

Archaeological Investigation of the Landscape History of an Oceanic Atoll: Majuro, Marshall Islands¹

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Abstract: Historical ecology has provided the field of geoarchaeology in Oceania with the concept of an island landscape as a historical product, invented from the dynamic interactions between natural processes and human agency. Since Davidson's work in Nukuoro (1971) and Dye's introduction to the prehistory of Majuro in the Marshall Islands (1987), systematic excavations of atoll islets have also been based on this tenet. Following this concept, this study presents a geoarchaeological examination of the long-term history of the pit-agricultural landscape in Laura Islet of Majuro Atoll, which now consists of 195 pits showing remarkable undulation and anthropogenic vegetation on their spoil banks. Our excavations, conducted since 2003, have revealed that human habitation on Laura began as early as 2,000 years ago, soon after the emergence of the core islet, which probably followed a relative drop in sea level in the late Holocene. Some centuries later, the inhabitants started excavating agricultural pits for the cultivation of wet taro, probably *Cyrtosperma* spp. The subsequent sea-level decline would have enlarged the foraminiferal sediment; the islet then extended its landform both oceanward and lagoonward as well as along the longitudinal axis stretching north to south. The land accretion caused its inhabitants to increasingly extend their activity space and readjust areas for habitation. It would also have enlarged the volume of the freshwater lens, prompting additional construction of agricultural pits even in the area just behind the lagoon-side beach ridge. Most of the current landscape was formed by around 1,000 years ago at the latest. Geoarchaeological synthesis of Pacific atolls will enable the precise elucidation of local chronological relationships between land accretion and expansion of human activities.

MORE THAN 170 coral atolls are scattered in the trade-wind zone from the westernmost

Caroline Islands to the easternmost Tuamotu Islands (Figure 1). Their islets of foraminiferal sand and coral shingle lie on mid-Holocene emergent reef flats, and a chain of these islets, which are covered with coconut trees, separate a turquoise lagoon from the surrounding navy blue ocean. On the surface, the scene appears to be a typical oceanic paradise. Most of the subaerial landforms, however, are no more than 2–3 m in elevation and a few hundred meters to less than a few kilometers at most in width. As such, they are highly susceptible to inundation by storm surges. Moreover, in the absence of running surface water, some atolls frequently suffer from droughts. Because of these and other factors, atolls have often been stereotyped as being extremely marginal environments for human settlement. This oversimplified image tends to be reflected even in the latest scientific reports on global warming,

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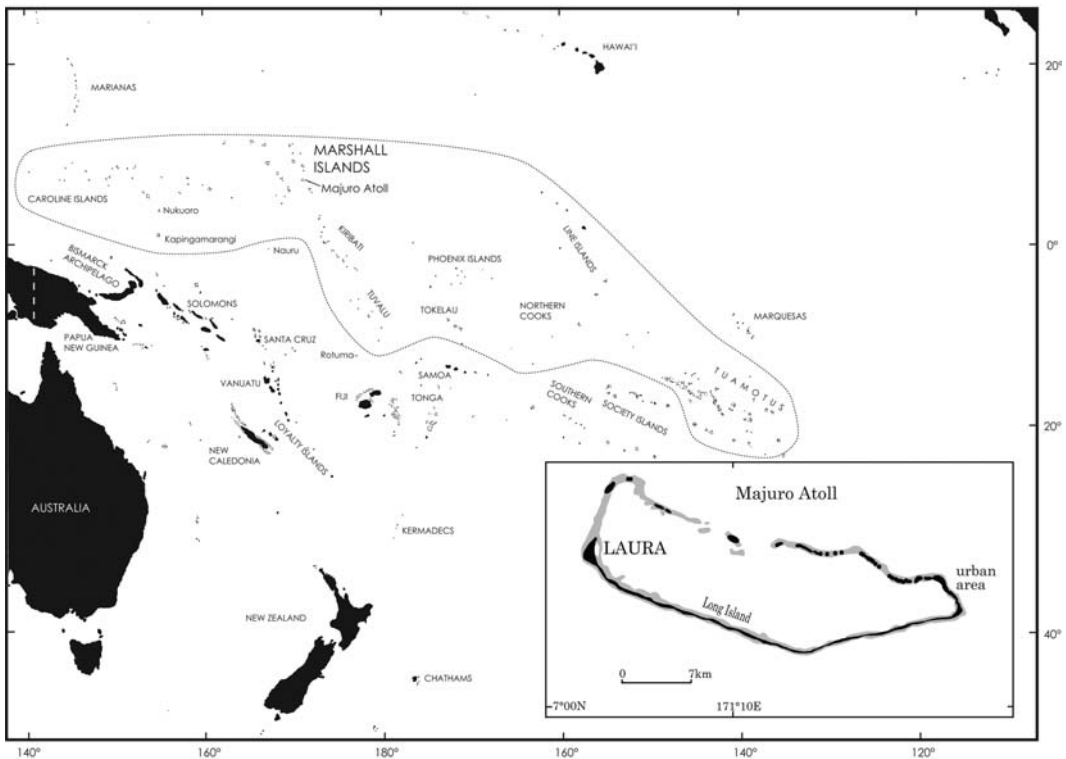


FIGURE 1. Distribution of oceanic atolls and map of Majuro Atoll in the Marshall Islands.

which lump atolls into the category of “small island countries.”

