (e.g., Hunter-Anderson 1991; Kirch 1994a; Latinis 2000; Terrell 2002), Near Eastern and European models cannot be easily applied (Leach 1997). Furthermore, preservation conditions are different, especially as organic materials tend to degrade much more quickly in tropical environments. Thus, Pacific Islands archaeologists, and researchers working in other tropical regions such as the Caribbean, Central and Eastern Africa and Central and much of South America, must rely on different tools to answer questions about food production and agriculture.

This study of variability and change through time in food production uses the approach referred to as historical ecology. Historical ecology examines the relationships of humans and their environments over time with the prediction that human societies, as part of the natural environment, are both shaped by their environment and play a role in shaping that environment through their own choices (Balée and Erickson 2006; Crumley 1994; Denevan 1992; Erickson 2008; Moran 2010; Redman 1999). In island environments, historical ecology can be a particularly useful framework, because, if settlement dates can be established, a clear delineation between pre- and post-settlement contexts can help understand human relationships with the environment. On oceanic islands, this means that the pre-human to human settlement boundary can provide an abrupt contrast that is archaeologically visible. Furthermore, island circumscription provides more decisive landscape boundaries than environments with wider ecotones,

meaning that localized effects may be more apparent (e.g., Carlquist 1974; Erlandson and Fitzpatrick 2006; Fitzpatrick and Keegan 2007; Gillespie et al 2008; Kirch 1997a; Rick et al. 2013). As such, island environments are ideal places to study human-environment relationships. Given that many plants that Pacific Islanders used throughout prehistory and history have been imported plants brought at the time of colonization or later, the study of human culture-environment relationships in the Pacific can provide cases that are especially informative.

In this study, the term “landscape” is defined as the physical and cultural environment that humans inhabit. The landscape has long been an interest to archaeologists in a variety of settings, as it is the setting in which humans interface with their physical environment. In order to conduct a study about human-environment relationships, it is necessary to study the ways in which humans create their landscapes, be it through transportation of materials from other locations, or indigenous development, both of which are crucial in Pacific settings.

In this dissertation, I make key contributions to the study of food production practices in the Pacific in terms of both historical ecology and paleoethnobotanical methods. I present an assessment of late prehistoric and historic food production practices, especially changes that result from European colonization and the introduction of pigs. I also work towards testing ethnographic assumptions about the function of archaeological features such as breadfruit fermentation pits, yam enclosures, and cooking areas through stratigraphic and plant remain analysis. This includes the recovery of charred breadfruit exocarp and banana phytoliths from an historic cooking area. Finally, I

present a thorough assessment of the utility of phytolith analysis in the Pacific Islands region and examples of its use from several sites.

### **1.1. Research on Pacific Islands Food Production**

Food production is a major topic of archaeological and anthropological research on Pacific Islands. Food production in the remote Pacific generally relies on imported crops and animals that people transported with them when they originally settled these islands, or on commensal species that were brought accidentally (Kirch 2000). Some (e.g., Gosden 1992; Kirch 2000) have argued that settlement of much of the remote Pacific would have been impossible if not for these transported crops, as the theory of island biogeography suggests that biodiversity is generally lower at further distances from the mainland (Gillespie et al. 2008; Kirch 2000; MacArthur and Wilson 1967) and thus there may not be enough natural resources to support human populations on many islands. Furthermore, many calorically rich plants, such as fleshy fruits, do not easily disperse to isolated locations. Thus, these transported biological resources provide the bulk of the human diet in the Pacific.

Interest in the Pacific Islands, including in food production practices of the region, began to intensify in the mid-20<sup>th</sup> century, as researchers started to more closely consider agricultural landscapes in the context of migrations. Ethnoarchaeological and ethnobotanical data were an initial focus, and remain important (e.g., Ayres and Mauricio 1999; Bayliss-Smith 2007; Hunter-Anderson 1991; Kirch 1976, 1979, 1994a, 1994b; Latinis 2000; Louwagie and Langohr 2007). The work of Jacques Barrau (1958, 1961, 1965), a mid-20<sup>th</sup> century ethnobotanist in the Pacific, provided an important foundation

for the understanding of the use of Pacific Islands plants; his work also began to demonstrate the implications of the modern plant record for past plant introductions and use (1965). Harold Conklin's research on shifting cultivation in the Philippines (1954, 1961) contributed significantly to understanding the role of swiddening as a sustainable system of food production. Harold Brookfield (1972, 1984, 2001), a Pacific Islands geographer, played a key role in establishing an understanding of systems of intensification. Finally, botanist Douglas Yen (e.g., 1973, 1974a, 1974b) was a pioneer in these ethnobotanical discussions, integrating botanical data with archaeological, linguistic, and ethnographic data to better understand human dispersals throughout the region, and especially the dispersal of sweet potatoes (*Ipomoea batatas*) as part of human migration. His work also included some of the earliest paleoethnobotanical investigations in the Pacific (e.g., Yen and McEldowney 1991), which identified mid-Holocene tree crop production in New Guinea. This integration of multiple lines of data is a standard that remains important today in understanding Pacific Islands food production and migration.

Archaeological materials such as stone, shell, or ceramic artifacts, or features on the landscape such as terraces and pits (e.g., Ayres 1979; Bayliss-Smith and Golson 1999; Field 2002; Haun 1984) as well as zooarchaeological data (e.g., Ayres et al. 1983; Boyer 2008; Butler 1988; Kataoka 1985; Steadman et al. 2002; Swadling 1986) have also been important for understanding past agricultural systems. Proxy data, although it does not necessarily provide information on exactly what people were eating, can provide a great deal of information on agricultural intensification and its relationship to social processes. Zooarchaeological data, as direct evidence of animal consumption and use,

provide information on what people were eating in the past. Because domesticated and commensal animals (primarily chickens, dogs, pigs, and rats) play a role in Oceanic diets, and fish and shellfish are another major source of protein, they can provide information on the time depth and dynamism of diet. However, direct plant remains are not as macroscopically visible and are more difficult to recover. Thus, they have only recently been systematically examined with a level of detail such that they are a significant source of data about food production systems in the Pacific.

Plant macroremains are generally recovered successfully through flotation, but they are less common in the Pacific Islands than in temperate regions. Furthermore, roots and tubers (and, in most cases, tree crops) cannot be quantified in the same way as cereals, but they are present at some sites and can be useful in the study of subsistence. This is especially true of tree nuts (Hather 1992), although roots and tubers may also be preserved (Hather 1991, 1994). Plant microremains are preserved in greater abundance, and thus studies of starch grains/residues (Babot 2003; Crowther 2005; Horrocks et al. 2004; Therin et al. 1999) and phytoliths (Carter 2003; Vrydaghs et al. 2003) have proven useful. Pollen has been used in other tropical regions as evidence of cultigens (e.g., Arford and Horn 2004). When used in conjunction with other types of archaeological data, plant microremains provide detail on specific types of plants used for subsistence and serve as evidence for the use of cultigens when other types of evidence cannot (e.g., Denham et al. 2003).

New Guinea is where most of the plants widely cultivated throughout the Pacific were originally domesticated. A great deal of multidisciplinary work has taken place on this island for the past few decades, focusing on both incipient agriculture and later

agricultural adaptations and adoptions (e.g., Bayliss-Smith 2007; Denham et al. 2003; Denham 2011; Fairbairn and Swadling 2005; Golson 1997; Therin et al. 1999; Yen and McEldowney 1991). The most significant of this work has come from Kuk Swamp, located in the Upper Wahgi New Guinea Highlands, where there is a record of plant cultivation going back 9000 years, with intensification that can be called agriculture at least 6000 years ago (Denham et al. 2003, Haberle et al. 2012). The Kuk Swamp project combines evidence from archaeological features, artifacts and associated starch residues, phytoliths, and pollen coring to present a clear record of increasing landscape disturbance and agricultural intensification. Notably, Denham and colleagues (2003) note a transition from forests to more annual species in the early-mid Holocene (10,200-7400 cal BP), with an abrupt decline 6950-6440 BP. This decline is associated with an increase in features related to agricultural intensification such as postholes and drainage channels. *Colocasia* taro grains and banana phytoliths were also recovered from this time. Denham (2011) has used the abrupt transition indicated here to define agriculture in terms of a changing relationship of humans to their local environments and does not necessarily require domestication, as some researchers working in other regions have done (e.g., Harris 1996; Harris 2007; Jones and Brown 2007). This not only provides a framework for understanding agriculture and firm data on incipient agriculture in the Pacific, but also a methodological model from which researchers studying other aspects of Pacific agriculture can draw. In this dissertation, I use the Denham definition of the word “agriculture,” although I generally prefer the phrase “food production” instead, to further emphasize the active relationship that humans have with plants.

## 1.2. Eastern Micronesia and Pohnpei

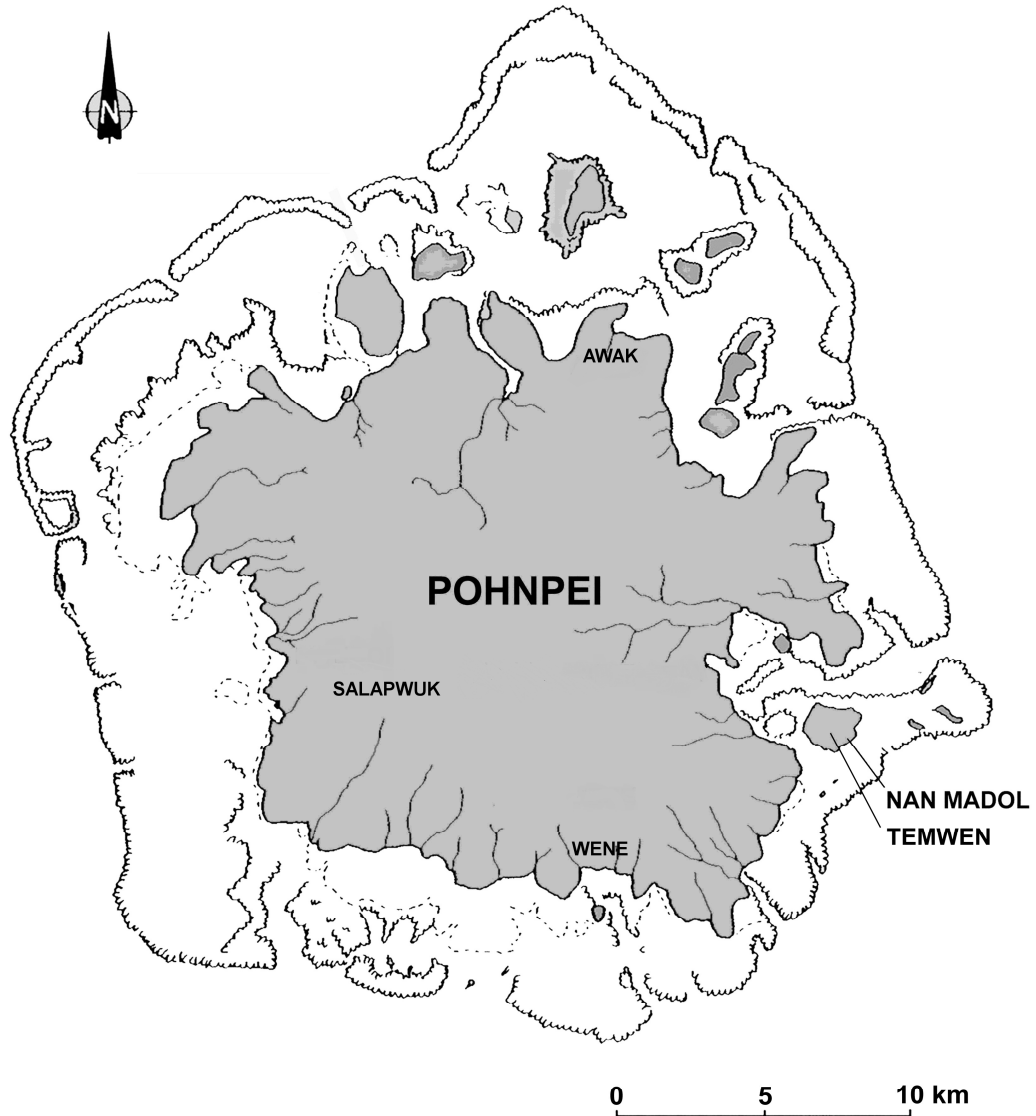
### 1.2.1. Pohnpei Geography and Climate

Pohnpei (see Figure 1.2) is a high island in the Federated States of Micronesia located at 6° 54' N, 158° 14' E (UTM 57N 42500E, 762762N). Much of the island consists of high ridges and peaks, the highest of which is approximately 790 m above sea level. It is one of the largest islands in Micronesia, with an area of 310 km<sup>2</sup>. The island is surrounded by a large lagoon, located in between barrier and fringing reefs (Haun 1984). Most of the modern settlement is along the coastline.

Precipitation is high year round, with an average yearly rate of approximately 4700 mm. The annual mean temperature is 29°C year round, and humidity is around 85%. Humidity and precipitation are somewhat lower between November and June when the weather patterns are dominated by trade winds (Bascom 1965; Haun 1984). The two major ethnographically known agricultural seasons are called *Rahk* and *Isol* (Merlin et al. 1992). *Rahk* takes place during the northern latitude summer months, when islanders focus on breadfruit (*Artocarpus altilis*) collection. *Isol* takes place during the winter when the focus is on yam (*Dioscorea* sp.) cultivation. However, although peak harvest is during the summer, breadfruit is still gathered year-round (Hunter-Anderson 1991).

Pohnpei can be divided into several ecological zones that are mostly elevation-linked (Balick 2009; Haun 1984). The shore is covered in mangrove forest, with strand vegetation slightly inland. This is followed by managed forest, and finally rainforest in the mountainous interior (Ayres and Haun 1985, 1990; Haun 1984; Hunter-Anderson 1991). It is in this mixed managed forest zone that most Pohnpeians live and produce crops. The most important tree and fruit producing species for Pohnpeians are breadfruit,

coconut, and bananas (Hunter-Anderson 1991:42). Yam and taro (*Colocasia* sp.) are also cultivated in small gardens prepared by swidden techniques (ibid. 42-3).



*Figure 1.2. Map of the island of Pohnpei showing main study location. Modified from original map created by W.S. Ayres.*

### *1.2.2. Prehistory and History in Eastern Micronesian Islands*

Archaeological research is in the beginning stages of testing ideas regarding the timing and sequence of island colonization and culture change in Eastern Micronesia over the past two millennia. Yet, there are some studies specific to the major islands and island groups in Micronesia, including on Pohnpei. Haun (1984) and Ayres (1979, 1985, 1990) have done extensive survey along with pollen coring at sites in the settlements of Awak and Wene on Pohnpei. Their survey data reveal over 250 agricultural terraces, over 100 artificially-constructed pits, some of which are related to agriculture, and include excavations of agricultural features, sediment cores, and radiocarbon dates (Ayres 1979; Ayres and Haun 1985, 1990; Haun 1984). Based on these data, Ayres and Haun have mapped out a timeline of subsistence production and defined the presence of managed forests early in the Pohnpeian sequence. The earliest evidence of possible occupation comes from pollen cores in the Leh en Luhk Swamp in Awak dating to 2920-2330 cal BP, indicating environmental disturbance (Haun 1984); higher layers of charcoal in the core at a slightly later time period are associated with land clearing. This evidence is dated to 1680-1280 cal BP (Ayres and Haun 1985). Thus, this early occupation was associated with swidden agriculture. Between ca. AD 400-1000, systems seem to have gradually shifted toward permanent cultivation plots, including significant arboriculture (Ayres and Haun 1990; Haun 1984). These data also demonstrate that, as food production (specifically yam and breadfruit production) became intensified on the island, it was used to support a “prestige economy,” one that reinforced social status through redistribution, likely through feasting (Bascom 1948, 1965; Haun 1984; Ayres and Haun 1985). One result of the development of social hierarchy in Pohnpei was the creation of the Nan

Madol complex. Nan Madol, one of the largest archaeological sites in the Pacific, consists of approximately 100 artificially constructed islets of basalt and coral off of the southeast coast of the island. They were built beginning around 1500 BP, but used most intensively between 1000-500 BP (Ayres and Scheller 2003; Ayres et al. 2009; Seikel 2011).

It is important to note that Pohnpeian sites tend to yield few artifacts. While ceramics from early occupation have been recovered from several sites on Pohnpei (Athens 1980, 1990; Ayres 1990), these disappear from sites by the early second millennium AD. Thus, archaeological research necessarily depends more on features, especially stone constructions. The paleoecological work that has been done on Pohnpei (Haun 1984) also adds significantly to an understanding of the record. Thus, with a dearth of artifacts, analysis of additional ecological data from archaeological sites, as is presented in this dissertation, is key to understanding past Pohnpeian food production.

Similar research on subsistence has been done on Kosrae, a Micronesian high island located 550 km to the east of Pohnpei. Through this work, conducted by Athens et al. (1996), specific prehistoric cultigens have been identified. This takes the record a step beyond what has been done on Pohnpei and provides some information on what type of research is possible. Using pollen and charcoal sequences derived from sediment coring, they have demonstrated that large-scale rapid forest burning occurred during early settlement of the island, at 1990-1825 cal BP. This was followed by the development of an agroforest. Botanical remains (pollen and charcoal) indicate that Kosraeans arrived on the island with much of the full assemblage of crops that they had at European contact. Athens et al. (1996) suggest that this indicates a high likelihood that residents migrated to

the island on deliberate voyages. Pollen and charcoal sequences were helpful in this study, as there are few overtly agricultural features and few agricultural plant remains on the island recovered from archaeological context. Cultigens dating to 1900 BP included breadfruit wood (*Artocarpus altilis*), taro (*Alocasia macrorrhiza*), coconut (*Cocos nucifera*), *Terminalia*, *Pandanus*, Tahitian chestnut (*Inocarpus fagifer*). Invasive non-food species included *Thespesia populnea*, *Cordyline fruticosa*, and probable *Morinda citrifolia*; they were likely introduced by humans to Kosrae. Pollen from common taro (*Colocasia esculenta*), breadfruit, coconut, and one grain of giant swamp taro (*Cyrtosperma chamissonis*) were also found in layers dating from 2000-1150 BP, a time period during which humans had likely arrived on Kosrae (Athens et al. 1996).

The Pohnpeian language is a Nuclear Micronesian language, which is itself part of the larger Austronesian language family (Rehg and Sohl 1979). Austronesian languages are thought to have originated in Taiwan, and began to spread throughout Southeast Asia 5000-6000 BP. This is supported by linguistic divergence and archaeological evidence (Bellwood 2007; Bellwood et al. 1995; Gray and Jordan 2000), as well as the DNA of humans (e.g., Duggan et al. 2014; Mirabal et al. 2013) and commensal species (e.g., Larson et al. 2007). Around 3500, one particular subgroup of the Austronesian expansion, known as Lapita (a name that refers to an archaeological culture defined by distinctive dentate-stamped ceramics), began to spread into the islands of Oceania, starting in Melanesia. Lapita cultures are thought to be ancestral to all current cultures in Remote Oceania, except those of western Micronesia (Ayres 1990; Kirch 2000). Characteristic of these populations were the cultivated and commensal plants and animals that they brought with them to new locations, leading to the formation of

“transported landscapes” (Kirch 1997). The islands of central and eastern Micronesia, including Pohnpei, were settled by the descendants of Lapita populations, who, based on linguistic patterns, most likely arrived from the Solomon Islands and/or Vanuatu (Kirch 2000). Early ceramics on Pohnpei, the production of which ceased by the beginning of the second millennium AD, resemble Lapita plainware (Athens 1990; Ayres 1990). Thus, Pohnpeian culture is considered to be a descendant of Lapita cultures that existed in the Pacific 3500-3000 years ago.

In summary, it has already been established that Pohnpei, and neighboring Kosrae, have been occupied from approximately 2500-2000 BP by the descendants of Lapita populations, and that subsistence systems started as swiddening and gradually moved toward a more intensified system. It has been inferred from the presence of storage pits and kava/*sakau* (*Piper methysticum*) pounding stones, and through ethnoarchaeology, that eventually non-utilitarian crops began to be grown for the purpose of ceremonial feasting and gaining status on Pohnpei. Thus, this study of plant remains makes a significant contribution to knowledge of Pohnpeian and Pacific food production systems.

### *1.2.3. Ethnographic Record of Pohnpei*

Food production systems have long been a topic of interest for ethnographic research on Pohnpei, and there is thus a strong base of knowledge for ethnographically derived interpretations of the archaeological record (e.g., Balick 2009; Bascom 1948, 1965; Hunter-Anderson 1991; Lawrence 1964; Petersen 1977; Ragone 2002). Caution must necessarily be used when applying ethnographic analogy to archaeological data, but

it can suggest possibilities for how gardening patterns may be interpreted. Ethnographic and ethnohistorical research points to a traditional economy revolving around permanent garden plots with tree and root crops, which involves occasional swiddening. Bascom (1948) divides the traditional Pohnpeian economic system into a “subsistence economy” and a “prestige economy.” The subsistence economy is plant production that is geared exclusively towards produce that a family will consume itself. The prestige economy, on the other hand, revolves around excess production for gifting at feasts. By bringing prestigious foods to feasts, men in the community can gain prestige for themselves. Large yams (*D. alata*) and pigs (*Sus scrofa*) are the most important feasting foods, although *sakau/kava*, *mahr*/fermented breadfruit (*Artocarpus altilis*), and dogs (*Canis lupus ssp. Familiaris*) can also play significant roles. All of these foods except for sakau also play a role in the subsistence economy, which also includes bananas (*Musa sp.*), coconut, and taro (*Cyrtosperma merkusii*, *Xanthosoma sagittifolium*, *Alocasia macrorrhizos*, and *Colocasia esculenta*), among others. As these plants are primarily prehistoric human introductions to Pohnpei, this type of data may be useful, when applied cautiously, to understanding food production systems of the past.

The ethnographic work of Glenn Petersen (e.g., 1977, 2006, 2009) has, for the past few decades, done much to illuminate the role of Pohnpeian agriculture in social organization, past and present. Specifically, Petersen has discussed the role of feasting within Pohnpei as it enters the world economic system (1977). He has also examined the role of breadfruit in connecting social systems through Micronesia (2006). My research takes advantage of the rich ethnographic record in interpreting the archaeological record, especially of the recent past. One goal is to use the archaeological record to try and work

backwards from these ethnographic descriptions to understand how systems may have changed over time.

Ethnographic data on spatial organization of food acquisition, storage, and preparation can be used to help develop models of food production systems, some of which are introduced here. Breadfruit can be prepared in multiple ways; it is most often roasted in a cookhouse, but it may also be fermented in large pits, boiled, or fried (Ragone 2002; Ragone and Raynor 2009). The fermentation process and roasting process are described in Chapters VI and VII respectively, and are used to to develop practices for archaeological recovery of plant remains.

Pohnpeians also have very particular ways that they prepare yams, as they are the most prestigious plant food in Pohnpei. Yam sites are selected carefully, as a well-suited physical environment is needed, as well as privacy, as yams play an important role in feasting. Yams must also be protected from free-roaming pigs, which is done by surrounding them with stones or, today, by metal. As yams are vines, they also must be trellised carefully, which is often accomplished by planting them beneath breadfruit trees, or dead *Hibiscus tiliaceus*. Because of the prestige of yams, there is a significant amount of secrecy surrounding some of the specifics of yam cultivation (Raynor et al. 2009).

Bananas, also a staple starch, have comparatively lower status (Fischer and Fischer 1957; Englberger 2003), so there are not as many particulars surrounding their cultivation, but conversely, no notable secrecy. Bananas are typically integrated into agroforests, and although they are botanically large herbs rather than trees, they perform an arboreal function in the Pohnpeian agricultural system. They can be prepared in a number of ways, including mashing (especially to feed to infants), baking, and frying, or

some varieties are eaten plain. Despite their high nutritional value, there is a certain stigma attached to eating bananas for some modern Pohnpeians because of their relatively lower status (Englberger et al. 2009).; it is not clear if this is a recent development.

*Sakau*, meanwhile, is not a calorically significant food source, but it plays an important ritual role in Pohnpeian society. Known elsewhere in the Pacific as *kava*, the root of this shrub is used to produce a mildly narcotic beverage. Traditionally, the root of this shrub is used to produce a mildly narcotic beverage. Traditionally, the ethnographic record suggests it was only consumed in ceremonial settings, although in modern times it is consumed recreationally as well. *Sakau* roots are pounded on a basalt slab and moistened with water. They are then wrapped in stripped *Hibiscus tiliaceus* bark and poured into a coconut husk for consumption. Sips of *sakau* are taken from the coconut husk in a ranked order; the cup is shared amongst many. The consumption of *sakau* is a vital part of feasts and ceremonies on Pohnpei (Balick and Lee 2009).

The *nahs*, a meeting house adjacent to the traditional Pohnpeian house, is central for the preparation and consumption of Pohnpeian food. A *nahs* is always U-shaped, with three side platforms that surround an earthen floor. Feasts generally take place within the *nahs*, at the time of feasts or meetings, seating location is determined by social status (Keating 2000; Mauricio 1993). The *nahs* is also the main place where *sakau* was traditionally pounded. These meeting houses can be useful for understanding the prestige economy (Bascom 1948) if they are located archaeologically.

Finally, Pohnpeian classifications of soils are also important for understanding cultivation activities. Generally, Pohnpeians use color and texture to determine soil quality. Darker, more crumbly soils are seen as good for agriculture, while, redder, compact soils are considered to be of poorer quality (Ayres and Mauricio 1997:65).

#### 1.2.4. Temwen Island and the Research Site

Temwen Island (Figure 1.3) is a small volcanic island of 2.5 square kilometers<sup>1</sup> located at the edge of Madolenihmw Bay and the adjacent reef flat forming Pohnpei's east coast. The earliest securely dated archaeological sites in Pohnpei come from Temwen Island, specifically at the Nan Madol Site. Ayres (1990) has dated pre-islet surfaces containing ceramics in the area to 2000 BP; Athens (1980, 1990) has also noted pottery. Previous archaeological work on Temwen Island has been associated mostly with Nan Madol; this is the first major archaeological project to be focused primarily on the island itself.

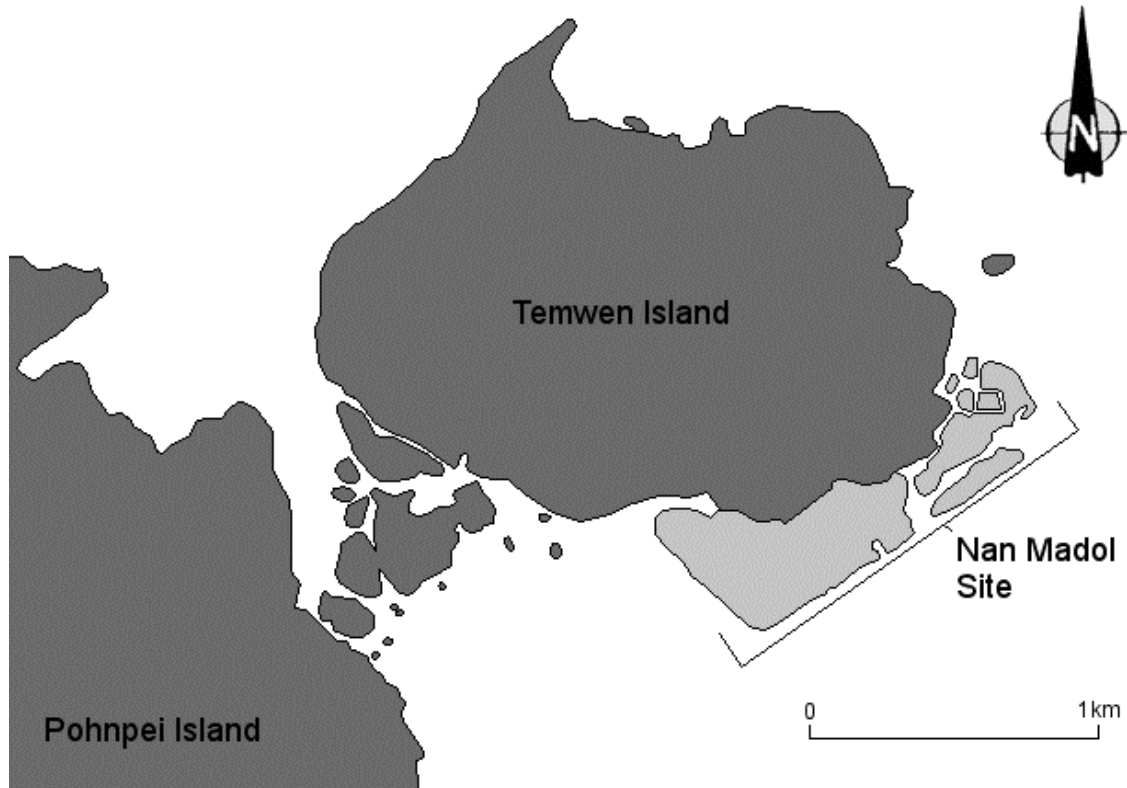
Nan Madol's artificial islets are composed of basalt columns and boulders and coral, where construction started around 1500 BP (Ayres 1990). However, much of the construction occurred from approximately 1000-500 BP, and the site was used most heavily during this time period (Athens 1990; Ayres 1990; Seikel 2011). The site remained in use to a lesser extent until the historic era; however, after significant political changes around 500 BP (Hanlon 1988), which resulted in a decentralization of political power according to oral histories, Nan Madol decreased in significance.

Ayres and colleagues located several features on Temwen Island itself, including multiple *lolong* (tomb structures), a house platform, and other types of stone architecture (Ayres and Tasa 1989). Work on architecture conducted concurrently with this project (Ayres et al. 2015) shows that these *lolong* features date to the second millennium AD. Given the proximity of Temwen Island to Nan Madol, it is clear that economic, social, and ritual activities on the island were closely tied into those occurring at Nan Madol

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<sup>1</sup> Measured using Daft Logic's Google Maps Area Calculator Tool (<http://www.daftlogic.com/projects-google-maps.area-calculator-tool.htm>). Accessed March 8, 2015.

during the height of its power 1000-500 BP. It is likely that many of the features identified during this project tied into the economic functioning of Nan Madol as a ritual complex.



*Figure 1.3. Map of Temwen Island.*

### **1.3. Dissertation Outline**

In this dissertation, the themes outlined are examined in the following sequence. In the second chapter, I outline the theoretical and methodological orientation of this work, drawing primarily on historical ecology and paleoethnobotanical techniques. In the third chapter, I describe the specific methods used for these analyses. In the fourth

chapter, I address spatial relationships among agricultural features. The fifth chapter deals primarily with reference materials and modern phytolith sampling. Specifically, it demonstrates results of the phytolith record in this environment as well as considers the potential for expanded study. The sixth chapter discusses breadfruit fermentation pit analysis, while the seventh chapter examines other types of features, including yam cultivation enclosures, cooking areas, gardens, and a ritual structure. Finally, the eighth chapter is a synthesis of the results of this project and their implications.

## CHAPTER II

### FRAMEWORK AND ORIENTATION

In this chapter, I review broader discussions on human relationships with the environment and the ways in which these play a role in topics of food production and culture change in archaeology. I then situate the research within historical and geographic frameworks.

#### **2.1. Approaches to the Archaeological and Paleoethnobotanical Record**

##### *2.1.1. Historical Ecology in Island Environments*

Historical ecology is a framework through which to view relationships between humans and their environments. The term “historical ecology” was defined by Crumley early in its use by archaeologists as “the study of past ecosystems by charting the change in landscapes over time” (1994:6). Historical ecology generally rejects ecological determinism in the study of human-environment relationships and concerns itself with studying how humans are integrated into and act upon their environment over long periods of time (Crumley 1994; Erickson 2008; Moran 2010).

The primary focus of historical ecology is the landscapes on which people live (Balée and Erickson 2006) and how people transform these landscapes. As defined in Chapter I, the landscape is the physical and culture environment that humans inhabit. Balée and Erickson (2006) discuss the landscape as a “text” (2) on which culture is “physically embedded and inscribed,” which is the sense in which the landscape is used here. While the physical landscape can be constraining, it is also a canvas for the actions

of humans. Humans are thus presented as a keystone species in environmental processes, a species that disproportionately affects its environment in relationship to its numbers (Mouquet et al. 2013).

There is a long history of scholarly interest in the relationship between humans and their environments (e.g., Marsh 1864; Sauer 1925). Specifically in anthropology, Julian Steward's pioneering work, *Theory of Culture Change: The Methodology of Multilinear Evolution*, (1955) was one of the earliest to be concerned with the relationship between humans and the physical environment. Specifically, Steward suggested that the physical environment plays a major role in the way that cultures organize themselves and develop. This so-called cultural ecology became an important framework in anthropology in the mid-20<sup>th</sup> century. It became integrated into cultural anthropology, notably by researchers such as Marvin Harris (1979) and Robert Netting (e.g., 1968, 1993). Also in the second half of the 20<sup>th</sup> century, the physical environment was playing an increasingly large role in archaeological research, especially with the development of processualism (e.g., Bender 1978; Binford 1980, 1990; Cohen 1977; Flannery 1965; Hole et al. 1969).

Historical ecology is an outgrowth of these mid-late 20<sup>th</sup> century ideas and attempts to incorporate an understanding of the environment into anthropology. Historical ecology recognizes the fundamental principle that humans must adapt to their physical environments, but it also emphasizes that people can and do drastically change the environments in which they live through their actions (Erickson 2008; Moran 2010). Thus, the dynamic interrelationships between humans and their environments take center

stage. As Balée discusses, “...the focus of historical ecology is a relationship, not an organism, species, society – not a ‘thing,’” (1994:1) a point that remains accurate today. While these organisms, species, and societies must be defined in order to understand the relationships, they themselves are not the main goal of study. A key element here is the recognition that humans have had impacts on their environments wherever they have lived and traveled, and thus “pristine” environments unaffected by humans are rare (Denevan 1992; Moran 2010; Redman 1999). (This makes Oceanic islands, settled late in prehistory, an interesting example, as examined later in this chapter.) Because of the emphasis on relationships rather than a “thing,” researchers who use the historical ecology approach generally study activities happening over long periods of time.

A key element in historical ecology is its multidisciplinary character, which draws on the social sciences, natural sciences, and humanities. While archaeology as a field is inherently interdisciplinary because it requires an understanding of geological and cultural processes, historical ecology makes a point of fully integrating ecological, biological, geological, chemical, and historical data into analyses. The historical ecology approach sits at the confluence of archaeology, history, paleoecology, and environmental history. Crumley (1994) argues that ecologists have tended to focus on non-human organisms, whereas anthropologists have sometimes underestimated the impact of the environment. Landscape ecologists, who concern themselves with broader patterns, have often created a natural-cultural landscape dichotomy, which does not hold up in the face of long-term evidence of human impacts on landscapes across the globe (Ingerson 1994; Ingold 2000). Thus recognition that humans are an integral part of their environments and

that multiple lines of evidence are necessary to investigate these relationships lends itself to interdisciplinary work.

Islands offer a unique and productive setting to apply the framework of historical ecology, because of their comparative isolation from mainland settings (Erlandson and Fitzpatrick 2006). The islands of Remote Oceania, including those of central-eastern Micronesia, have been settled by humans for less than 4000 years and this short time span of residence combined with previous non-habitation means the impact of humans on these environments is more readily apparent than in mainland settings. The changes to island environments upon human arrival can be quite drastic, and environmental proxies such as plant and animal remains or alluvial disruptions can offer evidence not only of introduced plants and animals, but also of radically altered landscapes (e.g., Anderson 2002; Kirch 1997a, 1997b; Kirch and Hunt 1997; Rick et al. 2013; Steadman 1995, 2006). Furthermore, the islands of Remote Oceania provide a diversity of landscapes, from large, continental landmasses such as New Zealand, to high volcanic islands such as Pohnpei or the Hawaiian chain, to ecologically marginal atolls and raised coral islands such as the Marshalls, allowing for study of humans in varying island landscapes. While the concept of islands as laboratories has been criticized for emphasizing isolation while downplaying the connections between island communities (e.g., Terrell 1986), the pre-/post-settlement dichotomy alone makes historical ecology in the Pacific a productive topic of study.

For these reasons, historical ecology has been a useful interpretive framework in the Pacific Islands over the past few decades. Kirch (1994a, 1997a, 1997b, 2000, 2005,

2007), for example, has been a pioneer in championing this approach, using this framework to understand settlement and human-environment dynamics on many islands throughout Polynesia and Micronesia. Key to Kirch's findings is that the diversity of island environments strongly impacts how people adjust when they settle in the Pacific, and also that human agency has played a major role in whether or not adaptations are successful. This approach has been used in multiple island environments throughout the Pacific. One example is on the remote volcanic island of Rapa Nui (Easter Island), where both ecological and archaeological data contribute to answering questions about the human role in altering Rapa Nui's prehistoric environment and how detrimental these changes were (or were not) to the maintenance of human populations (e.g., Flenley and Bahn 2003; Hunt 2007; Hunt and Lipo 2011; Mann 2008; Mieth and Bork 2010; Mulrooney 2012; Rainbird 2002). In the setting of the large continental island of New Guinea in Near Oceania, an approach based on historical ecology has helped to shed light on long-term landscape dynamics and vegetation manipulation and clearly by Pleistocene and Holocene hunter-gatherer populations, (e.g., Allen 1997; Golson 1997; Summerhayes et al. 2009; Summerhayes et al. 2010).

The theory of island biogeography makes significant contributions to understanding the historical ecology of the Pacific Islands. This theory, originally laid out by MacArthur and Wilson (1967), is intended to explain species composition richness in island contexts. It is primarily concerned with species richness as a result of equilibrium between colonization and extinction rates. These rates are affected by a number of factors, including island isolation and island size. Generally, the further an island is from

the mainland or from other islands, or the smaller an island is, the lower its biodiversity tends to be (Lomolino et al. 2010). Also affecting the biodiversity of islands is the ability of species to reach islands. It is very unlikely for most large terrestrial mammals to reach small, remote islands. This is exemplified by the evidence that humans, with our unique adaptive abilities to live in many types of environments and our complex tools, have only settled the Remote Pacific in the past few thousand years. However, animals adapted to air or sea dispersal, and plants with windborne seeds that travel long distances, can make the trip more readily. Through the process of adaptive radiation, rates of endemism within this restricted range of taxa can become high on islands (Carlquist 1974; Kier et al. 2009; Tershey et al. 2015). Human settlement of and adaptations to islands must be understood within what is known of biogeographical contexts. Furthermore, human settlement and human-related environment impacts can be used to test the robustness of biogeographical models.

Historical ecology has also recently been shaped by the ideas of niche construction theory, or NCT (e.g., Bleed and Matsui 2010; Broughton et al. 2010; Laland and O'Brien; Smith 2007, 2011; Zeder 2012, 2015). In turn, NCT has also helped to develop the direction of this dissertation. Originally developed in the field of evolutionary biology, NCT's main premise is that organisms, when they modify their own environments, alter the selection pressures acting upon themselves, their descendants, and other organisms in the same environment (Odling-Smee et al. 2003). Because humans, as a keystone species, heavily modify environments and affect the evolution of both themselves and other organisms, resulting in human traits such as

lactase persistence and malarial resistance (Gerbault et al. 2011; O'Brien and Laland 2012) and the domestication syndrome in a large number of other species. Thus, human food acquisition or production and cultural change, as discussed here, may influence not just environmental change, but also evolutionary processes. In island environments, with their high rates of endemism, this may be an especially important process. The time period on which my research focuses is not long enough for major evolutionary changes to take place; however, it is necessary to consider that some domesticates may be adapted to thrive in newly-altered, post colonization biological and social environments like those of late prehistoric and early historic Pohnpei, where prestige consumption is of high importance.

### *2.1.2. Culture Change and Food Production*

Thus, in addition to examining human-environment relationships in the past, this dissertation also addresses the relationship between food production and socio-cultural systems. The relationship between food production and human social systems and hierarchies is a long-standing research topic in anthropology, both generally and within the Pacific (e.g., Boserup 1965; Childe 1936; Haun 1984; Field et al. 2011; Kirch 1997a, 2010). Because of the relative isolation and circumscription of island environments, which often result in high population densities, it takes on special importance in the Pacific. Boserup (1965) posits that population growth causes agricultural intensification and technological innovation. Thus, when populations grow, agricultural change will necessarily occur. Small, isolated islands are sensitive to even small amounts of

population growth, so this effect may be amplified in an island environment. When production is intensified, social dynamics change. Intensification of production is correlated with exchange systems and the development of social hierarchies (e.g., Bar-Yosef 2001; Deur 2002; Price and Feinman 1995; Sahlins 1972), a process that Haun (1984) and Ayres and Haun (1985, 1990) demonstrated on Pohnpei, and that has been shown elsewhere in the Pacific (e.g., Field et al. 2011; Kirch 2007; Ladefoged and Graves 2008).

However, there are ways other than population growth through which intensification, innovation, and agricultural change can occur, and those must be considered here. The intensification process is not necessarily linear, and it is highly dependent on local environments and pre-existing social structures (Morrison 1994). Furthermore, as Leach (1999) discusses, Pacific Islands agricultural systems have multiple components, some of which have been intensive for long periods of time. Thus, the appearance of intensification in the archaeological record is not always a definitive indicator of population growth or other cultural changes; other elements of the archaeological record must be considered in conjunction. Brookfield, early in his career, discussed how social practices such as feasting and prestige accumulation can lead to agricultural intensification (1972). Throughout the course of his career, he increasingly came to view agricultural practices as being complex, with myriad social and environmental inputs (1984, 2001; See also Brown 2005).

Thus, culture change and agriculture are inexorably intertwined, and cannot be separated from the physical environment in which they exist. In this dissertation, I focus on past Pohnpeian subsistence in light of Pohnpeian cultural and environmental systems.

## **2.2. Research Questions on Food Production in Eastern Micronesia**

This project is ultimately concerned with addressing the question of how food production systems affect changes in the physical and cultural environments of humans. The Pohnpeian context provides an island example within which to study these interactions. A great deal of research in the Pacific Islands over the past few decades has focused on degradation as well as resiliency of human habitats (e.g., Athens et al. 2002; Hunt 2007; Kirch and Hunt 1997; Kirch et al. 2015; Ladefoged et al. 2010; Mann 2008; Mieth and Bork 2010; Mulrooney 2012; Rainbird 2002; Rick et al. 2013; Rolett and Diamond 2004), as these are pressing issues for our modern world, which is experiencing rapid anthropogenic environmental change. Overall, the story of Pohnpei appears to be one of persistence (e.g., Haun 1984). Stories of agricultural persistence in the face of ecological and cultural change are important in modern contexts, as they help us to understand how humans in the past successfully coped with change. Thus, ultimately, in this dissertation, I ask the question of how food production systems are embedded in and affect broader environmental and socio-cultural systems.

Through the study of the Pohnpeian context, we can address these questions on a localized scale and tie them into broader global phenomenon (e.g., Kirch 1997). To aid in

addressing the central question, I pose several targeted questions that can be considered with regard to the Pohnpeian record.

*How have Pohnpeian garden landscapes been organized as a fundamental element of food production, and how has this changed throughout late prehistory and early history?*

Historic (late 19<sup>th</sup> century onwards) and recent Pohnpeian agricultural practices are well known and recorded ethnographically (e.g., Balick 2009; Bascom 1948, 1965; Hunter-Anderson 1991; Lawrence 1964; Petersen 1977; Ragone 2002). Furthermore, subsistence agriculture is still very much alive as a practice on the island. However, as with any aspect of culture, agricultural systems change over time, and one cannot assume that they were organized the same way in the past. Archaeological evidence is essential to understand these processes of change. Haun (1984), and Ayres and Haun (1985, 1990) have described some aspects of these systems archaeologically, and Haun (1984) provides important paleoecological data from pollen analysis. The archaeological work of Ayres and Haun as well as the ethnographic record provide a foundation upon which this dissertation builds.

Here, I take this analysis one step further than previous studies by examining plant remains within archaeological contexts, including charred macroremains and phytoliths. Plants preserved within archaeological contexts provide important information on the use of specific microenvironmental zones, going beyond just broad regional patterns. I also examine how food production features are arranged on the landscape; that

is, the way that Pohnpeians of the past organized their food production spatially. Understanding specific plants associated with microenvironments and feature types helps to better interpret past agricultural systems and the nuances of change in these systems. This multidisciplinary type of study is key to understanding human-environment relationships.

*What types of phytoliths do Pohnpeian and Pacific Islands plants produce, and what does this tell us about the potential of the phytolith record to address questions about past food production systems in the Pacific Islands?*

Paleoethnobotany has become an increasingly important subfield of archaeology over the past few decades, and it is applied in various tropical Pacific Islands contexts (e.g., Allen and Ussher 2013; Crowther 2005; Horrocks 2007; Horrocks and Weisler 2006; Hunt 2007; Ladefoged et al. 2005; Millerstrom and Coil 2008; Tromp and Dudgeon 2015). However, specific plant communities have differing utility depending on the environment (Pearsall 2000; Piperno 2006). With regard specifically to phytoliths, Piperno (2006:19) broadly considers the Pacific Islands to be a region where phytolith analysis can be productive. Previous work supports this assertion, as the study of phytoliths has made several significant contributions to archaeology in the region (e.g., Denham et al. 2003; Horrocks and Rechtman 2009; Kealhofer et al. 1999; Kirch et al. 2005). Nevertheless, paleoethnobotany in the Pacific, especially in Micronesia, is in its infancy, and other work in the eastern Carolines has tended to focus on pollen cores

rather than archaeological contexts (e.g., Athens et al. 1996; Athens and Stevenson 2012; Haun 1984). Thus, one stated aim of this project is to assess the potential of the paleoethnobotanical record on Pohnpei both through examination of paleoethnobotanical samples and the assessment of taxonomic resolution in common economic botanical taxa.

*What types of archaeological features are important to understanding past food production on Pohnpei? Which ones occur frequently on the landscape?*

A broad range of features contributes to understanding food production processes. These features can be associated with growing, processing, storing, cooking, or eating food, or a combination. Common archaeological features include terraces, canals and other water-control features, old fields, storage pits and houses, hearths, cookhouses, and dining areas. However, not all of these features are necessarily easily recognizable as evidence on the landscape. In this dissertation, I am interested in which features are visible on the landscape, how they are arranged in ways from which we can glean significance, and how they may provide botanical or other types of data indicative of food production and consumption.

*What is the role of food preservation practice and technology in Pohnpei? How can this be recognized archaeologically, and how has it changed over the course of occupation of the island?*

Breadfruit fermentation is a well-known practice on Pohnpei and throughout many islands in the Pacific. It is still practiced today, although much less so since the latter part of the 20<sup>th</sup> century (Atchley and Cox 1985; Balick 2009; Hunter-Anderson 1991; Lawrence 1964; Pollock 1984; Ragone 2002) and elsewhere in the Pacific (Atchley and Cox 1985; Pollock 1984; Ragone 2002). Ethnographically, fermentation is known to preserve breadfruit, as fresh breadfruit will rot quickly. Haun (1984) documented historic fermentation pits and recorded archaeological examples of suspected pits, one dating to as early as AD 400. As these pits tend to be several meters in diameter, they are one of the more noticeable features on the landscape. Fermented breadfruit is also a prestigious food; the older the fruit paste sitting in the pit, the more prestigious it is (Ragone 2002). Its importance in feasting is not clear ethnographically (e.g., Lawrence 1964), although it definitely not nearly as prestigious as yams are today. Nevertheless, these large pits do represent a group effort requiring some organization of work, and they may provide information on community and social change in Pohnpei. They also have the potential to help us understand to role of breadfruit as a food, which is today one of the most important staples on the island.

*How can everyday food preparation and cooking be best recognized in the Pohnpeian archaeological record?*

In many areas of the world, including some parts of Micronesia, hearths appear in house foundation settings or in outdoor cookhouse settings (Ayres et al. 1981). However,

not all cooking sites are characterized by clear stone arrangements, and thus they can be more difficult to recognize, especially with Pohnpei's vegetation cover. One of the topics addressed here is developing strategies for recognizing cooking areas on the landscape, especially if they are not obvious stone features. Also addressed is potential macroscopic and microscopic plant remain preservation within this cooking area, involving the analysis of flotation samples and phytoliths.

### **2.3. Summary**

In summary, this dissertation takes an approach to the past rooted in historical ecology and island biogeography. These ideas have been significant in Pacific Islands archaeology over the past few decades, as well as to the broader archaeological community. My work builds on this existing research to further develop an interpretation of the relationships between food production, environment, and social structure, and how they functioned on Temwen Island, Pohnpei in the past.

Food production has been a topic of interest in Pacific Islands research since the mid-20<sup>th</sup> century. As research surrounding how food production systems function in the Pacific has developed, it has become clear that a multidisciplinary approach is ideal for understanding the ways these systems functioned in the past. Some archaeological work on food production has been previously conducted on Pohnpei, where there is an occupational sequence spanning at least 2000 years. However, previous work did not include systematic analysis of plant remains recovered from archaeological sites. This type of paleoethnobotanical work has been conducted in other areas of the Pacific, but

this aspect of Pacific Islands archaeology remains comparatively underdeveloped in general. In this dissertation, I specifically address archaeological food production through the study of both plant macroremains and phytoliths, as well as site features identified in landscape survey. It examines how past Pohnpeians produced the food that they ate and created the environments in which they lived.

## CHAPTER III

### METHODS

In line with the historical ecology approach of this dissertation, methods are interdisciplinary and are focused on understanding how humans interface with their physical and cultural environment. Methodologically, the major components of this project are archaeological field survey, mapping, excavation, and paleoethnobotanical sample collection and laboratory analysis. This allows for an understanding of plant use through time in the region and the spatial organization of gardening, storage, and production features.

#### **3.1. Methodological Background**

Using multiple lines of evidence is important for the study of prehistoric subsistence. Building on field data and interpretations of prehistoric Pohnpeian subsistence offered by Ayres and Haun (1985, 1990; Haun 1984), I examine archaeological data from site features, as well as plant macroremains and phytoliths.

##### *3.1.1. Paleoethnobotany and Food Production*

Paleoethnobotany is, broadly, the study of the relationships between people and plants in the past. These relationships are integral to human survival and have significantly shaped the ecology and biology of both human and plant communities. While proxy data such as archaeological features and artifacts can provide valuable information on these relationships, direct plant remains are the most important type of

evidence in paleoethnobotanical studies. These plant remains provide valuable information about what people were growing, collecting, and cooking, and where they were doing these activities. They can also provide information on the vegetation of local environments in the past.

Although most of the organic content of plants completely decomposes relatively quickly after a plant dies, several types of plant remains useful to archaeologists and paleoecologists can be preserved over long periods of time, depending on preservation conditions. This includes plant macroremains under special preservation conditions (charring, waterlogging, or dessication), and plant microremains such as pollen, phytoliths, starch, and raphides. Different types of plant remains have their own individual strengths and weaknesses as information sources, and thus complement each other and other types of data. Plant macroremains are the most robust form of evidence for the presence of specific cultigens at specific times, as they can be directly dated (Hastorf 1999). However, macroremains are less likely to be preserved in the archaeological record than other plant remains; they rarely survive unless they are charred (Minnis 1981). Pollen, which is released into the environment as part of plants' reproductive processes, is, on the other hand, more difficult to destroy because of its sturdy exine, or outer coating (Moore et al. 1991). Most types of pollen that are studied are wind-borne; this makes pollen useful for studying regional vegetation. Phytoliths are silica bodies that are present in the structural parts of plants. They are deposited locally (Piperno 2006), so they can be useful for determining growth or use in a specific area (e.g., Carter 2003; Pearsall et al. 2003; Parr and Carter 2003) and can also be used in

residue analysis (e.g., Kealhofer et al. 1999). Furthermore, as phytoliths from different parts of a plant can sometimes be distinguished from one another, they can be useful for understanding food preparation and culinary practices (e.g., Harvey and Fuller 2004). Finally, starch grains have been used most heavily in residue analysis of tools (e.g., Allen and Ussher 2013; Barton 1998, 2007; Crowther 2005; Dickau et al. 2007; Fullagar 2006; Tao et al. 2013) or dental calculus (e.g., Buckley et al. 2014; Hardy et al. 2009; Henry and Piperno 2008; Tromp and Dudgeon 2015), in which they can help to determine the presence of specific cultigens and tool function. However, they can also be analyzed in sediments under the right preservation conditions (Haslam 2004, 2008; Horrocks 2005; Therin et al. 1999), although this line of research is more preliminary. The main condition is that they be protected from soil organisms (including bacteria and fungi) that produce enzymes that degrade starch (Barton and Matthews 2006). Starch grains change with food preparation, and it is possible to distinguish heat-damaged starches from those that have not been processed, although damaged starch grains are much more likely to be destroyed and are more difficult to identify (Babot 2003; Henry et al. 2009; Weston 2008). Raphide analysis, the analysis of calcium oxalate crystals produced by plants (Weiner 2010), is in its infancy and is of limited use at this point; while it is a promising tool, especially in understanding Araceae (taro) production (Crowther 2009), it was not deemed sufficiently useful to apply here at this point.