Environmental diversity, however, is discernible even within a single atoll. Near the center of the larger islets are remarkable banks that are several meters higher than the surrounding flat and low surfaces. Each of them encircles an agricultural pit dug into the water table of the freshwater lens (Figure 2). The pit is infilled with soil containing much humus enriched by the deliberate additions of vegetable compost to provide a nutrient-rich layer. *Colocasia* and/or *Cyrtosperma* tubers are planted in this wet ground, and tall trees of Chinese lantern (*Hernandia sonora*), Pacific rosewood (*Cordia subcordata*), and fish-poison tree (*Barringtonia speciosa*), as well as coconut and breadfruit trees, grow on the banks of the agricultural pits, shading the interior so as to prevent the moisture of the hydromorphic terrain from evaporating.

The landscape, consisting of a chain of topographic undulations and diverse vegetation, contrasts with the prevailing image of the atoll environment. The main aim of this study was to geoarchaeologically examine the pit-agriculture landscape on an oceanic atoll as a historical product of the long-term interactions between two kinds of agents, natural and human. In the 1990s some academic volumes with the term “historical ecology” in their titles were published, one of which was edited by C. L. Crumley (1994). She stated that “historical ecology explores complex chains of mutual causation in human-environment relations and draws on concepts from the natural sciences—biology, geology, climatology—and from ecology, archaeology, history, and socio-cultural anthropology” (Crumley 1996:558) and pointed out the effectiveness of its regional approach, encompassing “the entire system, including both



FIGURE 2. Current landscape of pit agriculture in Majuro Atoll: *a*, matured *Cyrtosperma* in an agricultural pit, Laura; *b*, a well-controlled pit in Laura; *c*, a considerably disturbed pit where a small patch of *Cyrtosperma* remains; *d*, an abandoned pit covered with *Premna obtusifolia*.

human and nonhuman components” (Crumley 1994:5). Historical ecology is very close to our geoarchaeological approach in the interdisciplinary research we have conducted on Majuro Atoll, Marshall Islands, since 2003. Therefore, to begin, we offer a brief overview of atoll studies in the contexts of cultural ecology, environmental history, and historical ecology and then describe the landscape history of pit agriculture on Majuro.

AN OVERVIEW OF OCEANIC ATOLL HISTORICAL ECOLOGY

The idyllic image of an atoll has been stressed not only in the records of earlier European explorers but also in scholarly circles. Atoll environments have often been viewed as

“one of few possible simple ecological situations in the tropics” (Thomas 1965:22), and their variability in size and precipitation was applied to explain certain selected cultural differences. In the 1950s and 1960s, cultural ecology and cultural geography emphasized the limited quantity of land and general paucity of resources (Bayliss-Smith 1990:57), as these studies attempted to consider characteristics of atoll societies as adaptive strategies to make the most efficient use of limited resources. The distinctive atoll environment was contrasted with that of high islands, masking the atolls’ environmental and geological complexities (e.g., Sahlins 1958, Vayda and Rappaport 1965:139).

In general, atolls have primarily been of interest to researchers whose perspectives are

rooted in biogeography and ecology. For example, the U.S. Office of Naval Research conducted a number of studies on Bikini and Eniwetok in the Marshall Islands before atomic testing. In the beginning of his landmark volume that synthesized atoll environment and ecology Wiens (1962:xxi) stated that "it must be kept in mind that peculiarities unique to certain atolls do occur." Although acknowledging the uniformity of atolls, he also appears to have conceptualized "the holistic ecology of the atoll" (ibid.:xix), taking into account human-environmental interactions.

It is true that differences exist in annual and seasonal rainfalls among oceanic atolls that are widely scattered in the trade-wind zone extending west to east because the western Pacific is closer to the convergence zone than the eastern Pacific. The deviation of annual rainfall is discernible even within an island group. In the Marshall Islands, these atolls extend nearly 1,200 km between 4° and 12° N. The rainfall within this group increases from northwest to southeast along the island chain, ranging from less than 900 mm to more than 4,000 mm in mean annual precipitation (Taylor 1973). The freshwater lenses sit atop saline water permeating the porous underground of atoll islets, and their quality and volume are greatly affected by local precipitation. Their gradient within the Marshall Islands thus must be related to the variety of vegetation. A phytogeographical study of this island group indicates that wet taro, as well as banana and breadfruit trees, can generally be cultivated on atolls having more than 2,000 mm in mean annual precipitation (Stoddart 1992; see also Fosberg 1984).

Whitehead and Jones (1969) also conducted a study of the correlation between the land area of islets and the number of plant species on Kapingamarangi, which indicated a marked rise in the number of species on islets more than 3.5 acres (1.4 ha) in size. Their detailed classification of indigenous and recently introduced species, however, suggested that the area-diversity curve was greatly exaggerated by the latter species. As a result, they suggested that "the larger islands have been profoundly influenced by

humans through habitation, maintenance of coconuts, breadfruit, and taro, and the events of WWII" (ibid.:175).

These data have been referred to in various human ecological studies, some of which indicated a correlation between land area, precipitation, and human population size within the Marshall Islands (Williamson and Sabath 1982, 1984). Bayliss-Smith (1990), who conducted a field survey of Ontong Java Atoll in the Solomon Islands for his Ph.D. dissertation research, assessed the carrying capacities of oceanic atolls in relation to the frequency of droughts and hurricanes as well as land area and precipitation. Since the 1970s, in particular, human ecology has been used to estimate the carrying capacities of particular atolls (e.g., Bayliss-Smith 1974).

Both human and cultural ecology have conceptually relied on the assumption that human societies selectively use particular environmental elements relevant to their traditions or diffused technologies. As noted by Ballew (1998:3), however, these domains "focused on how 'natural' environments—replete with given geophysical and biotic conditions—affected localized societies and their cultural development over time." Clifford Geertz (1963) had already pointed out the importance of a historical perspective to describe the contrasting pattern of land use between Java and outer islands of Indonesia in his volume *Agricultural Involvement*. However, most culture-ecological studies in the Pacific, with fewer available historical materials documenting long-term processes of ecological change, tended to focus on synchronic relationships between environment and culture, thus emphasizing the impact of the former on the latter, even if using the notion of adaptation. They appear to have contributed to the ambiguous distinction between environmental determinism and possibilism.

Adaptation is conceptualized as an active process of self-regulation that includes both homeostasis and transformation. This is, however, a model with a logical problem, as Friedman (1979) has already described in detail. A homeostatic system needs a larger entity much like a "mystical superorganism" (Cronon 1983:11) that organizes the elimina-

tion as well as the survival of its constituents to maintain itself. The notion of transformation also implies a functional process that tends toward a static goal decided in advance by a large entity's intentions and thus is not historical but rather unilinear and predictable. The analogy comparing culture-ecological systems to organisms or its imputation with anthropomorphic qualities should be criticized for being teleological. Instead, individual constituents can be described in terms of their direct associations with others along a continuous range of systems. In this sense, both ecological and cultural changes arise not only from distinct events such as natural disasters and cultural contacts with other groups but also from dialectical relationships between two kinds of agents, natural and human. A chronological approach must therefore be useful in describing their dynamics.

Environmental history follows such a view. It "begins by assuming a dynamic and changing relationship between environment and culture, one as apt to produce contradictions as continuities" (Cronon 1983:13). Some studies have reexamined colonial and post-colonial histories focusing on how diseases, plants, and animals moved or were moved from one continent to another (e.g., Crosby 1986). Although such studies, referred to as "ecological imperialism," are sometimes criticized as being too biologically deterministic and Eurocentric (Arnold 1996:91), they certainly made clear that human decisions initiated particular forms of systemic biological interactions and thereby enhanced cultural behaviors that affected their environment (Whitehead 1998:35).

Oceanic islands have a special appeal for environmental history in that any ecological change is amplified by the effects of geographical remoteness. Their isolation from the species pools of continents has caused insular ecosystems to become hypersensitive to the introduction of exotic species transported accidentally or purposefully by humans (McNeill 1994:299, 340–341) and to European exploitation of island resources. For example, the exploitation of sandalwood and sea cucumber was increasingly active in the late years of the eighteenth and early decades of

the nineteenth centuries for trading with Chinese in Manila, the Philippines, and Canton, China (Shineberg 1966, Ward 1972). The human agency accompanying such exploitation not only depleted the trading resources themselves but also appears to have transported exotic species such as pineapple, pumpkin, potato, and cattle for the provision of foodstuffs to visiting vessels and to European residents as well as their pet dogs and cats, which would have largely changed the previous island biota. Oceanic atolls as well have not been immune from European exploitation. One of the documented cases is that of black-lipped pearl oysters (*Pinctada margaritifera*) in the Tuamotu Islands, French Polynesia; the study revealed historical entanglements involving local islanders, external entrepreneurs, and colonial administrations, which resulted in overexploitation and preservation of oyster stock in atoll lagoons (Rapaport 1995).

However, the interactions of natural processes and human agency are by no means restricted to the past 300 years of colonial expansionism but began when humans first colonized the islands. Archaeology in the Pacific has contributed substantially to understanding this issue from the viewpoint of historical ecology, which incorporates data collected from a variety of natural sciences, including geology, geomorphology, and paleontology, as noted by Kirch and Hunt (1997) in their landmark volume *Historical Ecology in the Pacific Islands*. It is noteworthy that many studies use the term "landscape" to scrutinize long-term processes of dialectic interactions between the process of nature and the work of humans, probably because positioning the notion of landscape between the two enables the smooth combination of the natural and social sciences.