The analysis in this dissertation concentrates on phytoliths and charred plant macroremains. Although it is possible to recover starches from sediments (e.g., Torrence 2006), the high acidity of Pohnpeian soils results in overall poor preservation of organic

remains, and recovery tends to be much lower (Perry 2009); tools surfaces appear to protect starch from various forms of decay (Fullagar 2006). A previous study (Ayres et al. 2009) showed that starch may theoretically be preserved on *sakau* pounding stones, but we were unable to recover any starch from archaeological examples at that time. Thus, I determined starch analysis to be a low priority because excavations have revealed few tools. Pollen is a widely used microremain in paleoecological contexts and can provide useful information about regional vegetation over long periods of time, especially windborne pollen. However, as the interest here is in local garden contexts and food production, windborne pollen is not as useful. Furthermore, while pollen that is dispersed by insects can be useful as a local indicator, many of the cultivated species on Pohnpei are vegetatively propagated and only rarely flower. Haun's (1984) pollen data provides a useful baseline for understanding long term vegetation patterns in Pohnpei.

#### 3.1.1.1. Phytoliths

Silica ( $\text{SiO}_2$ ), which forms phytoliths, is an abundant, naturally occurring compound. Plants absorb silica throughout the course of their lives, depositing it into intracellular and extracellular spaces to varying extents. This silica absorption is thought to help plant growth and to protect against herbivory and pathogens (Dorweiler and Doebley 1997; Massey and Hartley 2009; Piperno 2006; Reynolds et al. 2009). Deposition of this silica is often taxon-specific, which forms unique shapes. When a plant dies, most of the tissue decomposes rapidly in the majority of environmental conditions. However, as phytoliths are composed primarily of inorganic material (they do contain

small carbon inclusions as under 1% of mass), they can remain in sediments for long periods of time (Piperno 2006) While phytoliths can become windborne (Fredlund and Tieszen 1994; Latorre et al. 2011), they provide a much more local signature than pollen. In forest environments, in fact, phytoliths tend to be localized within a few meters (Piperno 1988; Piperno 2006). Furthermore, phytoliths tend to survive well in most soils, although very alkaline soils (above pH 9) can adversely affect preservation (Piperno 1988). Thus, they are a strong proxy for studying microenvironmental vegetation change and localized farming environments.

Phytolith analysis, however, has a few limitations. Significantly, phytolith production varies widely throughout the plant kingdom. Some plant families, such as Poaceae (grasses), Musaceae (bananas and ensete), and Arecaeae (palms) are highly silicified. Others absorb very little silica, such as Araceae (aroids), and Dioscoreaceae (true yams), and of course, phytolith production is dependent on the amount of silica in the soil. Thus, abundance of phytoliths does not correlate easily to the amount of a particular taxon in the environment, and some plants are completely invisible in the phytolith record. Furthermore, phytoliths have various degrees of taxonomic resolution. Some phytoliths are identifiable to family or in some cases genus or species. This is especially the case in grasses. Some phytoliths, such as those produced in tracheids, are produced throughout the plant kingdom and thus are not particularly useful for identification purposes. Despite these limitations, however, phytoliths can provide a great deal of useful data on a variety of plant taxa.

Phytoliths are produced in different parts of plants to varying degrees (multiplicity), and sometimes parts of the same plant will produce different types of phytoliths (Piperno 2006). Anatomical differentiation has both positive and negative aspects. Differences between phytoliths produced in different parts of the plant can allow for greater understanding of the activities that were taking place within an archaeological context; that is, it is possible to know what part of the plant was being used. However, it also means that even if a plant is a high phytolith producer in a general sense, it still may be invisible in archaeological contexts if the part of the plant being processed does not produce diagnostic phytoliths in sufficient quantities (although phytoliths will still be a good indicator of where such a plant is cultivated).

One other issue that is important in the context of this analysis is the presence of sponge spicules in samples processed for phytoliths. Sponges also produce silica bodies that can be preserved in ways similar to phytoliths and have a similar specific gravity (Wilding and Drees 1968). Thus, it is common for large numbers of sponge spicules to appear in phytolith samples from coastal contexts (e.g., Coil et al. 2003; Schwantes and Collins 1994). Sometimes, they can be transported in small and fragmentary quantities hundreds of miles inland (Wilding and Drees 1968). These sponge spicules can provide additional environmental and archaeological data concerning sea level fluctuations and construction in coastal sites.

In summary, phytolith analysis is a robust tool that can be used to complement archaeological or paleoecological work. Preservation of phytoliths can occur even when no other part of the plant survives. However, because variability in phytolith production

between taxa is so great and sufficiently specific diagnostic phytoliths can be an issue, it is best used in conjunction with other methods.

#### 3.1.1.2. Plant Macroremains

A plant macroremain is defined as a preserved plant or plant fragment that can be easily observed at 10-40 × magnification using a light microscope (Pearsall 2000). Most plants do not survive over long periods of time; however, some special conditions permit their preservation. The most common of these is charring; dessication and waterlogging are also possible. Dessicated remains occur in dry contexts and would almost certainly not occur on Pohnpei, one of the wettest locations in the world. Waterlogged contexts are possible and could occur; however, they tend to be rare in general, and no waterlogged archaeological sites were observed during the course of my fieldwork. Thus, the discussion here will focus on charred plant remains.

Plants become charred, or carbonized, through the process of burning. This includes natural fires, larger anthropogenic fires such as those produced through swiddening, and localized fires such as those used for warmth or cooking. There is a significant literature on how charred paleoethnobotanical assemblages are formed (e.g., Fuller et al. 2014; Hillman 1991; Hubbard and Clapham 1992; Lee 2012); however, what is important to emphasize here is that robust plant fragments that are burned under anaerobic conditions are most likely to be preserved. Thus, wood charcoals tend to be strongly represented, along with nuts and seeds. More fragile fragments, such as leaves and roots, are much less likely to survive. Although charring is a more infrequent event

than the deposition of phytoliths in soils, the range of plants that can be charred is greater and they can be identified to lower taxonomic levels. The plant macroremain analysis in this project focuses on a cooking feature in the context of archaeological evidence from Pohnpei and the broader Pacific macrobotanical evidence. In this dissertation, my main aim is to understand what types of plants were being cooked. Thus, the focus is on non-wood plant remains.

### **3.2. Methods Used in Previous Studies on Pohnpei**

As discussed in Chapter I, previous researchers have employed various methods to study both past and present food production systems on Pohnpei. This study draws upon previously successful methods of archaeological survey and excavation in the Pacific, incorporating newer methods to improve research design and develop additional datasets.

The most extensive work specifically on past Pohnpeian food production systems was conducted by Alan Haun for his dissertation work on Pohnpei, along with William Ayres (Ayres and Haun 1985, 1990; Haun 1984). Working in Awak (in the northeast portion of Pohnpei Island, in the Uh District) and Wene (in the southern portion of Pohnpei Island, in the Kitti District), Ayres, Haun, Mauricio and other colleagues conducted archaeological survey, locating site types related to food production, and mapping and excavating many of them. Haun also cored in Leh en Luhk swamp for pollen records, and talked to modern Pohnpeians about the landscape and gardening. The methods used in this project laid the groundwork for understanding Pohnpeian food

production related site types, and also developed an island-wide vegetation history. The data collected during this project greatly improved understanding of prehistoric Pohnpeian agriculture. However, there are a few key components that could be added to this methodology to develop a more complete interpretation, primarily in the context of sampling. While Ayres and Haun did collect sediment samples from archaeological sites, collection was not systematic or intensive enough for most kinds of paleoethnobotanical study. Flotation is the best way to extract the maximum number of macroremains, and this requires relatively large bulk samples that are ideally processed in the field to both avoid deleterious effects from floating already dry samples, and to reduce sample mass and volume for transportation purposes. While plant microremain analysis only requires a small quantity of sediment (approximately 20-50 ml is collected, and only about 1-10 g is generally required for laboratory processing), sample collection from multiple places within a feature is useful may help in interpreting intra-site differences. Thus, while this project draws on Ayres and Haun's methods a great deal, it adds more systematic sediment sampling.

Much of the other work on Pohnpei related to food production processes has been ethnographic or ethnoarchaeological in nature (e.g., Balick 2009; Bascom 1948, 1965; Hunter-Anderson 1991; Lawrence 1964; Petersen 1977; Ragone 2002). This kind of information is crucial in studies of modern Pohnpeian food production; it can be applied to the study of past systems, as discussed in Chapter I. However, it is simply not sufficient to use ethnographic analogy to understand the past. While modern Pohnpeians do, generally speaking, represent the descendant communities of the original colonizers

of Pohnpei, Pohnpeian culture has seen dramatic changes over the past 2000 years. Even in terms of recent centuries, there have been major changes associated with European contact and colonization (for example, see Chapter VII for ecological data regarding the effects of the introduction of pigs). Thus, while these ethnographic data are useful, it is important to not take them as providing a complete picture of earlier plant use. The methods used here are informed by ethnographic data, but they do not assume that there have not been significant changes in Pohnpeian food production during the past millenium.

### **3.3. Field Methods Used in This Study**

Fieldwork was conducted on Pohnpei, primarily on Temwen Island, during the summer of 2008 and the fall of 2011. Field methods included survey, mapping, excavation, sample collection for plant macroremains and microremains, flotation, and gathering and preparation of reference materials.

#### *3.3.1. Survey*

I directed and conducted intensive survey on four landowner plots on eastern Temwen Island with assistance from other archaeologists and field technicians. This type of survey allows for an understanding of spatial organization of archaeological features within a given area and a thorough description of the archaeology of the landscape. Due to the fact that almost all land ownership on Pohnpei is private, the methods used maximized survey in all land units where we obtained permission to work. Transects

were surveyed by teams of 2-3 archaeologists and/or field technicians at intervals of approximately 5 m, and were continued until all of the land area in a plot had been surveyed, with a few exceptions made for unservable land (either actively used modern taro patches or other swampland). Transects were frequently modified to account for heavy vegetation as well. At the time they were located, suspected archaeological features were cleared of vegetation, photographed with a digital Nikon Coolpix 10 megapixel color camera and illustrated in field notes. The location was then recorded with a hand-held Oregon 450 GPS Unit (accuracy <10 m); all locations were measured in UTM UPS coordinates. After survey of a land plot was completed, decisions were made about which features to map in more detail and to excavate. Two island-specific datum points are located at the College of Micronesia in Palikir, in the northwestern area of the Island (Sokehs Municipality). These datum points were also taken with the same GPS unit to allow conversion to local island points. As small stone-constructed features were dense on the landscape, features were divided into sites using geographic proximity as determined by clustering of GPS points, although feature type was also considered in the grouping.

### *3.3.2. Mapping*

Multiple features related to food production on Pohnpei were mapped and described in detail. This includes three breadfruit fermentation pits and six yam growing enclosures mapped at scales ranging from 1:10 to 1:50. We also mapped a larger garden area that contained several of these features at 1:200 scale. This allowed for a more

intermediate view of archaeological organization where individual features retain importance, but a larger pattern is also present.

### *3.3.3. Excavation and Paleoethnobotanical Sample Collection*

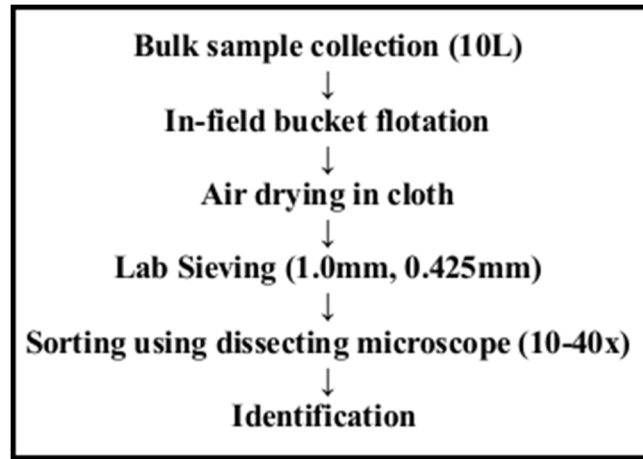
In order to collect additional data on site stratigraphy, vegetation and plant use, as well as dates of use, we conducted excavations at or near several features with an expected relationship to food production or storage. This includes three probable breadfruit fermentation pit sites several meters in diameter (PoC3-12, F2; PoC3-18, F1; PoC3-48, F1), one yam enclosure, one garden area directly adjacent to a yam enclosure, and a darkened patch of soil used as a hearth. Breadfruit pit excavations provide stratigraphic data that can be compared to that of previously excavated breadfruit pits (Ayres et al. 2009; Haun 1984). All three were trench excavations that cut through both the exterior and center of the pit in order to expose stratigraphy that may be associated with pit construction, use, and abandonment. The size varied to accommodate the particular pit dimensions, as described in individual results descriptions. The excavation into a yam enclosure was a 1 m × 1 m unit, cutting through the center of the yam pit to expose any stratigraphic change associated with feature usage. Both of the other excavations, the garden area adjacent to the yam pit and the hearth area, were also both 1 m × 1 m units.

Soil sample collection was a major part of these excavations. At minimum, small sediment samples (20-50 ml) for plant microremain analysis were collected at 10 cm levels, in addition to one-liter bulk sediment samples from different strata of the

excavation unit in order to get a full picture of the phytolith record of the site. Where charred plant remains were expected or found, we collected 10-liter flotation samples from each 10 cm level for on-site flotation. Where macroscopic charcoal was present, we collected multiple samples from each 10 cm level available for Accelerator Mass Spectrometry (AMS) dating. Charcoal samples and plant microremain analysis samples were wrapped in aluminum foil and stored in labeled plastic bags. One-liter bulk sediments were stored in labeled plastic bags.

#### *3.3.4. Flotation*

On-site flotation was conducted in order to recover macroscopic plant remains, using manual flotation system adapted from Pearsall (2000). A large bucket was filled approximately halfway with water and a small amount of laundry detergent was added for deflocculation. Given the high clay content of Pohnpeian soils, deflocculation is necessary for maximum recovery. A small amount of the 10 L bulk sample was added to the bucket and additional water was added to agitate the sample. It was then mixed vigorously mixed for a few minutes. The light fraction was captured using a nylon mesh, and more sediment was periodically added to the bucket and the materials re-agitated. Eventually, when the entire light fraction has been captured, the heavy fraction was separated using a 1 mm sieve. Light fractions were hung up to dry in cloth, and heavy fractions were set out to dry on trays. Figure 3.1 summarizes the plant macroremain analysis process.



*Figure 3.1. Plant macroremain analysis process.*

### *3.3.5. Plant Reference Material Collection*

A reference collection is an essential element of paleoethnobotanical analysis. Thus, modern botanical materials were collected in the field. The focus here was primarily on economic taxa, but commonly occurring plants in the area where fieldwork was conducted were also collected. Using Balick (2009) and Glassman (1950) as guides, specimens were collected on Temwen Island and on the island of O’ahu in Hawai’i. Phytoliths are produced mainly in the leaves of plants, so leaves were a priority, but other parts of the plant were also collected where possible. Multiple examples of these plant parts were collected. Plants were pressed as described in Pearsall (2000) using a plant press. They were then dried in the drying box present at the Conservation Society of Pohnpei or at the University of Hawai’i, Manoa Botany Department.

### 3.4. Laboratory Methods

Sample preparation and laboratory analysis was conducted primarily at the University of Oregon archaeological laboratories, with some work done at the Australian National University. These analyses include phytolith sample preparation and counting of both archaeological and modern plant reference materials, flotation sample sorting, production of feature maps using GIS software, and selection of materials for dating.

#### 3.4.1. Phytolith Analysis

Phytolith analysis consists of two major components: sample preparation and microscopy. The following sections describe the techniques used for each component, which are summarized in Figure 3.2.

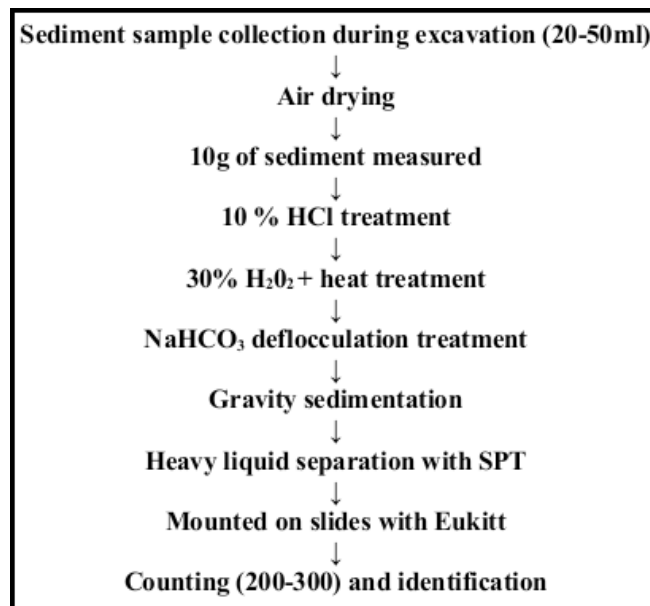


Figure 3.2. Archaeological phytolith analysis process for excavated samples.

#### 3.4.1.1. Sample Preparation

Sample preparation was carried out using a protocol based on Piperno (2006) with additional input from Matiu Prebble (ANU, pers. comm.). The following steps were used:

- 1) 10 g of each small sediment sample was used for preparation. It was placed in a labeled 50 ml centrifuge tube.
- 2) Measured sediments were treated with a 10% HCl solution to remove carbonates. The reaction was allowed to proceed at room temperature. When the reaction was complete, samples were centrifuged at 500rpm for 5 minutes, and the supernatant decanted. If samples were highly reactive, this process was repeated. Samples were then washed with distilled water, centrifuged at 500rpm for 5 minutes, and decanted three times to remove remaining HCl.
- 3) Sediments were then treated with a 30% H<sub>2</sub>O<sub>2</sub> solution to remove organic materials. They were heated in a water bath to speed up the reaction. Reaction time was variable, from a few hours to a few days to remove organic materials. When the reaction was complete and tubes were fully cooled, samples were centrifuged at 500rpm for 5 minutes, and the supernatant decanted. They were then washed with distilled water three times to remove remaining peroxides.
- 4) Although H<sub>2</sub>O<sub>2</sub> is an effective deflocculant, samples were then shaken in a 5% NaHCO<sub>3</sub> to further disaggregate particles, and left to sit in this solution overnight.

5) A gravity sedimentation procedure was then carried out to remove clays from sediments. Samples were placed in beakers filled with 10 cm of distilled water, stirred, and left to sit for 90 minutes. The supernatant was then decanted and the process was repeated until the supernatant was clearly free of suspended particles. It should be noted that, due to the high clay content of Pohnpeian soils, the placement of acid treatment before deflocculation and sedimentation in processing worked better than the reverse. When attempting deflocculation and sedimentation prior to acid and peroxide treatments, these treatments released additional clays, which necessitated further gravity sedimentation. Thus, in soils with high clay content, deflocculation after acid treatments appears to be advantageous.

6) Phytoliths were then extracted from the remaining material using a heavy liquid separation procedure. Sodium polytungstate, either fresh or thoroughly filtered, was mixed to a specific gravity of 2.35 g/ml and added to centrifuge tubes containing the remaining sediment. Sediments and the heavy liquid were thoroughly shaken and then centrifuged at 3000rpm for 10 minutes. The phytolith suspension was pipette from the tube and placed in a fresh centrifuge tube. The process was then repeated with the original sediments to float additional phytoliths that may not have been captured the first time around.

7) Distilled water was added to the fresh centrifuge tubes containing the phytolith extraction to significantly lower the specific gravity. Tubes were centrifuged at 2500rpm for 10 minutes and the supernatant was decanted and set aside for recycling.

This process was repeated an additional two times to remove any additional sodium polytungstate.

8) The phytolith extract then was mounted on glass microscope slides. First, 2-3 drops of extract were placed on round coverslips sitting on a piece of aluminum foil on a hot plate. Additional distilled water was added to spread the extract evenly across the cover slip; the round shape creates surface tension so that the extract stays in place and dries evenly. The extract was allowed to dry at low-medium heat. Once the extract was dry, the cover slips were removed from the hot plate and mounted on slides using Eukitt, a permanent mounting medium. Unused extract was placed in glass vials for long-term storage.

#### 3.4.1.2. Counting and Analysis

Phytoliths were viewed and counted using a Nikon AZ-100 light microscope bright field at  $400 \times$  magnification. Some larger phytoliths were viewed at  $200\text{-}300 \times$  magnification. Distinctive forms were counted to a total count of 200-300, and described using the International Code for Phytolith Nomenclature 1.0 (Madella et al. 2005) where possible (See Appendix A for dataset). Distinctive non-phytolith particles (e.g., diatoms, microcharcoal, and sponge spicules) were noted, but not included in the total count of 200-300. A Pacific Islands phytolith reference collection, including specimens collected on both Pohnpei and other Pacific Islands as described below, was used in identification. Select photographs of both archaeological and reference phytoliths were taken using NIS-Elements software.

After counting, stratigraphic diagrams were created using C2 paleoecology software<sup>2</sup>, with designations to the lowest possible taxonomic level; where taxonomic origin was unknown, morphology was described (Madella et al. 2005). Where applicable, changes in phytolith types through time were also tested for statistical significance using JMP software.

#### *3.4.2. Plant Macroremain Analysis*

Plant macroremain analysis involves the analysis of botanical materials found in flotation samples. Generally, these materials are charred. While waterlogged or arid conditions can, in rare circumstances, allow for the preservation of non-charred plant remains, plant materials rapidly disintegrate in most settings (Pearsall 2000). Given the extremely humid, but non-waterlogged preservation conditions at the sites investigated, it can be safely assumed that non-charred plant materials found in flotation samples are modern vegetation. Additionally, only light fractions were initially sorted, although the heavy fraction was saved for future reference. The light fractions were sieved using standard 1 mm and 0.425 mm geological sieves; sorting by size allows for easier viewing of materials. They were then viewed under a dissecting microscope at 10-40 × magnification and sorted using simple tools (brush, tweezers, probe).

#### *3.4.3. Plant Reference Material Preparation*

Using modern plants as phytolith reference material requires laboratory preparation. Phytolith reference materials were prepared from Pohnpei and Hawai'i

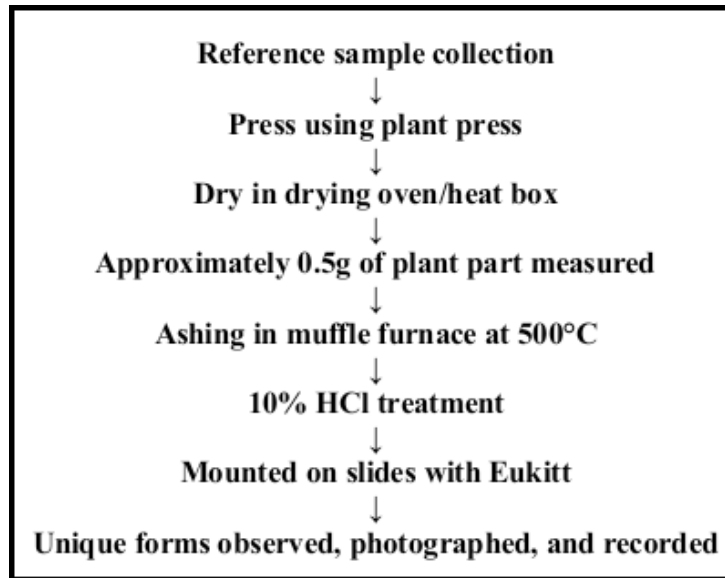
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<sup>2</sup> Downloaded at <https://www.staff.ncl.ac.uk/stephen.juggins/software/C2Home.htm>

specimens, as well as specimens held in the collections of the Department of Archaeology and Natural History and the Australian National University, using a modified version of Piperno's (2006) dry ashing procedure. The procedure is as follows:

- 1) Approximately 0.5 g of plant material from a single part of a dried specimen was measured. If needed, the plant material was washed with distilled water.
- 2) Each sample was placed in an uncovered crucible and ashed in a muffle furnace at 500 C for two hours. Plants were arranged as to have the maximum possible amount of surface area uncovered to avoid excessive charring.
- 3) Ashed samples were transferred to 15 ml centrifuge tubes and treated with a 10% HCl solution. This eliminates carbonates, of which the ash is primarily composed. Samples were then centrifuged at 1000 rpm for 5 minutes and the HCl decanted. Samples were then washed with distilled water, centrifuged, and decanted three times to remove the acids.
- 4) Phytolith extract was mounted on slides and excess extract saved for long term storage in the same way as phytolith extract from sediments.

Reference slides were scanned in their entirety using a Nikon AZ-100 microscope and unique phytolith types were recorded and described morphologically. They were photographed using NIS-elements software. The procedure is summarized in Figure 3.3.



*Figure 3.3. Reference sample processing.*

#### *3.4.4. Spatial Analysis*

Using GPS data collected in the field, maps were constructed of the survey area and of the locations of archaeological sites. GPS points were mapped according to feature type, and converted to shapefile format using Expert GPS. Feature distribution maps within the survey area were created using the simple open source GIS program Diva GIS. Clustering of samples was evaluated using a nearest neighbor analysis in Quantum GIS software.

#### *3.4.5. AMS Dating*

From collected charcoal samples, materials were selected for AMS (Accelerator Mass Spectrometry) radiocarbon dating. Samples for AMS dating were selected for stratigraphic relevance. Although a preference was given to short-lived materials in the

selection process, almost all of the material available for dating was small, fragmentary wood charcoal. In order to maximize precision and accuracy, only single pieces of charcoal were used. It should also be noted that in highly managed agroforestry settings, younger trees would be expected, and thus it is probable that these late prehistoric and early historic contexts are producing younger wood charcoal with greater accuracy than the old woods present in many regions of the world. Most samples were processed and analyzed by DirectAMS. However, two samples, both from PoC3-10, were pre-processed at the University of Oregon by Brendan Culleton and sent to the University of California, Irvine AMS laboratory.

### **3.5. Summary**

The methods used in this study involve multiple lines of analysis, and include archaeological, paleoethnobotanical, and spatial techniques. This project draws on methods used by researchers studying similar questions on Pohnpei and throughout the Pacific, but also incorporates additional techniques, specifically systematic sampling of sediments from excavation units, including surface levels. Field methods used include intensive survey, mapping at various scales, excavation and sample collection, flotation, and collection of reference plant materials. Laboratory techniques include plant macroremain analysis, archaeological phytolith processing, counting, and analysis, reference phytolith processing and analysis, spatial analysis of feature relationships, and AMS dating. These methods were designed to answer questions about the relationship of

food production to environmental changes. The next chapter begins to present the data gathered by discussing survey results and presenting spatial analyses.

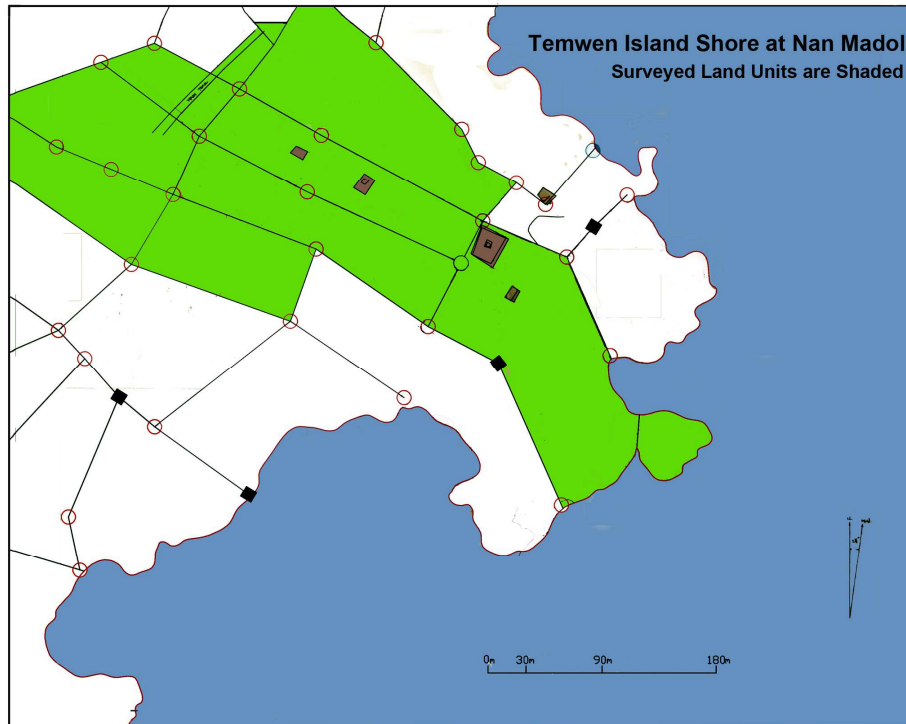
## CHAPTER IV

### ARCHAEOLOGICAL SURVEY, MAPPING, AND SPATIAL RELATIONSHIPS

Archaeological survey was conducted on four landowner plots on eastern Temwen Island, Pohnpei, by a team of archaeologists and field assistants, including the author and students from the University of Oregon, a researcher from the Australian National University, and the local community on Temwen Island (See Figure 4.1). Survey results on Temwen Island include yam cultivation and other gardening features, as well as breadfruit storage pits, and other architectural features. Enclosures or pits for yam cultivation were the most common overall feature identified in the survey; we located and described a total of 85 yam cultivation enclosures or pits (78 enclosures and seven pits). Seven enclosures were mapped in greater detail. Ten breadfruit fermentation pits were located. One (PoC3-10, Features 1-3) was described and excavated in 2008 (see also Ayres et al. 2009); the others were documented, and three mapped and excavated in 2011 (PoC3-12, Feature 2; PoC3-18, Feature 1, PoC3-48, Feature 2). One cooking area (PoC3-12, Feature 4) was also located and excavated.

Multiple other features were also identified and recorded. Ayres and colleagues (Ayres 1979, 1990; Ayres and Tasa 1989) had identified multiple sites in the area in previous field seasons. Newly described features include 13 boulder alignments, many of which are related to terracing or erosion control; seven stone platforms or enclosures; four stone walls; one *lolong* (tomb structure); a very large depression; four large basalt slabs forming a square aligned directly north-south; an historic latrine; and several

artificially modified clusters of basalt cobbles and/or boulders. Features were grouped together spatially to form multi-feature sites; potential site function was also considered in these groupings. However, there was often not enough data to know if all sites in a feature were contemporaneous. Isolated features were given their own site designation.



*Figure 4.1. Location of survey area on Temwen Island, Pohnpei. This shows contemporary land boundary lines, four larger archaeological ruins, and the shoreline. (Drafting: W. Ayres, M. Levin, A. Tudorach.)*

#### **4.1. Types of Features**

While Pohnpeian sites on both the main island and on Temwen do not typically produce large quantities of artifacts, archaeological features are common. These are

primarily features constructed of basalt stones, or are soil pits, and soil mounds. Previous researchers on Pohnpei (e.g., Ayres et al. 1981; Ayres and Haun 1978, 1985, 1990; Haun 1984) have located a diversity of feature types on which to base classification of Temwen Island features. Many of these features have functions related to food production, storage, or preparation.

One of the most common feature types in Pohnpei is an enclosure for growing yams. Haun (1984) called these “yam pits;” here I have changed the descriptor slightly to “yam enclosure” as is is a more precise descriptor and it differentiates them from other types of pits on the island, including pits from which yams have clearly been removed and pits for breadfruit fermentation (discussed below). Yam enclosures are typically circular, constructed of basalt stones, and approximately 1m in diameter. Yam pits are visibly disturbed, with a central pit of approximately 1 m in diameter, with basalt cobbles typically left around the edges. They are well known ethnographically on the island, and Pohnpeians have described these stone enclosures as being important for keeping pigs away from yams (Haun 1984). However, they are not used as often in modern times as they were in the historic past, with Pohnpeians often preferring metal enclosures to protect yams (Balick 2009), especially those located near the residence. Yams are one of the most important feasting foods on Pohnpei, and their successful growth is important for both prestige and subsistence purposes. As pigs are an historic introduction, it is likely that these enclosures anywhere on Pohnpei were built in the last 150 years.

Breadfruit fermentation pits are also relatively common on the landscape. While Chapter VI goes into more detail on breadfruit pits, they are discussed here in terms of

archaeological survey. Breadfruit pits typically have a depth of approximately 0.5-1 m, and a diameter or length ranging considerably, from approximately 2 m to 20 m. There are generally concentrations of basalt cobbles in and around the pit. These pits are used to ferment breadfruit, which is used in both feasting and in daily subsistence.

Ethnographically speaking, smaller breadfruit pits are typically used by family units, while larger breadfruit pits are for community use (Bascom 1965; Balick 2009; Lawrence 1964). Because the use of these pits is known ethnographically, they are relatively easy to identify. Haun (1984) identified breadfruit pits in both Awak and Wene, one pit dating as early as 1600 BP, suggesting a significant antiquity to this practice on the island.

Cookhouses and cooking areas are another important type of archaeological feature with implications for food production. Traditionally, these are rectangular rock oven cooking areas covered with a thatched roof supported by four posts. They have been archaeologically documented and excavated in Awak (Ayres et al. 1981; Ayres and Haun 1978). Typically, cookhouses are characterized by burned soils and charcoal fragments, fire-cracked rock, rectangular stone enclosures, and postholes. However, as discussed in Chapter VII, not every cooking feature necessarily retains all of these characteristics. These cookhouses are similar to Polynesian earth ovens (Carson 2002; Huebert et al. 2010; Leach 1982), with the major difference being that the Polynesian-style ovens are characterized by being subsoil baking pits, and Pohnpeian recent cookhouses are shallow or surface accumulations of fire-cracked rocks and cooking debris. Thus, cookhouse or cooking area remains tend to be more ephemeral on Pohnpei than they are throughout Polynesia.

Haun (1984) recorded a significant amount of terracing on the steep slopes of Awak Valley, counting a total of 229 such structures. This was not the case on Temwen Island, as shown below. However, slopes on Temwen Island tend to be gradual, and thus terracing would not have been as necessary. Terracing on Pohnpei ranges from short, single stone alignments to larger parallel structures. Most of these are non-irrigated, as this is not generally necessary in the Pohnpeian environment, although some irrigated terraces have been recognized (Haun 1984:151).

Stone platforms and enclosures of multiple types have also been recorded in many of the above contexts, as well as in this particular survey. These platforms and enclosures may represent house foundations, *nahs* (meeting house) structures, or other ceremonial structures. *Lolong*-type tombs are also recognized around Pohnpei (e.g., Ayres and Seikel 2014); these burials are rectangular with a central burial platform and are usually quite large (15+ meters). Large flat stones used for pounding *sakau* (a stone tool still used regularly on the island today) are commonly present near stone platform features. A number of military features from the Japanese occupation before and during World War II are also present, including large pits, trenches, and artillery. Ridge-like mounds have been recorded in Wene and elsewhere (Ayres and Mauricio 1999; Haun 1984: 61); they are used for plant cultivation.

Feature function on Pohnpei is determined using a combination of architectural, structural, and topographic features, as well as associated artifacts and ecofacts, and the ethnographic and historic record. Adding paleoethnobotanical assessments of these

features can help to improve the accuracy of interpretations. In Chapters VI and VII, I deal with the plant remains at several of the features described below.

## **4.2. Survey Results**

Like previous research on agriculturally productive areas of Pohnpei, survey results from this project show a high concentration of yam enclosures and yam pits, with 85 total located (See Table 4.1). Breadfruit pits were also relatively common, as were stone alignments and platforms. Notably absent were features that definitely agricultural represent terracing, although many of the alignments may have performed this function. This section discusses individual sites documented in survey, with special attention to sites related to food production processes.

Site PoC3-7, initially described during the 1989 Temwen survey (Ayres and Tasa n.d.), was reassessed. Feature 1 was originally described as a “house platform.” However, it is unclear if the platform is a dwelling, or if it has another function, as a central hearth could not be located. The southwest side is a steep slope, with basalt columns lining the base and the top of what Ayres and Tasa described as a ‘ramp,’ which is 4.2 m in length. Basalt cobbles and boulders line a platform located at the top. The structure is roughly rectangular-shaped, although it is clearly disturbed. It measures 14.5 m long (including ‘ramp’ and platform) and 8.5 m wide. Feature 2 was described as a historic pig fence in 1989, which was how a local resident had described it to Ayres and Tasa. It is a trench and lined with basalt boulders and cobbles. It is possible that it was initially built by the Japanese military during WWII.

Table 4.1. Site Types Located on Survey.

Feature Type	Number in Survey Area (Associated Site Numbers)	Expected Function
Yam Enclosure or Pit	85 (See Site Descriptions Below)	Growing and protecting yams
Breadfruit Fermentation Pit	10 (C3-10, C3-12, C3-18, C3-26, C3-35, C3-42, C3-48, C3-50, C3-52)	Fermenting and storing breadfruit
Stone Alignment	13 (C3-11, C3-13, C3-14, C3-17, C3-19, C3-31, C3-33, C3-41, C3-46, C3-49, C3-52, C3-54, C3-60)	Terracing; building boundaries or structures
Stone Platform or Enclosure	7 (C3-7, C3-14, C3-28, C3-44, C3-46, C3-51, C3-58)	House platform; ceremonial platform
Stone Wall	4 (C3-13, C3-16, C3-25, C3-38)	Boundary; defense; house wall
<i>Lolong</i> tomb	3 (C3-5, C3-8, C3-51)	Human burial
Large Depression	1 (C3-36)	Military
Basalt slab square	1 (C3-9)	?
Cooking area	1 (C3-12)	Cooking food
Historic latrine	1 (C3-30)	Human waste

Site PoC3-9 was also first described during the 1989 Temwen survey; however, at this time, only Feature 1 was included. Reassessment includes five additional features in the surrounding area to make this a multi-feature site.

Feature 1 consists primarily of an exterior wall constructed of basalt boulders and cobbles; the wall ranges from 30-80 cm in height. Currently, there are walls on both the east side (10.2 m) and south side (7.3 m) of the feature. In previous survey (Ayres and Tasa 1989), there were two other walls recorded, although they were not visible in 2011.

There is a *sakau*/kava stone at the northwest corner (Figure 4.2). A few boulders and cobbles extend out east from this stone approximately 2.9 m from the east wall of the structure, parallel to the south wall. There are also a few wooden planks on the southeast end. Feature 2 is a yam cultivation enclosure, consisting of basalt cobbles arranged in a roughly circular fashion. The enclosure has a diameter of 1.9 m, which is larger than the average (1 m in diameter is typical). We excavated a test pit through the center of this particular feature, described in Chapter VII. Feature 3 is a depression approximately 1.7 m in diameter. Based on the size and shape of the depression, it likely represents yam removal from the soil. Feature 4 consists of four basalt columns, rectangular in shape. They are planted solidly into the ground and placed apart at intervals of 2.45-2.5 m at exactly N-S-E-W corners. The function of this feature is unknown. Feature 5 is a yam cultivation enclosure of basalt cobbles measuring 1.5 m in diameter. Feature 6 is also a yam cultivation enclosure, approximately 1.5 m in diameter.



*Figure 4.2. Site PoC3-9, Sakau stone at Feature 1.*

Site PoC3-10 is a breadfruit pit complex approximately 5.5 m × 6 m in its entirety. It consists of three depressions arranged in a triangular formation. They are nested in an outcrop of boulders. Each depression is approximately 60 to 90 cm deep. There are also smaller cobble alignments encircling each depression. This site was excavated and is described further in Chapter VI.

Site PoC3-11 is a multi-feature site bordering the Temwen shoreline and consists primarily of agricultural features. Features 1-15 are circular basalt cobble enclosures for yam cultivation (See Figure 4.3 for an illustration). They are approximately 1m in diameter. Feature 16 is likely also a yam enclosure, although it is highly disturbed. Feature 17 is an alignment of four boulders, approximately 2 meters long, arranged in a straight line. Feature 18 is a stone enclosure surrounding a hibiscus tree; this may also be a disturbed yam enclosure. The site borders the eastern edge of Temwen Island, near Nan Madol, on a moderate southeast slope.

Site PoC3-12, another agricultural site, bordering PoC3-11, consists of four features related to gardening, storage, or cooking. Features 1 and 2 are large depressions measuring 11 m × 4.3 m and 15 m × 5 m, respectively, and approximately 0.5 m in depth. From their structure, they appear to have been used for breadfruit fermentation. Excavation results for this feature are discussed in Chapter VI. Feature 3 is a circular basalt cobble enclosure, likely used for yam cultivation. Feature 4 is a darkened patch of soil that represents a historic cooking area. Excavation results for this feature are discussed in Chapter VII. This site is located approximately 10 m to the east of a modern dwelling. Figure 4.4 shows the spatial layout of sites PoC3-11 and PoC3-12.

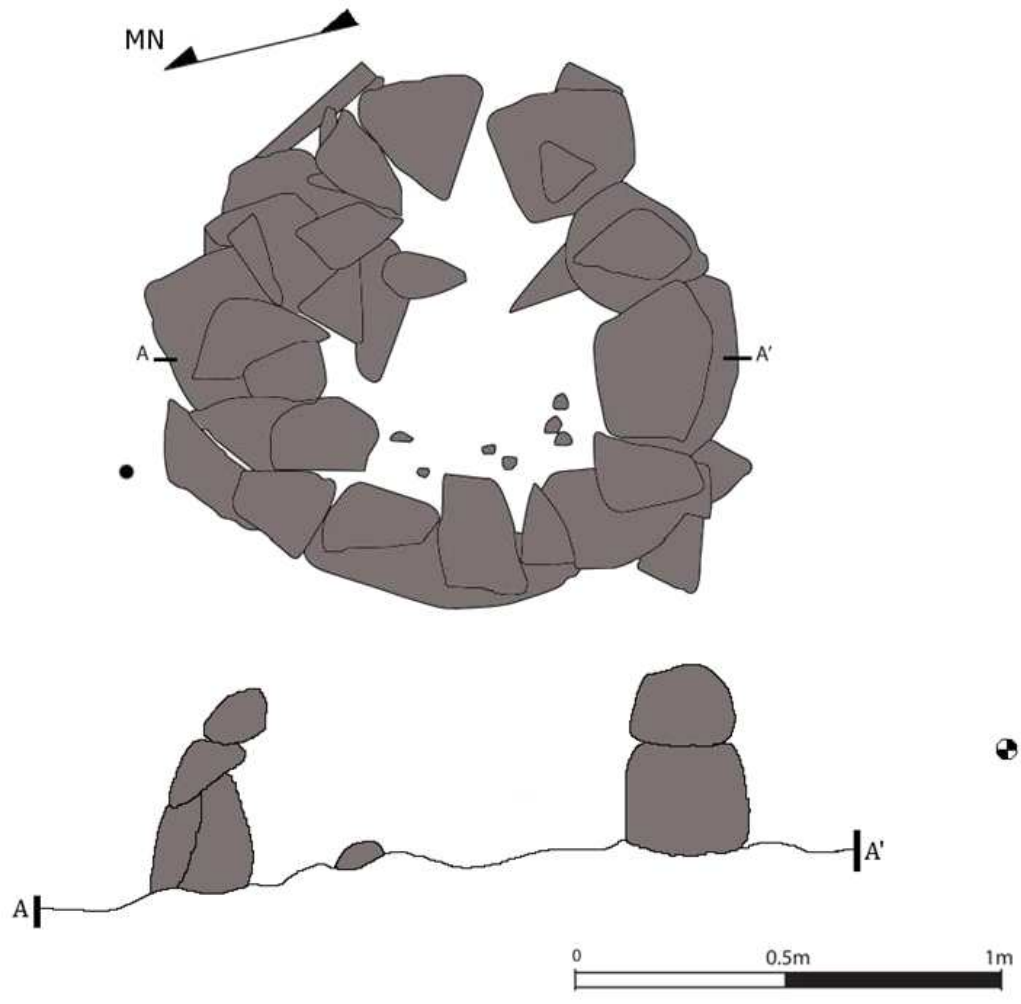


Figure 4.3. Site PoC3-11, Feature 2, Plan View.

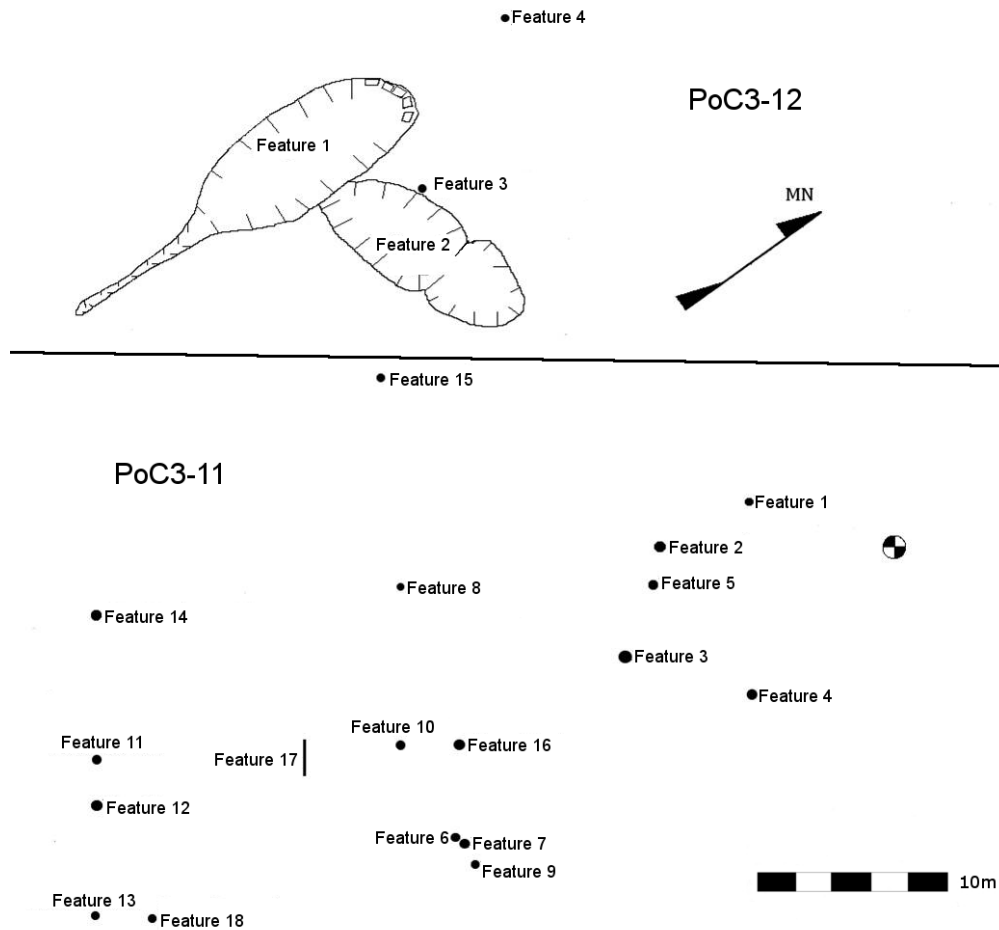


Figure 4.4. Sites PoC3-11 and PoC3-12.

Site PoC3-13 is a stone alignment composed of basalt cobbles and columns that extends along the shore of Temwen Island. It is adjacent to the Nan Madol complex located to the east. This alignment is built from layered cobbles, 2 to 3 stacked on top of each other, depending on location.. Its likely purpose is as a barrier to shoreline erosion.

Site PoC3-14 consists of two features. Feature 1 is a stone platform composed of basalt cobbles and boulders. The measurements are 5.85 m × 2.75 m, and it is angled to the NW. It has a slight elevation of approximately 0.5m from the base to the center. Feature 2 is a set of parallel stone alignments. They consist of basalt cobbles, measure 7 m long, and face NW. There is a 2.35 m gap between them. It is located to the southwest of Feature 1.

Site PoC3-15 is also a two-feature site. Feature 1 is a semi-circular structure made of basalt cobbles and boulders, as well as an adjacent row of basalt stones facing northeast. The semi-circular portion is 5 m in diameter. It is highly disturbed, and may be the result of the collapse of the structure. Feature 2 is a yam growing enclosure approximately 1 m in diameter. It is well preserved and is probably much more recent than Feature 1.

Site PoC3-16, a long wall covered in deep vegetation, was not measurable at the time of survey, but is estimated to be approximately 100 m in length. It is constructed of basalt boulders and cobbles and is approximately 2 m high at its highest, although height varies. The wall stretches roughly southwest to northeast.

Site PoC3-17 is a stone alignment on a hillside, made of basalt cobbles. It measures 10 south-north, and it has two perpendicular stone lines emerging from the middle. They are 2.86 m and 1.5 m long. It appears disturbed, and it could be related to a previous dwelling or to agricultural terracing.

Site PoC3-18 is a roughly “L” shaped pit measuring 5.3 m × 7.9 m (Figures 4.5 and 4.6). The depression is approximately 0.5m deep, and cobbles, mostly underground

(see Chapter VI), line the bottom of the depression. There are a few cobbles on the exterior of the pit. As such, its function was breadfruit fermentation. It was excavated, and the results of excavation and phytolith analysis are discussed in Chapter VI.

Site PoC3-19 is a multi-feature site. Features 1 and 2 are yam enclosures, 1m and 0.9m in diameter respectively. Feature 3 is an L-shaped alignment of large boulders. It measures approximately 8.8m north to south, and 6m west to east on the south end.

Site PoC3-20 is a three-feature site. Feature 1 is a yam enclosure 1.9-2.3 m in diameter. Feature 2 is also a yam enclosure, 1.2-1.6 m in diameter (Figure 4.7). Feature 3 is a small collection of basalt cobbles. It is roughly oval-shaped and 0.85-1 m in diameter. It is unclear if Feature 3 is a yam cultivation enclosure, although it is unlikely to be a natural outcrop.



*Figure 4.5. Site PoC3-18, Feature 1, Breadfruit Pit.*

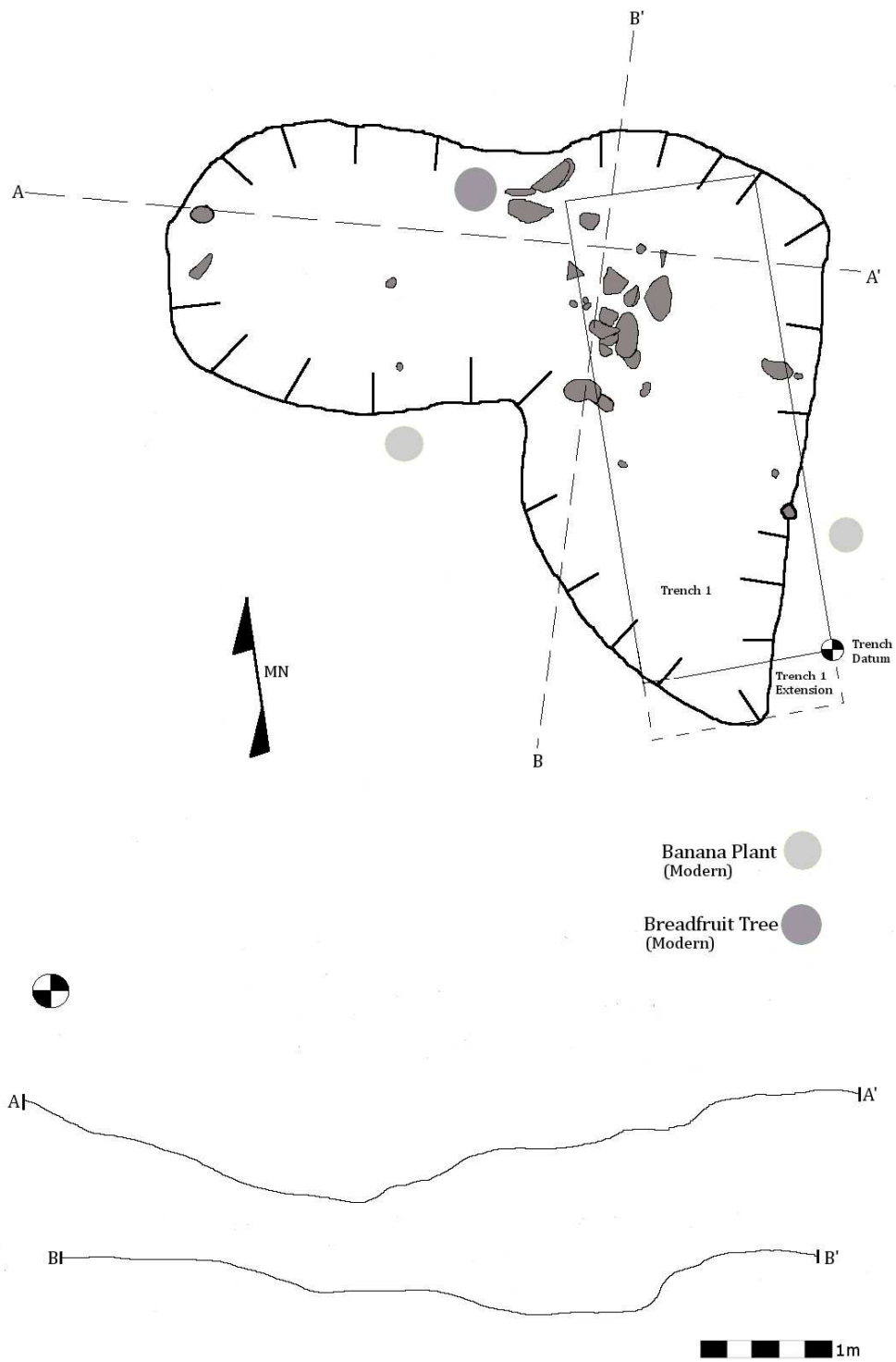


Figure 4.6. Site PoC3-18, Feature 1, Breadfruit Pit, Plan View.



*Figure 4.7. Site PoC3-20, Feature 2, Yam Enclosure.*

Site PoC3-21 is a small yam enclosure measuring 85-90 cm in diameter. It is not near any other archaeological features, and it is close to a modern taro patch (Figure 4.8).