Although Kirch and Hunt's volume did not include any studies of atolls, except for a semiatoll of Aitutaki (Allen 1997), Weisler (2001a:6–8), who has systematically initiated geoarchaeological excavations in the Marshall Islands of eastern Micronesia, advocates examining chronological relationships of human settlements in relation to the geomorphological formations of atoll islets and

anthropogenic alterations of atoll landscapes as a relevant topic in atoll archaeology.

ATOLL ARCHAEOLOGY AND LATE-HOLOCENE ISLET FORMATION

Several studies in the past few decades have focused on the settlement of atolls and long-term adaptations. A pioneering study conducted by Davidson (1971, 1992) in the 1960s focused on systematic excavations along a transect line between the ocean and the lagoon shores of Nukuoro Atoll, Caroline Islands. Davidson showed that the topographic undulations of Nukuoro Islet were historically produced by human activities, although some stratified sediments appear to reflect spoil deposits that had piled up from a nearby agricultural pit rather than “house and yard floors of fresh coral gravel and accumulations of cooking and other rubbish” (Davidson 1971:21).

Some notable perspectives on atoll archaeology were also offered by the Bishop Museum Expedition to the Marshall Islands. One such contribution was the association of human settlements with the land formation of atoll islets that coincided with the Holocene sea-level change (Dye 1987). It is readily possible to find reef-flat deposits of cemented coral rubble (also termed cap rocks, breccia sheets, or cemented rubble ramparts) exposed within the intertidal and supratidal positions along atoll beaches. These are thought to indicate the mid-Holocene hydroisostatic sea-level highstand (Buddemeier et al. 1975, Schofield 1977, Schoffin 1993, Nunn 1995), a conclusion that is supported by dated samples of *Tridacna* shells imbedded within typical emergent reef-flat deposits on Tarawa in Kiribati and on Bikini and Enewetak atolls in the Marshall Islands (Dickinson 1999:126). Some emergent reef flats seem to have formed resistant surfaces upon which pinned islets may nucleate (Dickinson 2004:262; see also Schofield 1977), but the timing of late-Holocene sea-level fall was distinctly variable. The duration of highstand persisted until the first millennium A.D. around the Tuamotu Archipelago (i.e., within the region of the South Pacific Superswell [SPS] and South

Pacific Isotopic and Thermal Anomaly [SOPITA], which are essentially coextensive features delineating a region underlain by anomalous oceanic mantle). In contrast, the highstand would have started to fall as early as 2,000 years ago in the central Pacific, including the Marshall Islands (Dickinson 2003:491).

These regional variations of the late-Holocene sea-level fall tend to fit with variations in initial human settlement on oceanic atolls. Several studies in the past few decades have offered evidence on the settlement of oceanic atolls: the Caroline Islands (Davidson 1967, 1971, Leach and Ward 1981, Craib 1984 [1981], Fujimura and Alkire 1984, Intoh 1984 [1981]), the Marshall Islands (Athens 1984, Dye 1987, Schilz 1989, Thomas 1989, Shun and Athens 1990, Streck 1990, Beardsley 1993, Weisler 1999*a,b*, 2000, 2001*a,b,c*, Yamaguchi et al. 2005), the Northern Cook Islands (Chikamori and Yoshida 1988, Yamaguchi 1990, 2000, Chikamori 1998), Tuvalu (Takayama and Sato 1987), Tokelau (Best 1988), the Line Islands (Sinoto 1973, Anderson et al. 2000, Di Piazza and Pearthree 2001), the Society Islands, and the Tuamotu archipelago (Sinoto and McCoy 1974, Sinoto 1976, Chazine 1982).

Radiocarbon ages of charcoal samples retrieved from these excavations reveal a distinction in the earlier phases of human occupation (Figure 3). Most Polynesian atolls were inhabited after ca. 1,000 years B.P. The earliest charcoal age from easternmost Reao Atoll in the Tuamotus shows 870 ± 80 years B.P. (N-2657) (Sinoto 1976), and those from the northern Cook Islands fall within a temporal range between 560 ± 50 years B.P. (WK-4094) from Tongareva (Yamaguchi 2000) and 1,800 years B.P. from Pukapuka (N-5107) (Chikamori and Yoshida 1988). Although the Pukapukan earlier ages are somewhat less reliable, Rakahanga and Manihiki atolls, located in the middle of the northern Cook Islands, provided ca. 600–1,000 years B.P. for the earliest human settlement (Chikamori 1998), a finding that was supported by our reexamination using more precise accelerator mass spectrometry (AMS) dating: 830 ± 25 years B.P. (PLD-3916) from Raka-

hanga and 605 ± 25 years B.P. (PLD-5831) from Manihiki (unpubl. data). These ages from the northern Cook Islands are consistent with reliable ones of charcoal samples from the Line Islands, 810 ± 50 years B.P. (Beta-142178) from Fanning Island (Di Piazza and Pearthree 2001), and 690 ± 80 years B.P. (WK-7748) from Christmas Island (Anderson et al. 2000).