Site PoC3-22 consists of two yam cultivation enclosures constructed of basalt cobbles. Feature 1 is 1.1 m in diameter, and Feature 2 is 2 m in diameter.

Site PoC3-23 also consists of two yam cultivation enclosures constructed of basalt cobbles. They are both 1-1.2 m in diameter.



*Figure 4.8. Site PoC3-21, Feature 1, Yam Enclosure.*

Site PoC3-24 is a multi-feature cluster of four yam cultivation enclosures on a SE slope in close proximity to one another. Feature 1 is disturbed and consists of a semicircle that is 1.65 m in diameter. Feature 2 is oval-shaped and ranges from 1-1.2 m in diameter. Feature 3 is also oval-shaped, but smaller, 0.85-1 m in diameter. Finally, Feature 4 is a smaller circular enclosure of basalt cobbles approximately 1m in diameter, surrounded by a larger oval of basalt boulders 2.2-2.8 m in diameter.

Site PoC3-25 is a multi-feature site located next to a dirt road, approximately 400 m from the coastline. Feature 1 is a cluster of basalt boulders, approximately 4.7 m × 3.4 m. This is not a natural outcrop, but it is highly disturbed and the function is unclear.

Feature 2 is a large stone wall stretching northwest to southeast, constructed of basalt boulders. It is 17.7 m long, 1.5 m in height, and ranges from 1.7 to 4.6 m in width. This feature is visible from the modern road. Feature 3 is a circular depression in the ground approximately 1.8 m in diameter. It is lined with a few basalt cobbles and likely represents the removal of yam from the soil.

Site PoC3-26 consists of a single feature, a depression measuring 3.95 m × 5.1 m. There are basalt boulders along the edges. These characteristics suggest that it is a breadfruit fermentation pit. There is a modern yam enclosure that contained a yam at the time of survey on the southwest side, and a large tree on the northern side. The tree has disturbed the interior of the feature. This feature is located 400 m northwest of the coastline.

Site PoC3-27 consists of a single yam cultivation enclosure with a diameter of approximately 1.8 m. At the northwest end, there is a large basalt boulder approximately 0.6m long. It is relatively isolated from other cultivation-related sites.

Site PoC3-28 is a large boulder platform that forms a rectangle. It is 12.4-13.4 m long on the northeast and southwest sides, and 8 m long on the southeast and northwest sides. It is approximately 2 m in height. The purpose of the structure is unclear, but it is clearly purposefully built. The area in which it is located, just north of PoC3-18, is noticeably grassier than other areas of the Temwen environment.

PoC3-29 is a single feature site, an isolated yam cultivation enclosure measuring 1-1.25 m in diameter. The structure has partially collapsed.

Site PoC3-30 is a three-feature site. Feature 1 is a collapsed yam cultivation enclosure measuring 0.75-1.5 m in diameter. Feature 2 consists of two small depressions that are each approximately 0.25 m wide. One is approximately 1 m long, and the other is 0.5 m long. The larger of the two depressions contains two wooden planks with nails on each end. They are lined up lengthwise and separated by about 0.1 m. This may be a historic latrine site. Feature 3 is a yam cultivation area where the yam was removed from the soil, a round depression approximately 1m in diameter.

Site PoC3-31 is located on a moderate southeast slope. It has six features that are all related to agriculture. Feature 1 is a small yam enclosure measuring 0.75 m in diameter. Feature 2 is a larger yam enclosure, 1-1.42 m in diameter. Feature 3 is a crescent of basalt cobbles and boulders on a slope. It consists of two lines of cobbles, one 2.4 m long, and one 2.6 m long, separated by a small (less than 0.5 m) gap. Given its location, it was probably used for agricultural terracing. Feature 4 is a yam enclosure 1.3 m in diameter. Feature 5 is a yam enclosure 1.2 m in diameter, with some disturbance on the east side. Finally, Feature 6 is an oval yam enclosure, 1.8 m at its widest. It is partially collapsed.

Site PoC3-32 has one feature, consisting of a yam cultivation enclosure with a diameter of 1.2 m. It is not located near any other features.

Site PoC3-33 is a single feature site with one stone alignment. It consists of 5 basalt boulders that run southwest to northeast over 2.7 m. Because there is a local slope, it is likely to have been constructed for purposes of terracing.

Site PoC3-34 is a multi-feature site related to yam cultivation located on a SE slope. Feature 1 is a pit approximately 1.2 m in diameter surrounded by a circle of basalt boulders 2.3m in diameter. It is likely that a yam was removed from the soil here. Feature 2 is a yam cultivation enclosure 1m in diameter. Feature 3 is a larger yam enclosure measuring 2 m in diameter. Feature 4 is another yam enclosure measuring 1.4 m in diameter, only 2 m from Feature 3. Feature 5 is a cluster of basalt boulders; the function is unclear. Feature 6 is an oval-shaped depression measuring 2.6 m × 1.8 m. It is lined with basalt cobbles. This depression is much smaller than most breadfruit fermentation pits, but larger than most pits related to yam removal, making the function unclear.

Site PoC3-35 is a depression measuring 3-4.8 m in diameter, making it an appropriate size for a small breadfruit fermentation pit. It is located on a southeast slope, which could potentially enable drainage.

Site PoC3-36 is a two-feature historic site. Feature 1 is a large circular depression measuring 12.3 m in diameter. The depth measure is estimated at 5 m, but as it was in modern use for garbage disposal at the time of survey, it could not be measured. The size and shape of the depression are not indicative of agricultural use. Feature 2 is a cluster of collapsed boulders that appear to have been deliberately moved to this location, but their purpose is unknown.

Site PoC3-37 is a yam cultivation site. Feature 1 is a yam enclosure measuring 1 m in diameter. Feature 2, 3 m from Feature 1, is also another 1 m diameter yam enclosure. Feature 3 is a yam enclosure measuring 1.3 m in diameter. Feature 4 is a pit depression approximately 1m in diameter, where a yam was likely removed from the soil.

Feature 5, 1.3 m in diameter, is of similar morphology and also likely represents yam removal.

Site PoC3-38 consists of a single large feature: a basalt boulder and cobble wall near the road to Nan Madol. It runs roughly parallel to this road and is about 5 m away. Behind the wall there is a steep northwest slope with large boulders strewn across the area. The wall is approximately 45 m long and 2 m high.

Site PoC3-39 is a two-feature yam cultivation site. Feature 1 is a yam enclosure 0.9 m in diameter. Feature 2 is a cluster of basalt cobbles approximately 0.7 m in diameter; it appears to be a disturbed yam enclosure.

Site PoC3-40 is a boulder wall approximately 1 m in height and 25 m long. The purpose is unclear; however, as it is located near a steep slope, it may have been constructed for erosion control.

Site PoC3-41 is a set of perpendicular boulder alignments. Both are approximately 8.4 m in length, and one is embedded into a hill slope. Like PoC3-40, it may represent erosion control or terracing.

Site PoC3-42 is interpreted as a breadfruit fermentation pit. It is a teardrop-shaped depression with a rounded west end, and an east end that tapers off, probably for drainage. It is located on a fairly flat area of land.

Site PoC3-43 is a multi-feature yam cultivation site. Feature 1 is a 1.8 m basalt cobble enclosure surrounding a pit depression in which a yam had likely been grown. Feature 2 is slightly larger, with a diameter ranging from 1.9 m-2.3 m; however, the morphology is similar. Feature 3 is a typical yam enclosure with no central depression.

Site PoC3-44 consists of a single feature, a flat rectangular platform constructed of basalt cobbles and boulders. The platform measures 8 m x 10.5 m. There is a clear outer edge on four sides measuring approximately 1m in width, and boulders and cobbles are strewn throughout the middle. There are more stones clustered towards the northwest end, and there is a seemingly rectangular platform structure on this end. Despite superficial similarities to lolong, this does not seem to be one. It is not built up, and instead is a single level of stones placed direction on the ground. It is located in a relatively flat area of managed agroforest, near a modern dwelling.

Site PoC3-45 is a yam cultivation site. Feature 1 is a yam cultivation enclosure 1 m in diameter, and Feature 2 is an enclosure 1.1 m in diameter.

Site PoC3-46 is a multi-feature, multi-function site. Feature 1 is a stone platform of basalt cobbles and boulders lying flat in a trapezoidal shape. The uneven sides of 6.2m and 4m; there is 7.8 m between these sides. This platform consists of a single layer of stones. Feature 2 is a boulder alignment 10.3 m in length, stretching north to south. These stones are deeply embedded in the ground, suggesting terracing. Feature 3 is a cluster of cobbles approximately 0.7 m in diameter. It is likely that this was a small yam enclosure, although it appears to have collapsed. Feature 4 is a small circular arrangement of cobbles approximately 0.5 m in diameter. These cobbles are very small and this feature is unlike most yam enclosures; thus, the function is unknown.

Site PoC3-47 is a single-feature yam cultivation site. It is of a similar size to most yam enclosures at 1.1 m in diameter. However, it is constructed out of a combination of

concrete, metal, and basalt cobbles. The inclusion of metal means that this structure was built in the historic era. There are no other nearby features.

Site PoC3-48 is a multi-feature agricultural site. Feature 1 is a yam cultivation enclosure 1.6 m in diameter. Feature 2 (Figure 4.9) consists of two linked depressions, likely related to breadfruit fermentation. The entirety of the depressions is 7.3 m long and 3.5 m wide. There are boulders lining the outside of the two depressions, and one separating the two in the middle, with a few cobbles in the southwest depression. The northwest depression is approximately 0.85 m deep. Feature 2 was mapped and excavated, as described in Chapter VI. The area where the site is located is densely wooded and on a steep south slope; it is transitional between managed agroforest and swamp.

Site PoC3-49 is also an agricultural site. Feature 1 is a stone alignment indicative of terracing; it is approximately 15 m long. Feature 2 is a yam cultivation enclosure 1.5m in diameter, located at the northeast end of Feature 1.

Site PoC3-50 is a single-feature site consisting of one large breadfruit fermentation pit. It is 17 m long and 5.4 m across in its widest parts. The pit has steep, boulder-lined walls that are about a meter high at maximum. The north end is wide and deep; the pit then narrows and flattens into a drainage ditch on the south end. It is located at the bottom of a steep slope in a swampy area.

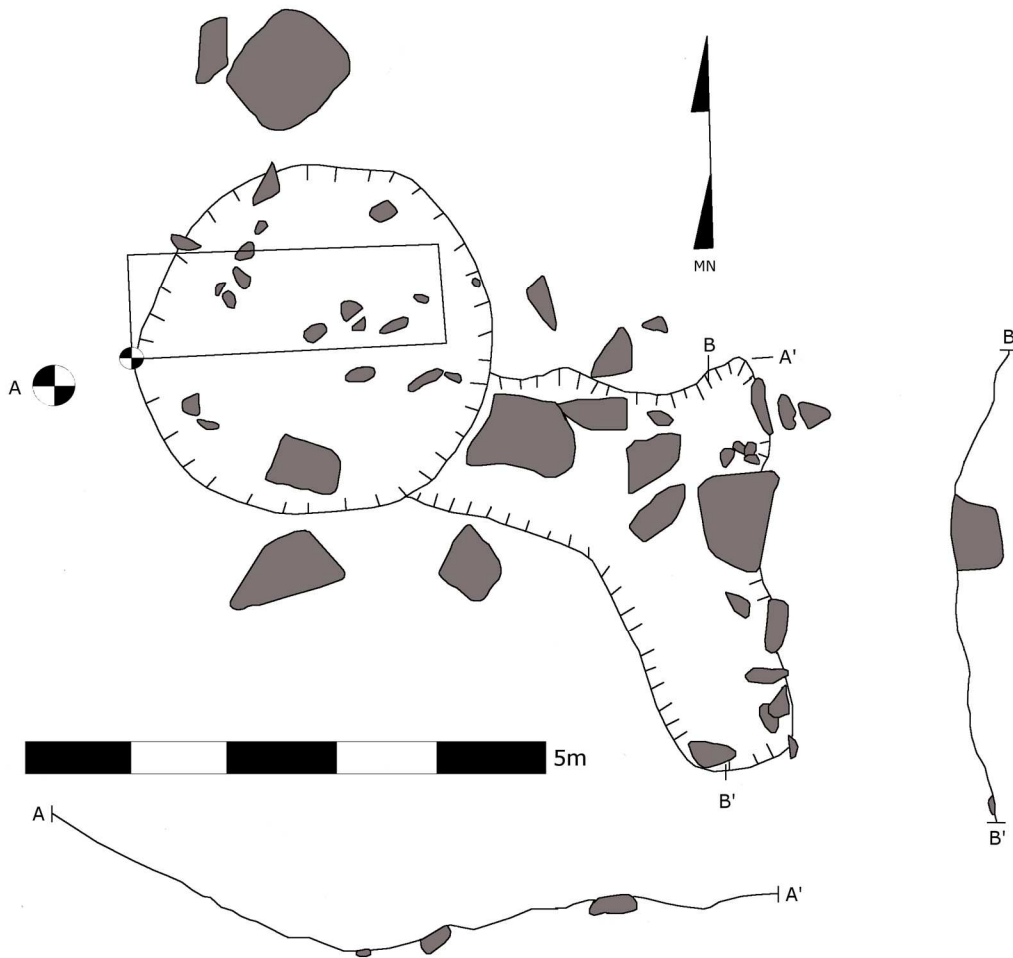


Figure 4.9. Site PoC3-48, Feature 2, Breadfruit Pit, Plan View.

Site PoC3-51 is a two-feature site. Feature 1 is a large structure with four exterior walls that are raised approximately 1 m each, and a central raised platform with some columns. This structure is highly suggestive of a *lolong* burial. It measures 14.2 m × 18.2 m. Feature 2 is a highly disturbed yam cultivation enclosure with a diameter of 2.2-5 m.

Site PoC3-52 is a five-feature agricultural site. Feature 1 is a disturbed yam growing enclosure with a diameter of 2 m. Feature 2 is a long, narrow breadfruit fermentation pit, with measurements of 15.6 m x 1-2 m. The depression runs west to east, with the west end being wider, and the east end being a narrow drainage area. Basalt cobbles and boulders surround the depression. Feature 3 consists of two parts, Feature 3a and Feature 3b. They are attached yam enclosures each about 1m in diameter. Feature 4 is an alignment to the north of Feature 1. It is 10.7 m and runs northeast to southwest, suggesting terracing. Feature 5 is located 2.1 m northwest of Feature 4. It is a yam cultivation enclosure approximately 1.8 m in diameter.

Site PoC3-53 consists of one feature, which contains in its interior one subfeature. The site consists of a large rectangular stone enclosure, measuring 13.1 m × 10 m. The walls range from 0.5-1 m in height and are constructed of basalt cobbles and boulders. There is no paving on the interior, although some cobbles and boulders are strewn around haphazardly. Subfeature 1a is a yam cultivation enclosure measuring approximately 1m in diameter. This subfeature is likely a much more recent than the rest of the site.

Site PoC3-54 is a two-feature agricultural site. Feature 1 is a yam cultivation enclosure 8 m in diameter. Feature 2 consists of two perpendicular alignments that probably represent terracing. One alignment is 9.2 m long and runs northwest to southeast; the other starts perpendicular to the first roughly in its center, and is 5.4 m long.

Site PoC3-55 is a four-feature yam cultivation site. Feature 1 is a yam cultivation enclosure 1 m in diameter. Feature 2 is a yam enclosure 0.8 m in diameter. Feature 3,

another yam enclosure, is 1.1 m in diameter. Finally, Feature 4 is 1.3 m in diameter and is also likely a yam cultivation enclosure. In addition to basalt cobbles, Feature 4 also contains a small piece of coral.

Site PoC3-56 also consists of four yam enclosures. Feature 1 is larger at 2.1 m in diameter. Feature 2 is 1.3 m in diameter; at the time of survey, there was wild taro growing in the center. Feature 3 is 1.5 m in diameter and is disturbed by a crab hole. Finally, Feature 4 is 1.3 m in diameter.

Site PoC3-57 is a two-feature yam cultivation site. Feature 1 is a yam enclosure approximately 1.5 m in diameter. Feature 2 is a yam enclosure 1.1 m in diameter.

Site PoC3-58 is a stone platform with raised basalt cobble and boulder walls. The walls range from 0.5-1 m in height and the interior is partially paved with basalt cobbles. It measures 9 m × 6 m. The southeast wall is collapsing due to a large tree near the wall; the site is in good condition otherwise.

Site PoC3-59 is a large structure of basalt boulders and cobbles, measuring 16.5 m × 13.5 m. It is walled on all four sides. The walls are 1-1.5 m in height. There are a few basalt columns in the center. However, it does not have the central platform characteristic of *lolong*.

Site PoC3-60 is a stone alignment of cobbles and boulders with two sides that meet at a corner. One side is 4.6 m long, and the other is 3.7 m long. There are several cobbles in the corner. The function is unknown; it appears to be highly disturbed.

### 4.3. Mapping and Spatial Analysis: Results and Interpretation

A GPS map of site distribution (Figure 4.10) shows a high density of archaeological features, which indicates heavy overall use of the area by Pohnpeians during the prehistoric and historic periods. Thus, these survey results provide an example of an inhabited and heavily managed arboricultural and root crop cultivation area. Features are primarily related to food production, although they are also indicative of settlement, as well as high status burial in the case of the *lolong*.

As yam cultivation is an important part of Pohnpeian food production and a significant number of yam enclosures were located, a nearest neighbor analysis was conducted on the 85 yam enclosures (Figure 4.11) to determine if the patterning of these enclosures is non-random. Results, as given by Quantum GIS software, are in Table 4.2.

Table 4.2. Nearest Neighbor Analysis Results, Yam Enclosures.

<b>Observed Mean Distance</b>	0.000115
<b>Expected Mean Distance</b>	0.000210
<b>Nearest Neighbor Index</b>	0.547806
<b>N</b>	85
<b>Z-Score</b>	-7.975632

These results are highly significant (a Z-score below -1.96 or above 1.96 indicates significance at the  $p < 0.05$  level), showing non-random clustering of yam enclosures. This indicates that residents of Temwen Island in the past chose yam planting locations carefully. Raynor et al. (2009:51) indicate six considerations that Pohnpeians traditionally use when determining where to plant yams. Three of these reasons are largely ecological,

while three of them are social. Ecological reasons cited by Raynor et al. (2009:51) include: a) the site's physical characteristics (e.g., wind, shade, soil fertility, drainage); b) the specific cultivar used; and c) vine support availability. Social reasons cited are: a) intended use (subsistence or prestige); b) availability of land to the specific farmer, and c) privacy. Because yam biology is more stable over time than social factors, ecological requirements for site selection are less likely than social ones to have changed over the occupation of the island. The most likely of the ecological candidates to change is the specific cultivar used, as new cultivars can be introduced or developed, and some cultivars may wax and wane in popularity.

In terms of social factors, it is likely that availability of land plays a major role in site selection. Farmers would generally be limited to using the land under their own control. During the historic period, the land tenure system would have intensified these limits. Thus, areas for yam selection were been limited socially; it may be that farmers chose the most fertile areas and/or private of their own land to plant yams for any purpose. However, most of the yam enclosures identified can be interpreted as being for subsistence yam production rather than for feasting yams. Given the proximity of the survey area to the large Nan Madol site, it is likely that this area has been heavily trafficked since antiquity. Thus, this is not a secluded area that is considered socially ideal for producing feasting yams.

Because it is established that the Pohnpeian dual subsistence/prestige economy has persisted for over a millennium (Haun 1984), these same social reasons for the placement of yam growing sites may have considerable time depth. At any rate, it is

likely a combination of ecological and social considerations that lead Pohnpeians to carefully select spots for yam cultivation practices, resulting in a non-random distribution of yam enclosures.

#### **4.4. Summary**

This chapter has discussed archaeological survey results on Temwen Island. This includes the types of sites and features that are located on the island, and the distribution of these features. Overall, archaeological features on Temwen Island are largely concentrated around food production practices, although not exclusively so. Notably, there is an abundance of non-randomly distributed yam pits and other types of features, such as breadfruit fermentation pits, stone alignments (possibly for terracing), and stone platforms. While archaeological survey data can provide a great deal of information on the organization of food production systems, paleoethnobotanical analysis provides complementary data about how these systems work. In Chapter V, I look at one aspect of paleoethnobotany, specifically phytolith analysis, and determine the utility of using phytolith data to understand Pacific Islands arboricultural and root crop cultivation systems.

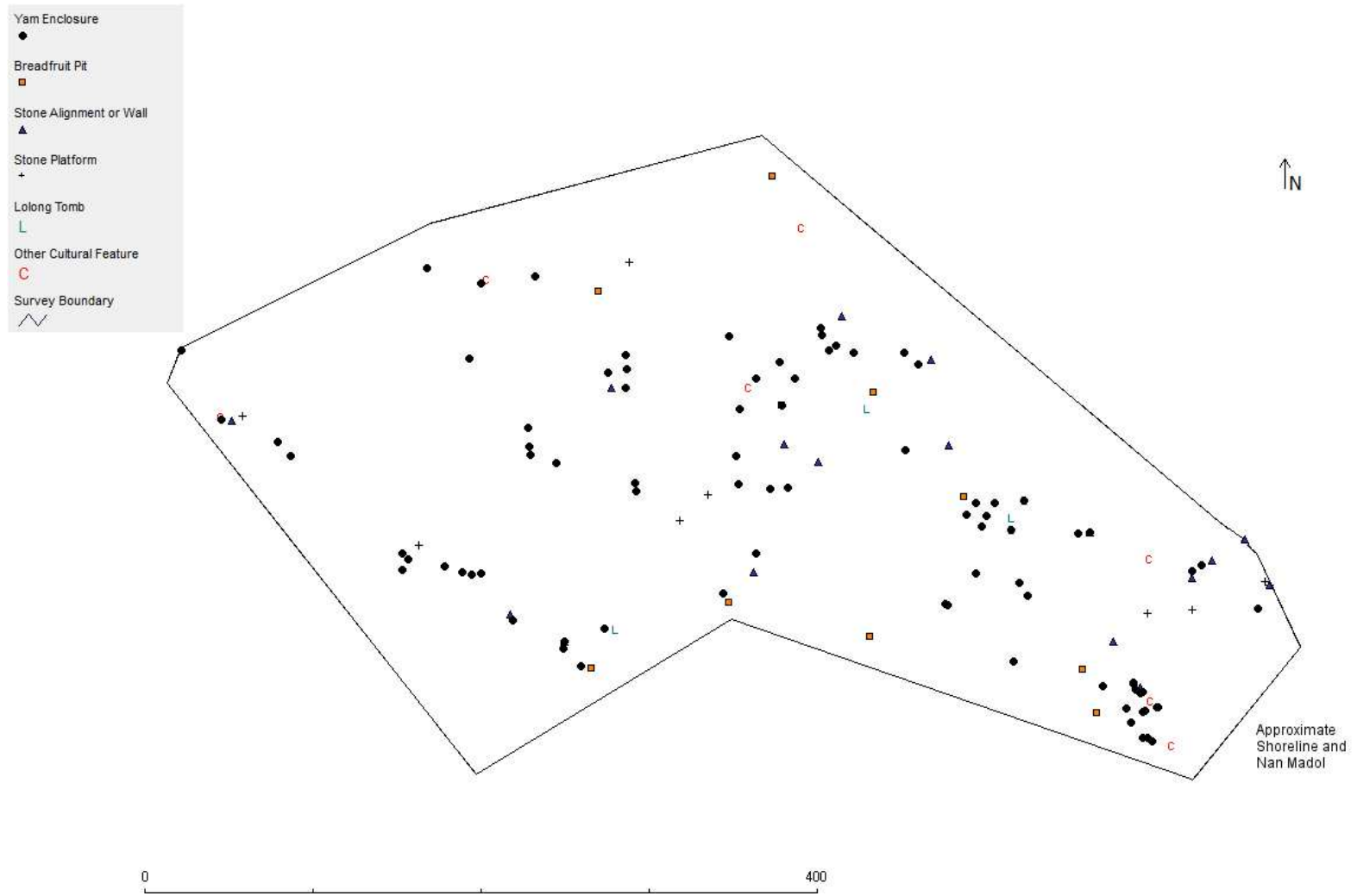
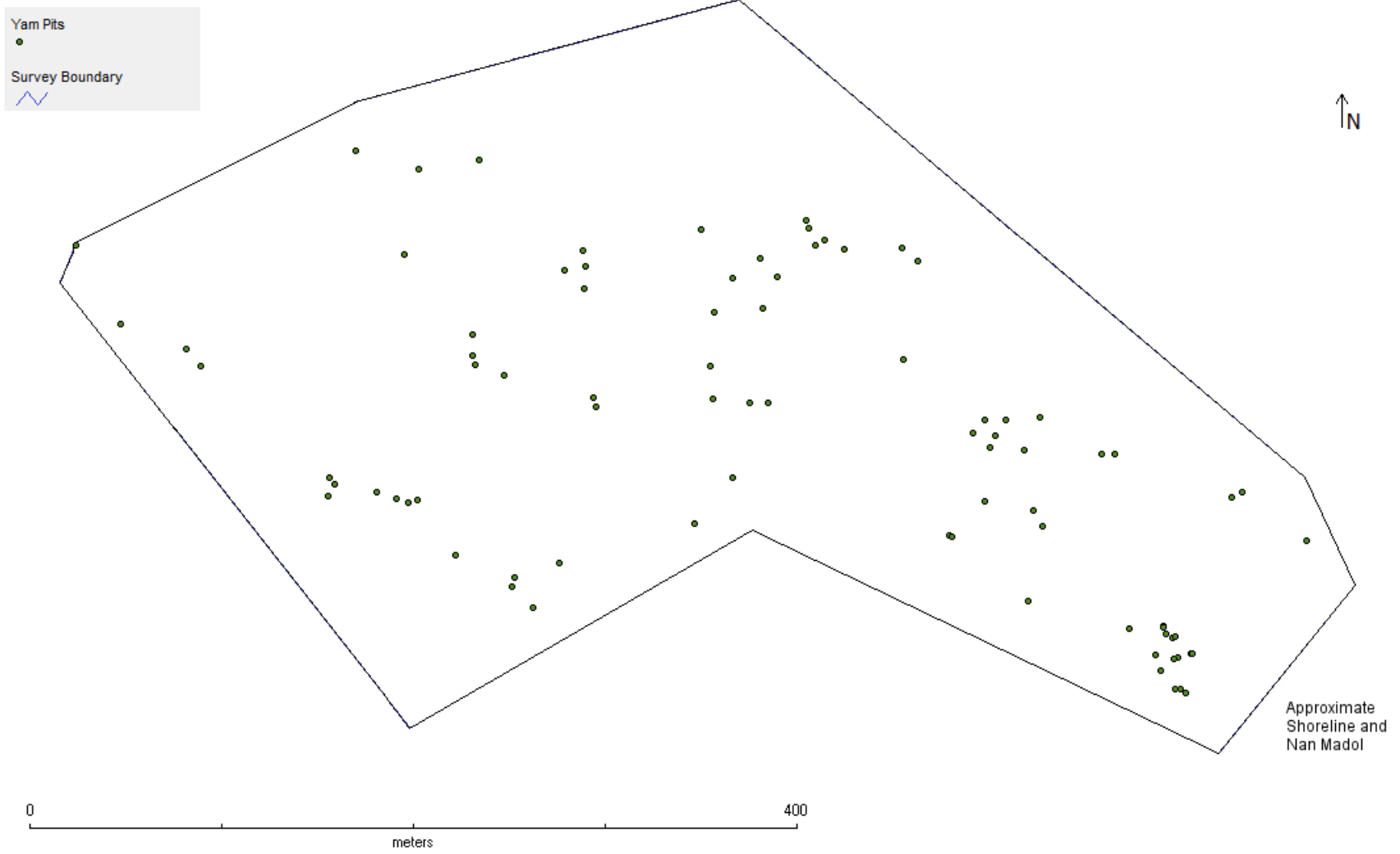


Figure 4.10. Overall survey feature distribution map.



*Figure 4.11. Yam enclosure distribution map.*

CHAPTER V  
PHYTOLITH REFERENCE MATERIALS AND APPLICABILITY IN  
ARCHAEOLOGY

In any paleoethnobotanical analysis, a broad modern reference collection is a key component to understanding the record (Pearsall 2000; Piperno 2006). This is especially true in phytolith analysis for multiple reasons. First, a few plant families, such as Poaceae (grasses), Cyperaceae (sedges), Arecaeae (palms), and Musaceae (bananas), produce a very large amount of phytoliths, many taxa produce some, and several taxa produce few or no phytoliths. Second, phytoliths vary in taxonomic resolution. Some taxa produce large numbers of phytoliths, but they may be indistinguishable in appearance from those of other local taxa, whereas other taxa produce phytoliths that are specific to family, genus, or in rare cases, species. A reference collection helps to better understand redundancies by providing more information about the phytolith production of a broad range of species. Only a broad-spectrum understanding of a local flora allows for a complete interpretation of a phytolith assemblage and assessment of the status of domesticates in the larger botanical sphere. Third, different phytoliths can occur in different parts of the same plant. While leaves tend to produce phytoliths in the greatest numbers, they can theoretically be produced in any part of the plant. An understanding of the anatomical origin of phytoliths helps to better interpret the archaeological and paleoecological setting from which plant materials are retrieved. Lastly, while breakage and wear can occur, and archaeological phytoliths are not often articulated into larger phytolith skeletons, there are few visible differences between archaeological and modern

phytoliths. Reference and archaeological phytoliths of the same taxa look virtually identical in most cases.

Silica by weight in plants varies widely, from over 10% in some grasses, to under 0.1% in many species. Piperno (2006) suggests that plants with 0.5% silica content are, for all intents and purposes, not generally going to be archaeologically visible. On the other hand, plants with high silica content are strongly overrepresented. Thus, phytolith analysis cannot create a strict 1:1 vegetation reconstruction. However, what it can do is indicate: a) indicate fluctuations in particular taxa over time; b) provide rough ratios of certain taxa to each other in the local environment; and c) mark presence/absence, even for taxa with low (but taxonomically relevant) phytolith production. The primary goal of this chapter is to systematically determine what Pacific plant taxa (primarily economic species, but also some common species in disturbed habitats) can be recognized archaeologically using phytoliths.

Plant reference materials were collected in the field in Temwen, Pohnpei, Micronesia and in O'ahu, Hawai'i. Additionally, plant specimens from locations around the Pacific present in the collection at the Australian National University Department of Archaeology and Natural History were also processed. Balick (2009) and Glassman (1950) were used as a guide to the most important economic taxa. Plants collected were pressed and dried as outlined by Pearsall (2000) and processed as described in the methods chapter. They were viewed at 400 × magnification using a Nikon AZ-100 light microscope and photographed using NIS-Elements software. Each slide was scanned in its entirety and all distinctive forms present in each part of each plant were recorded. In

total, 205 specimens from 77 taxa are included in this analysis. Six specimens were excluded from the analysis because of insufficient (family level only) or uncertain identification (listed with question marks in Appendix B).

An understanding of how the phytolith composition compares to the flora of the immediate surroundings is also important. For this purpose, four sediment samples were collected within the boundaries of the archaeological survey, two of which are analyzed in this chapter. While this sample does not provide an exhaustive example of the local flora, it is sufficient for pilot work in comparing local flora to phytolith assemblage. After collecting the soil, we recorded the plant taxa within three meters of the sample using Balick (2009) as a reference, with the help of a field crewmember familiar with local flora. Sediment samples were processed according to the same protocol as all archaeological sediment samples, and 300 phytoliths with distinctive form (e.g., clearly describable phytoliths) were counted on each slide. The phytolith contents of the sediment samples were then compared with the plant taxa recorded (Section 5.2).

### **5.1. Plant Reference Results**

Plant reference materials are divided here into three sections: 1) plant parts with phytoliths that are diagnostic at some level (Table 5.1); 2) plant parts that contained observable phytoliths, but not those that are taxonomically useful (Table 5.2); and 3) plant parts that contained no observable phytoliths (Table 5.3). A simple criterion was used to divide plant parts into these three categories (Figure 5.1). Plant parts with no phytoliths observed on an entire slide were placed into Category 3. Plants parts with

phytoliths observed that are known to be produced broadly across large taxonomic categories, but that did not contain any phytoliths more narrowly produced were placed in Category 2. This includes tracheids, elongate and cylindric phytoliths, and phytoliths originating from indistinct epidermal cells. Plant parts that included any other phytoliths were placed in Category 1, as these phytoliths are produced by a limited grouping of plants.



Category 1	Category 2	Category 3
<p>Taxonomically useful phytoliths observed</p>  <p>Example: <i>Musa troglodytarum</i> leaf, volcaniform</p>	<p>Only tracheid, elongate, cylindric, or indistinct epidermal phytoliths</p>  <p>Example: <i>Pandanus</i> sp. leaf, tracheid</p>	<p>No phytoliths observed</p>

Figure 5.1. Reference plant part categorization criteria.

It is important to note that most of the plant parts in Category 1 do not produce phytoliths distinct to their species and taxa. In fact, this is a relatively rare occurrence (Piperno 2006) and most plants in this category either: a) produce phytoliths distinctive to their family or order; or b) produce phytoliths that occur in a sufficiently low enough number of taxa that the occurrence of the phytoliths they produce is useful for vegetation

reconstruction. Also important is that many species are mentioned in multiple charts. Some plants produce taxonomically useful phytoliths in some parts of the plant (most commonly the leaves), but produce none in others. Understanding this distinction can be useful for interpreting activity areas at archaeological sites, because certain types of phytoliths may indicate the use of certain plant types.

Table 5.1. Category 1: Plant parts with phytoliths that are taxonomically useful at some level.

Family	Species (English Common Name in Parentheses Where Applicable; Balick 2009)	Plant Part	Phytolith Type(s)	Collection
<b>Ferns/Fern Allies</b>				
Marattiaceae	<i>Angiopteris evecta</i>	frond	rectangular scrobiculate, orbicular scrobiculate, oblong scrobiculate	O'ahu
Thelypteridaceae	<i>Cyclosorus heterocarpus</i>	frond	orbicular sulcate, segmented elongate psilate, amorphous castellate epidermal	Pohnpei

Table 5.1. continued.

<b>Monocotyledons</b>				
Arecaceae	<i>Areca catechu</i> (betel nut)	bark	globular echinate, globular psilate, elongate tabular epidermal	Pohnpei
Arecaceae	<i>Areca catechu</i> (betel nut)	leaf	globular echinate, elongate tabular epidermal	Pohnpei
Arecaceae	<i>Areca guppyana/ vestiaria</i>	leaf	globular echinate, tracheid	ANU
Arecaceae	<i>Clingostigma ponapense</i> (Pohnpei mountain palm)	leaf	globular echinate, elongate psilate, tracheid	ANU
Arecaceae	<i>Cocos nucifera</i> (Coconut)	bark	globular echinate, elongate epidermal, tracheid	ANU <sup>a</sup>
Arecaceae	<i>Cocos nucifera</i> (Coconut)	leaf	globular echinate	Pohnpei, O'ahu
Arecaceae	<i>Metroxylon amicarum</i> (sago palm)	leaf	globular echinate, psilate epidermal, elongate echinate epidermal, tracheid	O'ahu
Arecaceae	<i>Metroxylon amicarum</i> (sago palm)	root	globular echinate	O'ahu

Table 5.1. continued.

Arecaceae	<i>Metroxylon amicarum</i> (sago palm)	inflorescence	globular ecinate, tracheid	O'ahu
Arecaceae	<i>Nypa fruitcans</i> (swamp palm)	leaf	globular echinate, globular psilate, tracheid, elongate psilate epidermal, ovate psilate	Pohnpei
Arecaceae	<i>Ponapea ledermannia</i>	seed	globular echinate, elongate psilate	ANU
Cyperaceae	<i>Eleocharis dulcis</i>	leaf and stem	elongate psilate, elongate crenate epidermal, oblong	ANU
Cyperaceae	<i>Eleocharis dulcis</i>	flower	rectangular papillae	ANU
Musaceae	<i>Musa</i> sp. (banana)	leaf	orbicular, oval volcaniform, rectangular volcaniform	Pohnpei
Musaceae	<i>Musa</i> sp. (banana)	stem and bark	rectangular volcaniform	Pohnpei
Musaceae	<i>Musa troglodytarm</i> (karat banana)	bark	volcaniform, elongate psilate	Pohnpei
Musaceae	<i>Musa troglodytarm</i> (karat banana)	leaf	volcaniform, epidermal psilate	Pohnpei

Table 5.1. continued.

Poaceae	<i>Bambusa vulgaris</i> (bamboo)	leaf and stem	rondel, saddle, elongate tabular, elongate papillate bulliform, tracheid, rectangular scrobiculate, acicular psilate	O'ahu
Poaceae	<i>Ischaemum polystachyum</i> (paddle grass)	leaf and stem	bilobate, trapeziform, rondel sinuate elongate epidermal, elongate echinate	Pohnpei
Poaceae	<i>Miscanthus</i> sp. (sword grass)	leaf and stem	bilobate, elongate crenate tabular epidermal long cell, elongate papillate epidermal long cell, elongate tabular epidermal long cell	Pohnpei
Poaceae	<i>Oplismenus hirtuellus</i>	leaf and stem	bilobate, polylobate, cross-body, bulliform, elongate tabular, acicular psilate hair cell, trapeziform sinuate, favose, hegagonal epidermal	O'ahu

Table 5.1. continued.

Poaceae	<i>Phragmites karka</i>	leaf	elongate crenate tabular epidermal long cell, square, saddle, elongate striate	ANU
Poaceae	<i>Saccharum</i> sp. (sugarcane)	leaf	bilobate, elongate papillate epidermal long cell, elongate tuberculate epidermal long cell	ANU
Poaceae	<i>Thuarea involuta</i>	leaf	bilobate, elongate psilate	ANU
Zingiberaceae	<i>Cucurma longa</i> (tumeric)	leaf and stem	rectangular tabular epidermal, semi-orbicular tabular, folded ovate, rectangular scrobiculate, cuneiform, rectangular elongate, tracheid	O'ahu, ANU
Zingiberaceae	<i>Cucurma longa</i> (tumeric)	fruit	globular psilate	ANU
<b>Dicotyledons</b>				
Boraginaceae	<i>Cordia subcordata</i>	leaf and stem	psilate epidermal, orbicular psilate, rectangular echinate, trapeziform striate epidermal, elongate psilate, favose epidermal, tracheid, acicular echinate hair cell <sup>b</sup>	O'ahu, ANU

Table 5.1. continued.

Burseraceae	<i>Canarium</i> sp. (ngali nut)	leaf	epidermal papillae, oblong favose hair base, sinuate epidermal	ANU
Combretaceae	<i>Terminalia catappa</i> (Indian almond)	leaf	sinuate psilate epidermal, tracheid	ANU
Combretaceae	<i>Terminalia catappa</i> (Indian almond)	bark	rectangular striate	ANU
Euphorbiaceae	<i>Macaranga aleuritoides</i> (macaranga)	leaf	rectangular sinuate epidermal, orbicular favose epidermal, unciform hair cell, acicular psilate hair cell, elongate psilate	ANU
Euphorbiaceae	<i>Macaranga carolinensis</i> (macaranga)	leaf	sinuate epidermal, acicular psilate hair cell, hair base, elongate psilate, elongate sulcate one-side	Pohnpei
Fabaceae	<i>Paraderris elliptica</i>	leaf and stem	psilate sinuate epidermal (various shapes), ovate with central indentation, unciform hair cell	Pohnpei, O'ahu <sup>c</sup>

Table 5.1. continued.

Lamiaceae	<i>Vitex trifolia</i>	leaf and flower	unciform hair cell, elongate articulated, irregular epidermal, tracheid	ANU
Moraceae	<i>Artocarpus altilis</i> (breadfruit)	leaf	acicular echinate hair cell, unciform hair cell, hair base, irregular psilate epidermal, elongate, tracheid	Pohnpei, ANU
Moraceae	<i>Artocarpus altilis</i> (breadfruit)	bark	acicular echinate hair cell, elongate psilate, irregular psilate epidermal	ANU
Moraceae	<i>Artocarpus altilis</i> (breadfruit)	fruit	achicular echinate hair cell, acicular psilate hair cell, unciform hair cell, favose psilate epidermal, tracheid	ANU

Table 5.1. continued.

Moraceae	<i>Artocarpus camansi</i> (breadnut)	leaf	acicular echinate hair cell, unciform hair cell, hair base, acicular psilate hair cell, psilate epidermal	O'ahu
Moraceae	<i>Ficus prolixa</i>	leaf	acicular psilate, hair base, irregular epidermal	ANU
Moraceae	<i>Ficus prolixa</i>	bark	Pentagonal tabular epidermal, reticulate epidermal, elongate echinate, elongate papillate, tracheid	ANU
Moraceae	<i>Ficus tinctoria</i> (strangler fig)	leaf and stem	acicular psilate hair cell, unciform hair cell, globular psilate, rectangular scrobiculate epidermal, tracheid	O'ahu
Moraceae	<i>Ficus tinctoria</i> (strangler fig)	bark	acicular psilate hair cell, elongate scrobiculate, elongate echinate, favose epidermal, scrobiculate, tracheid	ANU

Table 5.1. continued.

Piperaceae	<i>Piper methysticum</i> (kava)	leaf and stem	pyramidal favose, trapeziform favose, ovate scrobiculate epidermal, ovate psilate epidermal, stellate epidermal, oblong	Pohnpei, ANU
Piperaceae	<i>Piper ponapense</i>	leaf and stem	octagonal favose, ovate psilate epidermal, stellate epidermal, scrobiculate epidermal, tracheid	Pohnpei
Piperaceae	<i>Piper</i> sp.	Leaf	favose epidermal, scrobiculate epidermal, hair base, orbicular stellate, tracheid	ANU
Urticaeae	<i>Pipturus</i> sp.	Leaf	acicular psilate hair cell, acicular echinate hair cell, unciform hair cell, globular echinate, lanceolate, elongate psilate, tracheid	ANU

Table 5.1. continued.

Urticaceae	<i>Pipturus</i> sp.	stem	acicular echinate hair cell, lanceolate, favose epidermal, tracheid	ANU
Urticaceae	<i>Pipturus</i> sp.	flower	lanceolate	ANU
Urticaceae	<i>Procris</i> sp.	stem	acicular psilate hair cell	ANU
<p><sup>a</sup> Phytoliths not present in collected samples from Pohnpei and O'ahu  <sup>b</sup> Acicular echinate hair cell likely to be contamination  <sup>c</sup> Appears to be taxonomically useful only in O'ahu sample, not in Pohnpei sample</p>				

Table 5.2. Category 2: Plant parts with phytolith production, but where no taxonomically useful phytoliths were observed.

Family	Species (English Common Name in Parentheses Where Applicable; Balick 2009)	Plant Part	Phytolith Type(s)	Collection
<b>Ferns/Fern Allies</b>				
Selaginellaceae	<i>Selaginella</i> sp.	frond	Elongate papillate, tracheid	ANU
Thelypteridaceae	<i>Cyclosorus heterocarpus</i>	stem	epidermal	Pohnpei
<b>Monocotyledons</b>				
Arecaceae	<i>Metroxylon amicarum</i> (sago palm)	bark	elongate, epidermal cells	O'ahu

Table 5.2. continued.

Arecaceae	<i>Metroxylon amicarum</i> (sago palm)	nut	psilate epidermal	O'ahu
Cyperaceae	<i>Eleocharis dulcis</i>	root	elongate	ANU
Dioscoreaceae	<i>Dioscorea bulbifera</i> (wild yam)	bulb	elongate psilate	O'ahu
Pandanaceae	<i>Pandanus</i> sp. (pandanus)	leaf	tracheid, square tabular epidermal	ANU
Poaceae	<i>Bambusa vulgaris</i> (bamboo)	stalk	elongate epidermal	O'ahu
<b>Dicotyledons</b>				
Boraginaceae	<i>Cordia subcordata</i>	fruit	elongate favose epidermal	ANU
Burseraceae	<i>Canarium indicum</i> (Ngali nut)	leaf	epidermal psilate	ANU
Burseraceae	<i>Canarium indicum</i> (Ngali nut)	stem	square to rectangular epidermal	ANU
Casuaraniaceae	<i>Casuarinia</i> sp. (beefwood, ironwood)	leaf	tracheid	ANU
Euphorbiaceae	<i>Aleurites moluccana</i> (candlenut)	leaf and stem	cuneiform psilate epidermal, favose epidermal, scrobiculate	O'ahu, ANU
Euphorbiaceae	<i>Aleurites moluccana</i> (candlenut)	fruit	opaque platelet, orbicular epidermal, tracheid	O'ahu

Table 5.2. continued.

Euphorbiaceae	<i>Aleurites moluccana</i> (candlenut)	bark	scrobiculate epidermal	ANU
Euphorbiaceae	<i>Aleurites moluccana</i> (candlenut)	seed husk	opaque platelet	ANU
Fabaceae	<i>Erythrina variegata</i> (coral tree)	leaf	psilate epidermal, orbicular facetate, tracheid	ANU
Lecythidaceae	<i>Barringtonia racemosa</i>	leaf	orbicular psilate epidermal, cuneiform psilate epidermal	O'ahu
Malvaceae	<i>Hibiscus tiliaceus</i> (hibiscus)	bark	cylindric psilate	Pohnpei, ANU <sup>a</sup>
Malvaceae	<i>Hibiscus tiliaceus</i> (hibiscus)	leaf	cylindric psilate. square and irregular epidermal	Pohnpei, ANU
Malvaceae	<i>Kleinhovia hospita</i>	leaf	tracheid	ANU
Nyctaginaceae	<i>Pisonia grandis</i>	leaf	irregular favose epidermal	ANU
Piperaceae	<i>Piper betle</i> (betel leaf)	leaf and stem	psilate epidermal, scrobiculate epidermal	O'ahu

Table 5.2. continued.

Piperaceae	<i>Piper betle</i> (betel leaf)	inflorescence	elongate psilate epidermal, ovate psilate epidermal	O'ahu
Rubiaceae	<i>Morinda citrifolia</i> (Indian mulberry)	leaf and stem	pentagonal epidermal, orbicular epidermal, tracheid	O'ahu
<sup>a</sup> No recorded phytoliths in ANU sample.				

Table 5.3. Category 3: Plant parts with no observed phytolith production.

Family	Species (English Common Name in Parentheses Where Applicable; Balick 2009)	Plant Part	Collection(s)
<b>Ferns/Fern Allies</b>			
Aspleniaceae	<i>Asplenium nidus</i> (bird's-nest fern)	frond	Pohnpei, O'ahu
Aspleniaceae	<i>Asplenium polyodon</i>	frond	Pohnpei
Aspleniaceae	<i>Asplenium polyodon</i>	stem	Pohnpei
Aspleniaceae	<i>Asplenium polyodon</i>	roots	Pohnpei
Polypodiaceae	<i>Microsorium scolopendria</i>	frond	O'ahu
Polypodiaceae	<i>Microsorium scolopendria</i>	stem and root	O'ahu
<b>Monocotyledons</b>			
Amaryllidaceae	<i>Crinum asiaticum</i> (white spider lily)	flower	ANU

Table 5.3. continued.

Amaryllidaceae	<i>Crinum asiaticum</i> (white spider lily)	stem	ANU
Amaryllidaceae	<i>Crinum asiaticum</i> (white spider lily)	leaf	ANU
Araceae	<i>Alocasia marcorrhizos</i> (wild taro)	leaf and stem	Pohnpei
Araceae	<i>Colocasia esculenta</i> (taro)	leaf and stem	Pohnpei
Araceae	<i>Cyrtosperma merkusii</i> (giant taro)	leaf and stem	Pohnpei
Arecaceae	<i>Nypa fruticans</i> (swamp palm)	bark	Pohnpei
Dioscoreaceae	<i>Dioscorea</i> sp. (yam)	leaf	Pohnpei
Dioscoreaceae	<i>Dioscorea</i> sp. (yam)	leaf and stem	Pohnpei
Dioscoreaceae	<i>Dioscorea bulbifera</i> (wild yam)	leaf, stem, and root	O'ahu
Dioscoreaceae	<i>Tacca leontopetaloides</i> (arrowroot)	leaf and stem	Pohnpei
Laxmanniaceae	<i>Cordyline fruticosa</i> (ti plant)	leaf and stem	Pohnpei, O'ahu, ANU
Laxmanniaceae	<i>Cordyline fruticosa</i> (ti plant)	bark	ANU
Musaceae	<i>Musa</i> sp. (banana)	root	Pohnpei
Pandanaceae	<i>Freycinetia arborea</i>	leaf	ANU
Pandanaceae	<i>Freycinetia arborea</i>	bark	ANU
Pandanaceae	<i>Pandanus tectorius</i> (pandanus)	bark	Pohnpei, O'ahu
Pandanaceae	<i>Pandanus tectorius</i> (pandanus)	leaf	Pohnpei, O'ahu
Pandanaceae	<i>Pandanus tectorius</i> (pandanus)	fruit	O'ahu

Table 5.3. continued.

Pandanaceae	<i>Pandanus</i> sp. (pandanus)	seed	ANU (Rapa Collection)
Pandanaceae	<i>Pandanus</i> sp. (pandanus)	bark	ANU
Poaceae	<i>Miscanthus</i> sp. (sword grass)	flower	ANU
Poaceae	<i>Thuarea involuta</i> .	flower	ANU
Zingiberaceae	<i>Zingiber zerumbet</i> (wild ginger)	whole plant	O'ahu <sup>a</sup>
Zingiberaceae	<i>Zingiber</i> sp. (ginger)	leaf	ANU <sup>a</sup>
Zingiberaceae	<i>Zingiber</i> sp. (ginger)	stem	ANU <sup>a</sup>
Zingiberaceae	<i>Zingiber</i> sp. (ginger)	root	ANU <sup>a</sup>
<b>Dicotyledons</b>			
Apiaceae	<i>Centella asiatica</i> (Indian pennywort)	Whole plant	O'ahu
Asteraceae	unknown species	whole plant	Pohnpei
Araliaceae	<i>Polyscias</i> sp. (panax)	flower	ANU
Araliaceae	<i>Polyscias</i> sp. (panax)	bark and wood	ANU
Araliaceae	<i>Polyscias</i> sp. (panax)	leaf	ANU
Boraginaceae	<i>Cordia subcordata</i>	flower	ANU
Casuaraniaceae	<i>Casuarinia</i> sp. (beefwood, ironwood)	bark	ANU
Casuaraniaceae	<i>Casuarinia</i> sp. (beefwood, ironwood)	wood	ANU
Fabaceae	<i>Adenanthera pavonina</i> (red sandalwood)	legume	O'ahu
Fabaceae	<i>Adenanthera pavonina</i> (red sandalwood)	bark	O'ahu
Fabaceae	<i>Erythrina varietgata</i> (coral tree)	bark and wood	ANU

Table 5.3. continued.

Fabaceae	<i>Inocarpus fagifer</i> (Tahitian chestnut)	leaf and stem	O'ahu
Fabaceae	<i>Inocarpus fagifer</i> (Tahitian chestnut)	nut exterior	O'ahu
Fabaceae	<i>Vigna marina</i> (seaside bean)	leaf and stem	ANU
Gentianaceae	<i>Fagraea berteriana</i>	leaf	ANU
Gentianaceae	<i>Fagraea berteriana</i>	bark	ANU
Goodeniaceae	<i>Scaevola taccada</i>	leaf	ANU
Goodeniaceae	<i>Scaevola taccada</i>	bark	ANU
Lamiaceae	<i>Clerodendrum inerme</i> (glorytower)	leaf and stem	Pohnpei
Lamiaceae	<i>Clerodendrum inerme</i> (glorytower)	fruit	ANU
Lamiaceae	<i>Clerodendrum inerme</i> (glorytower)	stem	ANU
Lamiaceae	<i>Clerodendrum inerme</i> (glorytower)	leaf	ANU
Lamiaceae	<i>Vitex trifolia</i>	stem	ANU
Malvaceae	<i>Hertiera littoralis</i> (chestnut of salt water)	leaf and stem	Pohnpei
Malvaceae	<i>Hibiscus tiliaceus</i> (hibiscus)	seed	ANU
Malvaceae	<i>Hibiscus tiliaceus</i> (hibiscus)	flower	ANU
Malvaceae	<i>Hibiscus tiliaceus</i> (hibiscus)	nut exterior	ANU
Malvaceae	<i>Kleinhovia hospita</i>	stem	ANU
Malvaceae	<i>Thespesia populnea</i>	leaf	ANU
Malvaceae	<i>Thespesia populnea</i>	bark and wood	ANU
Malvaceae	<i>Triumfetta procumbens</i> (bur bush)	stem	ANU

Table 5.3. continued.

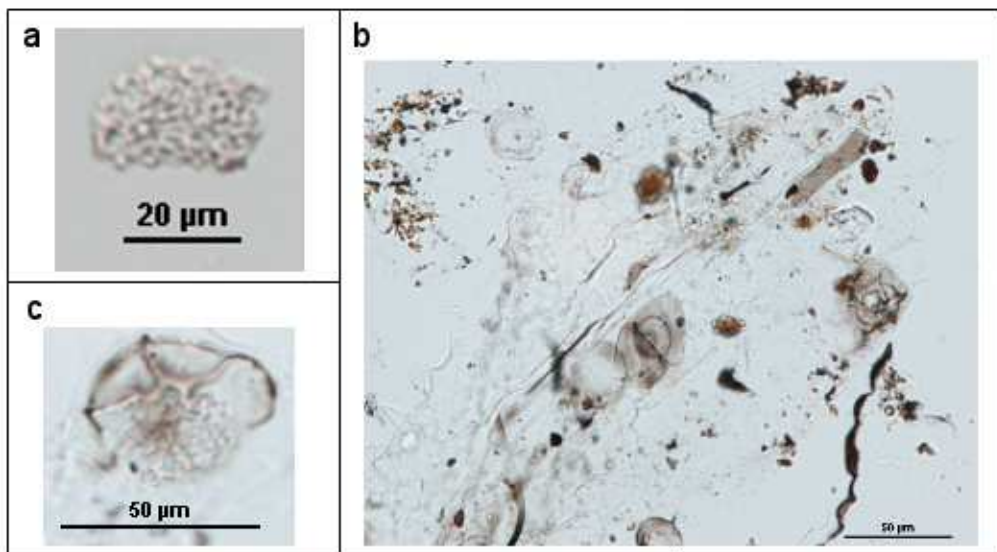
Malvaceae	<i>Triumfetta procumbens</i> (bur bush)	fruit	ANU
Malvaceae	<i>Triumfetta procumbens</i> (bur bush)	leaf	ANU
Melastomataceae	<i>Melastoma</i> sp.	Leaf	ANU
Melastomataceae	<i>Melastoma</i> sp.	Stem	ANU
Moraceae	<i>Artocarpus altilis</i> (breadfruit)	seed	ANU
Moraceae	<i>Artocarpus camansi</i> (breadnut)	nut	O'ahu
Mutingiaceae	<i>Mutingia</i> sp.	Fruit	ANU
Mutingiaceae	<i>Mutingia</i> sp.	Stem	ANU
Mutingiaceae	<i>Mutingia</i> sp.	Leaf	ANU
Nytaginaceae	<i>Pisonia grandis</i>	stem	ANU
Nytaginaceae	<i>Pisonia grandis</i>	flower	ANU
Piperaceae	<i>Piper methysticum</i> (kava)	flower	ANU
Rhamnaceae	<i>Colubrina asiatica</i>	fruit	ANU
Rhamnaceae	<i>Colubrina asiatica</i>	leaf	ANU
Rubiaceae	<i>Geophila repens</i>	stem	ANU
Rubiaceae	<i>Geophila repens</i>	leaf	ANU
Rubiaceae	<i>Ixora casei</i> (spear palm)	leaf	Pohnpei
Rubiaceae	<i>Morinda citrifolia</i> (Indian mulberry)	seed	O'ahu
Rubiaceae	<i>Morinda citrifolia</i> (Indian mulberry)	leaf	ANU
Rubiaceae	<i>Morinda citrifolia</i> (Indian mulberry)	bark	ANU

Table 5.3. continued.

Rubiaceae	<i>Morinda citrifolia</i> (Indian mulberry)	flower	ANU
Urticaceae	<i>Procris</i> sp.	fruit	ANU
Urticaceae	<i>Procris</i> sp.	leaf	ANU
<sup>a</sup> Inconsistent with Piperno 2006.			

Results are broadly consistent with Piperno's (2006) classifications of phytolith production in different plant families. Pacific Islands families that were observed to produce phytoliths with some taxonomic value include Marattiaceae, Thelypteridaceae (Ferns/Fern Allies); Arecaceae, Cyperaceae, Musaceae, Poaceae, Zingiberaceae (Monocotyledons); Boraginaceae, Burseraceae, Combretaceae, Euphorbiaceae, Lamiaceae, Moraceae, Piperaceae, and Urticaceae (Dicotyledons). However, not all members of these families produced taxonomically useful phytoliths. Hair cells and hair bases were especially common types among dicotyledons. Moraceae (specifically *Artocarpus altilis*) and Urticaceae (specifically *Pipturus* sp.) both produce acicular echinate hair cells that did not appear in any other observed species. Morphometric analysis may be helpful to distinguish between these two taxa, as *Artocarpus altilis* (breadfruit) is a plant with significant economic importance in the Pacific Islands. Importantly, all Piperaceae species except for *Piper betle* produced taxonomically useful phytoliths, although concentration from extracted residues appeared low. This suggests that phytolith analysis will be useful in the study of kava/sakau (*Piper methysticum*). Zingiberaceae, interestingly, has been reported to have wide ranging phytolith production

(Piperno 2006). In these samples, while *Cucurma longa* (tumeric) produced phytoliths, plants of the *Zingiber* genus did not, suggesting that the Zingiberaceae family may have levels of variable phytolith production. Example photos of a broad range of reference phytoliths can be seen in Figures 5.2-5.6.



*Figure 5.2. Select Fern/Fern Ally Phytoliths (modern reference). a. Angiopterus evecta (Marattiaceae), frond, scrobiculate, O'ahu. b. Cyclosorus heterocarpus (Thelypteridaceae), frond, various, Pohnpei. c. Cyclosorus heterocarpus (Thelypteridaceae), frond, orbicular, Pohnpei.*

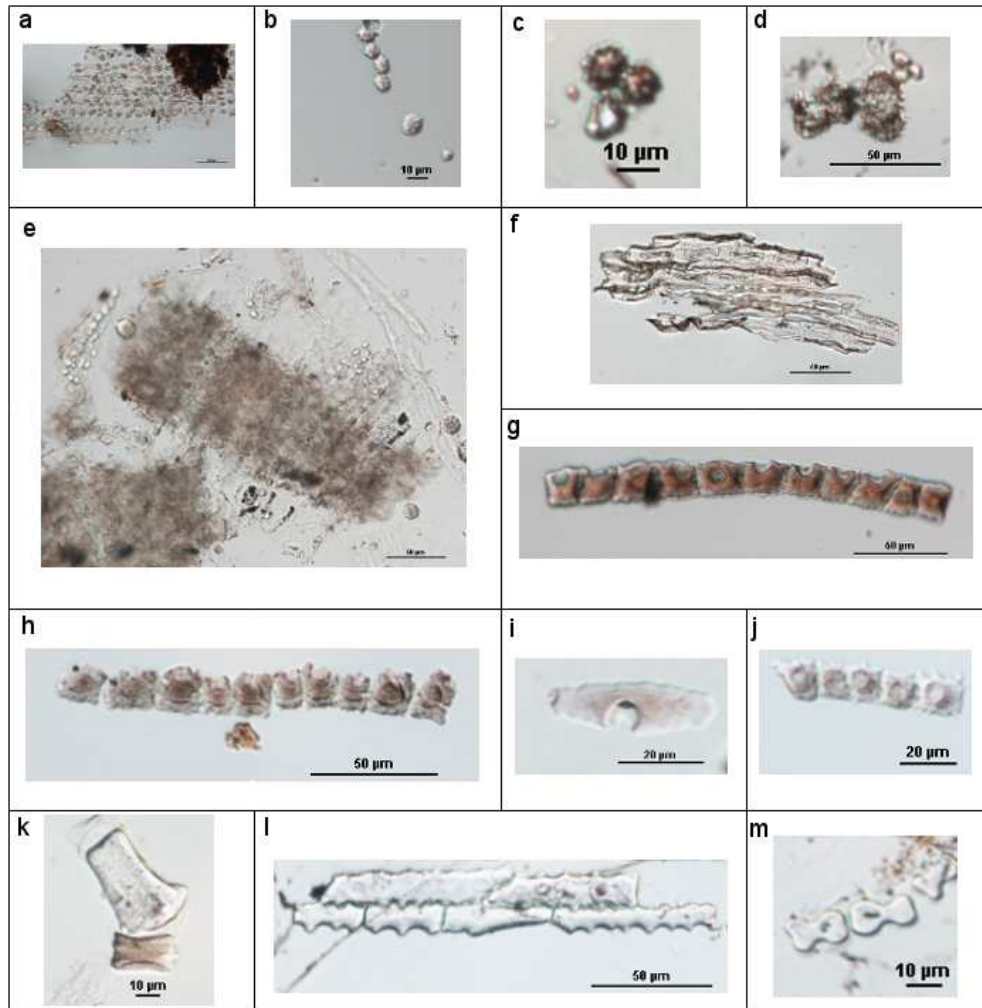


Figure 5.3. Select Monocotyledon Phytoliths (modern reference) 1. a. *Areca guppyana/vestiana* (Arecaceae) leaf, articulated cells, including globular echinate, ANU; b. *Clingostigma ponapense* (Arecaceae) leaf, globular echinate, ANU; c. *Cocos nucifera* (Arecaceae), bark, globular echinate, ANU; d. *Ponapea ledermannia* (Arecaceae), seed, globular echinate, ANU; e. *Metroxylon amicarum* (Arecaceae), leaf, various phytoliths, O'ahu; f. *Eleocharis dulcis* (Cyperaceae), leaf/stem, various epidermal phytoliths, ANU; g. *Musa sp.* (Musaceae), stem, rectangular volcaniform, Pohnpei; h. *Musa sp.* (Musaceae), leaf, rectangular volcaniform, Pohnpei; i. *Musa sp.* (Musaceae), stem, volcaniform, Pohnpei; j. *Musa troglodytarum* (Musaceae), leaf, volcaniform, Pohnpei; k. *Bambusa vulgaris* (Poaceae), leaf, bulliform (top) and saddle (bottom), O'ahu; l. *Ischaemum polystachyum* (Poaceae), leaf and stem, elongate echinate, Pohnpei; m. *Ischaemum polystachyum* (Poaceae), leaf and stem, bilobate, Pohnpei.

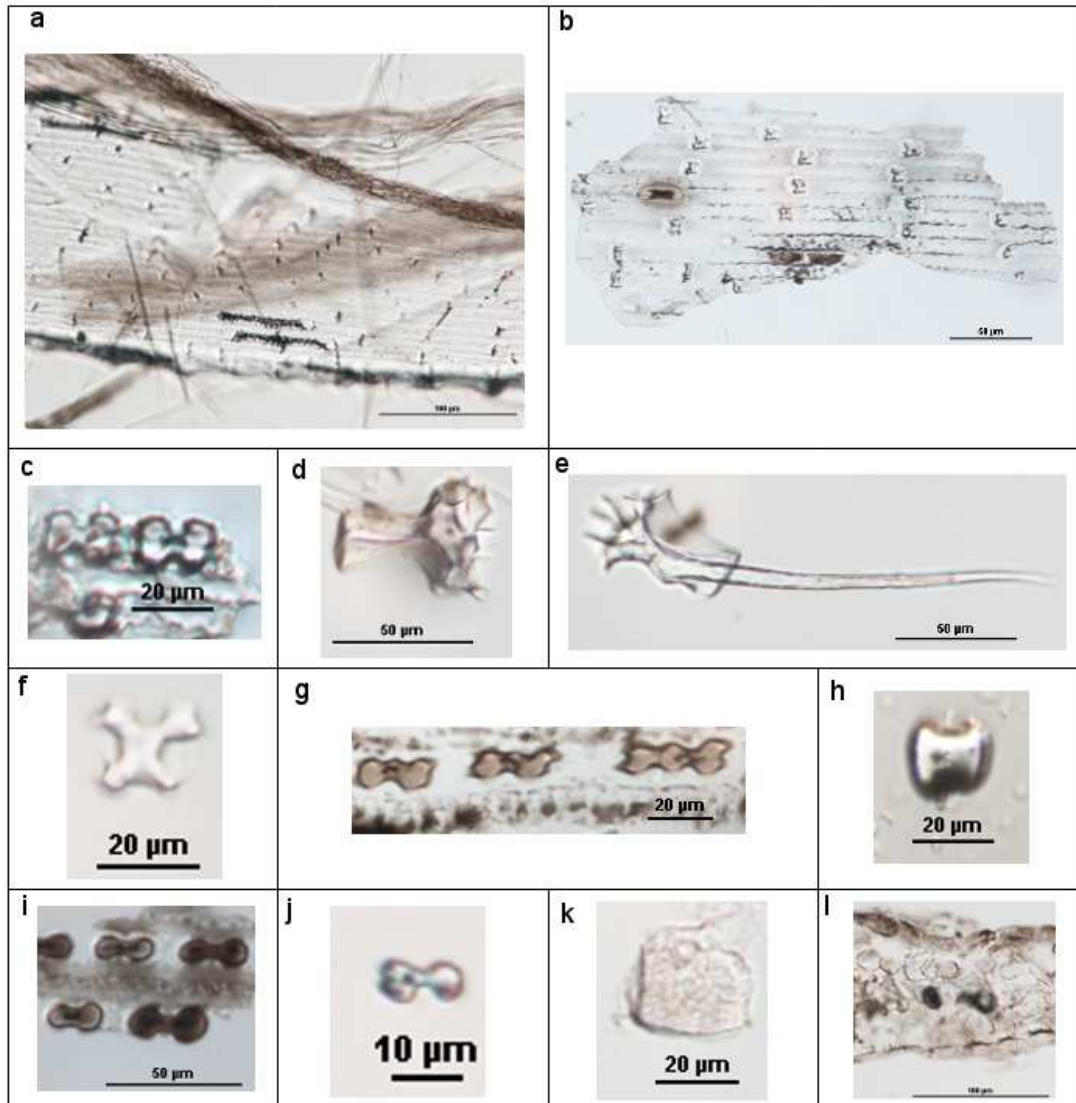


Figure 5.4. Select Monocotyledon Phytoliths (modern reference). 2. a. *Bambusa vulgaris* (Poaceae), stem, varioum, O'ahu; b. *Ischaemum polystachyum* (Poaceae), leaf and stem, various, Pohnpei; c. *Miscanthus* sp. (Poaceae), leaf and stem, bilobate, ANU; d. *Oplismenus hirtellis* (Poaceae), leaf and stem, bulliform, O'ahu; e. *Oplismenus hirtellis* (Poaceae), leaf and stem, bulliform and acicular psilate hair cell, O'ahu; f. *Oplismenus hirtellis* (Poaceae), leaf and stem, cross-body, O'ahu; g. *Oplismenus hirtellis* (Poaceae), leaf and stem, polylobate and bilobate, O'ahu; h. *Phragmites karka* (Poaceae), leaf, saddle, ANU; i. *Saccharum* sp. (Poaceae), leaf, bilobate, ANU; j. *Thuarea involuta* (Poaceae), leaf, bilobate, ANU; k. *Cucurma longa* (Zingiberaceae), leaf and stem, rectangular scrobiculate, O'ahu; l. *Cucurma longa* (Zingiberaceae), leaf and stem, various, O'ahu.

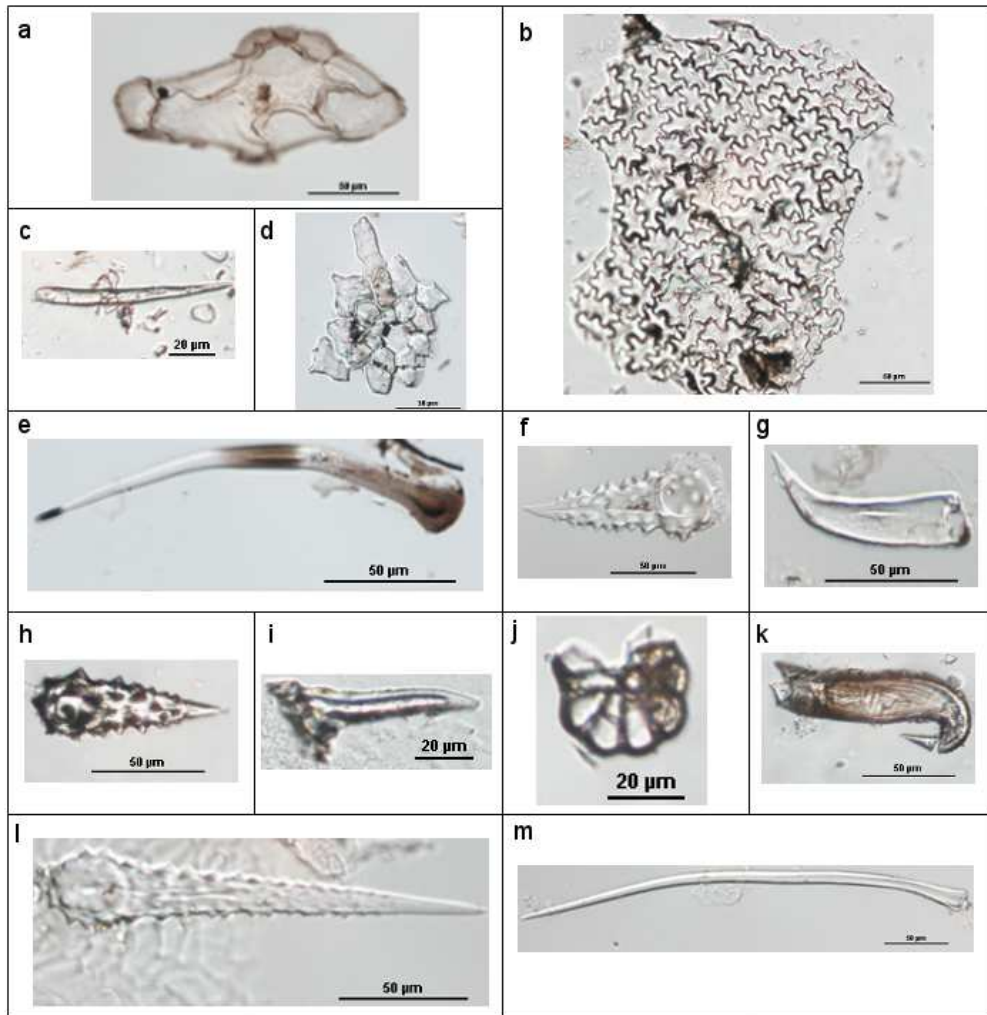


Figure 5.5. Select Dicotyledon Phytoliths (modern reference) I. a. *Cordia subcordata* (Boraginaceae), leaf and stem, favose, O'ahu; b. *Terminalia catappa* (Combretaceae), leaf, sinuate psilate epidermal, ANU; c. *Macaranga aleuritoides* (Euphorbiaceae), leaf, acicular psilate hair cell, ANU; d. *Macaranga carolinensis* (Euphorbiaceae), leaf, hair base, Pohnpei; e. *Macaranga carolinensis* (Euphorbiaceae), leaf, acicular psilate hair cell, Pohnpei; f. *Artocarpus altilis* (Moraceae), fruit, acicular echinate hair cell, ANU; g. *Artocarpus altilis* (Moraceae), fruit, unciform hair cell, ANU; h. *Artocarpus altilis* (Moraceae), leaf, acicular echinate hair cell, ANU; i. *Artocarpus altilis* (Moraceae), leaf, acicular psilate hair cell, ANU; j. *Artocarpus altilis* (Moraceae), leaf, hair base, ANU; k. *Artocarpus altilis* (Moraceae), leaf, unciform hair cell, ANU; l. *Artocarpus camansi* (Moraceae), leaf, acicular echinate hair cell, O'ahu; m. *Artocarpus camansi* (Moraceae), leaf, acicular psilate hair cell, O'ahu.

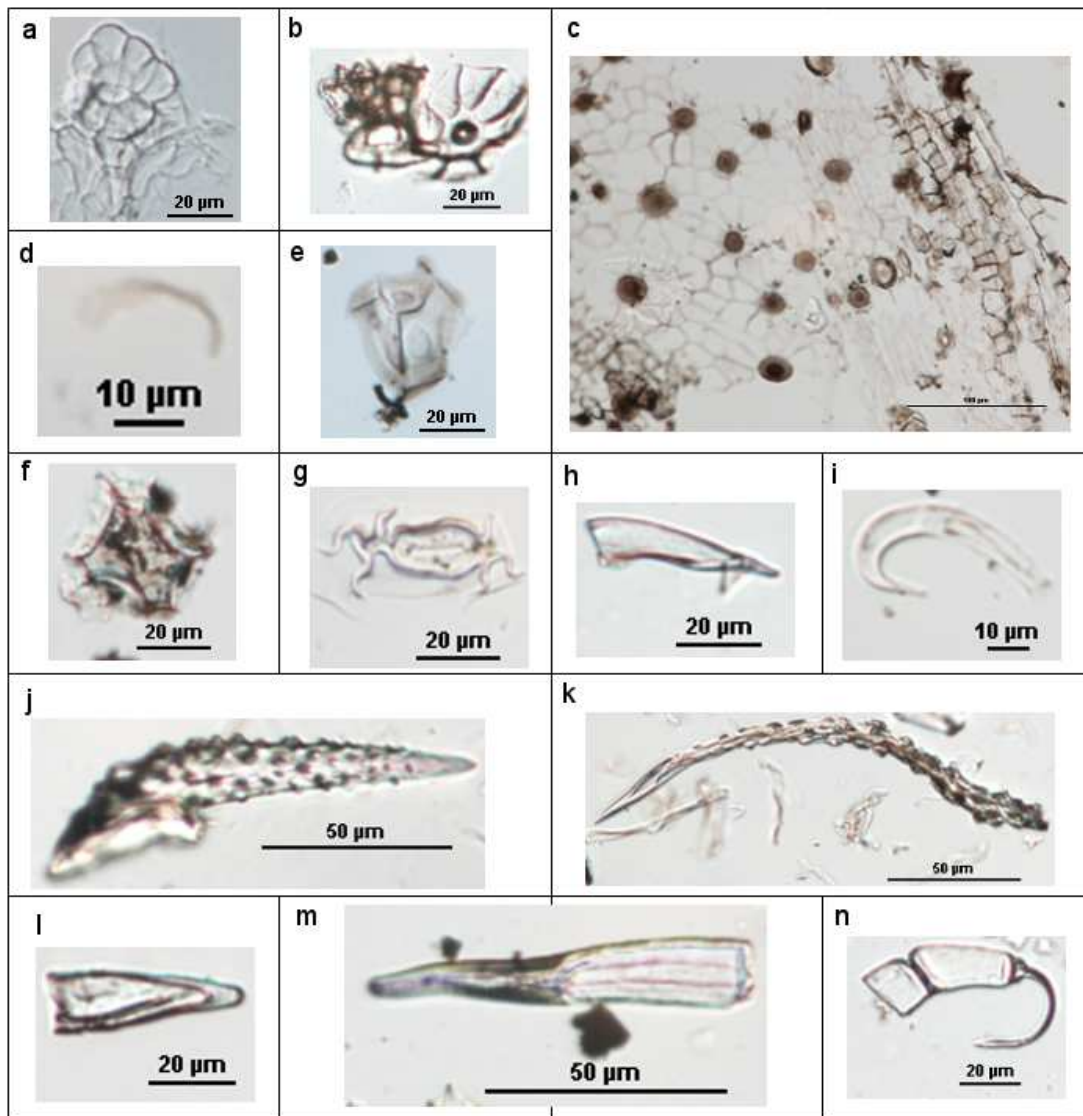


Figure 5.6. Select Dicotyledon Phytoliths (modern reference) 2. a. *Artocarpus camansi* (Moraceae), leaf, hair base, O'ahu; b. *Ficus prolixa* (Moraceae), leaf, hair base, ANU; c. *Ficus tinctoria* (Moraceae), leaf and stem, various epidermal, O'ahu; d. *Ficus tinctoria*, (Moraceae), leaf and stem, uniform hair cell, O'ahu; e. *Piper methysticum* (Piperaceae), leaf and stem, pyramidal favose, Pohnpei; f. *Piper ponapense* (Piperaceae), leaf and stem, octagonal favose, Pohnpei; g. *Paraderris elliptica* (Fabaceae), leaf and stem, ovate, Pohnpei; h. *Pipturus* sp. (Urticaceae), flower, lanceolate, ANU; i. *Pipturus* sp. (Urticaceae), leaf, uniform hair cell, ANU; j. *Pipturus* sp. (Urticaceae), leaf, acicular echinate hair cell, ANU; k. *Pipturus* sp. (Urticaceae), leaf, acicular echinate bent hair cell, ANU; l. *Pipturus* sp. (Urticaceae), stem, lanceolate, ANU; m. *Procris* sp. (Urticaceae), stem, acicular psilate hair cell, ANU; n. *Vitex trifolia* (Lamiaceae), leaf and flower, various, ANU.

## 5.2. Surface Sampling

Two modern surface samples were analyzed as a comparison of phytolith content to surrounding vegetation, to gain an understanding of how local vegetation impacts soil phytoliths. Each sample's location was recorded with a GPS point, and approximately 50 ml of surface sediment was collected. Then, all identifiable plants within a three-meter radius of the sample were noted. Sediment samples were processed and counted as described in Chapter III.

### 5.2.1. *Vegetation Sample 1, Temwen Island, Pohnpei.*

Vegetation Sample 1 was collected near the shoreline of Temwen Island where it meets the Nan Madol site. Most phytoliths counted were identifiable to family, and all phytoliths identifiable to particular taxa were monocotyledons. As is common at sites on Pohnpei (see Chapters VI and VII), the sample is dominated by *Arecaceae* phytoliths (Table 5.4), which comprise 83.6% of the phytoliths. *Poaceae* phytoliths comprised most of the rest of the sample, while *Musaceae* and *Cyperaceae* have counts of 3 and 1 respectively. This is consistent with the overrepresentation of *Arecaceae* and *Poaceae* in archaeological samples, although *Muaceae* and *Cyperaceae* are also prolific phytolith producers.

Table 5.4. Vegetation Sample 1, sediment phytolith contents.

Family	Phytolith Name	Number Present
Arecaceae	Globular Echinata	250
Cyperaceae	Hexagonal Scrobiculate	1
Musaceae	Volcaniform	3
Poaceae	Bilobate	30
Poaceae	Polylobate	2
Poaceae	Elongate Echinata	2
Poaceae	Elongate Echinata, one-side	2
Poaceae	Saddle	5
Unknown	Ovate psilate	4
<b>Total</b>		299
Sponge Spicules		12

The plant species identifiable within a 3 m radius (Table 5.5) included only ferns and monocotyledons, and only three plants that are known to produce phytoliths, *Cyclosorus* sp. (Thelypteridaceae), *Cocos nucifera* (Coconut, Arecaceae), and *Centosteca lappacea* (Poaceae). It should be noted that there was no *Centosteca* grass collected for phytolith reference, but it is well known that all grasses produce phytoliths in abundance. This suggests some overlap in taxa between the sediment sample and the surrounding vegetation, discussed more thoroughly in the final section of this chapter. There were no Musaceae or Cyperaceae plants within the 3 m radius, but given that both families are prolific phytolith producers and are common in gardening areas on Pohnpei in general, this may result from previous growth or movement of these species (especially

Musaceae, as banana leaves have wide-ranging social and economic uses in modern Pohnpei).

Table 5.5. Vegetation Sample 1, surrounding vegetation (within 3 m).

<b>Family</b>	<b>Scientific Name</b>	<b>Common Name, English (Balick 2009)</b>	<b>Common Name, Pohnpeian (Balick 2009)</b>	<b>Phytolith Production</b>
<b>Ferns</b>				
Aspleniaceae	<i>Asplenium polyodon</i>	-	<i>rehdil</i>	No
Davalliaceae	<i>Davallia</i> sp.	-	<i>ulungen kieil</i>	Unknown
Thelypteridaceae	<i>Cyclosorus</i> sp.	-	<i>mahrek</i>	Yes
<b>Monocotyledons</b>				
Arecaeae	<i>Cocos nucifera</i>	Coconut	<i>nih</i>	Yes
Costaceae	<i>Costus speciosus</i>	-	<i>dihng</i>	Unknown
Poaceae	<i>Centosteca lappacea</i>	-	<i>reh</i>	Yes
Zingiberaceae	<i>Zingiber zerumbet</i>		<i>oanginpele</i>	No

### 5.2.2. Vegetation Sample 2, Temwen Island, Pohnpei.

Results for Vegetation Sample 2 (Table 5.6) include only Arecaeae and Poaceae phytoliths, with Arecaeae accounting for a full 98% of the phytoliths counted.

Table 5.6. Vegetation Sample 2, sediment phytolith contents.

Family	Phytolith Name	Number Present
Arecaceae	Globular Echinata	294
Poaceae	Bilobate	4
Poaceae	Cross Body	1
Poaceae	Saddle	1
<b>Total</b>		300
Sponge Spicules		2

The surrounding vegetation for Sample 2 (Table 5.7) was rich in comparison to that from Sample 1. Both families recorded in the sediment sample, Arecaceae and Poaceae, are represented in the surrounding vegetation. Musaceae and none of the several phytolith producing Dicotyledon families were represented in the 300 counted phytoliths. This has important implications for phytolith counting from archaeological samples, as discussed below.

Table 5.7. Vegetation Sample 2, surrounding vegetation (within 3m):

Family	Scientific Name	Common Name, English (Balick 2009)	Common Name, Pohnpeian (Balick 2009)	Phytolith Production
<b>Ferns</b>				
Aspleniaceae	<i>Asplenium polyodon</i>	-	<i>rehdil</i>	No
Aspleniaceae	<i>Asplenium nidus</i>	bird's-nest fern	<i>tehlik</i>	No

Table 5.7. continued.

Thelypteridaceae	<i>Macrothepeteris torresiana</i>	-	<i>peipei aramas</i>	Unknown (but production in other plant of same family)
<b>Monocotyledons</b>				
Araceae	<i>Xanthosoma sagittifolium</i>	dryland taro	<i>sawahn awai</i>	No
Arecaeae	<i>Cocos nucifera</i>	Coconut	<i>nih</i>	Yes
Musaceae	<i>Musa</i> sp.	Banana	<i>uht</i>	Yes
Poaceae	<i>Centosteca lappacea</i>	-	<i>reh</i>	Yes
Zingiberaceae	<i>Zingiber zerumbet</i>	wild ginger	<i>oanginpele</i>	No
<b>Dicotyledons</b>				
Amaranthaceae	<i>Achyranthes bidentata</i>	-	<i>osenlikendinkep</i>	Unknown
Fabaceae	<i>Paraderris elliptica</i>	derris root	<i>peinuhpw</i>	Yes
Moraceae	<i>Artocarpus altilis</i>	breadfruit		Yes
Moraceae	<i>Ficus tictoria</i>	strangler fig		Yes
Piperaceae	<i>Piper methysticum</i>	kava	<i>sakau</i>	Yes
Piperaceae	<i>Piper ponapense</i>	-	<i>konok</i>	Yes

### 5.3. Implications for Archaeological Research

These reference data have important implications for archaeological use of phytolith data in Pohnpeian and broader Pacific contexts. Phytoliths can contribute a

great deal of useful data for archaeological research in the Pacific region. Given the number of Pacific taxa that produce abundant numbers of taxonomically useful phytoliths, phytolith analysis has the potential to understand landscape use over time, which is demonstrated in subsequent chapters. Importantly, the vegetation history record phytoliths produce is much more localized than that of pollen. While some phytoliths can become airborne and disperse (e.g., Latorre et al. 2012; Romero et al. 1999, 2003), they are not specifically equipped to do so, unlike windborne pollens. Thus, phytoliths are a useful tool for understanding the nuances of landscape change on a micro-scale. They are also more useful than starch for this purpose, as starches are much more fragile and likely to disintegrate, especially in the acidic soils of Pohnpei. Soil pH on Pohnpei is below 6.0 in most inhabited areas (Laird 1982), which is not a problem for phytolith production and preservation, but can cause issues for starches (Piperno 2006). Only at soil pH below 3 or above 9 does phytolith preservation become an issue (Piperno 1985a, 1985b, 1988, 2006).

Phytoliths can also be used to understand plant use at specific archaeological features or on tools. Based on this analysis, I predict that phytoliths may be especially useful for activities involving the use of leaves, such as breadfruit fermentation. As the edible parts of plants seem to produce fewer phytoliths, they are not as likely to produce residues on tools as starches. In Pohnpeian contexts, however, there are few tools recovered from archaeological sites to begin with, so this type of residue analysis is not as usable as in locations where tools are abundant.

However, phytolith analysis also has some significant limitations. Many of the plant samples observed did not contain diagnostic phytoliths. Neither yams (Dioscoreaceae) nor taros (Araceae) produce any observable phytoliths, diagnostic or not, and the Panadanaceae samples observed did not produce diagnostic phytoliths. Thus, at least three families containing important cultigens are either invisible or impossible to distinguish in the archaeological phytolith record. Furthermore, some important taxa produce phytoliths in a part of the plant that is not as useful for understanding food production. Notably, while the Piperaceae family (including *Piper methysticum*, or *sakau*) produces taxonomically useful phytoliths in the leaves, in Pohnpeian archaeological contexts, the most heavily used part of the plant is the roots, which do not contain diagnostic phytoliths. Thus, Piperaceae phytoliths are most likely to be useful in understanding landscape use. It should be noted that it is ethnographically known that the stems and leaves are transported into the *nahs* during feasting (Balick and Lee 2009), so they may provide some information on sakau processing and consumption, but not as much as would be produced if the heavily processed roots contained diagnostic phytoliths.

One other important observation that can be made from these data is that, as previously noted (e.g., Piperno 2006; Wallis 2003), phytolith production can vary not only between species of the same taxa, but also in the same taxa facing different environmental conditions. For example, as soil conditions become markedly more alkaline or acidic, silica uptake into plants decreases, although generally acidic conditions are more conducive to silica uptake (Piperno 1988; Piperno 2006). *Hibiscus tiliaceus*

bark and *Cocos nucifera* bark are prime examples of this, as there was differential production between samples from different locations (Tables 5.1 and 5.2). Furthermore, *Paraderris elliptica* produced phytoliths in both samples collected, but only the samples from O'ahu and not the samples from Pohnpei are taxonomically useful. This is likely to represent differential silica uptake in the two specimens.

Interestingly, as noted before, the *Zingiber zerumbet* (wild ginger) and other *Zingiber* sp. samples examined did not produce any phytoliths. It is unclear whether this is a function of these particular species or of the particular environments from which they were drawn. However, Piperno (2006) notes Zingiberaceae as a family that produces large numbers of phytoliths that can be used diagnostically, and it may be that not all taxa within Zingiberaceae are prolific phytoliths producers. This is significant in Pohnpeian contexts, as *Zingiber zerumbet* is known to be consumed as food ethnographically (Balick 2009). Another Zingiberaceae species, *Cucurma longa*, does produce phytoliths in the leaf, stem, and fruit. *C. longa* is a close relative of *C. australasica*, which is used, along with *Musa sp.*, as a wrapping in fermentation processes (Balick 2009; Ragone 2002). Thus, *C. australasica* phytoliths have the potential to be significant in breadfruit fermentation contexts (Chapter VI).

It is also notable that no *Cordyline fruticosa* phytoliths were observed from any of the examples selected. *C. fruticosa* is an important plant that is primarily used as an ornamental, but also has a consumable root. In modern times, it is often used to mark land ownership boundaries on Pohnpei (Balick 2009). It would not be expected for this plant to produce significant diagnostic phytoliths, as it is broadly classified either in the

Liliaceae family (Lentfer and Green 2004) or into a closely related family such as Laxmanniaceae (Balick 2009). Lilies typically do not produce phytoliths (Piperno 2006). However, *Cordyline* sp. has been previously reported to produce diagnostic forms and has been recorded in archaeological context from New Britain (Lentfer and Green 2004). This discrepancy illustrates the variability in phytolith production in different environments, and potentially different production between different species of the same genus, and perhaps even different varieties within an individual species. Therefore, obtaining reference materials from the area around the archaeological or paleoecological site being studied is ideal whenever possible.

In terms of the vegetation samples, results of this small pilot study broadly reflect the overproduction of Arecaceae and Poaceae phytoliths in comparison to just about every other common plant family in the area. However, both were also present in the surrounding vegetation of both samples. Because of the large discrepancies in phytolith production between different species, phytoliths cannot be used to directly interpret vegetation distribution, as several important taxa may be excluded. Instead, phytoliths are more useful for understanding fluctuations in vegetation through time, plant processing at archaeological features, or presence/absence of certain plants.

In order to conduct a more representative survey on a larger scale, the overproduction of Poaceae and Arecaceae is something researchers need to take into account. There are two ways to approach this. First, more phytoliths could be counted than the typical 300. A second, a likely more time-efficient, method would be to do separate counts for Arecaceae/Poaceae and all other phytoliths. This would accomplish

the goal of determining the ratios of these taxa to the rest of the phytolith assemblage, while also including rarer phytoliths. None of the dicotyledon phytolith producers in the surrounding area were represented in the 300 count in sediment from Vegetation Sample 2 (Tables 5.6 and 5.7). Thus, this revised method would be optimal when the goal is to understand phytolith diversity. It would also be advantageous to find an area of land (if possible) where Arecaeae and Poaceae families are not represented in the immediate area to understand how this affects the phytolith assemblage.

In the next chapter, this study moves on to assessing the phytolith record in archaeological context, specifically in breadfruit fermentation pits. Because breadfruit fermentation pits create significant sediment disturbances and the plants associated with their use produce phytoliths, they provide an interesting case in which to study phytolith content of archaeological soils.

## CHAPTER VI

### BREADFRUIT FERMENTATION PITS

Food storage related features are common in archaeological contexts. The technology that they represent is key to interpreting lifeways. However, interpreting the use of these features can pose challenges. They may or may not be located within core settlement areas, and they do not always contain artifactual evidence. Thus, environmental data and ethnographic analogy can be important for interpretation.

In this chapter, I examine breadfruit pits in the Temwen context. Breadfruit, most commonly *Artocarpus altilis* (although the common name also refers to *A. altilis x marianensis* or *A. marianensis*), is one of the most important cultigens on Pohnpei. Originally domesticated in Island Southeast Asia, breadfruit is a member of the mulberry family, Moraceae. Breadfruit is an important staple crop, the most commonly used during the Pohnpeian season of *rahk*. It is most often eaten fresh and roasted, but is also fermented in the large soil pits discussed in this chapter. Breadfruit that is fermented is sometimes used for feasting, and the longer it has been in a fermentation pit, the more prestigious it becomes. Thus, the study of breadfruit fermentation practices can help to understand the development of Pohnpeian subsistence practices and social systems. Previously, Haun (1984) excavated two large breadfruit pit features in Wene, located in Kiti Municipality on the southern part of the main Pohnpeian island. This chapter describes four breadfruit pits excavations (PoC3-10; PoC3-12, Feature 2; PoC3-18, Feature 1; and PoC3-48, Feature 2) from Temwen Island and presents spatial data from the others located during survey. Additionally, I present phytolith data from two of the

excavated breadfruit pits (PoC3-10 and PoC3-18, Feature 1). These data come from both the interior of the pit and the immediate surrounding soils. Plan and stratigraphic evidence reveal some common patterns in breadfruit construction that are similar to Haun's (1984) dissertation data.

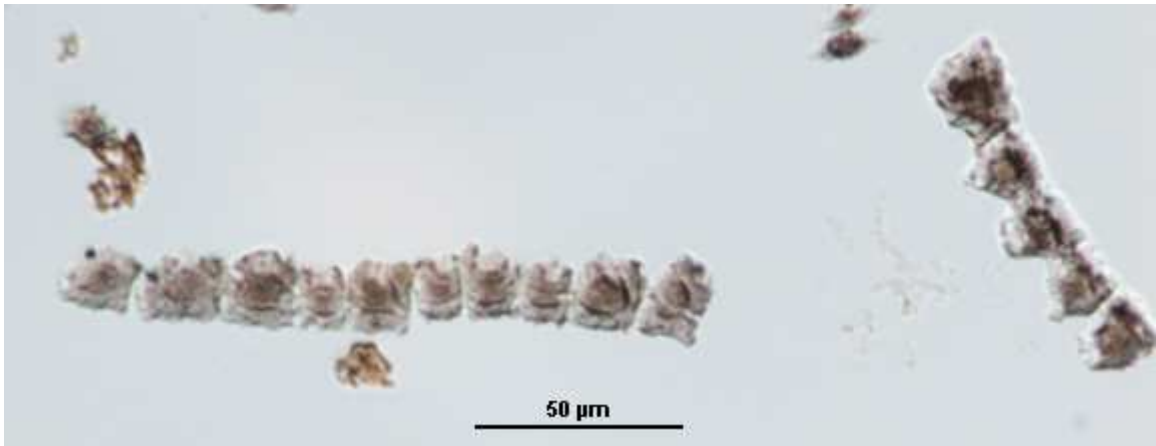
### **6.1. Techniques of Breadfruit Fermentation and Archaeological Interpretations**

Breadfruit has played an integral role in ethnographically studied Pohnpeian subsistence systems (Hunter-Anderson 1991; Ragone 2002; Ragone and Raynor 2009; Lawrence 1964; Petersen 2006). Breadfruit was introduced into eastern Micronesia by early colonizing humans by 1900 BP; this is informed by direct evidence of breadfruit pollen and charcoal from sites on Kosrae (Athens et al. 1996). When early agriculture shifted from swiddening to permanent agroforests, breadfruit played a major role (Ayres and Haun 1985, 1990; Athens et al. 1996; Haun 1984). Breadfruit grows during most of the year in the region, although as noted it is most abundant during the rainy season of *rahk* on Pohnpei (Hunter-Anderson 1991; Merlin et al. 1992).

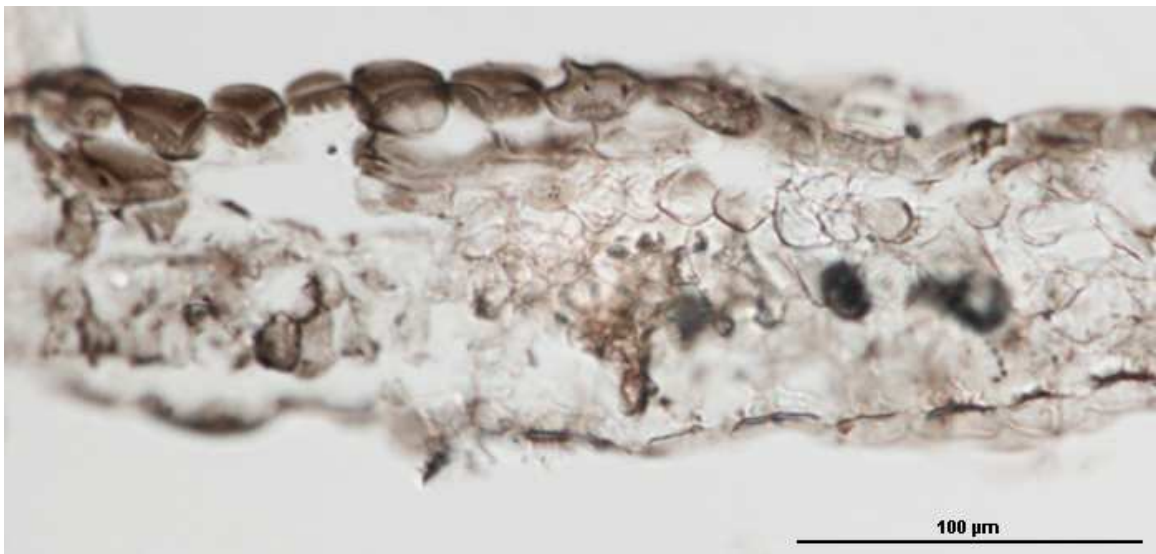
Fermented breadfruit, or *mahr* in Pohnpeian, is produced in large pits that range from approximately 1-20 m across and 0.5-2 m in depth, and can be circular or oval-shaped. Individual households produce smaller pits for private use, although large communal pits are also known to have been used. It is common to find a stone lining on larger pits (Hunter-Anderson 1991), which is consistent with archaeologically identified large pit features (Haun 1984). Bascom (1948, 1965) reports that some of these larger pits could contain up to 10,000 fruits and that fruit could be stored in them for up to 100

years. Pits are lined with banana and native tumeric (*Cucurma australiasica*) leaves. Hundreds of fruits are peeled, soaked, and the cores removed before being placed in the pit for fermentation for a period of months or years (Balick 2009; Lawrence 1964; Ragone 2002).

Given the ethnographic record, there are a few expectations for what one might expect in a breadfruit fermentation pit archaeologically. First, we expect to find large circular or oval pits, likely lined with heavy stones, in environments that allow of anaerobic fermentation. Smaller pits may be more indicative of yam cultivation (Haun 1984). Indicators of soil disturbance are likely, especially some sort of organic-rich layer indicative of storage. In the phytolith record, we may expect to find banana leaf (Figure 6.1) phytoliths and native tumeric (Figure 6.2; *Cucurma longa* pictured as *Cucurma australiasica* not available) phytoliths. Banana phytoliths are predicted to be the most likely as they compose the outer wrapping and thus would be likely to shed into the soil. While breadfruit does produce a large number of phytoliths, the most prolific are hair cells from leaves, and thus peeled breadfruits are not expected to produced a notable phytolith contribution. The fruit of breadfruit does produce some hair cell phytoliths (Figure 6.3; also see Chapter V), but peeled breadfruit would be less likely to leave a phytolith signature than fruit with a rind present. These types of phytoliths would be expected to be present in and around the layers where fermentation is anticipated to have taken place.



*Figure 6.1. Banana leaf phytoliths from reference material.*



*Figure 6.2. Cucurma longa (turmeric) phytoliths from reference material.*

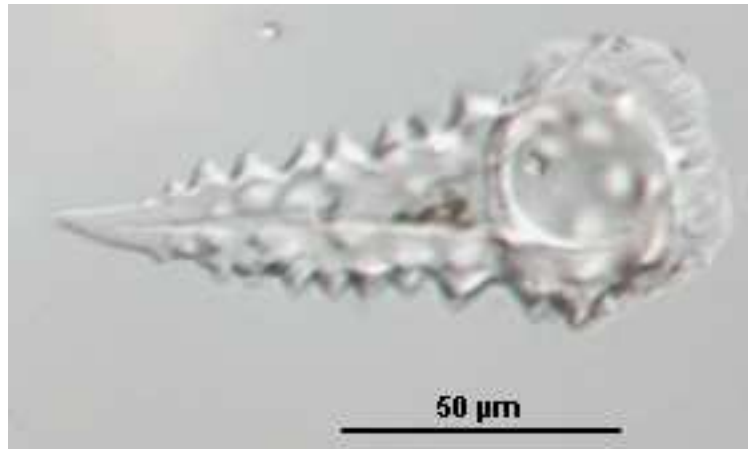


Figure 6.3. *Artocarpus alitis* (breadfruit) fruit phytolith from reference material.

## 6.2. Previous Research on Breadfruit Fermentation Pits

Breadfruit fermentation practices are known widely throughout Melanesia, Micronesia, and Polynesia (Atchley and Cox 1985; Bascom 1948; Cox 1980; Lawrence 1964; MacKenzie 1964; McKnight 1964; Pollock 1984; Ragone 2002; Ragone and Raynor 2009; Whistler 2000). Ethnohistorically speaking, breadfruit production is most significant to the diet on the Marquesas Islands in Eastern Polynesia, and Pollock (1984) suggests that fermentation techniques may have started here, although this is speculative and unlikely, given the origins of breadfruit in the Melanesian/Island Southeast Asian region and the widespread use of fermentation practices. Although methods of fermentation vary, the same principles of leaving breadfruit to ferment in a leaf-lined pit covered by rocks for long periods of time apply. Thus, these methods of study are

broadly applicable across the Pacific for studying breadfruit fermentation, and are also likely applicable in other archaeological settings around the world where fermentation practices occur.

Major archaeological work on breadfruit fermentation on Pohnpei was conducted by Ayres and Haun, who excavated and described breadfruit fermentation pits in Awak and Wene. Ayres and Haun identified breadfruit pit construction and possible fermentation practices as early as 1600 BP (Ayres 1990; Ayres and Haun 1985, 1990; Haun 1984). They link the increasing scale of these practices to the development of agricultural intensification and to the eventual development of chiefdoms on Pohnpei. Importantly, Haun's dissertation (1984) provides stratigraphic data for breadfruit pits, which helps in the development of models for recognizing breadfruit fermentation in archaeological contexts. These models also serve as a template for developing hypotheses of the distribution of botanical materials within these pits.

Diane Ragone's work on breadfruit ranges across the Pacific, but her major descriptions of fermentation come from Pohnpei (Ragone 2002; Ragone and Raynor 2009). Ragone describes this as a long-term practice in places such as the Eastern Caroline Islands, the Marshall Islands, Samoa, Fiji, and Vanuatu. However, it is a practice that is disappearing, and along with it, the associated cultural knowledge. Thus, recording breadfruit fermentation practices of the past helps to increase and preserve cultural knowledge in cases where revitalizing this tradition becomes desired or necessary.

### **6.3. Survey**

Pit features were located during my survey on Temwen Island, Pohnpei in 2008 and 2011. Pits were classified as potential breadfruit pits based on shape and size. Cobble and boulder lining was also used as a possible indicator of use as a breadfruit fermentation pit. The features were photographed and hand-mapped at a scale ranging from 1:10 to 1:50, depending on size, per Chapter III. As described in Chapter IV, trench excavations were designed to cut through both the center and the exterior of the pits to show stratigraphic changes as well as to allow the collection of sediment samples from both the interior and exterior of the pit. At a minimum, small (20-50 ml) sediment samples for microremain analysis were collected on the surface and at arbitrary 10 cm intervals. Where both the interior and exterior of the pit were exposed, samples were taken from both. Charcoal was collected for AMS dating wherever possible, although it was not present in all features. In the first excavation detailed, site PoC3-18, Feature 1, a large amount of charred plant material was present, and in this case, flotation scatter samples were taken at 10 cm intervals. However, minimal or no charcoal was recovered from other features and, given that the fermentation of breadfruit is not expected to produce charcoal, flotation was not deemed necessary at other pits.

### **6.4. Excavations and Phytolith Analysis**

#### *6.4.1. Site PoC3-18*

Site PoC3-18, Feature 1 (Figure 4.5) measures approximately 5.3 m × 7.9 m and is roughly “L” shaped. The depression is continuous and is approximately 0.5 m deep.

Cobbles, mostly underground, line the depression. There are a few cobbles on the exterior of the depression.

The excavation (Figure 6.4) was 3.5 m x 1 m running south to north through the east side of the pit. There was also a 0.5 m extension on the south end of the trench placed exclusively for the collection of flotation samples from the pit exterior. In terms of sediments, the stratigraphy of the pit contains just two layers: the humic layer (I) and the subsurface layer (II). They can be described as follows:

Layer I: Medium brown clay, loosely packed. 7.5YR 3/3

Layer II: Light brown reddish clay of medium to hard density, becoming harder and packed closer to the bottom of the layer. 7.5 YR 4/5

However, multiple alignments of angular basalt cobbles served to differentiate space in the pit. The 50-60 cm level served as the base for alignments of cobbles near the southeast, southwest, and northeast corners. The basalt cobbles in these alignments all rested on the same surface and were not distributed randomly throughout the deposit (Figures 6.5 and 6.6), so their placement was probably deliberate. It should also be noted that the ground surface in the low point of the pit was 48 cm, so the top of some of the cobbles at the north end were visible pre-excavation. However, they were resting on the same surface as the definitely covered cobbles at the south end of the deposit. In the northeast corner are two layers of cobbles, one with a surface in the 90-100 cm level, and one with a surface in the 100-110 cm level; they appear to have been stacked on top of

each other. The placement of the cobbles seems to follow logically from the hypothesized use as a breadfruit fermentation pit, as the organic material in the fermentation pit is typically covered with stones and sediment (Balick 2009). This is interpreted as evidence that the pit was used for breadfruit fermentation.

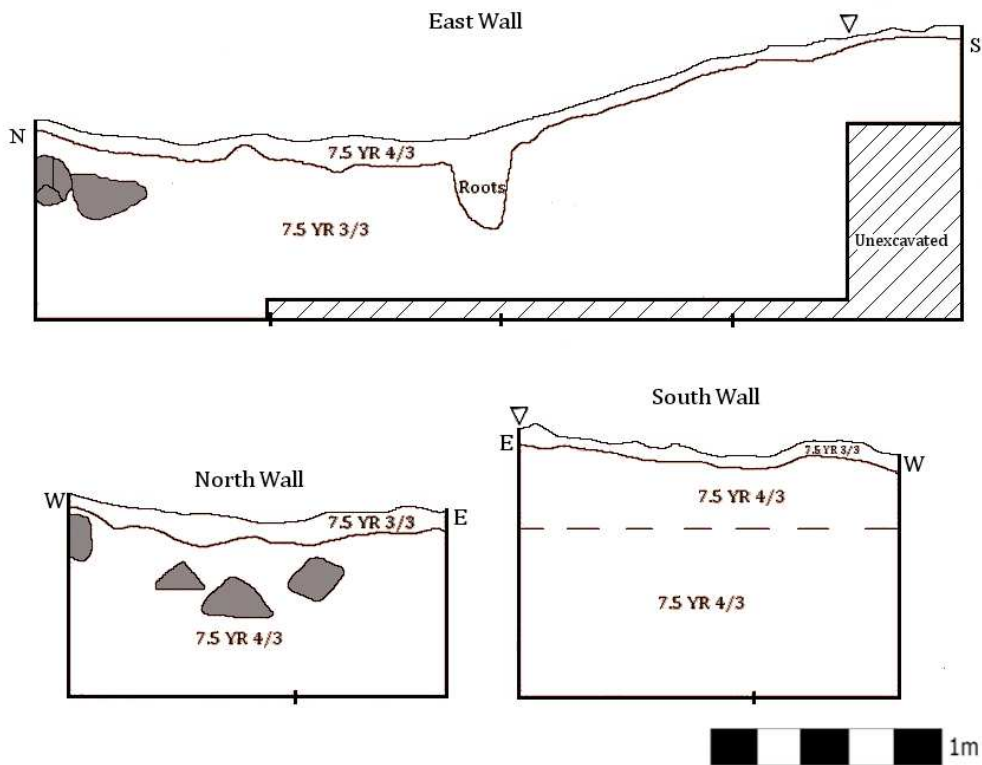


Figure 6.4. Site PoC3-18, Feature 1, Stratigraphic Profiles. Dashed line on south wall indicates extension of excavation trench an extra half meter. (Drafting: D. Stanzak, M. Levin.)