Many western atolls were inhabited earlier than the discussed eastern ones. Some earlier ages over 1,000 years B.P. were reported from the western Caroline Islands, although these ages are less reliable, having been taken from sources other than charcoal samples or from unknown materials. The most reliable charcoal ages for earliest human settlement on oceanic atolls, however, have been obtained from the central Pacific including the Marshall Islands and Kiribati. These date back to 1,500–2,000 years B.P.: $1,860 \pm 60$ years B.P. (Beta-103903) from Utrok Atoll (Weisler 2001a), $1,920 \pm 90$ years B.P. (Beta-21310) from Kwajalein Atoll (Beardsley 1993), $1,910 \pm 70$ years B.P. (Beta-79576) from Maloelap (Weisler 1999a), $1,660 \pm 60$ years B.P. (Beta-74845) from Ujae (Weisler 1999b), $2,050 \pm 90$ years B.P. (Beta-89960) from Nikunau in Kiribati (Di Piazza 1999), and our ages from Majuro Atoll described in the following sections.

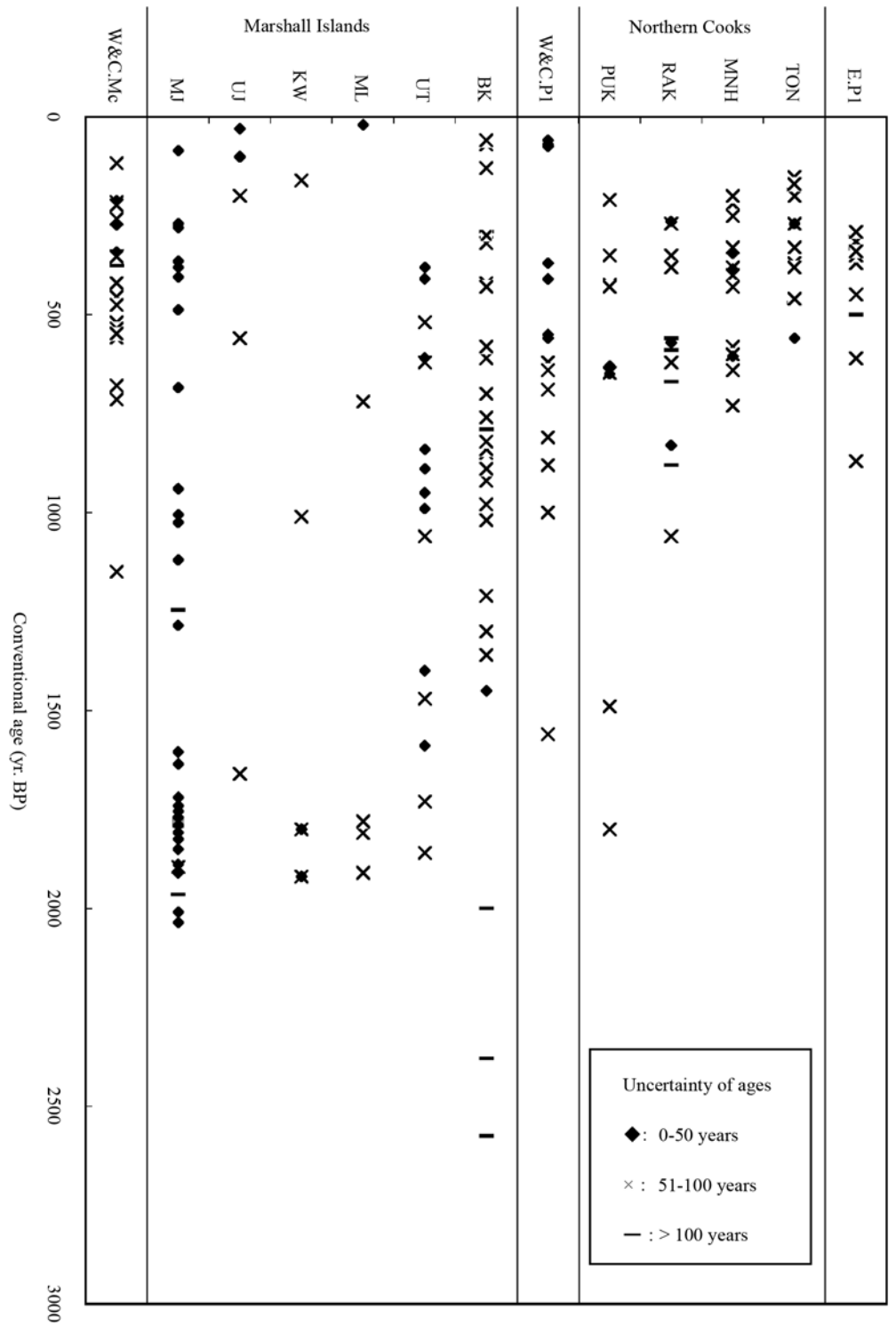
If the late-Holocene sea-level drop was regionally variable, as noted earlier, it is still reasonable for archaeologists to investigate the correlations between the chronological relationship of human colonization and the geomorphological formation of each atoll islet. In the central Pacific, radiocarbon ages reported from Enewetak by Tracey and Ladd include three yielded from apparently in situ corals. These were all from an elevation of approximately 1 m above the current mean sea level, and the radiocarbon ages ranged from 1,900 to 3,300 years B.P. (Tracey and Ladd 1974; see also Buddemeier et al. 1975:1583–1584). We also observed an emergent microatoll on a cemented terrace in Arno Atoll, and the close examination of its sample is in progress. It still remains unclear, however, whether popular terraces of cemented coral rubble, commonly observed