AMS dates from this excavation (Table 6.1) were taken from wood charcoal fragments from the southwest quadrant from the upper and lower areas of the stone

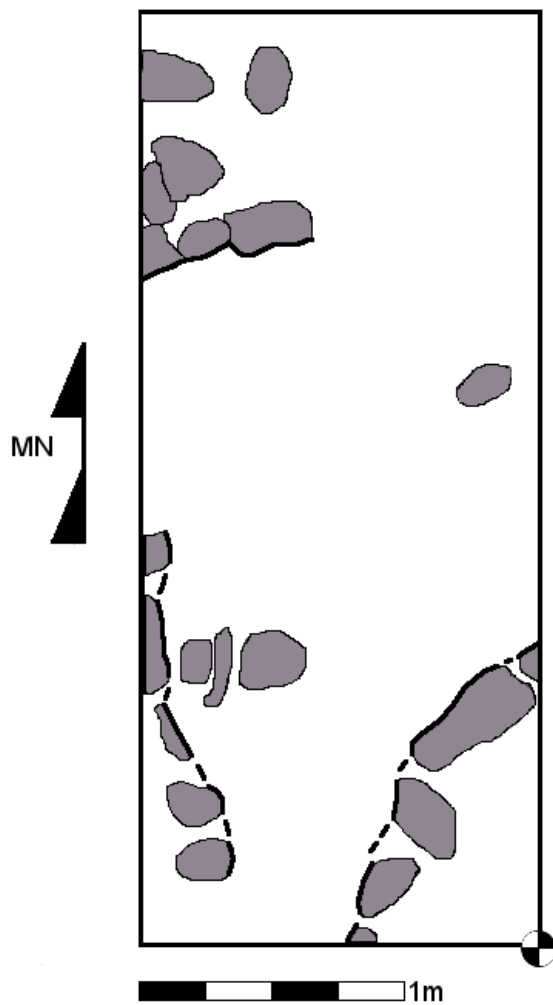
arrangements; the first was taken at 53 cm and the second was taken at 97 cm. Samples were processed by AMS Direct and recalibrated using the online OxCal 4.2 program using the IntCal13 calibration curve (Bronk Ramsey and Lee 2013). The top of the alignments, at 53 cm (D-AMS 001532) dated to  $85\pm 25$  BP, calibrated to 260-25 cal BP ( $2\sigma$ ). The bottom of the alignments, at 97 cm (D-AMS 001533) dated to  $40\pm 25$  BP, calibrated to 255-30 cal BP ( $2\sigma$ ). This suggests a late prehistoric or historic period use for the site.

*Table 6.1. AMS Dates, PoC3-18, Feature 1.*

<b>Sample #</b>	<b>Lab #</b>	<b>Depth</b>	<b>Material</b>	<b>Uncalibrated Date BP</b>	<b>Calibrated Date BP (<math>2\sigma</math>)</b>
1	D-AMS 001532	53 cm	wood charcoal (single piece)	$85\pm 25$	260-25
2	D-AMS 001533	97 cm	wood charcoal (single piece)	$40\pm 25$	255-30

Phytolith concentrations sufficient for counting to 200 were observed in most samples 80 cm and above; concentration drops precipitously below this point, where the soil begins to transition into decaying bedrock (Figures 6.7 and 6.8). Samples near the surface and stone alignments are dominated by globular echinate phytoliths, which in this context can be interpreted as palm family (Arecaceae). Grasses (Poaceae) are also strongly present in surface samples (as bilobate and some bulliform phytoliths), but drop off precipitously at lower levels. Given that a significant amount of charcoal is represented in the deposit, this may represent recent swiddening and landscape

succession. Other globular phytoliths, similar to those present in various woods, are also represented. Banana (*Musaceae*) phytoliths are present in low levels throughout the deposit, but do not appear in concentrations significant enough to confirm the past presence of banana leaves in soils. Nevertheless, breadfruit fermentation is supported by the architecture, the sediments, and, to some extent, the phytolith data.



*Figure 6.5. Site PoC3-18, Trench plan view at 55 cm, showing stone alignments in pit exterior area. (Drafting: M. Levin.)*

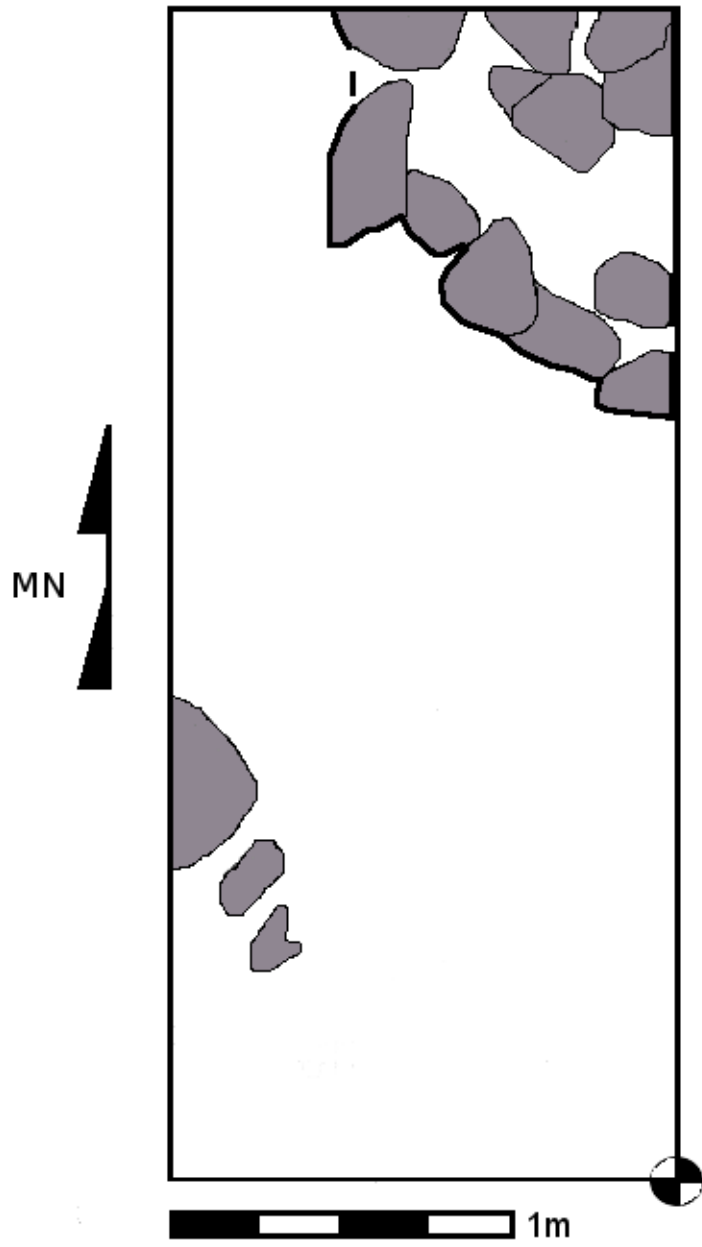


Figure 6.6. Site PoC3-18, Trench plan view at 95 cm, showing stone alignments in pit interior area. (Drafting: M. Levin.)

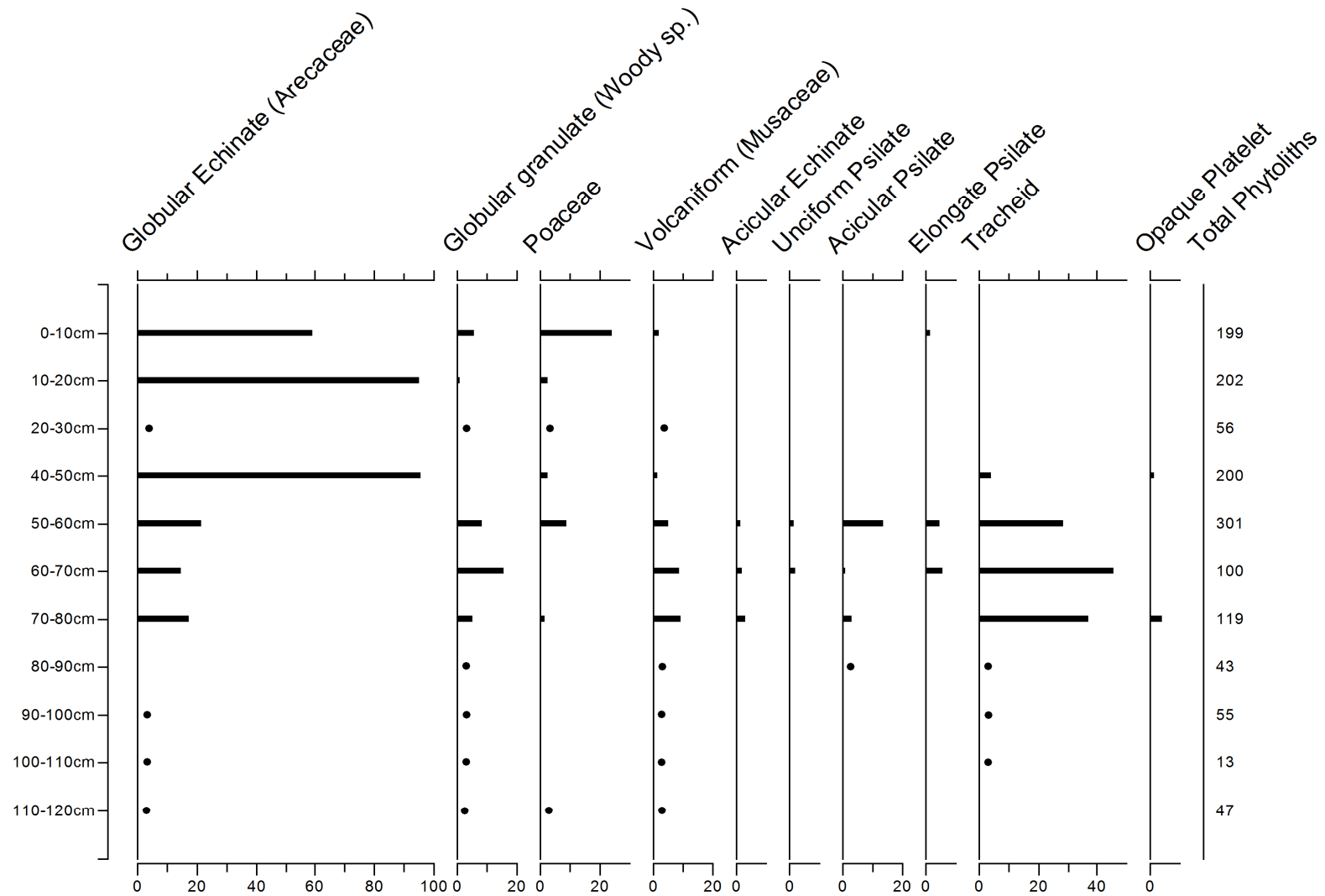


Figure 6.7. Site PoC3-18, Percentage phytolith diagram, trench area outside of pit. Where total phytolith count is under 100, presence/absence data only is included in diagram (presence indicated by dot).

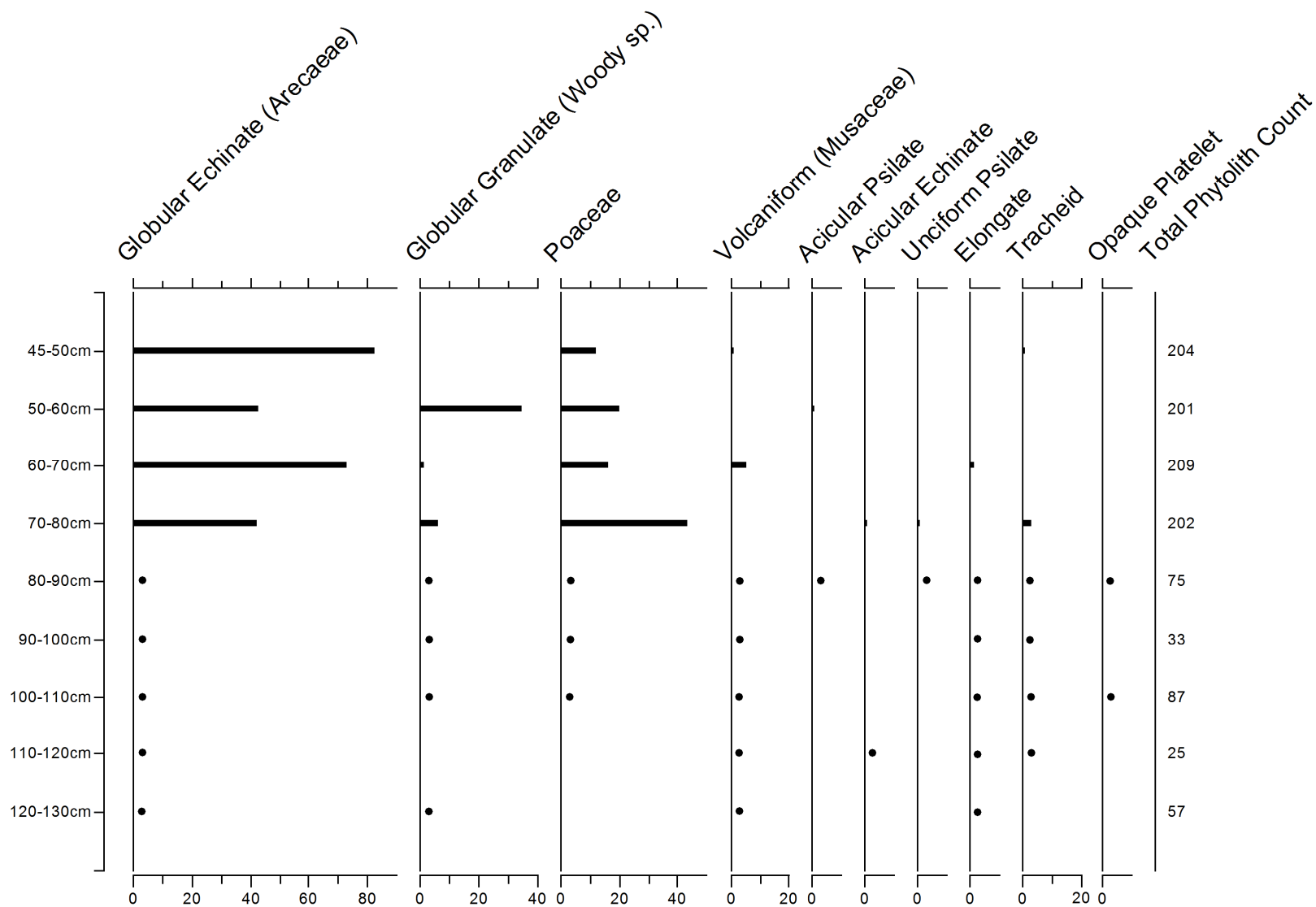


Figure 6.8. Site PoC3-18, Percentage phytolith diagram, trench area inside of pit. Where total phytolith count is under 100, presence/absence data only is included in diagram (presence indicated by dot).

#### 6.4.2. Site PoC3-10

Site PoC3-10 (Figures 6.9 and 6.10) is approximately 5.5 m × 6 m in its entirety. It consists of three depressions that range from 60 cm to 90 cm deep. They are spaced in roughly triangular formation and are surrounded by boulders, cobbles, and other stone debris. There are boulder and cobble alignments encircling each depression. A 75 cm × 2.5 m trench was placed in the largest of the depressions, digging through both soil outside and inside the stone perimeter. Soil samples of approximately 30-45 ml were collected every 10 cm, and were collected at both ends of the pit when both were exposed. Three 1 L bulk samples were also taken. One was taken at 50-60 cm outside the stone alignment, one at 90-100 cm outside the rock alignment, and one at 100-134 cm inside the stone alignment. Charcoal was also found at 10-20 cm and 20-30 cm in the area outside the stone alignment; it was associated with burnt soil and stone in lower layers. The subsoil in the pit interior is located at 134 cm. The trench displayed the following stratigraphy:

Layer Ia: Fine grained, loose humic soil, uniformly dark reddish-brown. 10 YR 4.5/6

Layer Ib: Dark brown fine-grain sediment. Significant vegetation disturbance. 10 YR 3/3.

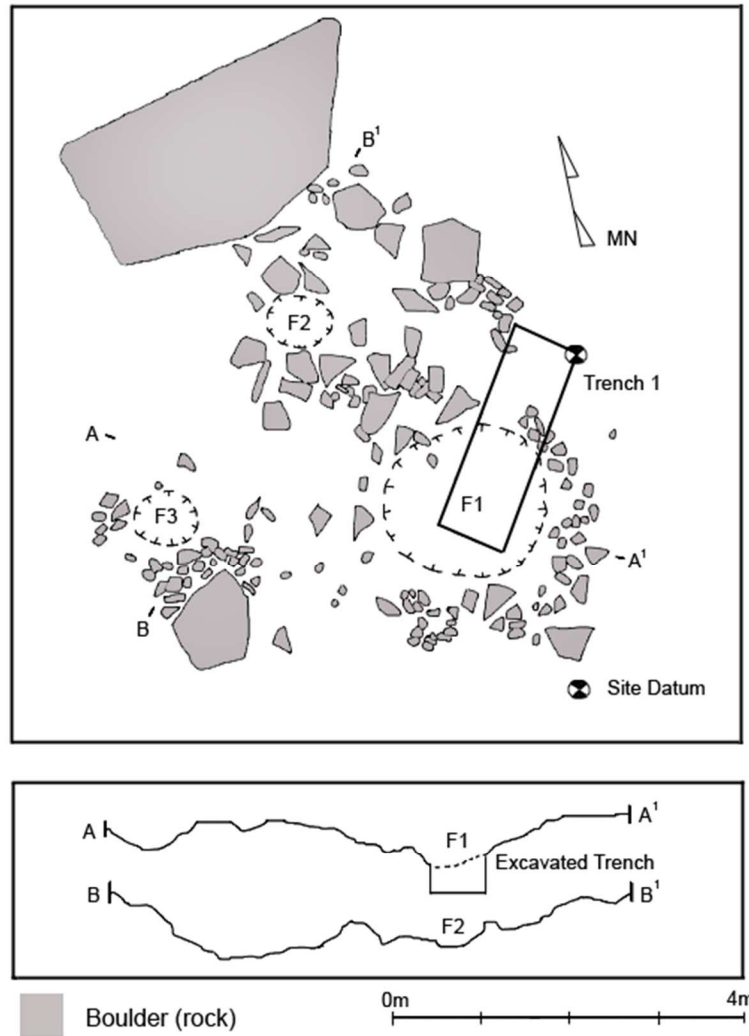
Layer IIa: Dark reddish-brown fine-grain sediment. There is a significant quantity of black, friable rock mixed into this layer with pebbles and cobbles. The layer becomes progressively rockier moving from top to bottom. 10 YR 4.25/6

Layer IIb: This layer is similar to IIa, except that it contains less black rock. 10 YR 4.25/6

Layer III: This sediment is dark brown and fine-grain. There are pebbles at the bottom of the layer. 10 YR 2.5/1.

Both inside and outside of the pit area, the phytolith assemblage is dominated by Poaceae (Figures 6.11 and 6.12). Decaying bedrock is much higher on the outside of the pit where there are minimal phytoliths below Layer I. There is, however, an anomaly at 60-70 cm, where phytolith counts spike and the assemblage is dominated by Arecaceae. As this is the level at which the top of the interior of the pit starts, this may represent construction activities happening at this level.

Phytolith concentrations are much denser on the interior of the pit. There were enough phytoliths per level for sufficient counts (300+) down to 120 cm on the interior. Poaceae phytoliths dominate although there are also a large number of elongate psilate forms in middle-lower levels (uncertain botanical origin) and Arecaceae forms in upper levels. Additionally, there is a presence of Musaceae phytoliths, which may indicate breadfruit fermentation. Again, though, the Musaceae phytoliths also occur outside the pit, as they do at Site PoC3-18, Feature 1, so this does not confirm use of banana leaves in breadfruit fermentation.



Site Po C3-10

Figure 6.9. PoC3-10, Feature 1, Plan View. (Drafting: M. Levin, W.S. Ayres.)

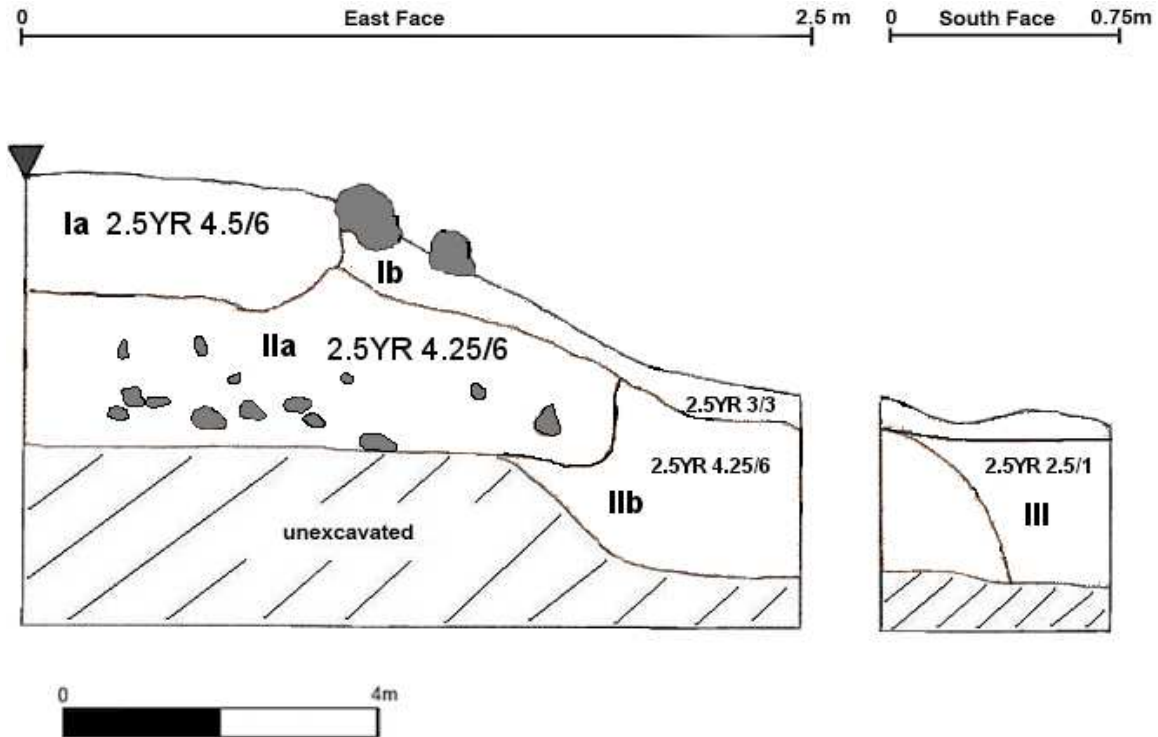


Figure 6.10. Site PoC3-10, Feature 1, Stratigraphic profiles. (Drafting: M. Levin, W.S. Ayres.)

Two samples were selected for AMS dating from this pit (Table 6.2). Both samples were preprocessed by Brendan Culleton at University of Oregon archaeological laboratories and sent to University of California, Irvine for dating. Calibrations were done using the online OxCal 4.2 program and the IntCal13 calibration curve. Sample 1, taken from the exterior burned layer in the 20-30 cm level (UCIAMS 76153), dates to  $385 \pm 20$  BP and is calibrated to 505-330 cal BP ( $2\sigma$ ). Thus, this suggests burning that pre-dates the pit construction in the area in the late prehistoric period, suggesting a maximum age for this fermentation pit. Sample 2, taken from a bulk sample in the bottom of the pit, consisted of a single (unidentified) seed. This sample (UCIAMS 76154) resulted in a date

of  $-2565 \pm 25$  BP, placing this sample firmly in the bomb era (post-1950). This charred seed was likely present as a consequence of local soil disturbance post-pit use. Thus, I interpret this pit as a late prehistoric feature.

Table 6.2. AMS Dates, PoC3-10, Feature 1.

Sample #	Lab #	Depth	Material	Uncalibrated Date BP	Calibrated Date BP (2 $\sigma$ )
1	UCIAMS 76153	20-30 cm	wood charcoal (single piece)	385 $\pm$ 20	505-330
2	UCIAMS 76154	Pit Fill (below 70 cm)	charred seed (single piece)	-2565 $\pm$ 25	AD 1975-1976 (modern)

#### 6.4.3. Site PoC3-12

PoC3-12, Feature 2 contains one large depression with additional slightly depressed areas in both the west and east ends of the depression (see Figures 6.13- 6.15). A 2.5 m  $\times$  1 m trench was excavated running roughly west to east through the western end of the pit. It was placed to expose stratigraphy and to collect samples from both the exterior and the interior of the depression. I chose to excavate the western side because there was taro (*Cyrtosperma merkusii*) growing in the east side of the pit, and thus the sediments in the eastern side had obvious vegetation disturbance.

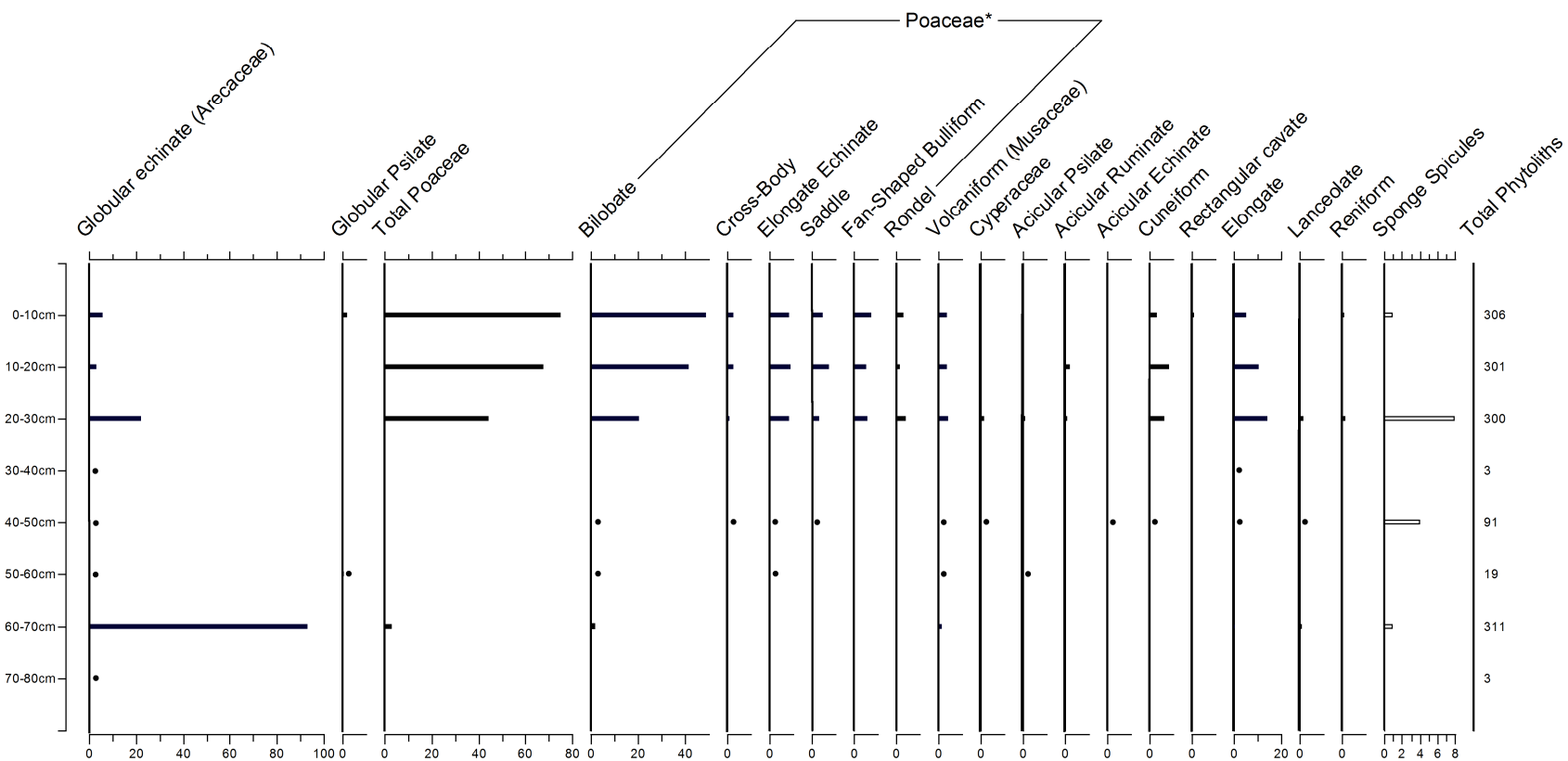


Figure 6.11. Site PoC3-10, Percentage phytolith diagram, trench area outside of pit. Where total phytolith is under 100, presence/absence data only included in diagram (presence indicated by dot). Sponge spicules were not included in the total and are listed by absolute count.

\*Listed as percentage of total phytoliths

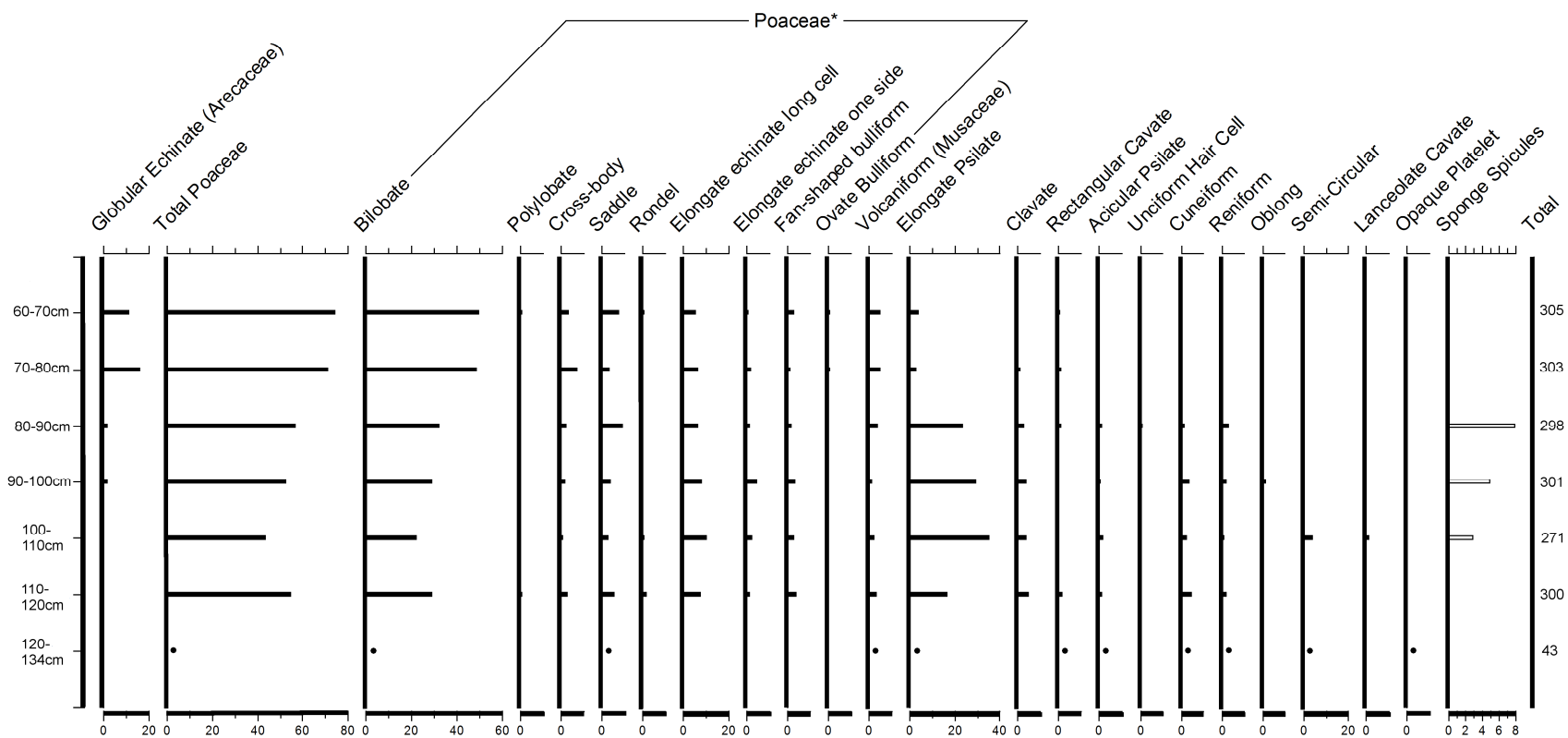


Figure 6.12. Site PoC3-10, Percentage phytolith diagram, trench area inside of pit. Where total phytolith is under 100, presence/absence data only included in diagram (presence indicated by dot). Sponge spicules were not included in the total and are listed by absolute count.

\*Listed as percentage of total phytoliths

Small sediment samples (20-50ml) were collected at 10 cm levels. When both sides of the trench were fully exposed, two samples (one from each end) were taken from these levels. Additionally, three 1 L bulk samples were taken representing different areas of the trench. There was no visible charcoal in the excavation unit. The inclusion of basalt columns in the feature, like those used at Nan Madol, suggests that this pit is likely of late prehistoric or historic origin.

The interior of the trench contained main large boulders, recorded in plan view (Figure 6.15). The sediments of this feature were also exceptionally hard. Three major sediment layers were identified, as follows:

Layer Ia (humic layer, exterior of pit): Medium brown crumbly clay, loosely packed.

10 YR 3/4.

Layer Ib (humic layer, interior of pit): Brown/black clay, containing many leaves and roots. 10 YR 2/1.

Layer II (sediment lens, exterior of pit): Light-to-medium brown clay. 10 YR 3/6.

Layer III (all sediment below Layers I and II): Reddish-brown clay with flecks of black rock, similar in color to Layer II, but extremely hard packed. 5 YR 4/6.

Samples were collected for phytolith analysis at this feature, but were not selected for analysis due to the somewhat disturbed nature of the feature.

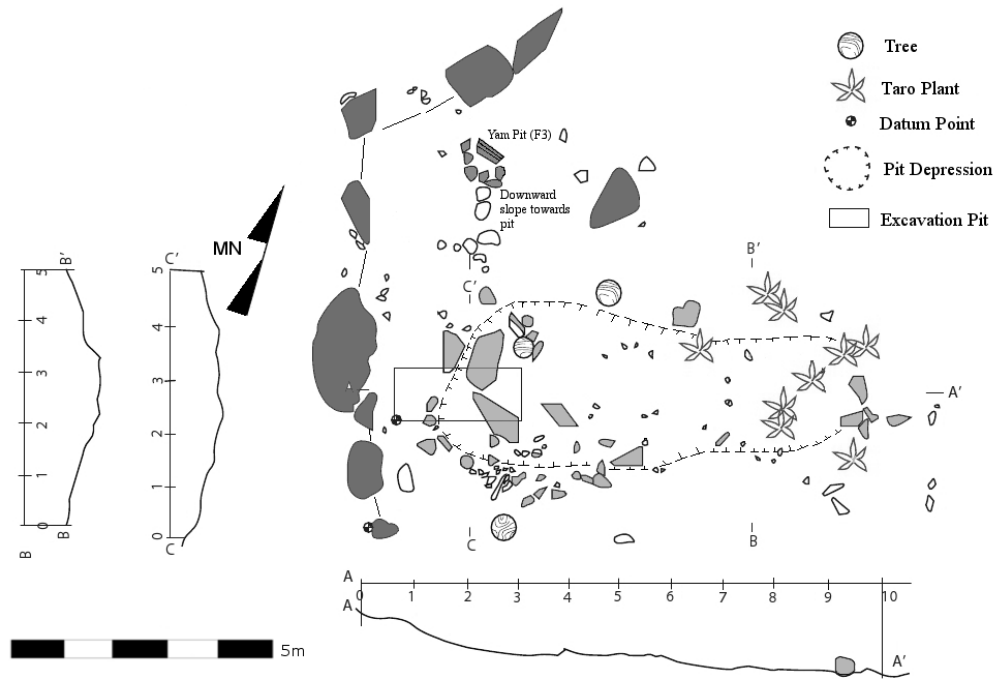


Figure 6.13. Site PoC3-12, Feature 2, Plan View. (Drafting: M. Levin, D. Stanzak, R. Suon.)

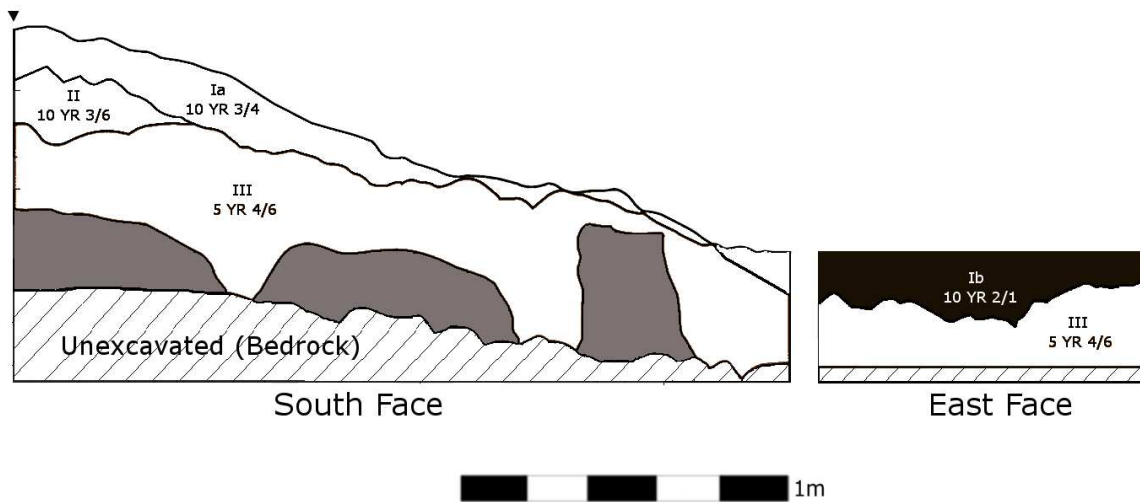
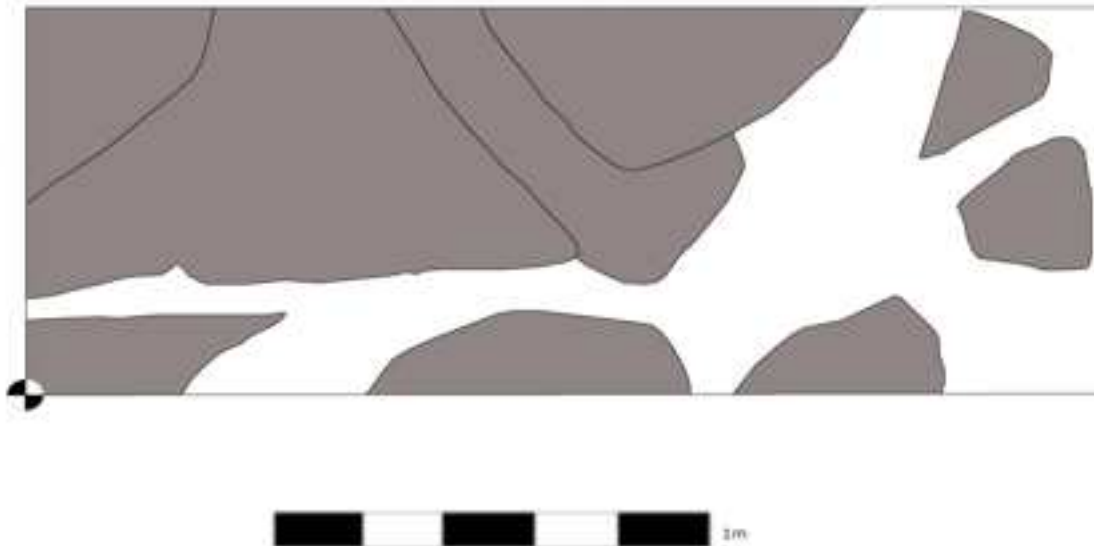


Figure 6.14. Site PoC3-12, Feature 2, Stratigraphic Profiles. (Drafting: W. Lainos, M. Levin.)



*Figure 6.15. Site PoC3-12, Feature 2, Excavation Unit Plan.*

#### *6.4.4. Site PoC3-48*

This pit was excavated in a similar manner to the pits described above in order to examine stratigraphy and collect samples (Figures 4.9 and 6.16). The trench excavated was 3 m x 1 m in the northwest depression. This depression is more circular and located further up on the slope; the second depression could be partially a result of erosion occurring from the first (excavated) depression. 1 L bulk sediment samples as well as smaller sediment samples for microremain analysis were collection at 10 cm intervals. No charcoal was observed in the deposit, and there does not appear to be an appropriate method available to date this pit. The water table in this location was higher than at other sites (around 60 cm), inhibiting the ability to excavate the full depth of the suspected

breadfruit fermentation area. Because of this, plant microremain analysis was not prioritized at this feature, although samples were collected for future analysis.

Nevertheless, the excavation did reach 1 m and valuable information on stratigraphy was available. Three layers were recorded at this site:

Layer I: Dark brown, root-saturated humic layer. 10YR 2/2

Layer II: Light brown soft clay, contains some roots. 10 YR 3/2

Layer III: Light brown hard clay. 10 YR 4/6

Layer I is present across the excavation deposit, as a top layer reaching down 5-20 cm below the surface across the trench. Due to the steepness of the pit and the quantity of water, the excavation did not extend past Layer I at the east end of the pit. Layer II is a lens that exists only in the area outside of the pit depression, extending less than a meter out from the west side of the trench. Layer III starts at approximately 50 cm of depth on the west end. There is also a large boulder in the northwest corner that takes a significant of the trench excavation unit. These layers are similar to those described for PoC3-10 and PoC3-12, as well as for earlier excavated breadfruit pits (Haun 1984).

In addition to the four breadfruit pits excavated, several other breadfruit pits, as discussed in Chapter IV, were located on survey. Breadfruit pits not yet discussed in this chapter include Sites PoC3-12, Feature 1; PoC3-26, Feature 1; PoC3-35, Feature 1; PoC3-42, Feature 1; Site PoC3-50, Feature 1; and Site PoC3-52, Feature 2. Additionally, Site PoC3-34, Feature 6 may be a very small breadfruit fermentation pit, but given its

small size (2.6 m x 1.8 m), its function is unclear. Nevertheless, breadfruit pits range significantly in size, 3 m x 4.8 m at Site PoC3-35, Feature 1, to 17 m x 5.4 m at site PoC3-50, Feature 1. As breadfruit pits are known to be used by both individual families and communally (Ragone and Raynor 2009), this would be expected. Additionally, most (but not all) pits seem to feature some sort of drainage capability, which is important at a pit feature in an environment that receives high rainfall.

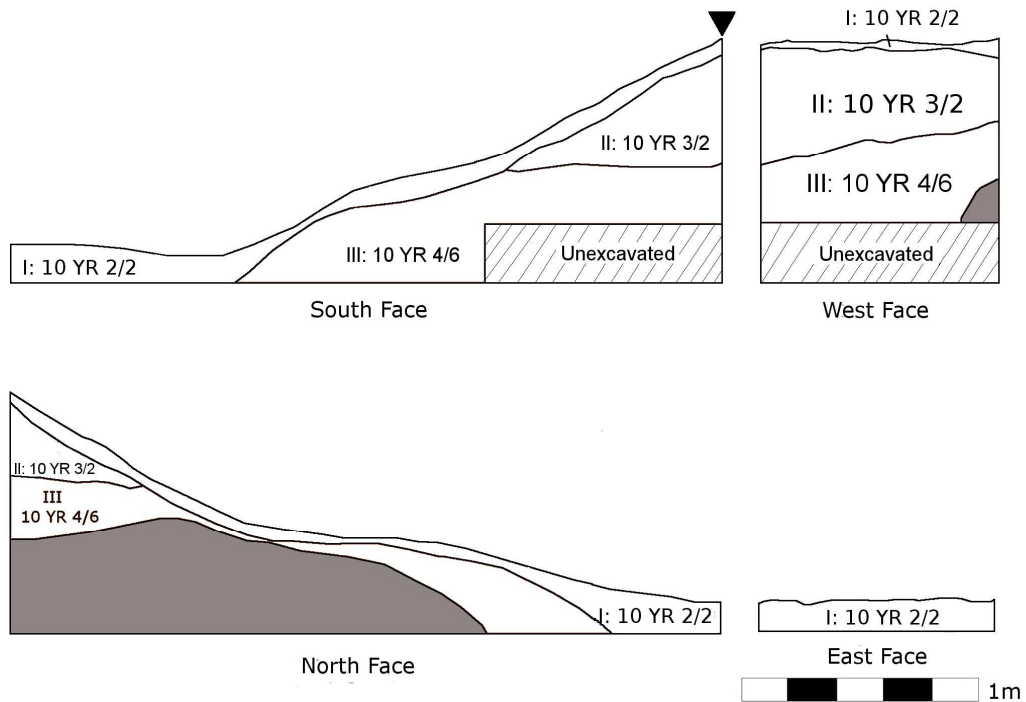


Figure 6.16. Site PoC3-48, Feature 2, Stratigraphic Profiles. (Drafting: M. Levin.)

## 6.5. Interpretation

There were not enough breadfruit pits located on survey for nearest neighbor analysis to provide relevant results (Chapter IV). However, the breadfruit pit distribution map (Figure 6.17) shows breadfruit pits spaced fairly evenly across the landscape, although there are fewer in the part of the survey area furthest from the coast. It was usual throughout the historic period for families to have one or two household breadfruit pits, and thus this would be the expected pattern. While much of the recent discussion surrounding breadfruit fermentation focuses on the large, community-oriented nature of the pits (Ragone 2002; Ragone and Raynor 2009), much of the fermentation in the late prehistoric and early historic periods was clearly taking place using smaller pits in what was probably household contexts.

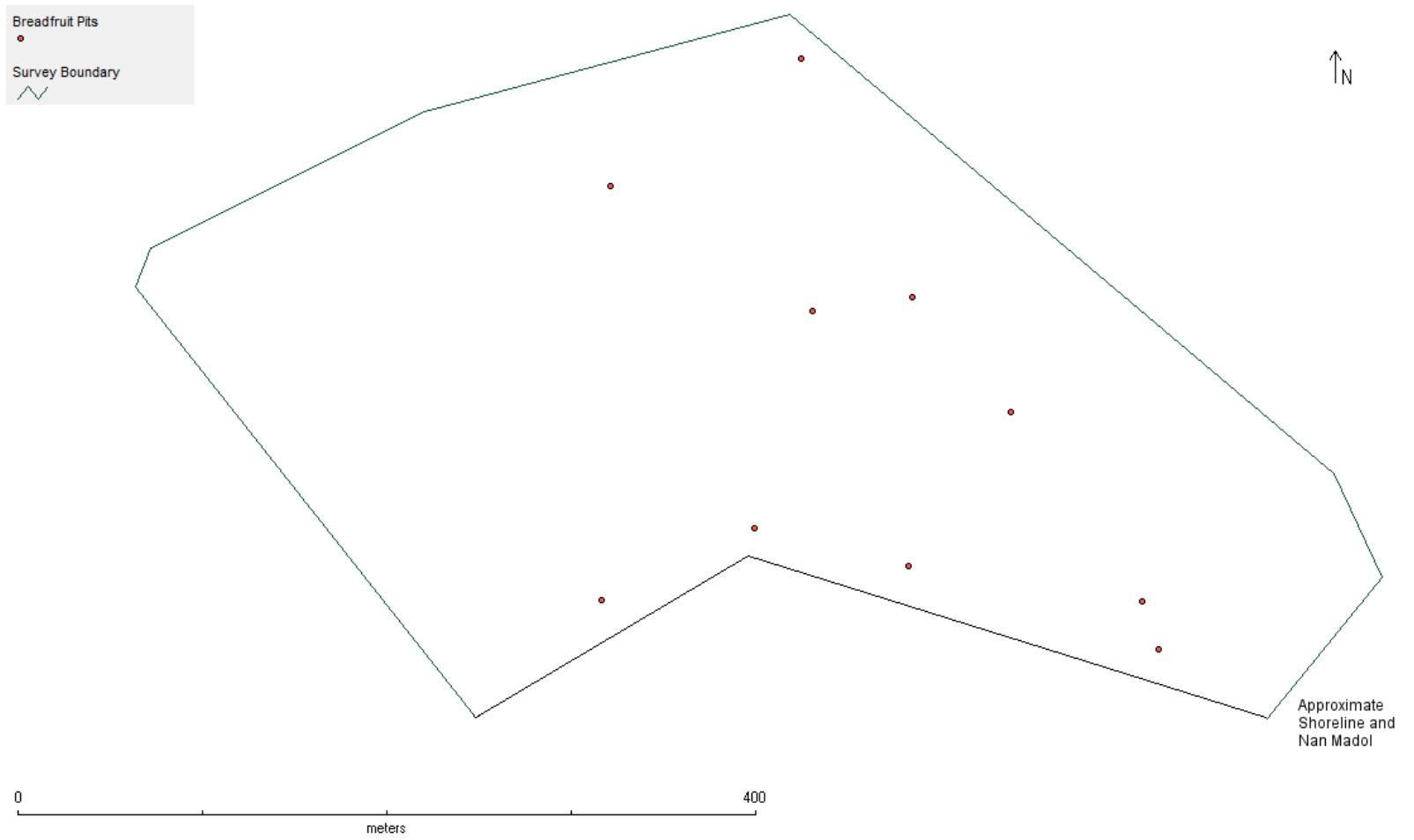
Breadfruit fermentation pits on Temwen Island have some soil characteristics in common. All breadfruit pits excavated were located on hard, clay-rich, and difficult-to-excavate sediments, which are considered poor for cultivation by Pohnpeians (Ayres and Mauricio 1997). The nature of these soils is likely important in keeping fermented breadfruit in place. The water tables also tended to be high; at three of the four excavated pits (PoC3-18, Feature 1 was the exception), the water table was encountered near the end of the excavation. This was not the case for any of the sites described in Chapter VII, although the excavations reached similar depths. Extra water would aid in creating an anerobic environment. Thus, it is clear that soils are carefully selected for breadfruit fermentation pits.

In terms of phytolith distribution, while neither Site PoC3-18, Feature 1 nor Site PoC3-10, Feature 1 showed a level of banana phytoliths or tumeric phytoliths representing fermentation (as discussed at the beginning of this chapter), there were in fact some unusual patterns represented in phytolith distribution. First, there was an uneven distribution of phytoliths in type, and some levels with very low counts. Both show high counts of phytoliths in two major areas – on the surface (which is typical) and around the area where fermentation would be expected to occur, both on the inside and the outside of the pit. Thus, although phytoliths do not provide direct evidence of the plants involved in fermentation, they do provide evidence of soil disturbances associated with ethnographically described breadfruit fermentation activities.

The breadfruit pit survey data are significant in understanding Pohnpeian prehistory and history for a few key reasons. First, they illustrate the common use of small household breadfruit fermentation pits. While there has been a fair amount of discussion in the ethnographic literature about production for prestige in large community pits, it is important to point out that the small household-level pits are the ones that Pohnpeians most commonly used on a day-to-day basis. In understanding the daily lives of past Pohnpeians, breadfruit fermentation, while serving some prestige functions, is viewed as primarily a household group practice for extending the life of their crop. Feasting cultures throughout the Pacific do play an important role. However, everyday production and consumption has a larger impact on people's lives and on local landscapes. Survey results suggest that on Temwen Island, individual families each had

their own small fermentation pits that they managed for their own subsistence purposes, and these constitute the vast majority of such features.

Furthermore, these data also illustrate how the construction of fermentation pits disturbs the landscape in subtle ways that are evident in the phytolith record. For example, in the case of PoC3-18, a spike in palm phytoliths at 60-70 cm indicates soil disturbance in the area surrounding the breadfruit fermentation pit. Many of the subsoil samples also did not contain sufficient quantities of phytoliths to count to 200-300, but overall phytolith counts rose around stone alignments thought to be related to fermentation. While phytolith analysis may not always provide direct evidence of fermentation practices in the form of botanical examples of expected leaves and fruits, phytoliths can show where local disturbances occur, and in what types of soils phytoliths do or do not regularly occur. The study of the historical ecology of a region is dependent on recognition of these subtle indicators of human site selection and use. This is also important to keep in mind in Chapter VII, where three sites are examined that show abundant phytoliths throughout the deposit. The low levels of phytoliths at breadfruit pits may be an indicator of particular soils that are good for fermentation, but not as much so for cultivation.



*Figure 6.17. Breadfruit pit distribution map, indicating locations of breadfruit pits within survey area.*

CHAPTER VII  
FOOD PRODUCTION LANDSCAPES AND COOKING

**7.1. Yam Enclosures**

Yams are one of the most important plants in Pohnpei (Balick 2009; Bascom 1948, 1965; Hunter-Anderson 1991; Petersen 1977). They form a central component of most feasting events, for which they are grown to sizes up to 100kg (Raynor et al. 2009) and also play a role as a staple food in the Pohnpeian diet. True yams are members of the genus *Dioscorea* in the family Dioscoreaceae<sup>3</sup>. There are seven species that have previously been identified on Pohnpei and close to 200 local named cultivars (Ayres and Haun 1985, 1990; Raynor et al. 2009). However, the most common species in Pohnpei are *D. alata* and *D. esculenta*.