above mean sea level, represent emergent mid-Holocene reef flats or consolidated deposits formed within the intertidal zone. Moreover, Woodroffe and Morrison (2001:258) pointed out that reef-island accretion occurred “on reefs in the West Indies where sea level has continued to rise during the late Holocene, implying that sea-level fall is not necessary for reef-island formation.” Thus more samples of emergent microatolls or *Tridacna* shells in growth position on such cemented terraces must be collected and analyzed to reach a firm conclusion.

Archaeologists in Oceania can also use other materials that directly reflect the subaerial land formation of atoll islets: unconsolidated calcitic deposits consisting of current atoll islets. In fact, Dye (1987:4–5) has already referred to radiocarbon-dated depositional features collected from four Marshall Island atolls and suggested that by “3,000 years ago, then, enough sediment had accumulated” on coral reef flats. Most of the materials Dye mentioned are, however, deposits of coral rubble or *Tridacna* shells in storm ridges or embedded in cemented terraces (see Curray et al. 1970), and thus these radiometric ages only show the upper limits of the sedimentary period and with a high degree of uncertainty. In the central Pacific, including the Marshall Islands, foraminiferal sand accounts for much of the unconsolidated sediment on atoll islets (Woodroffe and Morrison 2001). Because *Calcarina* and *Baculogypsina* tests among Foraminifera have several spicules that are easily abraded in the process of transportation by wave action on reef flats, the samples preserving fresh spicules should be effective in radiometric dating for calcitic sand sedimentation (Yamano et al. 2001). It is also proper that geoarchaeological studies of atoll prehistory must devise a way to compare radiocarbon ages of terrestrial wooden charcoal samples with those of marine calcitic samples.

LANDSCAPE OF PIT AGRICULTURE IN MAJURO ATOLL

The Marshall Islands consist of 29 atolls and five small coral islands that are spread



over approximately 2 million km² of ocean. The earliest radiocarbon age from Bikini Atoll is 3,450 ± 60 years B. P. (Streck 1990), but this age is highly dubious and seems to be from long-lived organic matter or old material from driftwood (Kirch and Weisler 1994:292). From four atolls in this group, Utrok, Kwajalein, Maloelap, and Majuro, radiocarbon dates of ca. 2,000 years B.P. have been reported. These are comparable with the earliest ages of settlement sites on high islands in East Micronesia. Atoll settlement was once viewed as being a relatively late phenomenon compared with that of the high islands, which the Pacific islanders would have settled first. However, it has become clear through archaeological investigations that some central Pacific atolls were settled contemporaneously, as Alkire (1978:21) had earlier hypothesized. One of the essential ingredients for human habitation appears to be the potential for wet taro cultivation in agricultural pits that were maintained by sufficient freshwater resources.

Majuro is situated at 7° N and 171° E, in the southern part of the Marshall Islands (Figure 1). This atoll consists of more than 60 islets on reef flats encircling a large lagoon measuring 41 by 11 km with the long axis extending from east to west. The total land area is just under 10 km². Most government buildings are located on the eastern islets of Djarrit, Uliga, and Delap. The largest and widest islet of Laura measures approximately 1.2 km² in area and 1,200 m at its widest point between the lagoon and ocean shorelines (Figure 4).

To accurately measure the size and distribution of agricultural pits, we established a

grid system based on 0.0015° of latitude/longitude (equaling approximately 166 by 166 m). Within the whole area of Laura, we recorded the upper edges of 195 agricultural pits distributed near the center of the islet using GPS (GpsMap76CSX, Garmin). These ranged in size from 35 to 7,797 m² in area, with more than half of the pits smaller than 500 m² (average = 721 m², SD = 875.6). Some of the grid sections in the center of the islet, namely B6, B7, C6, and C7, are, in particular, covered with a pit-agricultural landscape consisting of undulating pits and spoil heaps with dense vegetation (Figure 4).

Colocasia (katak) and/or *Cyrtosperma (iaraj waan)* tubers, the latter prevailing in Majuro, are planted in these pits. When *Cyrtosperma* is fully grown, it measures more than 3 m in height and produces tubers weighing 20–30 kg (Figure 2a). The upper quarter of a matured tuber is left after the harvest, and the cutting surface is dried for some days and then replanted in moist soil. The seed tuber (*pak*) grows quickly and can be reharvested within a year, whereas it takes 2–5 years for a small peripheral stalk (*il*) to mature in pits. *Cyrtosperma* tubers have the highest carbohydrate content per unit among the aroids and can also withstand high water levels or even flooding, provided that it does not result in an inflow of seawater. As a result, this species is more adaptable to the fluctuating water table associated with tidal change (Lambert 1982). This characteristic may be one reason why *Cyrtosperma* is the main aroid grown on atolls in the Marshall Islands.

Majuro Atoll, in the far southeast of the Marshall Islands, averages about 3,500 mm in annual rainfall. Although the annual rain-

FIGURE 3. Time differences of earlier settlements on oceanic atolls, on the basis of conventional ages of charcoal samples: W&C.Mc is West-Central Micronesia including Nukuoro (Davidson 1971, 1992) and Kapingamarangi (Leach and Ward 1981); MJ is Majuro in the Marshall Islands (Riley 1987, Rosendahl 1987, Yamaguchi et al. 2005); UJ is Ujae (Weisler 1999b); KW is Kwajalein (Shun and Athens 1990, Beardsley 1993); ML is Maloelap (Weisler 1999a); UT is Utrok (Weisler 2001a,b); BK is Bikini (Streck 1990); W&C.Pl is West-Central Polynesia including Fanning (Sinoto 1973) and Christmas (Anderson et al. 2000, Di Piazza and Pearthree 2001) in the Line Islands, Fakaofu and Atafu (Best 1988) in the Tokelau Islands, and Funafuti and Vaitupu (Takayama and Sato 1987; T.Y., unpubl. data) in Tuvalu; PUK is Pukapuka in the northern Cook Islands (Chikamori and Yoshida 1988, Yamaguchi 2000); RAK is Rakahanga (Yamaguchi 2000); MNH is Manihiki (Chikamori 1998, Yamaguchi 2000); TON is Tongareva (Yamaguchi 1990, 2000); and E.Pl is East Polynesia including Rangiroa (T.Y., unpubl. data) and Reao (Sinoto 1976, Chazine 1982) in the Tuamotu Islands, and Tetiaroa (Sinoto and McCoy 1974) in the Society Islands.