Despite the wealth of ethnographic knowledge, yams are exceptionally difficult to identify archaeologically. This is especially true in the absence of food preparation artifacts. Plants in the Dioscoreaceae family produce no phytoliths (Piperno 2006; also see Chapter V of this dissertation) and while yam parenchyma tissues can be charred and identified from such remains (e.g., Huw and Paz 2007), they would be found primarily in cooking contexts. Yam starches have also been identified on working edges of stone tools in the Pacific Islands (e.g., Fullagar et al. 2006; Loy et al. 1992; Summerhayes et al. 2010), but in the absence of tools, the use of starch to identify yam cultivation and use is a much more difficult option. As a vegetatively propagated plant, domesticated yams

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<sup>3</sup> This is a different plant than the plant often colloquially called “yam” in the Americas, *Ipomoea batatas* (family Convolvulaceae), also known as a “sweet potato.”

would also not be expected to produce significant quantities of pollen. One other potential botanical (but indirect) source of information about yams on Pohnpei might come from *Asplenium nidus*, a fern that is commonly used in the display of yams (Raynor et al. 2009). Unfortunately, as demonstrated in Chapter V, *A. nidus* leaves do not produce sufficient identifiable phytoliths to document their past presence. However, documentation of yam enclosures (see Chapter IV) and the localized phytolith record associated with their presence can provide an important proxy for yam cultivation, especially in the recent past. Even though yams themselves produce no phytoliths, the phytolith record associated with yam gardening is helpful to understanding their use.

Pohnpeians today say they build yam enclosures to protect them from free-roaming pigs (Bascom 1965; Raynor et al. 2009), which are likely to dig them up. Pigs are a recent introduction to Pohnpei; historic data shows that they were introduced some time during the 19<sup>th</sup> century. O'Connell, who lived on Pohnpei in the 1830s, makes no notes of pigs in his extensive memoirs (O'Connell 1841). Christian, meanwhile, who traveled through in the 1890s, discusses the ubiquity and importance of pigs on Pohnpei (Christian 1899). Thus, pigs were likely brought to the island in the mid-19<sup>th</sup> century by traders, perhaps multiple times, and grew in importance relatively quickly; Hanlon (1988) describes them as becoming a primary meat for chiefly feasting (71) within a short time span. While it is possible that similar types of yam enclosures served other purposes earlier, yam enclosures are thus interpreted as a phenomenon limited primarily to the historic period.

### *7.1.1. Results*

Yam cultivation enclosure PoC3-9, Feature 2, previously described in Chapter IV, was excavated to track the effect of yam cultivation on immediate stratigraphy in the stone enclosure, as well as to track the local vegetation signature in sediments. A 1 m × 1 m test pit that includes both the center and exterior of the enclosure, as indicated in Figure 7.1, was used. This design was intended to compare the interior stratigraphy of the pit, potentially indicating yam cultivation, with that of the immediately surrounding sediments. Collected materials include 1 L bulk sediment samples, smaller (20-50ml) sediment samples, and 10 L flotation samples, each at 10 cm level intervals.

Two sediment layers were recorded as follows (see Figure 7.2):

Layer I: Medium-brown humus and clay with significant modern root content. 10 YR 4/4

Layer II: Medium-light brown clay. 10 YR 4/6

Layer I was approximately 10-20 cm in depth, while Layer II was present throughout the rest of the unit below Layer I. However, the west wall, the wall that cut through the center of the yam pit, is a notable exception. In this area, Layer I dips to approximately 40 cm in the middle of the unit, and the soil is loose. This is highly suggestive of past yam cultivation in this layer.

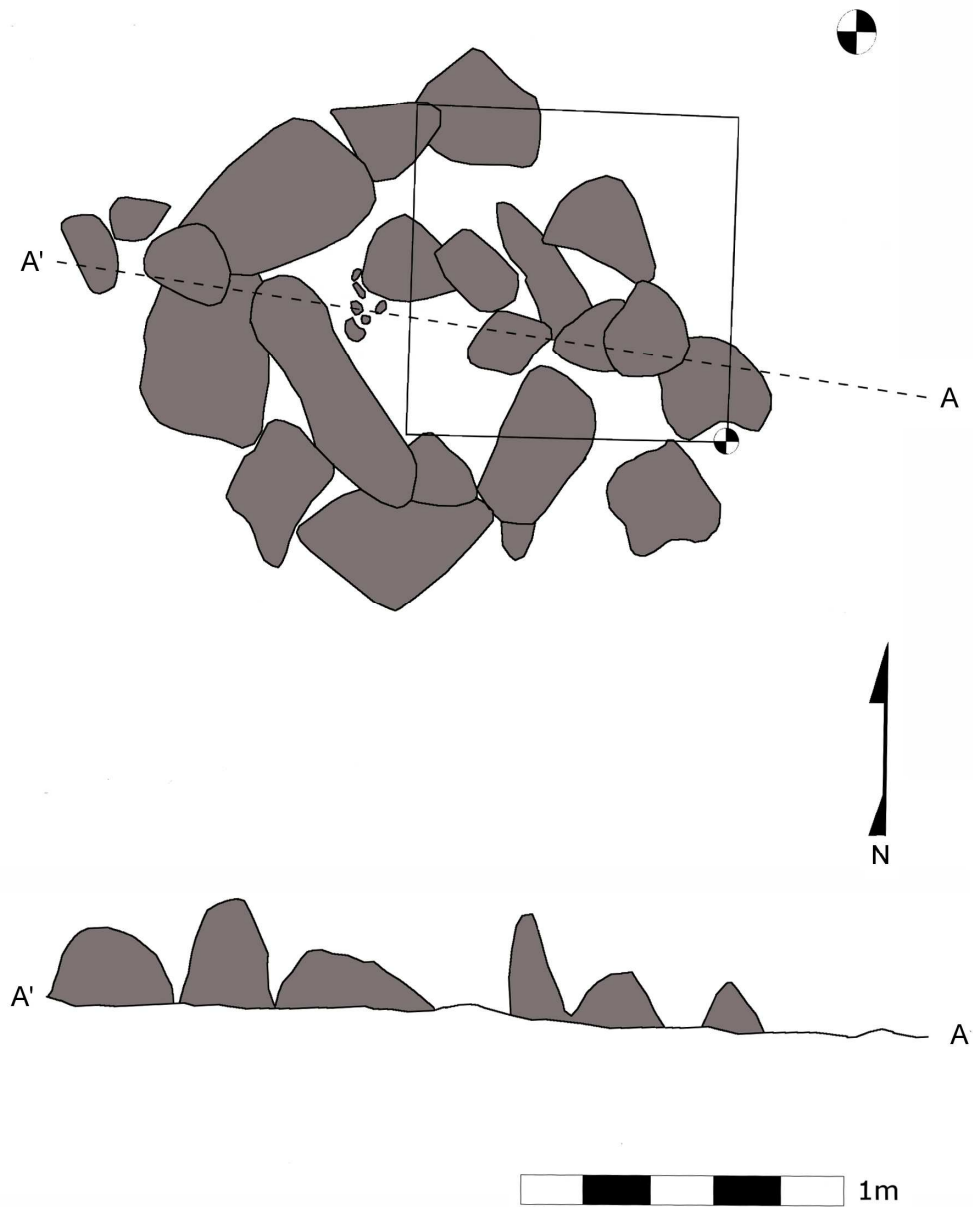


Figure 7.1. Site PoC3-9, Feature 2, Plan View. (Drafting: D. Stanzak, M. Levin.)

The phytolith assemblage (Figure 7.3) is overwhelmingly dominated by palms, even more so than at other features. The grasses that do appear are predominantly in the top layer. Microcharcoal was also prevalent in Layer II in this deposit.

Two small pieces of wood charcoal collected during excavation were submitted for dating from this site (Table 7.1). As charcoal recovery at this particular location was low, two samples from the upper part of layer II were selected in an attempt to determine the earliest possible use of this feature. Calibrations were done using the online OxCal 4.2 program using the IntCal13 calibration curve (Bronk Ramsey and Lee 2013). Sample 1, located at a depth of 45 cm (D-AMS 005376) dates to 1475±30 BP (1305-1410 cal BP, 2σ). Sample 2, located at a depth of 53 cm (D-AMS 005999) dates to 295±25 BP (450-295 cal BP, 2σ).

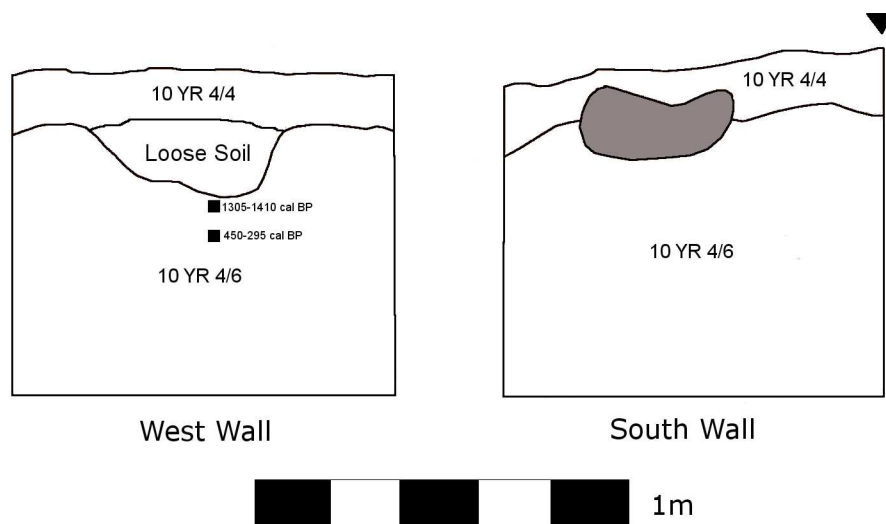


Figure 7.2. Site PoC3-9, Feature 2, Stratigraphic Profiles. (Drafting: A.C. Craib, M. Levin.)

*Table 7.1. AMS Dates, PoC3-9, Feature 2.*

<b>Sample #</b>	<b>Lab #</b>	<b>Depth</b>	<b>Material</b>	<b>Uncalibrated Date BP</b>	<b>Calibrated Date BP (2σ)</b>
PoC3-9 S1	D-AMS 005376	45 cm	wood charcoal (single piece)	1475±30	1305-1410
PoC3-9 S2	D-AMS 005999	53 cm	wood charcoal (single piece)	295±25	450-295

*7.1.2. Interpretation of PoC3-9, Feature 2*

The stratigraphic representation of this unit is, as predicted, indicative of pitting and digging within the stone enclosure for growing yams. Layer I, with significant amounts of loose soil at the bottom of the layer, protrudes into Layer II in the center of the enclosure. This suggests that a yam had previously been grown in this location. Given that a diversity of yam preparation depths exist for different cultivars and that some yams can grow extremely large (Raynor et al. 2009) and require over a meter of depth for growth, this is likely to have been for a cultivar requiring shallower conditions. This yam would not have been used for feasting purposes, but instead, consumed in the course of everyday life.

The two AMS dates from this feature, both taken from the upper portion of Layer II, significantly diverge from each other. Sample 1, at 1305-1410 cal BP, is probably the result of bioturbation, erosion, or pit excavation for yam planting or removal. It may also be the result of much earlier swiddening processes on the island, but the context in which this would have occurred is unclear. Sample 2, at 450-295 cal BP, is likely to represent a

pre-construction deposit, thus suggesting a construction of this pit during the past three centuries, and probably more recently. Thus, this yam enclosure can be placed in either late prehistoric or historic period.

The phytolith evidence (Figure 7.3) cannot be interpreted strictly stratigraphically, given the divergent AMS dates in the upper part of Layer II and the yam growth in Layer I. However, some observations can be made. Similar to other sites analyzed in this dissertation, Areceae (palm) phytoliths dominate the assemblage. Poaceae (grasses), meanwhile, are present primarily in the top of Layer I; they are a good marker of recent vegetation succession in the area, probably indicating disturbance from normal garden processes. The majority of the microcharcoal (particles >10  $\mu\text{m}$  viewable in field with counted phytoliths) in Layer II, with a concentration at 60-70 cm. Microcharcoal is generally a good indicator of local or regional swiddening (Lentfer et al. 2010), which is known ethnographically to happen on a seasonal basis in Pohnpei (Hunter-Anderson 1991; Manner 1993). This is especially true in extremely humid environments like those of Pohnpei, where natural fires are rare. Thus, it is likely that swiddening activities were taking place in the area before the construction of the pit, suggesting agricultural use over at least the past three centuries, if not longer.

## **7.2. Garden Area: Site PoC3-11, Test Pit 1**

In addition to direct testing of archaeological features, it is also important to understand the agricultural landscape. Chapter IV discusses the spatial layout of

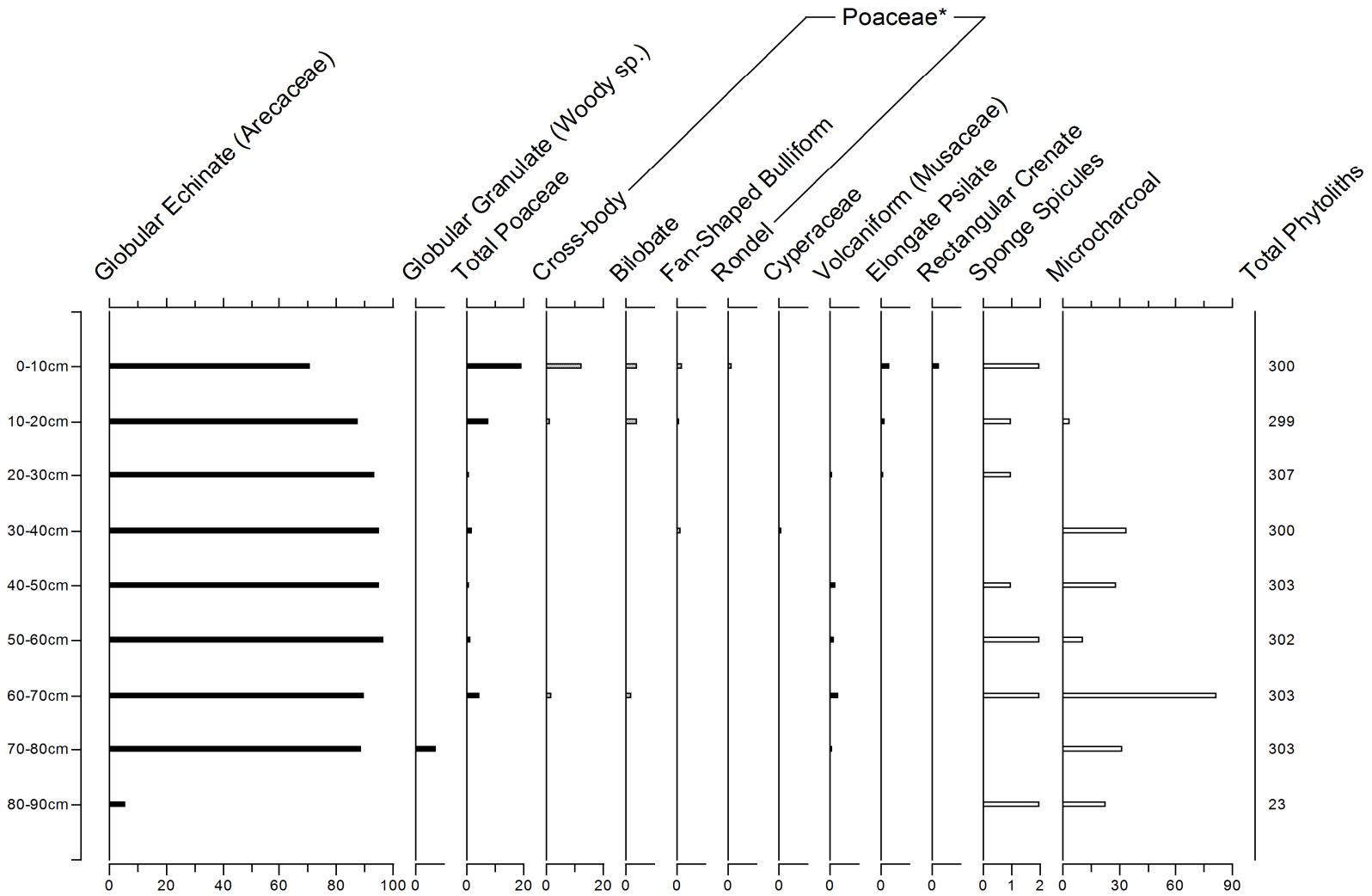


Figure 7.3. Site PoC3-9, Feature 2, Phytolith Diagram. Phytoliths represented by percentage, while sponge spicules and microcharcoal indicated by absolute count. 80-90 cm contains indication of presence/absence only for phytolith columns.  
 \*Listed as percentage of total phytoliths

archaeological food production landscapes. Here, I discuss the botanical record through time in the food production context. Human activities can have major impacts on soil layers and soil chemistry (Certini and Scalenghe 2011). This phenomenon has been well studied in the Amazonian region of South America (e.g., Mann 2000; McMichael et al. 2014; Novotny et al. 2007 Woods et al. 2009), and it has also been described in other regions (e.g., Cook-Patton 2014; Kristiansen 2001; Matney et al. 2014; McFadgen 1980). While arboricultural activities may not produce highly visible archaeological features on the landscape, past food production activities result in geological and biological changes in sediments that serve as markers of human activity. Thus, the examination of areas likely to have been subject to anthropogenic change as a result of cultivation is necessary for a full understanding of past human activities on the landscape. Here, I do so by analyzing and interpreting the phytolith record from a Pohnpeian garden landscape.

#### *7.2.1. Results of Garden Area Excavation and Analysis*

In order to examine changes in the local garden vegetation over time, a 1 m × 1 m test pit was placed adjacent to PoC3-11, Feature 1 (described in Section 4.2). This test pit was located within 30m of the coast and the northwestern edge of the Nan Madol site. The deposit contained a notable amount of charcoal, with a total of 14 charcoal samples (Appendix C). Excavation was completed at 100 cm, at which point no charcoal had been recorded for two levels and a large boulder in the southwest corner filled most of the excavation unit.

Two sediment layers from PoC3-11, Test Pit 1 were recorded as follows (see Figure 7.4):

Layer I: Dark brown clay containing a large quantity of roots. 10 YR 4/3.

Layer II: Reddish brown clay, friable, containing some roots. 5 YR 3/4.

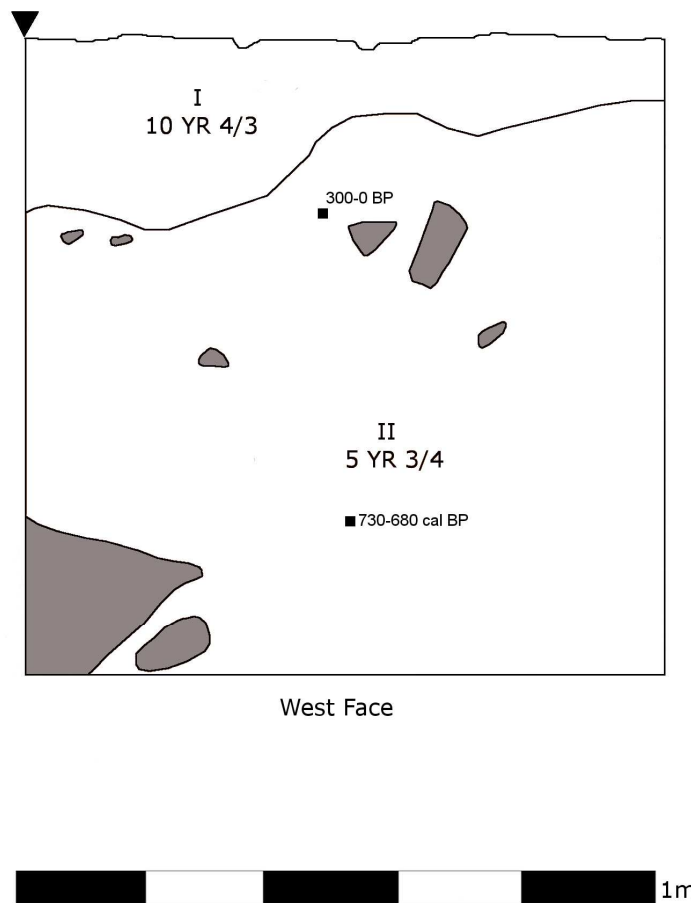


Figure 7.4. Site PoC3-11, Test Pit 1, Stratigraphic Profile. (Drafting: M. Levin.)

Layer I ranges from 10-20 cm in depth; Layer II extended to the bottom of the excavation unit at 100 cm. Also notable was a metal bar, likely a piece of rebar, at a 5 cm

depth in the northwest corner of the excavation unit. The stratigraphy of the unit does not suggest disturbance from yam cultivation outside the confines of the 1 m diameter stone yam enclosure located adjacent to the deposit.

Two small pieces of wood charcoal were submitted for dating from this site (Table 7.2). Calibrations were done using the online OxCal 4.2 program using the IntCal13 calibration curve (Bronk Ramsey and Lee 2013). Sample 1 (D-AMS #005998), collected at a depth of 30 cm, dated to  $200\pm 25$ BP (300-0 cal BP  $2\sigma$ ). Sample 2 (D-AMS #005375), collected at a depth of 74 cm, dated to  $750\pm 35$ BP (730-680 cal BP  $2\sigma$ ).

*Table 7.2. AMS Dates, PoC3-11, Test Pit 1.*

<b>Sample #</b>	<b>Lab #</b>	<b>Depth</b>	<b>Material</b>	<b>Uncalibrated Date BP</b>	<b>Calibrated Date BP (<math>2\sigma</math>)</b>
PoC3-11 #1	D-AMS #005990	30 cm	wood charcoal (single piece)	$200\pm 25$	299-0
PoC3-11 #2	D-AMS #005375	74 cm	wood charcoal (single piece)	$750\pm 34$	730-680

Phytolith analysis provides some details about the surrounding floral environment through time at this local garden area. As in most Pohnpeian soils, and indeed in soils where palm trees have been present in the local environment (see Dudgeon and Tromp 2014 and Tromp and Dudgeon 2015 for examples from Rapa Nui) the assemblage is dominated by palm phytoliths. However, the most noticeable pattern is a dramatic spike in grasses in the upper half of the unit, especially in the top layer. Bananas also appear in the top half of the unit in low levels, potentially suggesting an increase in banana

cultivation in the area during the past 500 years. Microcharcoal is more prominent in the lower level, with concentrations at the bottom of the unit and then again in the middle of Layer II, at 40-50 cm. There is also a much higher presence of sponge spicules from 30-50 cm.

### *7.2.2. Statistical Testing for Change Over Time*

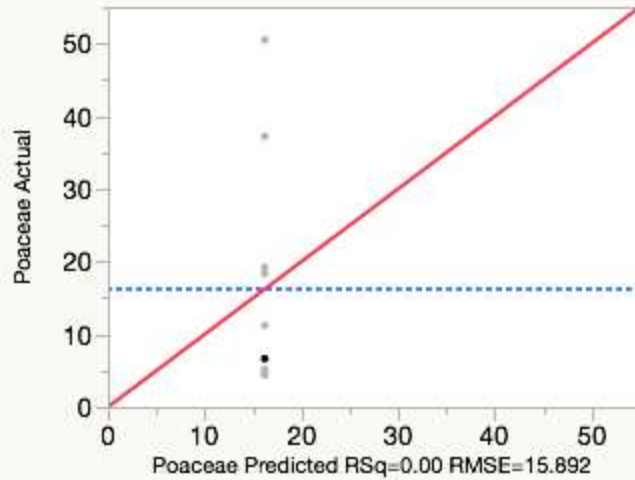
A goodness of fit test was performed specifically to evaluate the variation within Poaceae throughout the deposit (Figure 7.5). Results are significant ( $p=0.0104$ ), showing that the change in Poaceae throughout the deposit is non-random.

### *7.2.3. Interpretation*

The phytolith analysis (Figure 7.6) raises a few issues about vegetation and sea-level change on Temwen Island during the past 730-680 years. Most prominent is the recent spike in grasses, which does not coincide with an increase in microcharcoal counts. While an increase in microcharcoal along with grass phytoliths would suggest swiddening activities, an increase in grass without an increase in charcoal points towards other phenomenon. In more extreme scenarios of deforestation in the Pacific Islands, such as on Rapa Nui (Easter Island) or in some places in the Hawaiian archipelago, the disappearance of trees and introduction of increased grasslands has been attributed by some to an influx of human-introduced rats at the time of initial colonization (e.g., Athens

## Response Poaceae

### Actual by Predicted Plot



### Summary of Fit

RSquare	0
RSquare Adj	0
Root Mean Square Error	15.89203
Mean of Response	16.20425
Observations (or Sum Wgts)	10

### Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	0	0.0000	0.000	.
Error	9	2273.0098	252.557	Prob > F
C. Total	9	2273.0098		.

### Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob> t
Intercept	16.204248	5.025501	3.22	0.0104*

### Scaled Estimates

Term	Scaled Estimate	Std Error	t Ratio	Prob> t
Intercept	16.204248	5.025501	3.22	0.0104*

Figure 7.5. Site PoC3-11, Test Pit 1. Goodness of Fit, Poaceae.

2009; Hunt 2007). The ecological changes happening on Pohnpei are much more subtle than in these cases, and certainly do not represent widespread deforestation, but rather a more minor form of disturbance. However, the changes on Pohnpei do likely represent the introduction of an animal by humans: pigs. Pigs were introduced to Pohnpei after European contact, sometime during the 19<sup>th</sup> century. This coincides with the upper part of the PoC3-11, Test Pit 1 deposit. In the process of foraging, pigs dig up and consume or destroy tubers or young woody species. While woody species and tubers clearly still flourish on the island, these pig-induced processes create disturbances, which can lead to an increase of annual plant taxa, especially grasses. It is unclear if these grasses are endemic, prehistorically introduced, or historically introduced, but pigs on the landscape would have paved the way for them to flourish.

Microcharcoal spikes in the 80-90 cm level and the 40-50 cm level may be suggestive of swiddening processes in the island's late prehistory. This is consistent with the ethnographic record, in which localized seasonal swiddening is recorded (Balick 2009). However, it could be explained by other factors, such as regional winds bringing in smaller charcoal particles from off-island. In order to study localized swiddening, macrocharcoal quantification from flotation samples is necessary and is planned for the future. The increased sponge spicule count along with the low number of phytoliths and the high amount of microcharcoal on the slide from 40-50 cm depth suggests some possible sea-level instability; this area may have been within the tidal zone at some point after 730-680 cal BP, but before the introduction of pigs.

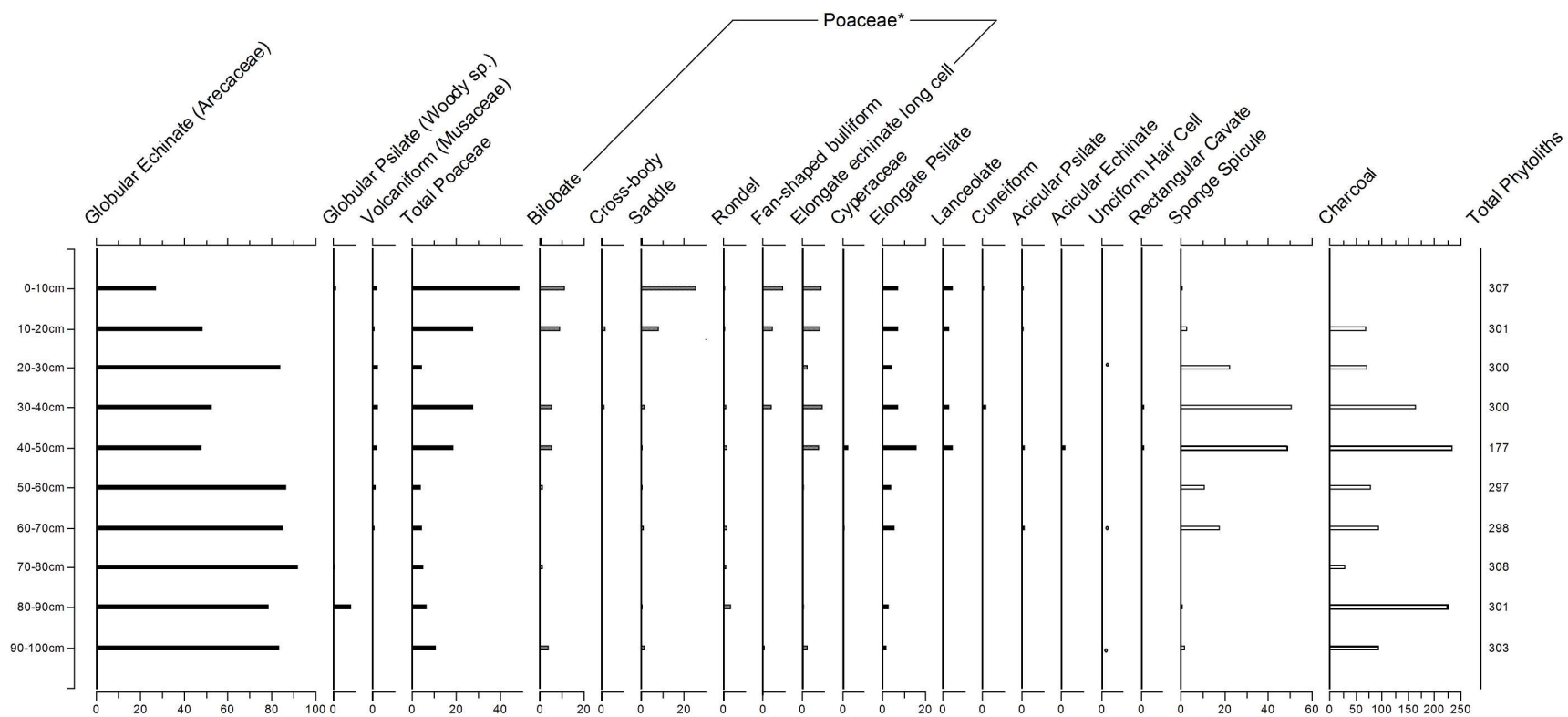


Figure 7.6. Site PoC3-11, Test Pit 1, Phytolith Diagram.

\*Listed as percentage of total phytoliths

### 7.3. Cooking Area: Site PoC3-12, Feature 4

The identification of features where people have prepared food and cooked is instrumental in paleoethnobotanical analysis. Cooking areas can provide information on how plants are prepared for consumption, and are thus closely linked to day-to-day household and community activities. However, in the absence of central hearth contexts (e.g., Meyer 2003, Snir et al. 2015) or other large structures such as *umu* in Polynesia (e.g., Carson 2002; Huebert et al. 2010; Whistler 2000), these areas can be difficult to locate. Thus, some forms of cooking and food preparation may be overlooked or left unidentified.

This section describes the excavation and paleoethnobotanical analysis at an historic cooking feature. Although this is a post-WWII feature as indicated by artifactual materials recovered, it is broadly significant for an understanding of past cooking activities for several reasons. First, charred breadfruit remains were recovered from the feature. This is a rare instance in Oceania, with only one other set of reported samples (see Kahn and Ragone 2013). However, the rarity of charred breadfruit recovered from archaeological deposits is not necessarily a preservation issue or lack of use in the past. More likely, it is because of a lack of systematic flotation at archaeological sites. Thus, these data demonstrate that flotation is an essential component of any archaeological project concerned with cooking contexts. Second, phytolith data are complementary, but not identical to flotation data, and this highlights how multiple lines of evidence can strengthen paleoethnobotanical interpretations. Third, the feature appeared simply as a darkened soil patch pre-excavation; it was not marked by any stones of cookhouse

foundations or other notable signifiers of human activity. This has important implications for locating other such features; it may be worth doing more extensive vegetation clearing in areas that are suspected to have been near households to find localized burning. Fourth, direct ethnographic analogy can be used for interpreting features such as the one described here, because it was built during a time that cultural anthropologists were working on Pohnpei. This both builds on the ethnographic record and aids in understanding its utility within archaeological contexts. Thus, this section presents a model for approaches to the study of plant remains and the first recorded instance of charred breadfruit exocarp from a site in Micronesia.

Cooking activities in Pohnpei have been previously investigated by Ayres and Haun (Ayres et al. 1981; Ayres and Haun 1978; Haun 1984), although the paleoethnobotanical records of sites were not systematically studied (charred coconut shell and coconut husk were recorded at one site, PoB7-59). Ayres et al. located several cookhouses during their Awak survey. These cookhouses are often indicated by the presence of low stone platforms or dark soils and postholes and tend to be associated with house platforms, although not exclusively so (Ayres and Haun 1978). Sites PoCB7-47 and PoB7-59 (Ayres et al. 1981) are open, rectangular structures with a central area that made them visible at ground level. Excavation at both Sites PoB7-47 and PoB7-59 revealed charcoal concentrations and fire-fractured rocks. These cooking activities provide a model for recognizing cooking sites, as well as clues to their location. However, not all cooking areas may be so easily recognizable from the surface, and

systematic flotation and paleoethnobotanical analysis can provide more details about the ways in which these sites are used.

### *7.3.1. Site PoC3-12, Feature 4 Excavation*

At Site PoC3-12, Feature 4, a 1 m x 1 m unit was placed over the cooking area. As the only thing particularly distinctive about the area from the surface was a significantly darker color than the surrounding soil, mapping was unnecessary. From each 10 cm level, we collected one smaller sediment sample (approximately 50 ml) and one flotation sample (10 L). On-site flotation was performed concurrently with excavation. Additionally, 43 visible charred plant remains were collected throughout the deposit for the purpose of AMS dating. However, as this deposit appears to be quite recent based on the relatively modern artifacts, no samples for dating were submitted from this particular excavation. All sediments in the upper 30 cm were screened using a 3 mm screen. However, as almost all of the artifacts were recovered from the upper 20 cm and flotation was being used to recover organic remains, screening was considered unnecessary in lower layers. Excavation continued to 80 cm, as the deepest charcoal deposit was at 63 cm and the unit was culturally sterile below this point.

Three sediment layers were recorded (one of which is divided into two sublayers) as follows (see Figure 7.7):

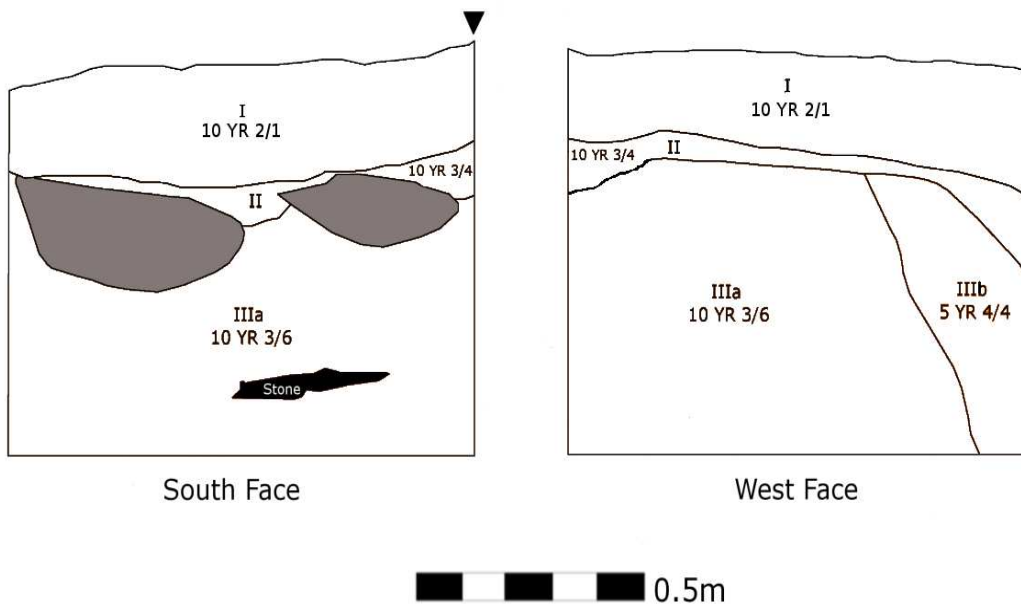
Layer I: Black organic-rich clay containing mainly roots. This layer contains a significant quantity of charcoal. 10 YR 2/1

Layer II: Dark yellowish brown moisture-rich clays. 10 YR 3/4

Layer IIIa: Dark yellowish brown hard-packed clay, with some streaks of black rock.

10 YR 3/6

Layr IIIb: Dark yellowish brown clay. 5 YR 4/4.



*Figure 7.7. Site PoC3-12, Feature 4, Stratigraphic Profiles.*

Layer I varies from 20-30 cm in depth, and it contains all of the artifactual material recovered from the site. Layer II ranges from 4 cm to 40 cm in depth, being thicker on the north and east walls, and thin on the south and west walls. Layer IIIa comprises most of the rest of the deposit below Layer II. Layer IIIb is a lens in the

northwest corner extending vertically from Layer II to the bottom of the excavation unit. Layer III appears to be culturally sterile and has minimal visible charcoal. Thus, differentiation within Layer III is expected to be the result of a geomorphological rather than cultural process.

Artifacts recovered in Layer I include 11 nails, four linoleum tile fragments, three plastic container fragments, two glass fragments, one cloth fragment, and one piece of metal in a solid tubular shape. The nails are wire, machine-made, and most closely resemble the 6d (2" or 51 mm) nail produced in the US. Artifactual materials were recovered from the top 30 cm using a screen or by hand. Also recovered was one small-medium mammal bone, which is likely dog or pig. Layer I was, however, most notably filled with large quantities of charcoal (described in flotation section below). Given the US manufacture of the nails, this feature is thus identified as a post-WWII cooking area.

#### *7.3.2. Plant Macroremains from Site PoC3-12, Feature 4*

Initially, the mass of the light fraction from flotation samples was measured in grams using a standard balance. The light fraction of each 10 L flotation sample was further divided for easier sorting using 1 mm and 0.425 mm standard geological brass sieves. The 1 mm fraction was sorted using a stereozoom microscope at 10-40x magnification using tweezers, a probe, and a fine brush. As the overall density of non-wood charcoal was quite low and plant remains smaller than 1 mm were unlikely to provide additional data, the 0.425 mm fraction was not sorted. Wood charcoal, other charred plant parts, land snails, termite droppings, and cultural remains were sorted from

remaining sediment and uncharred plant materials. As plant remains only preserve in uncharred condition in exceptional circumstances such as dessication, waterlogging, and freezing (Miksicek 1987; Pearsall 2000), none of which apply to this site, all uncharred remains can be safely assumed to be modern intrusions only a few years old. All materials were retained.

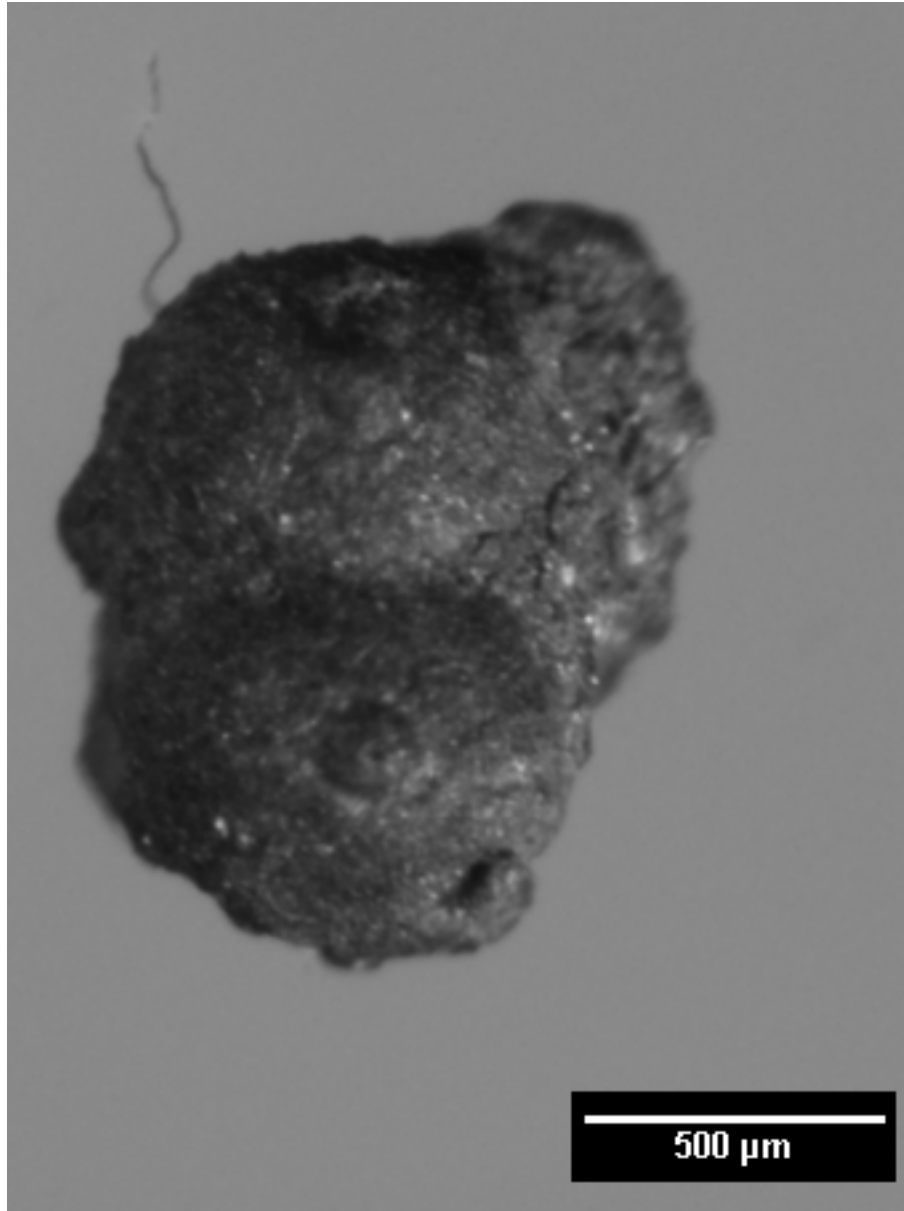
Charcoal remains (Table 7.3) support the interpretation of this feature as a roasting area with an original cooking surface at 30 cm, at the boundary between Layer I and Layer II. Charcoal concentrations are by far the highest in Layer I, especially in the 20-30 cm level, suggesting heavy wood burning and build-up of sediment and charcoal through repeated use. Charcoal does occur throughout the entire deposit, although in much lower quantities. This is consistent with regular charcoal occurrence at other local sites on eastern Temwen Island as described earlier and thus represents swiddening across the land area rather than concentrated cooking fire.

*Table 7.3. Wood Charcoal content of PoC3-12, Feature 4 flotation sample light fractions, 1 mm sieve*

<b>Depth</b>	<b>Layer</b>	<b>1mm Fraction Mass (g)</b>	<b>Wood Charcoal</b>	
			<i>Mass (g)</i>	<i>Count</i>
<b>0-10 cm</b>	<b>I</b>	52.69	4.28	478
<b>10-20 cm</b>	<b>I</b>	24.09	8.82	1026
<b>20-30 cm</b>	<b>II</b>	37.92	22.63	4258
<b>30-40 cm</b>	<b>III</b>	6.17	0.66	83
<b>40-50 cm</b>	<b>III</b>	1.10	0.70	207
<b>50-60 cm</b>	<b>III</b>	10.09	0.59	34
<b>60-70 cm</b>	<b>III</b>	8.80	0.31	158
<b>70-80 cm</b>	<b>III</b>	6.35	<0.01	12

Non-woody plant remains (Table 7.4), including charred breadfruit exocarp (Figure 7.8), are also present almost exclusively in the upper levels. Nutshell fragments and seeds were not identifiable using macroscopic reference materials and are likely representative of weedy species with small seeds. The only clearly cultivated plant recovered was breadfruit (*Artocarpus altilis*), of which 11 fragments were recovered. As with wood charcoal, the majority of the breadfruit exocarp fragments occurred in the 20-30 cm level. This indicates that specific use of this feature includes the cooking of breadfruit.

Additionally, several other types of organic remains were recovered from flotation samples (Table 7.5). The top 10 cm of the excavation unit included 556 land snail shells and 49 land snail shell fragments, 6 other mollusk shell fragments, and a mammal bone fragment. Given that there are a total of 8 land snails throughout the remainder of the deposit (6 in the 10-20 cm level, one in 40-50 cm, and one in 60-70 cm), it is likely that the land snails are a post-cultural phenomenon; the old cooking area may have created a hospitable environment for these animals. The remainder of the biological remains consists of two termite pellets in Layer III. Termite pellets are indicative of the presence of wood and indicate termite infestation in some archaeological contexts (Adams 1984), but their small numbers and position in an arboricultural context suggest they are not significant archaeologically here.



*Figure 7.8. Breadfruit Exocarp fragment, Site PoC3-12, Feature 4.*

Table 7.4. Non-wood plant content of PoC3-12, Feature 4, flotation sample light fractions, 1 mm sieve.

Depth	Layer	Breadfruit Exocarp Fragments	Nutshell Fragments	Seeds	Seed Fragments	Spores
0-10 cm	I	3	7	16	2	24
10-20 cm	I	-	-	-	-	-
20-30 cm	II	8	-	5	-	-
30-40 cm	III	-	-	-	-	-
40-50 cm	III	-	1	-	-	-
50-60 cm	III	-	-	-	-	-
60-70 cm	III	-	-	-	-	1
70-80 cm	III	-	-	-	-	-

Table 7.5. Other biological content of PoC3-12, Feature 4, flotation sample light fractions, 1 mm sieve.

Depth	Land Snails	Land Snail Fragments	Shell Fragments	Bone Fragments	Termite Pellets
0-10 cm	556	49	6	1	-
10-20 cm	6	-	-	-	-
20-30 cm	-	-	-	-	-
30-40 cm	-	-	-	-	-
40-50 cm	1	-	-	-	1
50-60 cm	-	-	-	-	1
60-70 cm	1	-	-	-	-
70-80 cm	-	-	-	-	-

### 7.3.3. Phytoliths from Site PoC3-12, Feature 4

Photographs of phytoliths are pictured in Figure 7.9 (See Figures 5.2-5.6 for select reference materials), and major types of phytoliths are represented in Figure 7.10.

The results of the phytolith analysis reveal a set of data complementary to the

microremain evidence. Notably, there are almost no phytoliths below 50 cm; the drop off is quite dramatic, with only single digit counts being present on an entire slide. This is similar to the pattern seen in the macroremain data, with flotation samples consisting primarily of small charcoal fragments in Layer III.

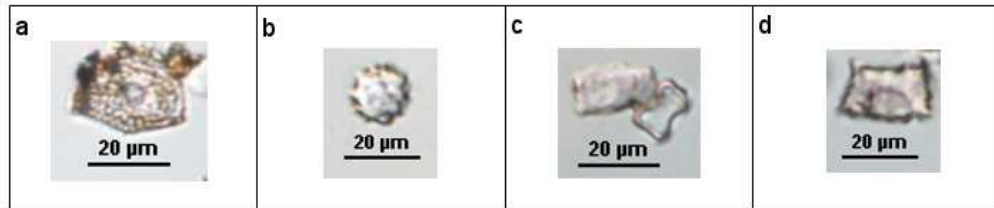


Figure 7.9. Selected phytoliths from PoC3-12, Feature 4. a. *Cyperaceae* (sedge) phytolith, 0-10 cm. b. *Arecaceae* (palm) globular echinate phytolith, 10-20 cm. c. Left: *Musaceae* (banana) volcaniform phytolith. Right: *Poaceae* (grass) bilobate phytolith, 0-10 cm. d. *Musaceae* volcaniform phytolith, 20-30 cm.

The most common taxa present were *Arecaceae* (palms) and *Poaceae* (grasses). *Arecaceae* phytoliths, however, are more common near the surface level, whereas grasses are more common in Layer 2 and the upper part of Layer 3. This is a reversal of the pattern seen at many gardening (rather than cooking) features, where grasses tend to be more prevalent in upper levels (see previous discussion of PoC3-9, Feature 2 and PoC3-11, Feature 1). This supports the interpretation of a cooking surface at 20-30 cm, as higher levels of grasses can indicate more localized disturbance. *Musaceae* phytoliths are also present consistently in relatively low numbers throughout the upper two layers of the deposit. This may indicate the use of banana leaves in cooking. There is little direct indication of breadfruit cooking in the phytolith evidence specifically, except for the

presence of five acicular echinate phytoliths, which are present in breadfruit, but also in other plants of the Moraceae and Urticaceae families (See Chapter V). Sponge spicules are also present throughout the deposit. As discussed earlier, this is a common occurrence in features analyzed from Temwen Island, representing proximity to the shoreline.

#### 7.3.4. Breadfruit Cooking

The combination of charred plant macroremain and phytolith data are strongly suggestive of this feature as a cooking area, especially one where breadfruit was cooked. As previously discussed, breadfruit on Pohnpei is often cooked in a rock oven. However, as they are generally not located in a pit like their Polynesian counterparts, it would be expected for them to occur at surface level. There were not many stones at this feature as might generally be expected. However, stones can easily be moved for use at another *uhmw* or for other household activities. Botanical remains and stratigraphic characteristics play an important role in this interpretation. Large, dense quantities of charcoal indicate a setting with intensive wood burning. This charcoal occurs in far higher quantity than the background charcoal (generally indicative of swiddening) occurs at other sites. Furthermore, breadfruit rind chars in and is peeled after cooking, which explains its occurrence here. Taro, banana, and breadfruit leaves are commonly used in oven cooking; however, taro does not produce phytoliths and thus would be invisible in this analysis. Banana does produce significant numbers of phytoliths (Piperno 2006; also see Chapter V of this dissertation), which explains its presence here.

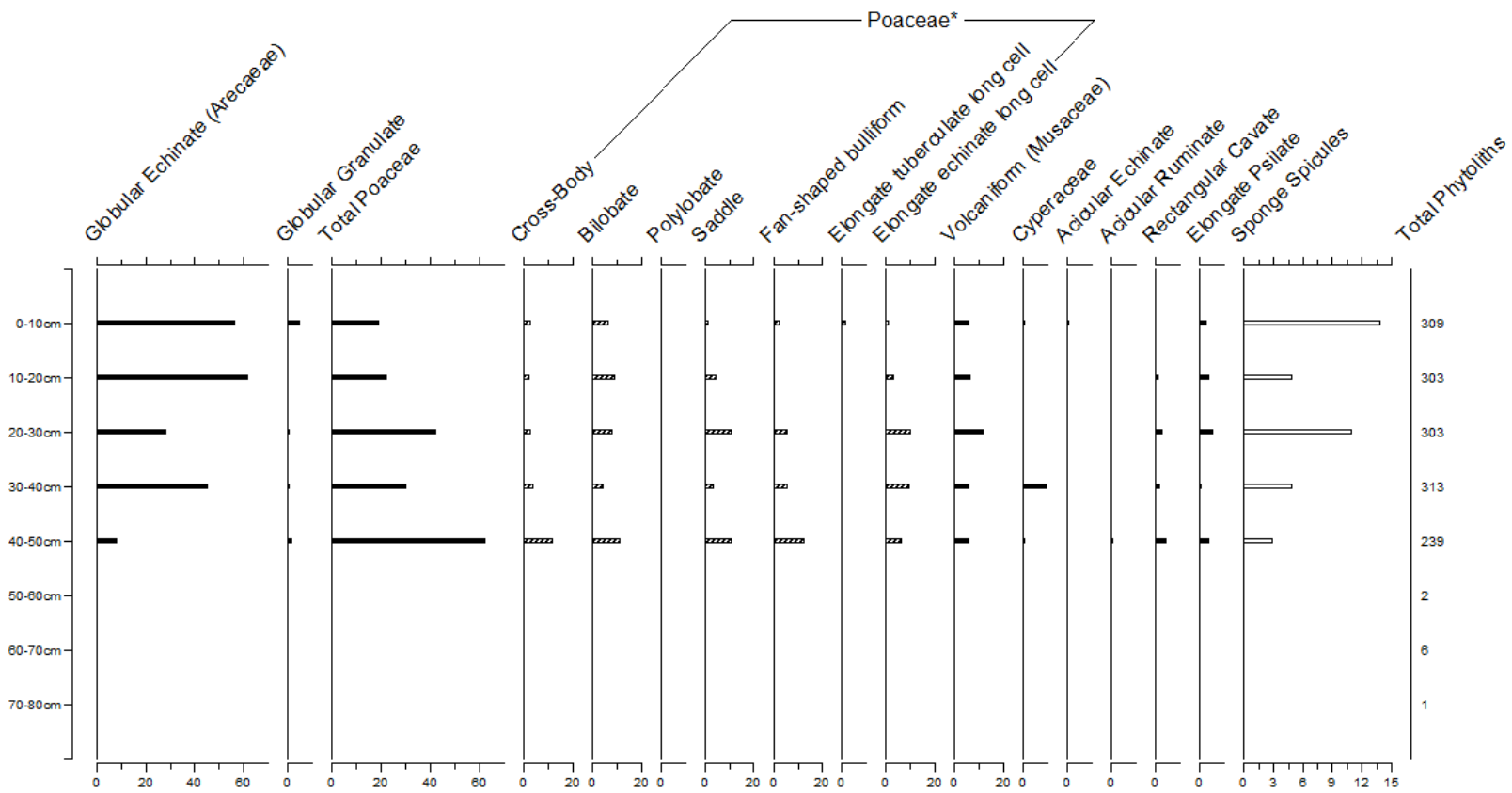


Figure 7.10. Site PoC3-12, Feature 4, Phytolith Diagram.

\*Subdivisions of Poaceae represented as percentage of total phytoliths.

The results from this particular feature indicate that many similar older features may be missed. A great deal of the evidence for past cooking practices may be completely overlooked not only in Pohnpei, but in any area with large amounts of modern vegetation. This feature was located near a modern dwelling, so the surrounding area had little vegetation compared to most of the area surveyed. In fact, the location of the modern dwelling probably has not changed since use of this recent feature. Thus, in regions with thick vegetation, especially on the Pacific Islands, I recommend systematic vegetation clearance several meters from the edge of identified house foundations or platforms. This may help to identify cooking-related soil disturbances that would be invisible if only the immediate structure was cleared.

Use of systematic paleoethnobotanical sample collection is also crucial to botanical recovery. As previous research (Kahn and Ragone 2013) and my work indicate, parts of the breadfruit fruit can be preserved through charring and recovered through flotation. It is true that systematic flotation is often not as productive in the Pacific as in other regions because of a reliance of vegetatively propagated plants and thus a lack of seeds. However, not performing systematic flotation, especially at sites where plants were likely charred, is likely to result in significantly reduced detail in analyses of cooking activities.

Phytolith analysis, meanwhile, preserves a different spectrum of plants. Leaves are extremely unlikely to be preserved through charring (Pearsall 2000). However, leaves produce large numbers of phytoliths, and thus phytolith analysis can help to understand past use of leaves in taxa that deposit silica. While palm and grass phytoliths are present

in large numbers in soils from other local sites the elevated presence of banana phytoliths suggests the use of banana leaves in cooking activities. Both phytolith analysis and plant macroremain analysis contribute data about site activity and function, and these two forms of botanical data are clearly complementary (see also Harvey and Fuller 2005 for a discussion on the use of phytoliths in cereal crop processing analyses, in which macroremains are often exclusively used). As would be expected at an *umhw* cooking site, charred breadfruit and banana phytoliths are present here, and both types of analysis are crucial to this interpretation.

This feature represents only the second reported instance of breadfruit exocarp from sites in the Pacific Islands. However, I suggest that this does not represent a lack of evidence, but a lack of proper systematic survey and paleoethnobotanical investigation. Thorough vegetation clearance, flotation, and the use of multiple lines of evidence can help to develop a clearer picture of past plant cultivation practices. Models of food processing should directly inform the methods used to study them in the past. Furthermore, more recent historical features, such as this one, should not be ignored. They provide information about site activity and can be used to develop or refine archaeological and paleoethnobotanical methods and models.

#### **7.4. Summary**

This chapter examined human gardening and cooking activities on Temwen Island, Pohnpei, through the study of a number of feature types. Yam Enclosure PoC3-9 provides evidence of yam cultivation activities in the historic period. Site PoC3-11, Test

Pit 1, documents landscape change on Pohnpei over a period of 730-680 years. The phytolith and microcharcoal record suggest a relatively stable environmental landscape through the late prehistoric period, with some swiddening activities. The historic period saw an increase of localized disturbance with an increase in grass phytoliths, which is explained by the introduction of pigs in the mid-19<sup>th</sup> century. Site PoC3-12, Feature 4 provides an example of historic cooking on Pohnpei, presenting combined phytolith and macroremain analysis to show historic methods of breadfruit cooking using banana leaves.

The results presented in this chapter are a key example of how the historical ecology approach can help to better understand the archaeological record. The absence of all but 20<sup>th</sup> century artifacts from these sites means that the incorporation of multidisciplinary methods, including the study of plant remains, is essential to understanding agricultural features on the landscape. These data help to develop an understanding of food production systems on Temwen Island in late prehistoric and early historic period of relative stability and persistence through some changes, as will be elaborated in Chapter VIII.

## CHAPTER VIII

### CONCLUSIONS

Food production systems, especially managed forest and root crop gardening ones, have been a fundamental element in human adaptation to Oceanic islands over the last several thousand years. They continue to be essential to island life today. Such patterns of cultivation and resource use can be effectively studied through a combination of archaeological and paleoethnobotanical evidence. In this dissertation, I have integrated field and laboratory data from archaeological survey and botanical remains preserved in sites on Pohnpei, Micronesia, which serves as a case study for Remote Oceania. When viewed from the standpoint of historical ecology, this helps us to better understand the long-term development of subsistence methods and the interrelationships of cultigens and local environments.

Data show that managed forest and root crop systems functioned through the second millennium AD and exhibited persistence even with regard to 19<sup>th</sup> century environmental changes. They also provide strong evidence for past breadfruit use, including the first recovery of archaeological breadfruit exocarp from Micronesia. In this dissertation, I also presented methods for systematic paleoethnobotanical investigation in the tropical Pacific, including an assessment of phytolith production by economic plant taxa.

As discussed in Chapters I and II, this dissertation broadly addressed the question of how food production systems affect social and environmental factors. The Pohnpeian food production system is one that depends primarily on tree and root staples, along with

fishing and some domestic animals (dogs, chickens, and, from the historic period, pigs). Important plants include breadfruit, yam, banana, coconut, taro, and pandanus. Pohnpeians grow these plants in a mixed-managed forest and root crop garden system. During the past millenium, Pohnpeians have had a system of food production that shows a level of equilibrium and persistence in subsistence strategies. Evidence from Site PoC3-11, Test Pit 1 shows few disruptions in the late prehistoric period. While there is periodic swiddening represented, the phytolith proportions do not change until the historic period, approximately 150 years ago. Furthermore, although there are environmental and social changes with European colonization and the adoption of the pig in the mid-19<sup>th</sup> century, Pohnpeians still practice subsistence- and prestige-related food production in a sustainable manner. Latinis (2000) describes both stewardship and long-term planning as important factors in the arboricultural process, as trees often take years or even decades to develop to maturation. This is certainly characteristic of the situation on Pohnpei. Some islands, especially those in East Polynesia such as Mangareva (Kirch et al. 2015) and Mangaia (Kirch 1997; Kirch et al. 1991) experienced prolonged environmental degradation during the prehistoric period as a result of human impacts, but this does not appear to be the case with Pohnpei. Instead, prehistoric Pohnpei presents a case of persistence in food production practices on a remote island. Pohnpei is certainly not the only Pacific Islands example of such processes. Nearby Kosrae shows very similar processes in the development of sustainable managed forests and gardens (Athens et al. 1996). Tikopia is also a well-known example of a successful arboricultural system, with evidence for systemic changes in the wake of environmental degradation (Kirch 1997;

Kirch and Yen 1982). This work from Pohnpei adds to the growing body of evidence that managed forests and root crop gardening have been commonly used methods of sustainable food production in many parts of the Pacific over the time these islands have been occupied.

The historic period, starting in the mid-19<sup>th</sup> century, saw some dramatic changes to this system, primarily related to the introduction of pigs by foreign traders. Pigs, introduced prehistorically to Melanesia and many areas of Polynesia and, but not to eastern Micronesia, can be major agents of landscape change. In fact, on the island of Tikopia, a Polynesian outlier, people are known to have purged pigs from the island prehistorically because they were too much of an environmental stressor (Giovas 2006; Kirch 1997; Kirch and Yen 1982). It would be expected that the introduction of pigs to other locations would have real impacts on landscapes.

Historic records (Christian 1899; Hanlon 1988; O'Connell 1841) and faunal remains (Ayres, pers. comm.) suggest the introduction of pigs to Pohnpei occurred sometime in the mid-19<sup>th</sup> century. There is also an influx of grasses in phytolith samples during this time period (see Chapter VII), which is likely related to soil disruption from pigs. Ethnographically, Pohnpeians built enclosures to protect their yams from free-ranging pigs, and it appears that this arose in the mid-19<sup>th</sup> century. Therefore, the 19<sup>th</sup> century environmental changes represent more landscape change on Temwen Island than any time in at least the previous 500 years. While Pohnpeian managed forests and root crop production still continue based on the same plants that people brought to Pohnpei more than 2000 years ago (albeit with an influx of some new varieties in the 19<sup>th</sup>

century), the environment on which this system has been practiced has changed over time, and especially over the past 150 years. This culturally driven niche construction process means that oral history and ethnographic data must be interpreted with the understanding that European trade and colonialism have had a significant impact on the island environment and food production practices during the last 150 years.

### **8.1. Garden Landscapes**

At a more specific level, one of the questions this project addressed is how garden landscapes have been organized as a fundamental element of food production. Today, and in the past, Pohnpeians have understood managed forests where arboriculture was practiced, complemented with the production of root crops, as central to the local landscape. These food production systems are by and large vegetative polycultures where multiple crops are grown in one location, although some areas, such as taro patches, focus exclusively on one crop. In addition to demonstrating a major temporal shift in the 19<sup>th</sup> century, this study has added to our understanding of the design of Pohnpeian garden landscapes in the island's late prehistory and early history.

It appears that certain types of archaeological food production related features cluster spatially. This is especially true of yam cultivation enclosures, which occur non-randomly on Temwen Island. The non-random patterning of yam cultivation occurred for a combination of environmental and social reasons. Raynor et al. (2009) discuss several methods that Pohnpeians use to select planting locations, including ecological considerations such as soil fertility and vine support, and prestige-related social

considerations, such as site privacy (2009:51; see also Ayres and Mauricio 1997). There is no clear evidence for yam enclosures before the historic period so they are a relatively recent phenomenon, but there is no reason to believe that similar considerations for yam planting were not employed in the past, even if stone enclosures were not used. From an ecological standpoint, yam growing must take place in areas where cultivation will result in a mature and edible product. However, planting locations must also satisfy social criteria such as being hidden away from major roads/trails or the homes of others (especially in the case of yams planted for prestige use). Furthermore, given both the traditional and colonial land tenure systems on Pohnpei, which limit land use patterns, some landowners may have no choice but to select less than optimal locations for their enclosures.

## **8.2. Food Preservation Practices**

Another question addressed was the role of food preservation practice and technology in the Pohnpeian setting. Plant foods can be preserved a number of ways, such as fermentation or drying. Notable on Pohnpei is the use of breadfruit fermentation pits to both preserve this food for use throughout the year and to present at feasts. In terms of these pits, assessment of sediments suggests that they are more dense and compacted than in locations where features were growing were built. These types of sediments may create better environments for breadfruit fermentation as they help to retain water; they are regarded by Pohnpeians as poor growing soils (Ayres and Mauricio 1997). The number of breadfruit pits located on survey is too low for quantitative

assessment of clustering, but they are spread across the landscape fairly consistently. Both smaller home and larger community breadfruit pits are known to exist ethnographically (Ragone 2002; Ragone and Raynor 2009) and have been observed archaeologically during the course of this project and by previous researchers on the island (Ayres and Haun 1985; Haun 1984).

Breadfruit fermentation pits documented in survey are highly variable, ranging from circular pits a few meters in diameter to long, large pits 17 m in length. However, there are certain characteristics that tie together breadfruit fermentation pits. They are generally associated with rocks, which are both part of construction and indicative of past use, as rocks are an important part of the fermentation process (Ragone and Raynor 2009). They also tend to be approximately 0.5 m-1 m in depth. Excavation of breadfruit pits (Chapter VI) shows that they generally have layers that indicate construction through digging out a central area. Phytolith evidence considered here is from just two breadfruit pits, but do show soil disturbances in the portions of the pit that would be expected to be used for breadfruit fermentation processes. There are more phytoliths and different types of phytoliths present in levels where fermentation is expected to occur. Thus, while the phytolith signature of breadfruit fermentation does not match the initial hypotheses that large amounts of banana and tumeric would be present, there is in fact a subtle soil disturbance signature for breadfruit fermentation. For this reason, structural features of breadfruit pits, such as cobble alignments or sediment layers indicating pit construction activities are key.

### **8.3. Archaeological Features Important for Documenting Food Production**

This project also asked the question about what types of features are important for understanding past food production. The most common features located during the course of this project were yam enclosures and breadfruit pits, as discussed in sections 8.1. and 8.2. However, some differences between survey results from this project on Temwen Island and from previous projects elsewhere on Pohnpei should be addressed.

Interestingly, while Haun (1984) indicated extensive terracing interpreted as agricultural areas during his survey on the main island, this was not found on Temwen. While there were basalt stone alignments that were placed to prevent soil erosion and enhance gardening, there were no extensive terracing systems visible on Temwen Island comparable to those on the main island. While this may be related to social differences between farming on Temwen and the main Pohnpeian island, it is more likely due to the fact that many slopes in surveyed areas on the main island such as Awak are steeper. There is also more surface stone overall in Awak. Most of the area on Temwen surveyed was slightly sloping, or flat enough that terracing would not be necessary.

Also not recorded in the Temwen survey was a significant amount of mounding, often used for yam planting on Pohnpei (Ayres et al. 1981; Haun 1984). They have high soil fertility and thus are useful for cultivation, and they were probably developed in antiquity by Pohnpeians for the purpose of cultivation. The fact that they were not noted on Temwen could mean that they simply do not occur in large numbers or are not needed in the Temwen environment. It is clear from the sheer number of yam enclosures

recorded on Pohnpei that the soils on Temwen are productive for yam cultivation, so further soil enhance may not have been necessary.

#### **8.4. Food Preparation and Cooking**

Methods of recognizing food preparation and cooking also represent a key topic of this dissertation. In order to understand food production practices, it is important to understand not just the growing and storage of food, but also cooking practices. One would also expect to find substantial plant macro- and microremain evidence associated with cooking features. The ethnographic record for cooking practices on Pohnpei is extensive (Balick 2009; Bascom 1948, 1965; Lawrence 1964; Petersen 1977; Ragone 2002). However, the archaeological record is less so. Previous work has been done by Ayres and colleagues (1978, 1981), who located cookhouses in Awak (Chapter VII). Large soil pit earth ovens are present throughout Polynesia (Carson 2002; Huebert et al. 2010; Leach 1982) and cooking activities have also been documented in Polynesian house settings (Kahn and Ragone 2013). Historically used Pohnpeian earth ovens are different than Polynesian earth ovens in that they are generally not subsurface, so they are more difficult to identify as archaeological features. However, Ayres et al. (1981) did show a clear archaeological signature for these cooking structures. Most of the structures they located were characterized by rectangular stone enclosures, charcoal-stained soils, and fire-cracked rocks. The historic cooking feature located on this project survey was only physically visible as a darkened patch of soil. As this is a recent (post-WWII) feature and was located a few meters from a modern dwelling (in an area with partially

cleared vegetation), locating many cooking features of greater antiquity that are not clearly stone-defined cookhouse structures is a much more difficult task. The analysis here, however, suggests a few ways in which this problem may be approached. First, in the course of survey, vegetation should be cleared not only from expected residence areas, but also from several meters surrounding house platforms. A cooking area could easily be missed if covered with thick vegetation, and thus good vegetation clearance is key to a complete survey. Cooking areas are likely to be evidenced by changes in soil color; very dark soils are likely to indicate charcoal deposits.

Once cooking features are located, paleoethnobotanical analysis is key for understanding their function. Fire can preserve plant materials through charring, and thus these areas are the most likely ones in which to find preserved macrobotanical remains. Phytolith analysis can also add to this understanding, especially the use of certain leaf types in cooking, as is common in the Pacific. As heat alters starches, rendering them unidentifiable, starch analysis of sediments at these types of features is not recommended. The cooking feature analyzed during this project showed clear evidence of breadfruit cooking through the paleoethnobotanical record. This is the first time that charred breadfruit skin has been recovered archaeologically in Micronesia, and only the second recorded time in the Pacific (Kahn and Ragone 2013). This highlights the need for sediment flotation at cooking sites. Furthermore, phytolith analysis from this site showed the use of banana leaves in cooking, a practice that is well known in the ethnographic record. This practice would have been invisible without phytolith analysis, as charred leaves almost never preserve in archaeological sites. Thus, this dissertation presents clear

archaeological evidence for breadfruit cooking using leaves as part of the roasting process in the historic period, and develops a model for future paleoethnobotanical recovery of these features.

### **8.5. Pacific Islands Phytolith Analysis and Archaeology**

Finally, I wish to specifically address the questions posed regarding phytolith production in Pacific Islands taxa and the potential of the phytolith record to answer archaeological questions. In order to develop future models for paleoethnobotanical recovery, it is necessary to understand what type of recovery is possible, given the demonstrated variability in phytolith concentrations among plants taxonomically and within different components of individual plants. As phytolith analysis is a relatively new tool in archaeological study (Piperno 2006), an evaluation of the phytolith potential of economic plants in the Pacific is an important result of this study. Phytolith data have been known to be useful in interpreting agricultural activities in the tropical Pacific Islands settings for the past few decades (e.g., Denham et al. 2003; Lentfer and Green 2004; Parr and Carter 2003; Piperno 2006; Tromp and Dudgeon 2015). However, studies of reference materials in the Pacific region are relatively rare, and thus it has previously been unclear how broadly phytolith analysis is applicable. From the data presented in Chapter V, based on an extensive phytolith reference collection, it is evident that many economically important Pacific Islands plants produce taxonomically useful phytoliths. This includes, most notably, palms, grasses, sedges, bananas, breadfruit/breadnut, and kava/*sakau*. On the other hand, as has previously been observed (Piperno 2006), there are

some economically key Pacific taxa, notably yams and taro, which absorb almost no silica and do not produce observable phytoliths. Thus, phytolith analysis is useful for understanding a variety of taxa in Pacific contexts, but cannot provide information on the full spectrum of plant food production activities.

These results are encouraging for the applications of phytolith assemblages in the Pacific Islands, where the humidity and acidic soils are such that preservation of organic remains in the form of plant macroremains is poor. In general, phytoliths are more useful for arboreal taxa and some herbaceous taxa than they are for tuber crops. Thus, phytolith analysis is a critical tool for studying agroforestry systems in the Pacific. Because arboriculture has been considered invisible archaeologically (Latinis 2000), this tool can and should be employed more frequently in projects aiming to study past arboricultural systems.

However, as phytolith analysis is not possible for all important economic Pacific taxa, and as shown in Chapter V, it cannot be used alone to strictly reconstruct local flora, phytolith analysis is most useful in tandem with other forms of analysis. As demonstrated in Chapter VII, phytolith analysis combined with flotation can help one develop a more complete interpretation of features such as cooking areas, as some plants may be more readily preserved by charring, while others are more likely to leave silica bodies. Especially where agricultural preparation tools are preserved, starch analysis is also a useful tool to combine with phytolith analysis, as starchy plants include both significant economic taxa that do not produce phytoliths (yam and taro), as well as those taxa that do (e.g., banana, breadfruit/breadnut, kava/*sakau*, and some palms). Combining starch and

phytolith analysis has the added benefit of pointing towards use of different parts of the plant. Ethnographic analysis, which has been extensively used in the past in understanding arboricultural systems (e.g., Hunter-Anderson 1991; Latinis 2000), can also be used in tandem with phytolith evidence. While ethnographic evidence cannot be used as a direct interpretation of past activities as cultural behavior is continually changing, what it can do is help to develop models of past activity that can then be tested. Evaluating how the activities of food production can take place and the phytoliths that are produced can help to interpret archaeological sites. This type of modeling is seen in Chapters VI and VII, where ethnographic models of breadfruit fermentation and cooking activities are applied towards interpretation of the phytolith record. Key to developing these models is the use of a regional reference collection, which provides invaluable data on phytoliths forms and levels of production.

## **8.6. Future Directions**

While the work conducted in this dissertation answers several key questions on past Pohnpeian food production, as well as further developing and archaeological and paleoethnobotanical techniques that can be applied in studying subsistence, several questions arise from the data presented here that can be explored in future projects. First, some of the vegetation disturbance may be attributed to seasonal swiddening practices on the island, while some of it seems to be more related to the introduction of pigs to the island. It is also possible there could be other yet unknown causes for landscape disturbances. While microcharcoal is interpreted as evidence of swiddening practices, the

relatively regional nature of microcharcoal makes it difficult to evaluate the type of disturbance. Thus, in order to differentiate between localized swiddening and other types of localized vegetation change, macrocharcoal quantification will be necessary. Standardized measurement of macrocharcoal from flotation samples that can be compared with phytolith samples will help to determine whether the swiddening practices suggested by the microcharcoal data are actually local.

As discussed earlier, there is non-random distribution of feature types, especially yam enclosures, within the garden landscape. The reasons for clustering or careful selection are related to both ecological and social factors. While qualitative assessment of soil types suggests that compacted soils are often used for breadfruit pit construction, there may be certain types of soils characterized by particular nutrients that may be more likely to be associated with the construction of agricultural features such as fermentation pits, yam enclosures, and taro gardens. Ladefoged et al. (2010) have conducted analyses on Rapa Nui to show that rock mulch gardens have higher levels of some nutrients than surrounding areas; work like this on Pohnpei could help to explain garden functioning and organization.

Additionally, ethnoarchaeological data could help with interpreting social factors in the spatial organization of gardening. While the Pohnpeian landscape changed with the introduction of pigs to the island, most of the cultivated plants were brought by early settlers and much of the basic traditional ecological knowledge surrounding plant cultivation is of significant antiquity. Thus, mapping of modern garden areas and

interviewing Pohnpeians about how they construct their gardens would aid social interpretations of past gardening activities.

Finally, in terms of methodological issues, fine-grained morphometric analysis of phytolith materials will help distinguish between different plants of the same family or even the same genus. Phytolith morphometric analysis, which focuses on quantitative measurement of individual phytoliths (as opposed to morphological analysis, which relies primarily on qualitatively assessed shape) is becoming increasingly recognized as an important means of identifying phytoliths at lower taxonomic levels (Ball et al. 2015). In Pacific contexts, this is useful in terms of palms (see Bowdery, in press; Fenwick et al. 2011 on this topic), bananas, grasses, and Moraceae/Urticaceae types. It is possible that morphometric analysis of phytoliths may even be able to help distinguish among different varieties of the same cultigen, shedding light on both trade and indigenous development of plant varieties.

Thus, this study presents significant data and interpretation of food production practices in the Pacific past and the relationship of those practices to environmental and social systems. It also paves the way for additional research. The historical ecology of Pohnpei shows that residents have been practicing an arboricultural system with significant tree and root crop production components for long periods of time (Ayres and Haun 1985; Haun 1984). This food production system is managed through periodic swiddening, and took place primarily at the household level, with some larger communal activities. The garden test pit data suggest that the system was relatively stable in its environmental signature until the historic period, which saw the introduction of goods

brought in by foreign traders, including pigs. This led to significant environmental and social change, as pigs became important in Pohnpeian food systems at this time. Pohnpei fits into a larger group of Pacific Islands that have long practiced stable systems of arboriculture, such as Kosrae and Tikopia. This system has been in place since early settlement of the island.

APPENDIX A

ARCHAEOLOGICAL PHYTOLITH DATA

Site PoC3-9, Feature 2, Absolute Counts.

	<b>Globular Echinates</b>	<b>Cross-body</b>	<b>Bilobate</b>	<b>Polylobate</b>	<b>Fan-Shaped Bulliform</b>	<b>Opaque Platelet</b>	<b>Cyperaceae</b>	<b>Volcaniform</b>
<b>0-10 cm</b>	213	38	12	1	7	1	1	2
<b>10-20 cm</b>	262	5	13	1	3	2	0	2
<b>20-30 cm</b>	288	1	0	0	2	0	1	3
<b>30-40 cm</b>	286	1	0	0	4	0	3	0
<b>40-50 cm</b>	289	0	1	1	1	1	1	6
<b>50-60 cm</b>	293	1	1	0	0	0	0	4
<b>60-70 cm</b>	272	6	7	0	1	0	2	10
<b>70-80 cm</b>	270	0	0	0	0	0	0	3
<b>80-90 cm</b>	17	0	1	0	2	0	0	0

	<b>Cylindric</b>	<b>Clavate</b>	<b>Acicular Ruminates</b>	<b>Elongate 1 side echinate</b>	<b>Rondel</b>	<b>Rectangular Crenate</b>	<b>Cuneiform</b>	<b>Y-Shaped</b>
<b>0-10 cm</b>	9	2	1	1	4	8	0	0
<b>10-20 cm</b>	4	2	0	1	0	0	1	1
<b>20-30 cm</b>	3	0	5	2	0	0	0	0
<b>30-40 cm</b>	0	0	3	1	0	0	0	0
<b>40-50 cm</b>	1	0	2	0	0	0	0	0
<b>50-60 cm</b>	0	0	0	0	2	0	0	0
<b>60-70 cm</b>	1	0	2	1	0	0	0	0
<b>70-80 cm</b>	0	0	3	0	0	0	0	0
<b>80-90 cm</b>	0	0	0	0	0	0	0	0

Site PoC3-9, Feature 2, Absolute Counts, continued.

	<b>Elongate Echinata</b>	<b>Cylindric Verrucate</b>	<b>Ovate</b>	<b>Cylindric Pockmarked</b>	<b>Tracheid</b>	<b>Globular Granulate</b>
<b>0-10 cm</b>	0	0	0	0	0	0
<b>10-20 cm</b>	2	0	0	0	0	0
<b>20-30 cm</b>	0	2	0	0	0	0
<b>30-40 cm</b>	1	0	1	0	0	0
<b>40-50 cm</b>	0	0	0	0	0	0
<b>50-60 cm</b>	0	0	0	1	0	0
<b>60-70 cm</b>	0	0	0	0	1	0
<b>70-80 cm</b>	0	0	0	0	1	23
<b>80-90 cm</b>	0	0	0	0	1	1

	<b>Trapeziform Short Cell</b>	<b>Ovate Sinuate</b>	<b>Elongate Sinuate</b>	<b>Total Poaceae</b>	<b>Total Phytoliths</b>	<b>Sponge Spicules</b>	<b>Microcharcoal</b>
<b>0-10 cm</b>	0	0	0	58	300	2	0
<b>10-20 cm</b>	0	0	0	24	299	1	4
<b>20-30 cm</b>	0	0	0	3	307	1	1
<b>30-40 cm</b>	0	0	0	6	300	0	34
<b>40-50 cm</b>	0	0	0	3	303	1	29
<b>50-60 cm</b>	0	0	0	4	302	2	11
<b>60-70 cm</b>	0	0	0	14	303	2	82
<b>70-80 cm</b>	1	2	0	0	303	0	32
<b>80-90 cm</b>	0	0	1	0	23	2	23

Site PoC3-10, Pit Exterior, Absolute Counts.

	<b>Globular echinate</b>	<b>Bilobate</b>	<b>Cross-Body</b>	<b>Elongate Echinata</b>	<b>Elongate</b>	<b>Saddle</b>	<b>Fan-Shaped Bulliform</b>	<b>Volcaniform</b>	<b>Clavate</b>
<b>0-10 cm</b>	17	149	8	25	16	15	22	12	1
<b>10-20 cm</b>	10	125	8	27	32	22	16	11	2
<b>20-30 cm</b>	66	61	3	25	42	9	18	12	3
<b>30-40 cm</b>	1	0	0	0	2	0	0	0	0
<b>40-50 cm</b>	37	11	4	3	10	2	0	3	1
<b>50-60 cm</b>	3	1	0	1	0	0	0	8	0
<b>60-70 cm</b>	289	3	0	0	1	0	0	5	0
<b>70-80 cm</b>	1	0	0	0	0	0	0	0	0
<b>80-90 cm</b>	0	0	0	0	0	0	0	0	0
<b>90-100 cm</b>	0	0	0	0	0	0	0	0	0

	<b>Acicular Psilate</b>	<b>Cuneiform</b>	<b>Reniform</b>	<b>Rondel</b>	<b>Globular Psilate</b>	<b>Stellate</b>	<b>Hexagonal</b>	<b>Polylobate</b>	<b>Elongate echinate one-sided</b>
<b>0-10 cm</b>	1	10	3	9	6	1	2	1	2
<b>10-20 cm</b>	0	26	1	5	0	0	0	1	7
<b>20-30 cm</b>	3	19	5	12	0	0	0	1	5
<b>30-40 cm</b>	0	0	0	0	0	0	0	0	0
<b>40-50 cm</b>	0	2	0	0	0	0	0	0	2
<b>50-60 cm</b>	2	0	0	0	1	0	0	0	0
<b>60-70 cm</b>	0	0	0	0	0	0	0	0	0
<b>70-80 cm</b>	0	0	0	0	0	0	0	0	0
<b>80-90 cm</b>	0	0	0	0	0	0	0	0	0
<b>90-100 cm</b>	0	0	0	0	0	0	0	0	0

Site PoC3-10, Pit Exterior, Absolute Counts, continued.

	Jigsaw	Rectangular cavate	Acicular Ruminant	Elongate Ruminant	Cyperaceae	Lanceolate	Oblong	Tracheid
0-10 cm	2	4	0	0	0	0	0	0
10-20 cm	0	0	7	1	0	0	0	0
20-30 cm	0	1	3	0	5	5	2	0
30-40 cm	0	0	0	0	0	0	0	0
40-50 cm	0	0	0	0	10	4	0	1
50-60 cm	0	0	0	0	0	0	0	0
60-70 cm	0	0	0	0	2	3	0	0
70-80 cm	0	0	0	0	0	0	0	0
80-90 cm	0	0	0	0	0	0	0	0
90-100 cm	0	0	0	0	0	0	0	0

	Acicular Echinat	Globular Granulate	Bulliform	Smooth Fan Bulliform	Unknown Seed-Shaped	Sponge Spicules
0-10 cm	0	0	0	0	0	1
10-20 cm	0	0	0	0	0	0
20-30 cm	0	0	0	0	0	8
30-40 cm	0	0	0	0	0	0
40-50 cm	1	0	0	0	0	4
50-60 cm	0	2	1	0	0	0
60-70 cm	0	0	3	4	1	1
70-80 cm	0	0	2	0	0	0
80-90 cm	0	0	0	0	0	0
90-100 cm	0	0	0	0	0	0

Site PoC3-10, Pit Interior, Absolute Counts.

	<b>Globular Echinata</b>	<b>Volcaniform</b>	<b>Elongate 1 side echinate</b>	<b>Bilobate</b>	<b>Cross-body</b>	<b>Elongate echinate</b>	<b>Elongate tuberculate</b>
<b>60-70 cm</b>	35	16	3	153	11	17	1
<b>70-80 cm</b>	49	16	6	148	22	20	0
<b>80-90 cm</b>	6	12	5	98	8	20	0
<b>90-100 cm</b>	6	4	15	89	6	26	0
<b>100-110 cm</b>	1	7	7	61	3	28	0
<b>110-120 cm</b>	2	11	5	89	10	23	0
<b>120-134 cm</b>	0	1	0	5	0	0	0

	<b>Elongate psilate</b>	<b>Ovate Bulliform</b>	<b>Saddle</b>	<b>Fan-shaped bulliform</b>	<b>Polylobate</b>	<b>Rondel</b>	<b>Jigsaw</b>	<b>Clavate</b>	<b>Rectangular Cavate</b>
<b>60-70 cm</b>	13	4	24	9	3	4	4	2	4
<b>70-80 cm</b>	9	3	11	5	0	1	2	4	5
<b>80-90 cm</b>	71	0	29	7	1	2	0	9	4
<b>90-100 cm</b>	90	0	12	11	0	0	2	12	0
<b>100-110 cm</b>	97	0	8	9	0	3	0	11	0
<b>110-120 cm</b>	51	0	18	12	3	6	7	15	6
<b>120-134 cm</b>	7	0	2	0	0	0	0	0	1

Site PoC3-10, Pit Interior, Absolute Counts, continued.

	Lanceolate	Acicular Psilate	Hexagonal	Lanceolate Ruminate	Unciform Hair Cell	Cuneiform	Reniform	Oblong
<b>60-70 cm</b>	2	0	0	0	0	0	0	0
<b>70-80 cm</b>	0	1	1	0	0	0	0	0
<b>80-90 cm</b>	0	5	1	2	3	5	10	0
<b>90-100 cm</b>	1	3	0	0	1	11	7	5
<b>100-110 cm</b>	0	6	0	0	0	7	3	2
<b>110-120 cm</b>	1	5	0	0	0	15	7	1
<b>120-134 cm</b>	0	1	0	0	0	1	10	0

	Semi- Circular	Trapeziform Short Cell	Acicular Echinate	Lanceolate Cavate	Trapeziform Sinuate	Sickle-shaped
<b>60-70 cm</b>	0	0	0	0	0	0
<b>70-80 cm</b>	0	0	0	0	0	0
<b>80-90 cm</b>	0	0	0	0	0	0
<b>90-100 cm</b>	0	0	0	0	0	0
<b>100-110 cm</b>	11	1	1	4	1	0
<b>110-120 cm</b>	2	0	0	2	0	3
<b>120-134 cm</b>	14	0	0	0	0	0

Site PoC3-10, Pit Interior, Absolute Counts, continued.

	Cyperaceae	Teardrop Shaped	Opaque Platelet	Sponge Spicules
60-70 cm	0	0	0	0
70-80 cm	0	0	0	0
80-90 cm	0	0	0	8
90-100 cm	0	0	0	5
100-110 cm	0	0	0	3
110-120cm	1	5	0	0
120-134cm	0	0	1	0

Site PoC3-11, Test Pit 1, Absolute Counts.

	Globular Echinate	Volcaniform	Elongate 1 side echinate	Bilobate	Cross-body	Elongate echinate	Elongate	Saddle
0-10 cm	85	6	3	36	2	27	24	53
10-20 cm	147	3	0	29	6	26	22	25
20-30 cm	253	8	0	2	0	8	14	2
30-40 cm	159	8	6	18	4	29	22	7
40-50 cm	85	4	3	10	0	14	29	2
50-60 cm	258	4	0	4	1	3	13	3
60-70 cm	254	3	0	1	0	1	17	4
70-80 cm	284	0	0	5	2	2	2	2
80-90 cm	237	1	0	1	1	3	9	3
90-100 cm	253	0	0	13	1	8	7	7

Site PoC3-11, Test Pit 1, Absolute Counts, continued.

	<b>Fan-shaped bulliform</b>	<b>Clavate</b>	<b>Cuneiform</b>	<b>Reniform</b>	<b>Rondel</b>	<b>Acicular</b>	<b>Lanceolate cavate</b>	<b>Lanceolate</b>
<b>0-10 cm</b>	29	2	4	2	3	4	2	15
<b>10-20 cm</b>	14	1	0	3	3	3	0	9
<b>20-30 cm</b>	0	0	1	0	0	2	0	0
<b>30-40 cm</b>	12	1	7	0	5	2	1	10
<b>40-50 cm</b>	1	1	1	0	4	3	0	8
<b>50-60 cm</b>	0	0	0	0	2	2	0	0
<b>60-70 cm</b>	1	0	0	0	7	4	0	0
<b>70-80 cm</b>	0	0	1	0	5	0	0	0
<b>80-90 cm</b>	0	0	0	0	11	0	0	1
<b>90-100 cm</b>	3	0	0	0	2	1	0	2

	<b>Rectangular Cavate</b>	<b>Jigsaw</b>	<b>Smooth Fan-Shaped Bulliform</b>	<b>Hexagonal pockmarked</b>	<b>Bulliform other type</b>	<b>Cyperaceae</b>
<b>0-10 cm</b>	2	1	0	0	0	0
<b>10-20 cm</b>	2	0	7	1	0	0
<b>20-30 cm</b>	2	0	1	0	1	1
<b>30-40 cm</b>	5	0	2	0	0	0
<b>40-50 cm</b>	3	0	0	0	0	5
<b>50-60 cm</b>	0	0	0	0	0	0
<b>60-70 cm</b>	1	0	0	0	0	4
<b>70-80 cm</b>	1	0	0	0	0	0
<b>80-90 cm</b>	0	0	0	0	0	0
<b>90-100 cm</b>	0	0	0	0	0	2

Site PoC3-11, Test Pit 1, Absolute Counts, continued.

	<b>Unciform Hair Cell</b>	<b>Bulb-Shaped Bulliform</b>	<b>Rectangular with central notch</b>	<b>Acicular Echinete</b>	<b>Lanceolate Ruminante</b>
<b>0-10 cm</b>	0	0	0	0	0
<b>10-20 cm</b>	0	0	0	0	0
<b>20-30 cm</b>	1	0	0	0	0
<b>30-40 cm</b>	0	1	1	0	0
<b>40-50 cm</b>	0	0	0	4	0
<b>50-60 cm</b>	0	0	0	0	7
<b>60-70 cm</b>	1	0	0	0	0
<b>70-80 cm</b>	0	0	0	0	0
<b>80-90 cm</b>	0	0	0	0	0
<b>90-100 cm</b>	1	0	0	0	0

	<b>Seed-shaped bulliform</b>	<b>Elongate Ruminante</b>	<b>Tracheid</b>	<b>Total</b>	<b>Sponge Spicule</b>	<b>Microcharcoal</b>
<b>0-10 cm</b>	0	0	0	307	1	0
<b>10-20 cm</b>	0	0	0	301	3	70
<b>20-30 cm</b>	0	0	0	296	23	72
<b>30-40 cm</b>	0	0	0	300	51	166
<b>40-50 cm</b>	0	0	0	177	49	232
<b>50-60 cm</b>	0	0	0	297	11	80
<b>60-70 cm</b>	0	0	0	298	18	95
<b>70-80 cm</b>	0	0	0	308	0	32
<b>80-90 cm</b>	1	7	0	301	1	225
<b>90-100 cm</b>	0	0	3	303	2	95

PoC3-12, Feature 4, Absolute Counts.

	<b>Globular Echinata</b>	<b>Globular Granulate</b>	<b>Globular Psilate</b>	<b>Bilobate</b>	<b>Cross-Body</b>	<b>Cuneiform</b>	<b>Trapeziform Short Cell</b>	<b>Acicular Psilate</b>
<b>0-10 cm</b>	175	16	3	21	10	1	1	2
<b>10-20 cm</b>	188	2	0	28	8	0	0	0
<b>20-30 cm</b>	87	3	0	25	10	3	0	0
<b>30-40 cm</b>	143	3	0	15	14	1	1	0
<b>40-50 cm</b>	20	5	0	28	29	5	0	0
<b>50-60 cm</b>	0	0	0	0	0	0	0	0
<b>60-70 cm</b>	4	1	0	0	0	0	0	0
<b>70-80 cm</b>	0	0	0	0	0	0	0	0

	<b>Cyperaceae</b>	<b>Elongate</b>	<b>Acicular Echinata</b>	<b>Ovate Bulliform</b>	<b>Cavate Ovate</b>	<b>Saddle</b>	<b>Elongate Cavate</b>	<b>Fan-shaped bulliform</b>	<b>Clavate</b>
<b>0-10 cm</b>	3	10	3	5	2	5	1	8	0
<b>10-20 cm</b>	1	12	0	2	0	14	0	1	3
<b>20-30 cm</b>	2	18	1	0	0	35	0	18	4
<b>30-40 cm</b>	31	3	0	0	0	12	0	18	5
<b>40-50 cm</b>	3	10	1	5	0	28	0	31	0
<b>50-60 cm</b>	0	1	0	0	0	0	0	0	0
<b>60-70 cm</b>	0	0	0	0	0	0	0	0	0
<b>70-80 cm</b>	0	0	0	0	0	0	0	0	0

PoC3-12, Feature 4, Absolute Counts, continued.

	<b>Acicular Ruminate</b>	<b>Mushroom Shaped</b>	<b>Elongate tuberculate</b>	<b>Elongate echinate</b>	<b>Elongate 1 side echinate</b>
<b>0-10 cm</b>	0	0	6	5	2
<b>10-20 cm</b>	0	0	0	11	3
<b>20-30 cm</b>	0	1	0	32	8
<b>30-40 cm</b>	0	0	0	32	3
<b>40-50 cm</b>	3	0	0	17	12
<b>50-60 cm</b>	0	0	0	0	0
<b>60-70 cm</b>	0	0	0	0	0
<b>70-80 cm</b>	0	0	0	0	0

	<b>Elongate 1 side tuberculate</b>	<b>Large globular echinate</b>	<b>Volcaniform</b>	<b>Tracheid</b>	<b>Sponge Spicules</b>
<b>0-10 cm</b>	5	1	19	5	14
<b>10-20 cm</b>	0	0	21	0	5
<b>20-30 cm</b>	0	0	36	3	11
<b>30-40 cm</b>	0	0	19	2	5
<b>40-50 cm</b>	0	0	15	4	3
<b>50-60 cm</b>	0	0	0	0	0
<b>60-70 cm</b>	0	0	1	0	0
<b>70-80 cm</b>	0	0	0	1	0

PoC3-18, Feature 1, Outside Pit (South End), Absolute Counts.

	<b>Globular Echinat</b>	<b>Poaceae</b>	<b>Woody sp.</b>	<b>Musaceae</b>	<b>Acicular Psilate</b>	<b>Elongate Psilate</b>	<b>Tracheid</b>	<b>Opaque Platelet</b>
<b>0-10 cm</b>	118	48	11	4	1	3	1	0
<b>10-20 cm</b>	192	5	2	0	1	0	0	0
<b>20-30 cm</b>	24	3	11	6	0	0	0	0
<b>40-50 cm</b>	192	5	0	3	0	0	8	3
<b>50-60 cm</b>	65	27	25	16	41	15	86	0
<b>60-70 cm</b>	15	0	16	9	1	6	46	0
<b>70-80 cm</b>	21	2	6	11	4	0	44	5
<b>80-90 cm</b>	0	0	2	8	1	0	31	0
<b>90-100 cm</b>	10	0	14	7	0	0	6	0
<b>100-110 cm</b>	3	0	4	6	0	0	15	0
<b>110-120 cm</b>	1	1	4	11	0	0	0	0

	<b>Acicular Echinat</b>	<b>Unciform Hair Cell</b>	<i>Total Phytoliths</i>
<b>0-10 cm</b>	0	0	199
<b>10-20 cm</b>	0	0	202
<b>20-30 cm</b>	0	0	56
<b>40-50 cm</b>	0	0	200
<b>50-60 cm</b>	5	5	301
<b>60-70 cm</b>	2	2	100
<b>70-80 cm</b>	4	0	119
<b>80-90 cm</b>	0	0	43
<b>90-100 cm</b>	0	0	55
<b>100-110 cm</b>	0	0	13
<b>110-120 cm</b>	0	0	47

PoC3-18, Feature 1, Inside Pit (North End), Absolute Counts.

	Arecaeae	Poaceae	Musaceae	Woody sp.	Acicular Hair Cell	Cylindric	Tracheid	Opaque Platelet
<b>45-50 cm</b>	169	25	2	1	0	1	2	0
<b>50-60 cm</b>	86	41	0	71	2	0	0	0
<b>60-70 cm</b>	153	34	11	3	0	4	0	0
<b>70-80 cm</b>	86	88	0	12	1	0	6	0
<b>80-90 cm</b>	27	5	4	6	5	2	15	3
<b>90-100 cm</b>	7	3	6	12	0	2	3	0
<b>100-110 cm</b>	4	3	11	9	0	6	40	1
<b>110-120 cm</b>	1	0	1	0	0	0	1	0
<b>120-130 cm</b>	1	0	1	1	0	0	0	0

	Acicular Echinat Hair Cell	Unciform Hair Cell	<i>Total Phytolith Count</i>
<b>45-50 cm</b>	0	0	204
<b>50-60 cm</b>	0	0	201
<b>60-70 cm</b>	0	0	209
<b>70-80 cm</b>	2	2	202
<b>80-90 cm</b>	0	1	75
<b>90-100 cm</b>	0	0	33
<b>100-110 cm</b>	0	0	87
<b>110-120 cm</b>	1	0	25
<b>120-130 cm</b>	0	0	57

## APPENDIX B

## REFERENCE PHYTOLITH DATA

## Samples from Temwen Island, Pohnpei.

Species	Variety	Family	Plant Part	Phytolith Type	Example #	Max. Width (µm)	Max Height (µm)
<i>Alocasia macrorrhizos</i>		Araceae	leaf/stem	NONE			
<i>Colocasia esculenta</i>		Araceae	leaf/stem	NONE			
<i>Cyrtosperma merkusii</i>		Araceae	leaf/stem	NONE			
<i>Areca catechu</i>		Arecaceae	bark	globular echinate	1	7.18	7.55
<i>Areca catechu</i>		Arecaceae	bark	globular psilate	2	8.03	8.02
<i>Areca catechu</i>		Arecaceae	bark	elongate tabular epidermal	3		
<i>Areca catechu</i>		Arecaceae	leaf	globular echinate	1	6.62	5.18
<i>Areca catechu</i>		Arecaceae	leaf	elongate tabular epidermal	2		
<i>Cocos nucifera</i>		Arecaceae	bark/stem	NONE			
<i>Cocos nucifera</i>		Arecaceae	leaf	opaque platelet (may not be phytolith)			
<i>Nypa fruticans</i>		Arecaceae	bark	NONE			

Samples from Temwen Island, Pohnpei, continued.

Species	Variety	Family	Plant Part	Phytolith Type	Example #	Max. Width (µm)	Max Height (µm)
<i>Nypa fruticans</i>		Arecaceae	leaf	elongate epidermal	1		
<i>Nypa fruticans</i>		Arecaceae	leaf	various (tracheid, epidermal, globular)	2		
<i>Nypa fruticans</i>		Arecaceae	leaf	divided oval	3	73.7	44.76
<i>Asplenium nidus</i>		Aspleniaceae	frond	NONE			
<i>Asplenium polyodon</i>		Aspleniaceae	frond	NONE			
<i>Asplenium polyodon</i>		Aspleniaceae	stem	NONE			
<i>Asplenium polyodon</i>		Aspleniaceae	roots	NONE			
??		Asteraceae	whole plant	NONE			
??		Cyperaceae	leaf	various	1		
??		Cyperaceae	leaf	various	2		
??		Cyperaceae	leaf	various	3		18.55
??		Cyperaceae	leaf	bulliform	4	27.34	37.2
??		Cyperaceae	leaf	acicular echinate hair cell	5	77.23	8.74
??		Cyperaceae	leaf	hexagonal scrobiculate	6	93.57	41.43
??		Cyperaceae	flower	hexagonal scrobiculate	1	81.87	42

Samples from Temwen Island, Pohnpei, continued.

Species	Variety	Family	Plant Part	Phytolith Type	Example #	Max. Width (µm)	Max Height (µm)
??		Cyperaceae	flower	hexagonal scrobiculate in context	2		
??		Cyperaceae	flower	scrobiculate	3		
??		Cyperaceae	flower	various	4		
??		Cyperaceae	flower	hexagonal scrobiculate (side view)	5	73.56	
??		Cyperaceae	root	NONE			
<i>Dioscorea sp.</i>	Variety 2	Dioscoreaceae	leaf	NONE			
<i>Dioscorea sp.</i>		Dioscoreaceae	leaf/stem	NONE			
<i>Tacca leontopetaloides</i>		Dioscoreaceae	leaf/stem	NONE			
<i>Macaranga carolinensis</i>		Euphorbiaceae	leaf	sinuate epidermal	1		
<i>Macaranga carolinensis</i>		Euphorbiaceae	leaf	sinuate epidermal	2		
<i>Macaranga carolinensis</i>		Euphorbiaceae	leaf	acicular hair cell, bent	3	22.55	163.61
<i>Macaranga carolinensis</i>		Euphorbiaceae	leaf	sinuate epidermal	4	42	27.06
<i>Macaranga carolinensis</i>		Euphorbiaceae	leaf	acicular psilate hair cell	5	91.04	12.12

Samples from Temwen Island, Pohnpei, continued.

Species	Variety	Family	Plant Part	Phytolith Type	Example #	Max. Width (µm)	Max Height (µm)
<i>Macaranga carolinensis</i>		Euphorbiaceae	leaf	hair base	6	62.57	80.61
<i>Macaranga carolinensis</i>		Euphorbiaceae	bark	cylindric	1	81.74	
<i>Macaranga carolinensis</i>		Euphorbiaceae	bark	elongate one-sided sulcate	2	52.42	19.45
<i>Paraderris elliptica</i>		Fabaceae	leaf	epidermal	1	32.13	30
<i>Clerodendrum Inerme</i>		Lamiaceae	leaf/stem	NONE			
<i>Cordyline fruticosa</i>		Laxmanniaceae	leaf/stem	NONE			
<i>Cordyline fruticosa</i>		Laxmanniaceae	leaf	NONE			
<i>Hertiera littoralis</i>		Malvaceae	leaf/stem	NONE			
<i>Hibiscus tiliaceus</i>		Malvaceae	bark	cylindric	1	141.49	3.38
<i>Hibiscus tiliaceus</i>		Malvaceae	leaf	cylindric	1	133.31	4.79
<i>Artocarpus altilis</i>	Mei Unpw	Moraceae	leaf	acicular echinate hair cell	1	141.63	
<i>Artocarpus altilis</i>	Mei Unpw	Moraceae	leaf	acicular echinate hair cell	2	71.31	

Samples from Temwen Island, Pohnpei, continued.

Species	Variety	Family	Plant Part	Phytolith Type	Example #	Max. Width (µm)	Max Height (µm)
<i>Artocarpus altilis</i>	Mei Unpw	Moraceae	leaf	acicular echinate hair cell	3	52.61	
<i>Artocarpus altilis</i>	Mei Unpw	Moraceae	leaf	hair base	1	35.44	
<i>Artocarpus altilis</i>	Mei Unpw	Moraceae	leaf	hair cell and hair base	1		21.28
<i>Artocarpus altilis</i>	Mei Unpw	Moraceae	leaf	various	1		
<i>Piper methysticum</i>	sakau	Piperaceae	leaf/stem	epidermal	2	22.83	16.91
<i>Piper methysticum</i>	sakau	Piperaceae	leaf/stem	pyramidal favose	3	10.43	10.43
<i>Piper methysticum</i>	sakau	Piperaceae	leaf/stem	stellate	4	13.53	18.32
<i>Piper methysticum</i>	sakau	Piperaceae	leaf/stem	ovate	5	26.21	24.38
<i>Piper methysticum</i>	sakau	Piperaceae	leaf/stem	scrobiculate, epidermal	6		
<i>Piper methysticum</i>	sakau	Piperaceae	leaf/stem	various	7		
<i>Piper ponapense</i>		Piperaceae	leaf/stem	octagonal	1	35.42	38.16
<i>Piper ponapense</i>		Piperaceae	leaf/stem	epidermal (tabular and scrobiculate)	2		

Samples from Temwen Island, Pohnpei, continued.

Species	Variety	Family	Plant Part	Phytolith Type	Example #	Max. Width (µm)	Max Height (µm)
<i>Piper ponapense</i>		Piperaceae	leaf/stem	epidermal (tabular)	3		
<i>Piper ponapense</i>		Piperaceae	leaf/stem	tracheid	4		
<i>Ischaemum polystachyum</i>	reh padil	Poaceae	leaf/stem	bilobate	1	18.18	8.6
<i>Ischaemum polystachyum</i>	reh padil	Poaceae	leaf/stem	various epidermal	2		
<i>Ischaemum polystachyum</i>	reh padil	Poaceae	leaf/stem	trapeziform	3	7.33	7.05
<i>Ischaemum polystachyum</i>	reh padil	Poaceae	leaf/stem	sinuate elongated epidermal	4	18.6	7.33
<i>Ischaemum polystachyum</i>	reh padil	Poaceae	leaf/stem	elongate segmented	5	72.43	4.51
<i>Ischaemum polystachyum</i>	reh padil	Poaceae	leaf/stem	elongate echinate	6	79.2	19.17
<i>Ischaemum polystachyum</i>	reh padil	Poaceae	leaf/stem	rondel	7	15.22	7.05
??		Poaceae	leaf	various	1		
??		Poaceae	leaf	cross-body	2	13.87	10.15
??		Poaceae	leaf	bilobate	3	18.18	9.91
??		Poaceae	leaf	trapeziform	4	11.98	7.6

Samples from Temwen Island, Pohnpei, continued.

Species	Variety	Family	Plant Part	Phytolith Type	Example #	Max. Width (µm)	Max Height (µm)
??		Poaceae	leaf	epidermal, various (incl. long cells)	5		
??		Poaceae	leaf	elongate sinuate	6	71.73	15.2
??		Poaceae	leaf	elongate papillate	7	61.29	28.86
??		Poaceae	leaf	square	8	23.95	20.98
??		Poaceae	leaf	elongate	9	44.39	9.58
<i>Ixora casei</i>		Rubiaceae	leaf	NONE			
<i>Cyclosorus heterocarpus</i>		Thelypteridaceae	leaves/frond	amorphous castelate epidermal cell	1	55.52	72.15
<i>Cyclosorus heterocarpus</i>		Thelypteridaceae	leaves/frond	segmented elongate	2	266.49	
<i>Cyclosorus heterocarpus</i>		Thelypteridaceae	leaves/frond	orbicular sulcate	3	46.93	35.22
<i>Cyclosorus heterocarpus</i>		Thelypteridaceae	leaves/frond	various	4		
<i>Cyclosorus heterocarpus</i>		Thelypteridaceae	leaves/frond	orbicular (double circle)	5	16.07	16.91
<i>Cyclosorus heterocarpus</i>		Thelypteridaceae	stem	epidermal	1		

**Samples From Manoa, O'ahu, Hawai'i.**

<b>Species</b>	<b>Variety</b>	<b>Family</b>	<b>Plant Part</b>	<b>Phytolith Type</b>	<b>Example #</b>	<b>Max Width (µm)</b>	<b>Max Height (µm)</b>
<i>Centella asiatica</i>		Apiaceae	whole plant	NONE			
<i>Cocos nucifera</i>		Areaceae	bark	NONE			
<i>Cocos nucifera</i>		Areaceae	leaf	globular echinate	1	8.16	8.08
<i>Cocos nucifera</i>		Areaceae	leaf	globular echinate cluster	2		
<i>Metroxylon amicarum</i>		Areaceae	leaf	globular echinate	1	16.28	16.43
<i>Metroxylon amicarum</i>		Areaceae	leaf	globular echinate	2	8.03	7.74
<i>Metroxylon amicarum</i>		Areaceae	leaf	epidermal	3		
<i>Metroxylon amicarum</i>		Areaceae	leaf	elongate echinate epidermal	4	29.68	11.3
<i>Metroxylon amicarum</i>		Areaceae	leaf	tracheid	5	175.59	21.7
<i>Metroxylon amicarum</i>		Areaceae	leaf	various	6		
<i>Metroxylon amicarum</i>		Areaceae	bark	epidermal	1		
<i>Metroxylon amicarum</i>		Areaceae	bark	elongate	2	195.6	17.47
<i>Metroxylon amicarum</i>		Areaceae	root	globular echinate	1	10.57	12.73

Samples From Manoa, O'ahu, Hawai'i, continued.

Species	Variety	Family	Plant Part	Phytolith Type	Example #	Max Width (µm)	Max Height (µm)
<i>Metroxylon amicarum</i>		Areaceae	nut	epidermal mass (amorphous)	1		
<i>Metroxylon amicarum</i>		Areaceae	nut	elongate epidermal	2		
<i>Metroxylon amicarum</i>		Areaceae	inflorescence	various	1		
<i>Metroxylon amicarum</i>		Areaceae	inflorescence	tracheid	2	34.01	7
<i>Metroxylon amicarum</i>		Areaceae	inflorescence	globular echinate	3	6.2	5.64
<i>Asplenium nidus</i>		Aspleniaceae	frond	NONE			
<i>Cordia subcordata</i>		Boraginaceae	leaf/stem	orbicular epidermal	1	12.97	14.34
<i>Cordia subcordata</i>		Boraginaceae	leaf/stem	rectangular epidermal	2	35.42	22.13
<i>Cordia subcordata</i>		Boraginaceae	leaf/stem	rectangular echinate (one sided)	3	59.39	53
<i>Cordia subcordata</i>		Boraginaceae	leaf/stem	amorphous epidermal	4		
<i>Cordia subcordata</i>		Boraginaceae	leaf/stem	tracheid	5	240.65	39.18
<i>Dioscorea bulbifera</i>		Dioscoreaceae	leaf/stem/root	NONE			

Samples From Manoa, O'ahu, Hawai'i, continued.

Species	Variety	Family	Plant Part	Phytolith Type	Example #	Max Width (µm)	Max Height (µm)
<i>Dioscorea bulbifera</i>		Dioscoreaceae	bulb	elongate	1	7.33	
<i>Aleurites moluccana</i>		Euphorbiaceae	leaf/stem	cuneiform epidermal	1		
<i>Aleurites moluccana</i>		Euphorbiaceae	fruit	tracheid	1		
<i>Aleurites moluccana</i>		Euphorbiaceae	fruit	orbicular cluster	2		
<i>Aleurites moluccana</i>		Euphorbiaceae	fruit	opaque platelet	3	116.69	44.79
<i>Adenanthera pavonina</i>		Fabaceae	leaf/stem	NONE			
<i>Adenanthera pavonina</i>		Fabaceae	legume	NONE			
<i>Adenanthera pavonina</i>		Fabaceae	bark	NONE			
<i>Inocarpus fagifer</i>		Fabaceae	leaf/stem	NONE			
<i>Inocarpus fagifer</i>		Fabaceae	nut exterior	NONE			
<i>Paraderris elliptica</i>		Fabaceae	leaf/stem	sinuate epidermal	1	39.74	22.56
<i>Paraderris elliptica</i>		Fabaceae	leaf/stem	sinuate epidermal	2	46.84	36.78

Samples From Manoa, O'ahu, Hawai'i, continued.

Species	Variety	Family	Plant Part	Phytolith Type	Example #	Max Width (µm)	Max Height (µm)
<i>Paraderris elliptica</i>		Fabaceae	leaf/stem	ovate with central indentation	3	19.73	17.47
<i>Paraderris elliptica</i>		Fabaceae	leaf/stem	hook cell	4	118.67	15.02
<i>Paraderris elliptica</i>		Fabaceae	leaf/stem	elongate epidermal	5	18.32	8.46
<i>Barringtonia racemosa</i>		Lecythidaceae	leaf	cuneiform	1	10.57	11.34
<i>Barringtonia racemosa</i>		Lecythidaceae	leaf	orbicular/globular	2	10.95	10.03
<i>Cordyline fruticosa</i>		Laxmanniaceae	leaf/stem	NONE			
<i>Hibiscus</i> sp. (?)		Malvaceae	leaf/stem	tabular epidermal	1	18.6	
<i>Hibiscus</i> sp. (?)		Malvaceae	leaf/stem	acicular papillate	2	164.61	17.8
<i>Hibiscus</i> sp. (?)		Malvaceae	leaf/stem	tracheid	3	61.72	15.78
<i>Hibiscus</i> sp. (?)		Malvaceae	leaf/stem	various	4		
<i>Hibiscus</i> sp. (?)		Malvaceae	leaf/stem	epidermal bundle	5		
<i>Hibiscus</i> sp. (?)		Malvaceae	leaf/stem	epidermal single pits	6		

Samples From Manoa, O'ahu, Hawai'i, continued.

Species	Variety	Family	Plant Part	Phytolith Type	Example #	Max Width (µm)	Max Height (µm)
<i>Hibiscus</i> sp. (?)		Malvaceae	leaf/stem	ovate	7		
<i>Hibiscus</i> sp. (?)		Malvaceae	leaf/stem	acicular hair cell	8	116.33	12.67
<i>Hibiscus</i> sp. (?)		Malvaceae	nut	epidermal, tracheid	1		
<i>Angiopteris evecta</i>		Marattiaceae	frond	various scrobiculate	1		
<i>Angiopteris evecta</i>		Marattiaceae	frond	rectangular scrobiculate	2	17.47	11.84
<i>Artocarpus camansi</i>		Moraceae	leaf	various (epidermal, hair base)	1		
<i>Artocarpus camansi</i>		Moraceae	leaf	epidermal	2	10.15	12.68
<i>Artocarpus camansi</i>		Moraceae	leaf	unciform hair cell	3	185.17	28.47
<i>Artocarpus camansi</i>		Moraceae	leaf	acicular echinate hair cell	4	135.85	16.63
<i>Artocarpus camansi</i>		Moraceae	leaf	hair base	5	19.17	20.86
<i>Artocarpus camansi</i>		Moraceae	leaf	acicular psilate hair cell	6	203.49	9.58
<i>Artocarpus camansi</i>		Moraceae	leaf	acicular echinate hair cell	7	168.93	32.9

Samples From Manoa, O'ahu, Hawai'i, continued.

Species	Variety	Family	Plant Part	Phytolith Type	Example #	Max Width (µm)	Max Height (µm)
<i>Artocarpus camansi</i>		Moraceae	leaf	various	8		
<i>Artocarpus camansi</i>		Moraceae	nut	NONE			
<i>Ficus tinctoria</i>		Moraceae	leaf	acicular hair cell curled base	1	127.78	5.14
<i>Ficus tinctoria</i>		Moraceae	leaf	various epidermal	2		
<i>Ficus tinctoria</i>		Moraceae	leaf	orbicular	3	25.29	22.3
<i>Ficus tinctoria</i>		Moraceae	leaf	hook cell	4	20.29	5.36
<i>Ficus tinctoria</i>		Moraceae	leaf	various epidermal	5		
<i>Ficus tinctoria</i>		Moraceae	leaf	tracheid	6		
<i>Ficus tinctoria</i>		Moraceae	leaf	rectangular scrobiculate	7	49.75	28.39
<i>Ficus tinctoria</i>		Moraceae	leaf	acicular papillate	8	53.07	7.82
<i>Ficus tinctoria</i>		Moraceae	leaf	globular	9	13.39	9.96
<i>Pandanus tectorus</i>		Pandanaceae	bark	NONE			
<i>Pandanus tectorus</i>		Pandanaceae	leaf	NONE			
<i>Pandanus tectorus</i>		Pandanaceae	fruit				
<i>Piper betle</i>		Piperaceae	leaf/stem	epidermal (blocky)	1		
<i>Piper betle</i>		Piperaceae	leaf/stem	scrobiculate epidermal	2		

Samples From Manoa, O'ahu, Hawai'i, continued.

Species	Variety	Family	Plant Part	Phytolith Type	Example #	Max Width (µm)	Max Height (µm)
<i>Piper betle</i>		Piperaceae	inflorescence	amorphous	1		
<i>Piper betle</i>		Piperaceae	inflorescence	elongate	2	34.43	12.02
<i>Piper betle</i>		Piperaceae	inflorescence	epidermal	3		
<i>Bambusa vulgaris</i>		Poaceae	leaf/stem	rondel	1	19.59	17.99
<i>Bambusa vulgaris</i>		Poaceae	leaf/stem	elongate	2	49.24	12.73
<i>Bambusa vulgaris</i>		Poaceae	leaf/stem	bulliform	3	41.57	38.75
<i>Bambusa vulgaris</i>		Poaceae	leaf/stem	rondel	4	11.56	9.58
<i>Bambusa vulgaris</i>		Poaceae	leaf/stem	rondel	5	14.66	8.74
<i>Bambusa vulgaris</i>		Poaceae	leaf/stem	bulliform	6	22.27	15.22
<i>Bambusa vulgaris</i>		Poaceae	leaf/stem	epidermal	7		
<i>Bambusa vulgaris</i>		Poaceae	leaf/stem	short cell and epidermal	8	8.74	8.17
<i>Bambusa vulgaris</i>		Poaceae	leaf/stem	elongate papillate	9	12.12	7.61
<i>Bambusa vulgaris</i>		Poaceae	leaf/stem	saddle	10	27.2	16.37
<i>Bambusa vulgaris</i>		Poaceae	leaf/stem	acicular hair cell	11	202.51	7.93

Samples From Manoa, O'ahu, Hawai'i, continued.

Species	Variety	Family	Plant Part	Phytolith Type	Example #	Max Width (µm)	Max Height (µm)
<i>Bambusa vulgaris</i>		Poaceae	leaf/stem	epidermal	12		
<i>Bambusa vulgaris</i>		Poaceae	leaf/stem	tracheid	13	127.68	12.12
<i>Bambusa vulgaris</i>		Poaceae	leaf/stem	rectangular scrobiculate	14	21.7	12.68
<i>Bambusa vulgaris</i>		Poaceae	stalk	elongate	1	179.26	2.82
<i>Bambusa vulgaris</i>		Poaceae	stalk	epidermal elongate	2		
<i>Bambusa vulgaris</i>		Poaceae	stalk	epidermal	3		
<i>Oplismenus hirtuellus</i>		Poaceae	leaf/stem	elongate epidermal	3		
<i>Oplismenus hirtuellus</i>		Poaceae	leaf/stem	acicular hair cell	4	207.44	9.99
<i>Oplismenus hirtuellus</i>		Poaceae	leaf/stem	cross Body	5	19.67	17.07
<i>Oplismenus hirtuellus</i>		Poaceae	leaf/stem	bulliform	6	57.36	44.95
<i>Oplismenus hirtuellus</i>		Poaceae	leaf/stem	bulliform, hair cell	7		
<i>Oplismenus hirtuellus</i>		Poaceae	leaf/stem	trapeziform sinuate	8	68.48	33.37

Samples From Manoa, O'ahu, Hawai'i, continued.

Species	Variety	Family	Plant Part	Phytolith Type	Example #	Max Width (µm)	Max Height (µm)
<i>Oplismenus hirtuellus</i>		Poaceae	leaf/stem	favose	9	25.08	18.6
<i>Oplismenus hirtuellus</i>		Poaceae	leaf/stem	various epidermal	10		
<i>Oplismenus hirtuellus</i>		Poaceae	leaf/stem	hexagonal	11	30.65	35.94
<i>Oplismenus hirtuellus</i>		Poaceae	leaf/stem	spiked bundle (raphides?)	12	71.59	
<i>Oplismenus hirtuellus</i>		Poaceae	leaf/stem	trapeziform short cell	13	18.18	12.11
<i>Microsorium scolopendria</i>		Polypodiaceae	frond	NONE			
<i>Microsorium scolopendria</i>		Polypodiaceae	stem/root	NONE			
<i>Paraderris elliptica</i>		Fabaceae	leaf/stem	ovate with central indentation	6	22.92	13.76
<i>Morinda citrifolia</i>		Rubiaceae	seed	NONE			
<i>Morinda citrifolia</i>		Rubiaceae	leaf/stem	epidermal pentagonal	1	32.05	30.92
<i>Morinda citrifolia</i>		Rubiaceae	leaf/stem	epidermal (orbicular)	2	10.97	8.38
<i>Morinda citrifolia</i>		Rubiaceae	leaf/stem	tracheid	3	145.57	15.88

Samples From Manoa, O'ahu, Hawai'i, continued.

Species	Variety	Family	Plant Part	Phytolith Type	Example #	Max Width (µm)	Max Height (µm)
<i>Cucurma longa</i>		Zingiberaceae	leaf/stem	rectangular tabular epidermal	1	26.21	11.27
<i>Cucurma longa</i>		Zingiberaceae	leaf/stem	tracheid	2		
<i>Cucurma longa</i>		Zingiberaceae	leaf/stem	semi-orbicular tabular	3	31.08	16.85
<i>Cucurma longa</i>		Zingiberaceae	leaf/stem	folded ovate	4	37.36	29.22
<i>Cucurma longa</i>		Zingiberaceae	leaf/stem	rectangular scrobiculate	5	30.16	28.35
<i>Cucurma longa</i>		Zingiberaceae	leaf/stem	cuneiform	6	24.8	18.88
<i>Cucurma longa</i>		Zingiberaceae	leaf/stem	cuneiform	7	22.01	19.9
<i>Cucurma longa</i>		Zingiberaceae	leaf/stem	rectangular elongate	8	85.19	38.62
<i>Cucurma longa</i>		Zingiberaceae	leaf/stem	folded form (sickle-shaped)	9	55.49	51.49
<i>Cucurma longa</i>		Zingiberaceae	leaf/stem	various epidermal	10		
<i>Cucurma longa</i>		Zingiberaceae	leaf/stem	pointed rectangular	11	41.57	26.78
<i>Cucurma longa</i>		Zingiberaceae	leaf/stem	various epidermal	12		

**Samples From Manoa, O'ahu, Hawai'i, continued.**

<b>Species</b>	<b>Variety</b>	<b>Family</b>	<b>Plant Part</b>	<b>Phytolith Type</b>	<b>Example #</b>	<b>Max Width (µm)</b>	<b>Max Height (µm)</b>
<i>Cucurma longa</i>		Zingiberaceae	leaf/stem		1	24.42	24.51
<i>Zingiber zerumbet</i>		Zingiberaceae	whole plant	NONE			
<i>Zingiber zerumbet</i>		Zingiberaceae	root	NONE			

**Samples From the Australian National University Collections.**

<b>Species</b>	<b>Variety</b>	<b>Family</b>	<b>Plant Part</b>	<b>Phytolith Type</b>	<b>Example #</b>	<b>Max Width (µm)</b>	<b>Max Height (µm)</b>
<i>Centella asiatica</i>		Apiaceae	whole plant	NONE			
<i>Cocos nucifera</i>		Arecaceae	bark	NONE			
<i>Cocos nucifera</i>		Arecaceae	leaf	globular echinate	1	8.16	8.08
<i>Cocos nucifera</i>		Arecaceae	leaf	globular echinate cluster	2		
<i>Metroxylon amicarum</i>		Arecaceae	leaf	globular echinate	1	16.28	16.43

Samples From the Australian National University Collections, continued.

Species	Variety	Family	Plant Part	Phytolith Type	Example #	Max Width (µm)	Max Height (µm)
<i>Metroxylon amicarum</i>		Arecaceae	leaf	globular echinate	2	8.03	7.74
<i>Metroxylon amicarum</i>		Arecaceae	leaf	epidermal	3		
<i>Metroxylon amicarum</i>		Arecaceae	leaf	elongate echinate epidermal	4	29.68	11.3
<i>Metroxylon amicarum</i>		Arecaceae	leaf	tracheid	5	175.59	21.7
<i>Metroxylon amicarum</i>		Arecaceae	leaf	various	6		
<i>Metroxylon amicarum</i>		Arecaceae	bark	epidermal	1		
<i>Metroxylon amicarum</i>		Arecaceae	bark	elongate	2	195.6	17.47
<i>Metroxylon amicarum</i>		Arecaceae	root	globular echinate	1	10.57	12.73
<i>Metroxylon amicarum</i>		Arecaceae	nut	epidermal mass (amorphous)	1		
<i>Metroxylon amicarum</i>		Arecaceae	nut	elongate epidermal	2		
<i>Metroxylon amicarum</i>		Arecaceae	inflorescence	various	1		
<i>Metroxylon amicarum</i>		Arecaceae	inflorescence	tracheid	2	34.01	7

Samples From the Australian National University Collections, continued.

Species	Variety	Family	Plant Part	Phytolith Type	Example #	Max Width (µm)	Max Height (µm)
<i>Metroxylon amicarum</i>		Arecaceae	inflorescence	globular echinate	3	6.2	5.64
<i>Asplenium nidus</i>		Aspleniaceae	frond	NONE			
<i>Cordia subcordata</i>		Boraginaceae	leaf/stem	orbicular epidermal	1	12.97	14.34
<i>Cordia subcordata</i>		Boraginaceae	leaf/stem	rectangular epidermal	2	35.42	22.13
<i>Cordia subcordata</i>		Boraginaceae	leaf/stem	rectangular echinate (one sided)	3	59.39	53
<i>Cordia subcordata</i>		Boraginaceae	leaf/stem	amorphous epidermal	4		
<i>Cordia subcordata</i>		Boraginaceae	leaf/stem	tracheid	5	240.65	39.18
<i>Dioscorea bulbifera</i>		Dioscoreaceae	leaf/stem/root	NONE			
<i>Dioscorea bulbifera</i>		Dioscoreaceae	bulb	elongate	1	7.33	
<i>Aleurites moluccana</i>		Euphorbiaceae	leaf/stem	cuneiform epidermal	1		
<i>Aleurites moluccana</i>		Euphorbiaceae	fruit	tracheid	1		
<i>Aleurites moluccana</i>		Euphorbiaceae	fruit	orbicular cluster	2		

Samples From the Australian National University Collections, continued.

Species	Variety	Family	Plant Part	Phytolith Type	Example #	Max Width (µm)	Max Height (µm)
<i>Aleurites moluccana</i>		Euphorbiaceae	fruit	opaque platelet	3	116.69	44.79
<i>Adenanthera pavonina</i>		Fabaceae	leaf/stem	NONE			
<i>Adenanthera pavonina</i>		Fabaceae	legume	NONE			
<i>Adenanthera pavonina</i>		Fabaceae	bark	NONE			
<i>Inocarpus fagifer</i>		Fabaceae	leaf/stem	NONE			
<i>Inocarpus fagifer</i>		Fabaceae	nut exterior	NONE			
<i>Paraderris elliptica</i>		Fabaceae	leaf/stem	sinuate epidermal	1	39.74	22.56
<i>Paraderris elliptica</i>		Fabaceae	leaf/stem	sinuate epidermal	2	46.84	36.78
<i>Paraderris elliptica</i>		Fabaceae	leaf/stem	ovate with central indentation	3	19.73	17.47
<i>Paraderris elliptica</i>		Fabaceae	leaf/stem	hook cell	4	118.67	15.02
<i>Paraderris elliptica</i>		Fabaceae	leaf/stem	elongate epidermal	5	18.32	8.46
<i>Paraderris elliptica</i>		Fabaceae	leaf/stem	ovate with central indentation	6	22.92	13.76

Samples From the Australian National University Collections, continued.

Species	Variety	Family	Plant Part	Phytolith Type	Example #	Max Width (µm)	Max Height (µm)
<i>Barringtonia racemosa</i>		Lecythidaceae	leaf	cuneiform	1	10.57	11.34
<i>Barringtonia racemosa</i>		Lecythidaceae	leaf	orbicular/globular	2	10.95	10.03
<i>Cordyline fruticosa</i>		Laxmanniaceae	leaf/stem	NONE			
<i>Hibiscus tiliaceus</i> (?)		Malvaceae	leaf/stem	tabular epidermal	1	18.6	
<i>Hibiscus tiliaceus</i> (?)		Malvaceae	leaf/stem	acicular papillate	2	164.61	17.8
<i>Hibiscus tiliaceus</i> (?)		Malvaceae	leaf/stem	tracheid	3	61.72	15.78
<i>Hibiscus tiliaceus</i> (?)		Malvaceae	leaf/stem	various	4		
<i>Hibiscus tiliaceus</i> (?)		Malvaceae	leaf/stem	epidermal bundle	5		
<i>Hibiscus tiliaceus</i> (?)		Malvaceae	leaf/stem	epidermal single pits	6		
<i>Hibiscus tiliaceus</i> (?)		Malvaceae	leaf/stem	ovate	7		
<i>Hibiscus tiliaceus</i> (?)		Malvaceae	leaf/stem	acicular hair cell	8	116.33	12.67
<i>Hibiscus tiliaceus</i> (?)		Malvaceae	nut	epidermal, tracheid	1		

Samples From the Australian National University Collections, continued.

Species	Variety	Family	Plant Part	Phytolith Type	Example #	Max Width (µm)	Max Height (µm)
<i>Angiopteris evecta</i>		Marattiaceae	frond	various scrobiculate	1		
<i>Angiopteris evecta</i>		Marattiaceae	frond	rectangular scrobiculate	2	17.47	11.84
<i>Artocarpus camansi</i>		Moraceae	leaf	various (epidermal, hair base)	1		
<i>Artocarpus camansi</i>		Moraceae	leaf	epidermal	2	10.15	12.68
<i>Artocarpus camansi</i>		Moraceae	leaf	unciform hair cell	3	185.17	28.47
<i>Artocarpus camansi</i>		Moraceae	leaf	acicular echinate hair cell	4	135.85	16.63
<i>Artocarpus camansi</i>		Moraceae	leaf	hair base	5	19.17	20.86
<i>Artocarpus camansi</i>		Moraceae	leaf	acicular psilate hair cell	6	203.49	9.58
<i>Artocarpus camansi</i>		Moraceae	leaf	acicular echinate hair cell	7	168.93	32.9
<i>Artocarpus camansi</i>		Moraceae	leaf	various	8		
<i>Artocarpus camansi</i>		Moraceae	nut	NONE			
<i>Ficus tinctoria</i>		Moraceae	leaf	acicular hair cell curled base	1	127.78	5.14

Samples From the Australian National University Collections, continued.

Species	Variety	Family	Plant Part	Phytolith Type	Example #	Max Width (µm)	Max Height (µm)
<i>Ficus tinctoria</i>		Moraceae	leaf	various epidermal	2		
<i>Ficus tinctoria</i>		Moraceae	leaf	orbicular	3	25.29	22.3
<i>Ficus tinctoria</i>		Moraceae	leaf	hook cell	4	20.29	5.36
<i>Ficus tinctoria</i>		Moraceae	leaf	various epidermal	5		
<i>Ficus tinctoria</i>		Moraceae	leaf	tracheid	6		
<i>Ficus tinctoria</i>		Moraceae	leaf	rectangular scrobiculate	7	49.75	28.39
<i>Ficus tinctoria</i>		Moraceae	leaf	acicular papillate	8	53.07	7.82
<i>Ficus tinctoria</i>		Moraceae	leaf	globular	9	13.39	9.96
<i>Pandanus tectorus</i>		Pandanaceae	bark	NONE			
<i>Pandanus tectorus</i>		Pandanaceae	leaf	NONE			
<i>Pandanus tectorus</i>		Pandanaceae	fruit				
<i>Piper betle</i>		Piperaceae	leaf/stem	epidermal (blocky)	1		
<i>Piper betle</i>		Piperaceae	leaf/stem	scrobiculate epidermal	2		

Samples From the Australian National University Collections, continued.

Species	Variety	Family	Plant Part	Phytolith Type	Example #	Max Width (µm)	Max Height (µm)
<i>Piper betle</i>		Piperaceae	inflorescence	amorphous	1		
<i>Piper betle</i>		Piperaceae	inflorescence	elongate	2	34.43	12.02
<i>Piper betle</i>		Piperaceae	inflorescence	epidermal	3		
<i>Bambusa vulgaris</i>		Poaceae	leaf/stem	rondel	1	19.59	17.99
<i>Bambusa vulgaris</i>		Poaceae	leaf/stem	elongate	2	49.24	12.73
<i>Bambusa vulgaris</i>		Poaceae	leaf/stem	bulliform	3	41.57	38.75
<i>Bambusa vulgaris</i>		Poaceae	leaf/stem	rondel	4	11.56	9.58
<i>Bambusa vulgaris</i>		Poaceae	leaf/stem	rondel	5	14.66	8.74
<i>Bambusa vulgaris</i>		Poaceae	leaf/stem	bulliform	6	22.27	15.22
<i>Bambusa vulgaris</i>		Poaceae	leaf/stem	epidermal	7		
<i>Bambusa vulgaris</i>		Poaceae	leaf/stem	short cell and epidermal	8	8.74	8.17
<i>Bambusa vulgaris</i>		Poaceae	leaf/stem	elongate papillate	9	12.12	7.61
<i>Bambusa vulgaris</i>		Poaceae	leaf/stem	saddle	10	27.2	16.37
<i>Bambusa vulgaris</i>		Poaceae	leaf/stem	acicular hair cell	11	202.51	7.93

Samples From the Australian National University Collections, continued.

Species	Variety	Family	Plant Part	Phytolith Type	Example #	Max Width (µm)	Max Height (µm)
<i>Bambusa vulgaris</i>		Poaceae	leaf/stem	epidermal	12		
<i>Bambusa vulgaris</i>		Poaceae	leaf/stem	tracheid	13	127.68	12.12
<i>Bambusa vulgaris</i>		Poaceae	leaf/stem	rectangular scrobiculate	14	21.7	12.68
<i>Bambusa vulgaris</i>		Poaceae	stalk	elongate	1	179.26	2.82
<i>Bambusa vulgaris</i>		Poaceae	stalk	epidermal elongate	2		
<i>Bambusa vulgaris</i>		Poaceae	stalk	epidermal	3		
<i>Oplismenus hirtuellus</i>		Poaceae	leaf/stem	elongate epidermal	3		
<i>Oplismenus hirtuellus</i>		Poaceae	leaf/stem	acicular hair cell	4	207.44	9.99
<i>Oplismenus hirtuellus</i>		Poaceae	leaf/stem	cross Body	5	19.67	17.07
<i>Oplismenus hirtuellus</i>		Poaceae	leaf/stem	bulliform	6	57.36	44.95
<i>Oplismenus hirtuellus</i>		Poaceae	leaf/stem	bulliform, hair cell	7		
<i>Oplismenus hirtuellus</i>		Poaceae	leaf/stem	trapeziform sinuate	8	68.48	33.37

Samples From the Australian National University Collections, continued.

Species	Variety	Family	Plant Part	Phytolith Type	Example #	Max Width (µm)	Max Height (µm)
<i>Oplismenus hirtuellus</i>		Poaceae	leaf/stem	favose	9	25.08	18.6
<i>Oplismenus hirtuellus</i>		Poaceae	leaf/stem	various epidermal	10		
<i>Oplismenus hirtuellus</i>		Poaceae	leaf/stem	hexagonal	11	30.65	35.94
<i>Oplismenus hirtuellus</i>		Poaceae	leaf/stem	spiked bundle (raphides?)	12	71.59	
<i>Oplismenus hirtuellus</i>		Poaceae	leaf/stem	trapeziform short cell	13	18.18	12.11
<i>Microsorium scolopendria</i>		Polypodiaceae	frond	NONE			
<i>Microsorium scolopendria</i>		Polypodiaceae	stem/root	NONE			
<i>Morinda citrifolia</i>		Rubiaceae	seed	NONE			
<i>Morinda citrifolia</i>		Rubiaceae	leaf/stem	epidermal pentagonal	1	32.05	30.92
<i>Morinda citrifolia</i>		Rubiaceae	leaf/stem	epidermal (orbicular)	2	10.97	8.38
<i>Morinda citrifolia</i>		Rubiaceae	leaf/stem	tracheid	3	145.57	15.88
<i>Cucurma longa</i>		Zingiberaceae	leaf/stem	rectangular tabular epidermal	1	26.21	11.27

Samples From the Australian National University Collections, continued.

Species	Variety	Family	Plant Part	Phytolith Type	Example #	Max Width (µm)	Max Height (µm)
<i>Cucurma longa</i>		Zingiberaceae	leaf/stem	tracheid	2		
<i>Cucurma longa</i>		Zingiberaceae	leaf/stem	semi-orbicular tabular	3	31.08	16.85
<i>Cucurma longa</i>		Zingiberaceae	leaf/stem	folded ovate	4	37.36	29.22
<i>Cucurma longa</i>		Zingiberaceae	leaf/stem	rectangular scrobiculate	5	30.16	28.35
<i>Cucurma longa</i>		Zingiberaceae	leaf/stem	cuneiform	6	24.8	18.88
<i>Cucurma longa</i>		Zingiberaceae	leaf/stem	cuneiform	7	22.01	19.9
<i>Cucurma longa</i>		Zingiberaceae	leaf/stem	rectangular elongate	8	85.19	38.62
<i>Cucurma longa</i>		Zingiberaceae	leaf/stem	folded form (sickle-shaped)	9	55.49	51.49
<i>Cucurma longa</i>		Zingiberaceae	leaf/stem	various epidermal	10		
<i>Cucurma longa</i>		Zingiberaceae	leaf/stem	pointed rectangular	11	41.57	26.78
<i>Cucurma longa</i>		Zingiberaceae	leaf/stem	various epidermal	12		
<i>Cucurma longa</i>		Zingiberaceae	leaf/stem		1	24.42	24.51

**Samples From the Australian National University Collections, continued.**

<b>Species</b>	<b>Variety</b>	<b>Family</b>	<b>Plant Part</b>	<b>Phytolith Type</b>	<b>Example #</b>	<b>Max Width (µm)</b>	<b>Max Height (µm)</b>
<i>Zingiber zerumbet</i>		Zingiberaceae	whole plant	NONE			
<i>Zingiber zerumbet</i>		Zingiberaceae	root	NONE			

APPENDIX C

SEDIMENT AND RADIOCARBON SAMPLES COLLECTED

Site PoC3-9, Feature 2.

Site	Feature	Unit	Location	Type	Date
PoC3-9	F2	1	0-10 cm	microremains	11/3/2011
PoC3-9	F2	1	10-20 cm	microremains	11/4/2011
PoC3-9	F2	1	20-30 cm	microremains	11/7/2011
PoC3-9	F2	1	30-40 cm	microremains	11/7/2011
PoC3-9	F2	1	40-50 cm	microremains	11/7/2011
PoC3-9	F2	1	50-60 cm	microremains	11/7/2011
PoC3-9	F2	1	60-70 cm	microremains	11/7/2011
PoC3-9	F2	1	70-80 cm	microremains	11/8/2011
PoC3-9	F2	1	0-10 cm	10L float	11/3/2011
PoC3-9	F2	1	10-20 cm	10L float	11/4/2011
PoC3-9	F2	1	20-30 cm	10L float	11/7/2011
PoC3-9	F2	1	30-40 cm	10L float	11/7/2011
PoC3-9	F2	1	40-50 cm	10L float	11/7/2011
PoC3-9	F2	1	50-60 cm	10L float	11/7/2011
PoC3-9	F2	1	60-70 cm	10L float	11/7/2011
PoC3-9	F2	1	70-80 cm	10L float	11/8/2011
PoC3-9	F2	1	20-30 cm, N56, E100, D24	C14	11/7/2011
PoC3-9	F2	1	20-30 cm, N5, E75, D27	C14	11/7/2011
PoC3-9	F2	1	30-40 cm, N95, E24, D32	C14	11/7/2011
PoC3-9	F2	1	40-50 cm, N15, E95, D43	C14	11/7/2011
PoC3-9	F2	1	40-50 cm, N100, E90, D45	C14	11/7/2011
PoC3-9	F2	1	50-60 cm, N20, E93, D53	C14	11/7/2011
PoC3-9	F2	1	70-80 cm, N34, E81, D71	C14	11/8/2011

**Site PoC3-11, Feature 1.**

<b>Site</b>	<b>Feature</b>	<b>Unit</b>	<b>Location</b>	<b>Type</b>	<b>Date</b>
PoC3-11	F1	1	surface	for microremains	9/29/2011
PoC3-11	F1	1	10-20 cm	for microremains	9/29/2011
PoC3-11	F1	1	20-30 cm	for microremains	9/30/2011
PoC3-11	F1	1	30-40 cm	for microremains	9/30/2011
PoC3-11	F1	1	40-50 cm	for microremains	9/30/2011
PoC3-11	F1	1	50-60 cm	for microremains	10/3/2011
PoC3-11	F1	1	60-70 cm	for microremains	10/3/2011
PoC3-11	F1	1	70-80 cm	for microremains	10/3/2011
PoC3-11	F1	1	80-90 cm	for microremains	10/3/2011
PoC3-11	F1	1	90-100 cm	for microremains	10/3/2011
PoC3-11	F1	1	surface	10L float	9/29/2011
PoC3-11	F1	1	10-20 cm	10L float	9/29/2011
PoC3-11	F1	1	20-30 cm	10L float	9/30/2011
PoC3-11	F1	1	30-40 cm	10L float	9/30/2011
PoC3-11	F1	1	40-50 cm	10L float	9/30/2011
PoC3-11	F1	1	50-60 cm	10L float	9/30/2011
PoC3-11	F1	1	60-70 cm	10L float	10/3/2011
PoC3-11	F1	1	70-80 cm	10L float	10/3/2011
PoC3-11	F1	1	80-90 cm	10L float	10/3/2011
PoC3-11	F1	1	90-100 cm	10L float	10/3/2011
PoC3-11	F1	1	10-20 cm, SW corner	C14	9/29/2011
PoC3-11	F1	1	20-30 cm, center	C14	9/29/2011
PoC3-11	F1	1	20-30 cm @ 30, center	C14	9/30/2011
PoC3-11	F1	1	40-50 cm @ SW Quad	C14	9/30/2011

**Site PoC3-11, Feature 1, continued.**

Site	Feature	Unit	Location	Type	Date
PoC3-11	F1	1	40-50 cm @45, SW Quad	C14	9/30/2011
PoC3-11	F1	1	50-60 cm @52, SW Quad	C14	9/30/2011
PoC3-11	F1	1	50-60 cm@53, SW Quad	C14	9/30/2011
PoC3-11	F1	1	50-60 cm @58, SW	C14	10/3/2011
PoC3-11	F1	1	50-60 cm @59, NE	C14	10/3/2011
PoC3-11	F1	1	60-70 cm @65, SW	C14	10/3/2011
PoC3-11	F1	1	60-70 cm@70, NE	C14	10/3/2011
PoC3-11	F1	1	70-80 cm@71, NE	C14	10/3/2011
PoC3-11	F1	1	70-80 cm @74, center	C14	10/3/2011
PoC3-11	F1	1	70-80 cm @ 77, NE	C14	10/3/2011

**Site PoC3-12, Feature 2.**

Site	Feature	Unit	Location	Type	Date
PoC3-12	F2	1	SW end, surface	1L bulk	9/26/2011
PoC3-12	F2	1	SE end, surface	for microremains	9/26/2011
PoC3-12	F2	1	central, surface	for microremains	9/26/2011
PoC3-12	F2	1	10-20 cm, W wall	for microremains	9/26/2011
PoC3-12	F2	1	20-30 cm, W wall	for microremains	9/26/2011
PoC3-12	F2	1	30-40 cm, W wall	for microremains	9/26/2011
PoC3-12	F2	1	40-50 cm, W wall	for microremains	9/26/2011
PoC3-12	F2	1	50-60 cm, S wall	for microremains	9/26/2011
PoC3-12	F2	1	60-70 cm, S wall	for microremains	9/26/2011
PoC3-12	F2	1	60-70 cm, W wall	1L bulk	9/26/2011
PoC3-12	F2	1	100 cm, base of E wall	1L bulk	9/26/2011
PoC3-12	F2	1	W wall, 70-80 cm	for microremains	9/26/2011
PoC3-12	F2	1	70-80 cm, N wall	for microremains	9/26/2011
PoC3-12	F2	1	80-90 cm, N wall	for microremains	9/26/2011
PoC3-12	F2	1	80-90 cm, N wall	for microremains	9/26/2011
PoC3-12	F2	1	90-100 m N wall	for microremains	9/26/2011

**Site PoC3-12, Feature 4.**

<b>Site</b>	<b>Feature</b>	<b>Unit</b>	<b>Location</b>	<b>Type</b>	<b>Date</b>
PoC3-12	F4	1	0-10 cm, center	microremains	10/26/2011
PoC3-12	F4	1	10-20 cm, center	microremains	10/26/2011
PoC3-12	F4	1	20-30 cm, center	microremains	10/27/2011
PoC3-12	F4	1	30-40 cm, center	microremains	10/27/2011
PoC3-12	F4	1	40-50 cm, center	microremains	10/28/2011
PoC3-12	F4	1	50-60 cm, center	microremains	10/31/2011
PoC3-12	F4	1	60-70 cm, center	microremains	10/31/2011
PoC3-12	F4	1	70-80 cm, center	microremains	10/31/2011
PoC3-12	F4	1	0-10 cm	10L float	10/26/2011
PoC3-12	F4	1	10-20 cm	10L float	10/26/2011
PoC3-12	F4	1	20-30 cm	10L float	10/27/2011
PoC3-12	F4	1	30-40 cm	10L float	10/27/2011
PoC3-12	F4	1	40-50 cm	10L float	10/28/2011
PoC3-12	F4	1	50-60 cm	10L float	10/31/2011
PoC3-12	F4	1	60-70 cm	10L float	10/31/2011
PoC3-12	F4	1	70-80 cm	10L float	10/31/2011
PoC3-12	F4	1	0-10 cm @8, SW	C14	10/26/2011
PoC3-12	F4	1	0-10 cm @9, NW	C14	10/26/2011
PoC3-12	F4	1	0-10 cm @9, SW	C14	10/26/2011
PoC3-12	F4	1	10-20 cm @11, SE	C14	10/26/2011
PoC3-12	F4	1	10-20 cm @11, NE	C14	10/26/2011
PoC3-12	F4	1	10-20 cm @13, SE	C14	10/26/2011
PoC3-12	F4	1	10-20 cm @14, NE	C14	10/26/2011
PoC3-12	F4	1	10-20 cm @16, NE	C14	10/26/2011
PoC3-12	F4	1	10-20 cm @17, NE	C14	10/26/2011
PoC3-12	F4	1	10-20 cm @19, SE	C14	10/26/2011
PoC3-12	F4	1	20-30 cm @20, near S wall	C14	10/27/2011
PoC3-12	F4	1	20-30 cm @21, NW	C14	10/27/2011
PoC3-12	F4	1	20-30 cm @21, NE	C14	10/27/2011
PoC3-12	F4	1	20-30 cm @23, SE	C14	10/27/2011
PoC3-12	F4	1	20-30 cm @24, NW	C14	10/27/2011
PoC3-12	F4	1	20-30 cm @25, center	C14	10/27/2011
PoC3-12	F4	1	20-30 cm @26	C14	10/27/2011
PoC3-12	F4	1	20-30 cm @27, NW	C14	10/27/2011
PoC3-12	F4	1	20-30 cm @28, SW	C14	10/27/2011

Site PoC3-12, Feature 4, continued.

Site	Feature	Unit	Location	Type	Date
PoC3-12	F4	1	20-30 cm @30, center	C14	10/27/2011
PoC3-12	F4	1	30-40 cm @31, NW	C14	10/27/2011
PoC3-12	F4	1	30-40 cm @32, center	C14	10/27/2011
PoC3-12	F4	1	30-40 cm @32, NW	C14	10/27/2011
PoC3-12	F4	1	30-40 cm @33, NW	C14	10/28/2011
PoC3-12	F4	1	30-40 cm @33, NE	C14	10/27/2011
PoC3-12	F4	1	30-40 cm @33, SE	C14	10/27/2011
PoC3-12	F4	1	30-40 cm @37, SW	C14	10/27/2011
PoC3-12	F4	1	30-40 cm @38, SW	C14	10/27/2011
PoC3-12	F4	1	30-40 cm @38, SE	C14	10/27/2011
PoC3-12	F4	1	30-40 cm @39, SE	C14	10/27/2011
PoC3-12	F4	1	30-40 cm @39, center	C14	10/27/2011
PoC3-12	F4	1	40-50 cm @41, NE	C14	10/27/2011
PoC3-12	F4	1	40-50 cm @41, SW	C14	10/27/2011
PoC3-12	F4	1	40-50 cm @41, SW	C14	10/27/2011
PoC3-12	F4	1	40-50 cm @41, NE	C14	10/27/2011
PoC3-12	F4	1	40-50 cm @42, NE	C14	10/27/2011
PoC3-12	F4	1	40-50 cm @43, NE	C14	10/27/2011
PoC3-12	F4	1	40-50 cm @49, NE	C14	10/28/2011
PoC3-12	F4	1	50-60 cm @51, NW	C14	10/31/2011
PoC3-12	F4	1	50-60 cm @52, SE	C14	10/31/2011
PoC3-12	F4	1	50-60 cm @57, SE	C14	10/31/2011
PoC3-12	F4	1	60-70 cm @61, NW	C14	10/31/2011
PoC3-12	F4	1	60-70 cm @63, NW	C14	10/31/2011

**Site PoC3-18, Feature 1.**

<b>Site</b>	<b>Feature</b>	<b>Unit</b>	<b>Location</b>	<b>Type</b>	<b>Date</b>
PoC3-18	F1	1	20-30 cm@24, SE	C14	10/13/2011
PoC3-18	F1	1	30-40 cm@31, SW	C14	10/13/2011
PoC3-18	F1	1	30-40 cm@31, SW	C14	10/13/2011
PoC3-18	F1	1	30-40 cm@32, SE	C14	10/13/2011
PoC3-18	F1	1	30-40 cm@35, SW	C14	10/13/2011
PoC3-18	F1	1	30-40 cm@37, SW	C14	10/13/2011
PoC3-18	F1	1	30-40 cm@38, SW	C14	10/13/2011
PoC3-18	F1	1	30-40 cm@39, SW	C14	10/13/2011
PoC3-18	F1	1	40-50 cm@41, SW	C14	10/13/2011
PoC3-18	F1	1	40-50 cm@43, SW	C14	10/13/2011
PoC3-18	F1	1	40-50 cm@44, SW	C14	10/13/2011
PoC3-18	F1	1	40-50 cm@45, SW	C14	10/13/2011
PoC3-18	F1	1	40-50 cm@45, SW	C14	10/13/2011
PoC3-18	F1	1	40-50 cm@46, SW	C14	10/13/2011
PoC3-18	F1	1	50-60 cm, NW	C14	10/13/2011
PoC3-18	F1	1	50-60 cm, NW	C14	10/13/2011
PoC3-18	F1	1	50-60 cm, NE	C14	10/13/2011
PoC3-18	F1	1	50-60 cm@52, NW	C14	10/13/2011
PoC3-18	F1	1	50-60 cm@53, NW	C14	10/13/2011
PoC3-18	F1	1	50-60 cm@53, SW	C14	10/13/2011
PoC3-18	F1	1	50-60 cm@55, NW	C14	10/13/2011
PoC3-18	F1	1	50-60 cm@55, NW	C14	10/13/2011
PoC3-18	F1	1	50-60 cm@57, NW	C14	10/13/2011
PoC3-18	F1	1	50-60 cm@57, NW	C14	10/13/2011
PoC3-18	F1	1	50-60 cm@59, NE	C14	10/13/2011
PoC3-18	F1	1	60-70 cm@60, NW	C14	10/14/2011
PoC3-18	F1	1	60-70 cm@61, SW	C14	10/14/2011
PoC3-18	F1	1	60-70 cm@62, N wall	C14	10/14/2011
PoC3-18	F1	1	60-70 cm@63, NE Quad	C14	10/14/2011
PoC3-18	F1	1	60-70 cm@65, NW	C14	10/14/2011
PoC3-18	F1	1	60-70 cm@68, SE Quad	C14	10/14/2011
PoC3-18	F1	1	70-80 cm@70, SW Quad	C14	10/14/2011
PoC3-18	F1	1	70-80 cm@70, NE	C14	10/14/2011
PoC3-18	F1	1	70-80 cm@70, N wall	C14	10/14/2011
PoC3-18	F1	1	70-80 cm@75, SE	C14	10/17/2011
PoC3-18	F1	1	70-80 cm@76, SE	C14	10/17/2011
PoC3-18	F1	1	70-80 cm@79, NW	C14	10/17/2011
PoC3-18	F1	1	80-90 cm@81, SW	C14	10/17/2011

Site PoC3-18, Feature 1, continued.

Site	Feature	Unit	Location	Type	Date
PoC3-18	F1	1	80-90 cm@83, SE	C14	10/17/2011
PoC3-18	F1	1	80-90 cm@83, SW	C14	10/17/2011
PoC3-18	F1	1	80-90 cm@85, SW	C14	10/17/2011
PoC3-18	F1	1	80-90 cm@88, SE	C14	10/18/2011
PoC3-18	F1	1	90-100 cm@90, SE	C14	10/17/2011
PoC3-18	F1	1	90-100 cm@90, NW	C14	10/17/2011
PoC3-18	F1	1	90-100 cm@90, NE	C14	10/18/2011
PoC3-18	F1	1	90-100 cm@95, NE	C14	10/18/2011
PoC3-18	F1	1	90-100 cm@95, SE	C14	10/18/2011
PoC3-18	F1	1	90-100 cm@97, SW	C14	10/18/2011
PoC3-18	F1	1	90-100 cm@99, SE	C14	10/18/2011
PoC3-18	F1	1	100-110 cm@100, NE	C14	10/18/2011
PoC3-18	F1	1	100-110 cm@107, NE (w/in stone cluster)	C14	10/18/2011
PoC3-18	F1	1	110-120 cm@118, SE (near ctr)	C14	10/18/2011
PoC3-18	F1	1	surface, S wall	microremains	10/13/2011
PoC3-18	F1	1	surface, center	microremains	10/13/2011
PoC3-18	F1	1	surface, N wall	microremains	10/13/2011
PoC3-18	F1	1	10-20 cm, S wall	microremains	10/13/2011
PoC3-18	F1	1	20-30 cm, S wall	microremains	10/13/2011
PoC3-18	F1	1	30-40 cm, S wall	microremains	10/13/2011
PoC3-18	F1	1	40-50 cm, S wall	microremains	10/13/2011
PoC3-18	F1	1	50-60 cm, S wall	microremains	10/13/2011
PoC3-18	F1	1	50-60 cm, N wall	microremains	10/13/2011
PoC3-18	F1	1	60-70 cm, S end	microremains	10/13/2011
PoC3-18	F1	1	60-70 cm, N end	microremains	10/13/2011
PoC3-18	F1	1	70-80 cm, N end	microremains	10/17/2011
PoC3-18	F1	1	70-80 cm, S end	microremains	10/17/2011
PoC3-18	F1	1	80-90 cm, N end	microremains	10/17/2011
PoC3-18	F1	1	80-90 cm, S end	microremains	10/17/2011
PoC3-18	F1	1	90-100 cm, S end	microremains	10/18/2011
PoC3-18	F1	1	90-100 cm, N end	microremains	10/18/2011
PoC3-18	F1	1	100-110 cm, N end	microremains	10/18/2011
PoC3-18	F1	1	110-120 cm, S end	microremains	10/18/2011
PoC3-18	F1	1	110-120 cm, N end	microremains	10/18/2011
PoC3-18	F1	1	120-130 cm, NE	microremains	10/19/2011
PoC3-18	F1	1	surface, S wall	1L bulk	10/13/2011
PoC3-18	F1	1	surface, center	1L bulk	10/13/2011
PoC3-18	F1	1	surface, N wall	1L bulk	10/13/2011

**Site PoC3-18, Feature 1, continued.**

<b>Site</b>	<b>Feature</b>	<b>Unit</b>	<b>Location</b>	<b>Type</b>	<b>Date</b>
PoC3-18	F1	1	10-20 cm, S wall	1L bulk	10/13/2011
PoC3-18	F1	1	20-30 cm, S wall	1L bulk	10/13/2011
PoC3-18	F1	1	30-40 cm, S wall	1L bulk	10/13/2011
PoC3-18	F1	1	40-50 cm, S wall	1L bulk	10/13/2011
PoC3-18	F1	1	50-60 cm, scatter	1L bulk	10/13/2011
PoC3-18	F1	1	60-70 cm, scatter	1L bulk	10/14/2011
PoC3-18	F1	1	70-80 cm, scatter	1L bulk	10/17/2011
PoC3-18	F1	1	80-90 cm, scatter	1L bulk	10/17/2011
PoC3-18	F1	1	90-100 cm, scatter	1L bulk	10/18/2011
PoC3-18	F1	1	100-110 cm, scatter	1L bulk	10/18/2011
PoC3-18	F1	1	110-120 cm, scatter	1L bulk	10/18/2011
PoC3-18	F1	1	120-130 cm, N end	1L bulk	10/19/2011
PoC3-18	F1	1	0-10 cm, S extension	10L float	10/19/2011
PoC3-18	F1	1	10-20 cm, S extension	10L float	10/19/2011
PoC3-18	F1	1	20-30 cm, S extension	10L float	10/19/2011
PoC3-18	F1	1	30-40 cm, S extension	10L float	10/19/2011
PoC3-18	F1	1	40-50 cm, S wall	10L float	10/13/2011
PoC3-18	F1	1	50-60 cm, scatter	10L float	10/13/2011
PoC3-18	F1	1	60-70 cm, scatter	10L float	10/13/2011
PoC3-18	F1	1	70-80 cm, scatter	10L float	10/17/2011
PoC3-18	F1	1	80-90 cm, scatter	10L float	10/17/2011
PoC3-18	F1	1	90-100 cm, scatter	10L float	10/18/2011
PoC3-18	F1	1	100-110 cm, scatter	10L float	10/18/2011
PoC3-18	F1	1	110-120 cm, scatter	10L float	10/18/2011
PoC3-18	F1	1	120-130 cm, N end	10L float	10/19/2011

**PoC3-48, Feature 2.**

<b>Site</b>	<b>Feature</b>	<b>Unit</b>	<b>Location</b>	<b>Type</b>	<b>Date</b>
PoC3-48	F2	1	0-10 cm, W end	microremains	11/7/2011
PoC3-48	F2	1	10-20 cm, W end	microremains	11/7/2011
PoC3-48	F2	1	20-30 cm, W end	microremains	11/7/2011
PoC3-48	F2	1	30-40 cm, W end	microremains	11/7/2011
PoC3-48	F2	1	40-50 cm, W end	microremains	11/7/2011
PoC3-48	F2	1	50-60 cm, W end	microremains	11/7/2011
PoC3-48	F2	1	60-70 cm, W end	microremains	11/7/2011

**PoC3-48, Feature 2, continued.**

<b>Site</b>	<b>Feature</b>	<b>Unit</b>	<b>Location</b>	<b>Type</b>	<b>Date</b>
PoC3-48	F2	1	70-80 cm, center of trench	microremains	11/7/2011
PoC3-48	F2	1	80-90 cm, E end (surface)	microremains	11/7/2011
PoC3-48	F2	1	80-90 cm, W end	microremains	11/7/2011
PoC3-48	F2	1	90-100 cm, E end (center of pit, surface)	microremains	11/7/2011
PoC3-48	F2	1	0-10 cm, W end	Bulk soil	11/7/2011
PoC3-48	F2	1	10-20 cm, W end	Bulk soil	11/7/2011
PoC3-48	F2	1	20-30 cm, W end	Bulk soil	11/7/2011
PoC3-48	F2	1	30-40 cm, W end	Bulk soil	11/7/2011
PoC3-48	F2	1	40-50 cm, W end	Bulk soil	11/7/2011
PoC3-48	F2	1	50-60 cm, W end	Bulk soil	11/7/2011
PoC3-48	F2	1	60-70 cm, W end	Bulk soil	11/7/2011
PoC3-48	F2	1	70-80 cm, center of trench	Bulk soil	11/8/2011
PoC3-48	F2	1	80-90 cm, scatter	Bulk soil	11/8/2011
PoC3-48	F2	1	90-100cm, E end (center of pit, surface)	Bulk soil	11/8/2011

**Vegetation Survey, Temwen.**

<b>Sample Type</b>	<b>Sample #</b>	<b>Type</b>	<b>Date</b>
Vegetation Survey	1	microremains	11/4/2011
Vegetation Survey	2	microremains	11/4/2011
Vegetation Survey	3	microremains	11/4/2011
Vegetation Survey	4	microremains	11/4/2011

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