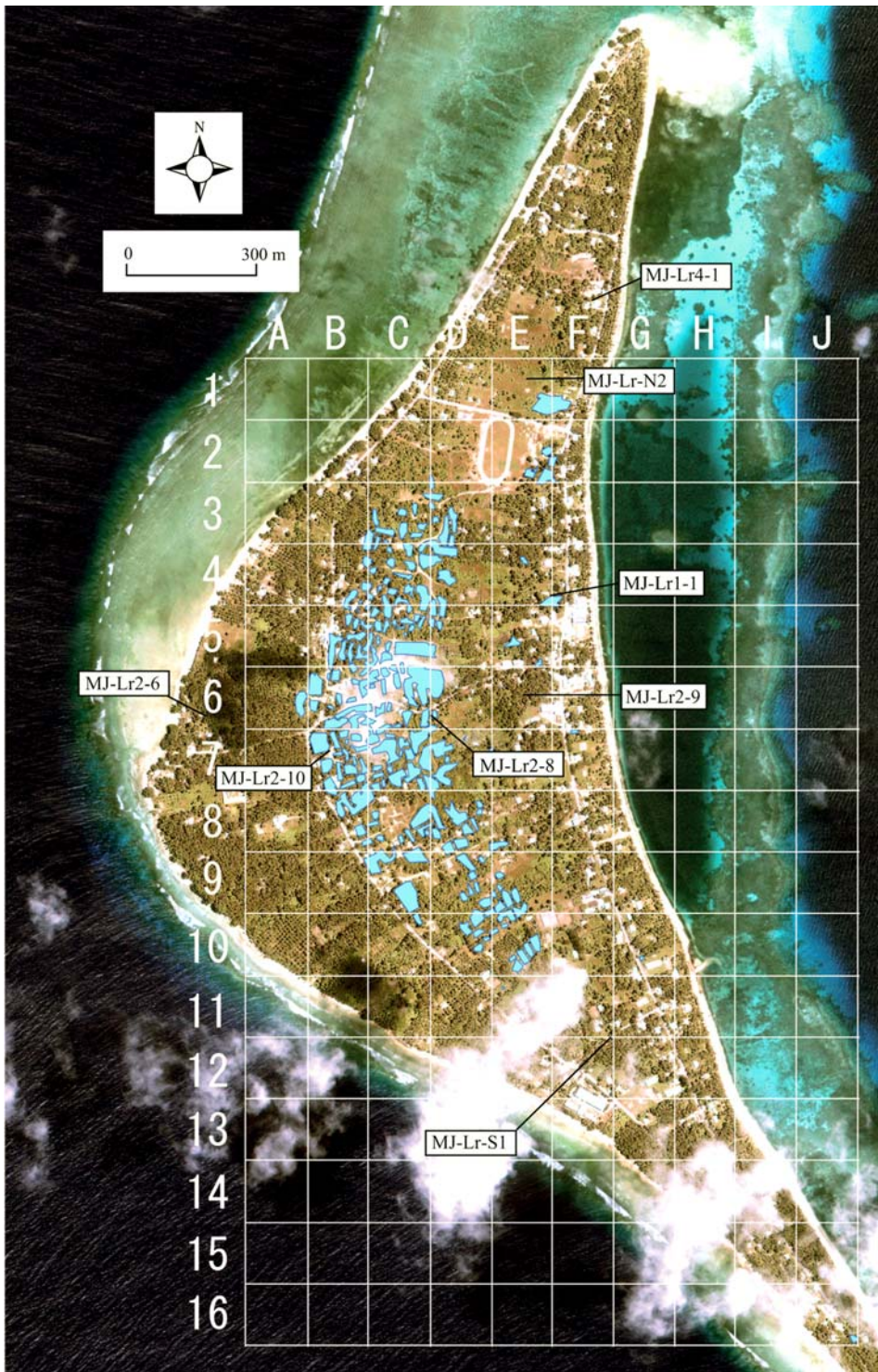


FIGURE 4. Spatial distribution of agricultural pits and locations of excavated sites. This map is drawn on an IKONOS satellite image, and Laura is divided into grids along each 0.0015° of latitude and longitude (each grid is approximately 166 by 166 m). Agricultural pits are shown by blacked-out portions.

fall distribution on oceanic atolls is generally seasonal and occurs in the wet season, there is regional variation, which appears to be comparatively small in Majuro according to precipitation data collected between 1955 and 1972 (Taylor 1973). The Marshallese government uses the Majuro airport (88 ha) to collect rainfall, storing it in huge water reservoirs of 37 million gallons (140,000 kl), to satisfy the demand for freshwater for the more than 20 thousand people living on this atoll. Serious water shortages have occurred, the most notable of which was during the 1997–1998 El Niño event. Monthly rainfall was less than 2.54 cm in the dry season between February and April 1998, and residents came to rely primarily on Laura's freshwater lens. It is estimated that 90% (March 1998) and 64% (May 1998) of the total drinking water that Majuro Water and Sewer Company supplied during that period originated from Laura (Presley 2005:18). Although the excessive pumpage could have affected the size and the quality of the freshwater lens, no serious damage or trouble, such as the withering of *Cyrtosperma*, was reported from this heavy use. This islet has the largest catchment of rainfall, so its underground freshwater lens could probably remain relatively intact even during extensive droughts lasting several months.

As noted earlier, the freshwater sits atop saline water permeating the porous underground of the islets, and its quality and volume is also affected by tidal and seasonal fluctuations in the water table that cause diffusion between the two. Its magnitude is inversely proportional to the width and size of the islets (Tracey et al. 1961). The permeability of underground sediments is more crucial to the fluctuation of water lenses. According to a hydrogeological survey, the near-surface lithological framework beneath Laura comes in two primary hydrologic units (Hamlin and Anthony 1987, Anthony et al. 1989). The lower unit represents a porous aquifer of limestone that was subaerially exposed and leached during a Pleistocene glacial-lowstand sea level. The upper unit is “an uncemented grainstone composed of a heterogeneous mixture of moderately well-sorted forami-

fera sand and fragments of coralline algae” (Anthony et al. 1989:1068), and the lower sediment of the upper unit contains a relatively higher abundance of silt. This unconsolidated unit is markedly less permeable than the leached Pleistocene limestone and coarse gravel deposited at the oceanside that are more porous or have cavities (see also Marshall and Jacobson 1985, Peterson 1997).

Drillholes on Laura have revealed that the upper unit of fine sand is about 25 m thick on the lagoonward edge and 16 m even inland. The sand's relatively low permeability and its thickness would prevent saline water from moving upward from the lower porous aquifer into the freshwater lens (Underwood et al. 1992). It is probably the accumulation of this foraminiferal sand along with rich precipitation annually averaging approximately 3,500 mm and the wide catchment of rainfall that cause Laura to contain the largest freshwater lens on the atoll, which sustains its variety of vegetation, particularly *Cyrtosperma*, in the agricultural pits.

A Geoarchaeological Excavation of Pit-Agricultural Landscape Site MJ-Lr2-8

Although the inland portion of Laura today has been somewhat modified for the development of residential areas, it is still covered with dense vegetation and a chain of undulating pits circled by spoil banks. Because most remote atolls were not affected by alluvial or volcanic deposits, there has been little surface accumulation of soil in the past. As such, the only soil deposition seen relates to that of anthropogenic spoil from agricultural pits, which serve to protect intact A horizons and cultural features as was demonstrated in previous excavations (Riley 1987:216–217, Weisler 1999a). The 2003 excavation of site MJ-Lr2-8 on a spoil bank also offered an opportunity to examine the chronological formation of this pit-agricultural landscape on Majuro Atoll.

The top of the spoil bank was about 3 m above the current mean sea level, and the bottom of the pits was 0.4 m above (Figure 5). This is remarkable considering that the islet is uniformly flat. A 2 by 4 m trench was ex-

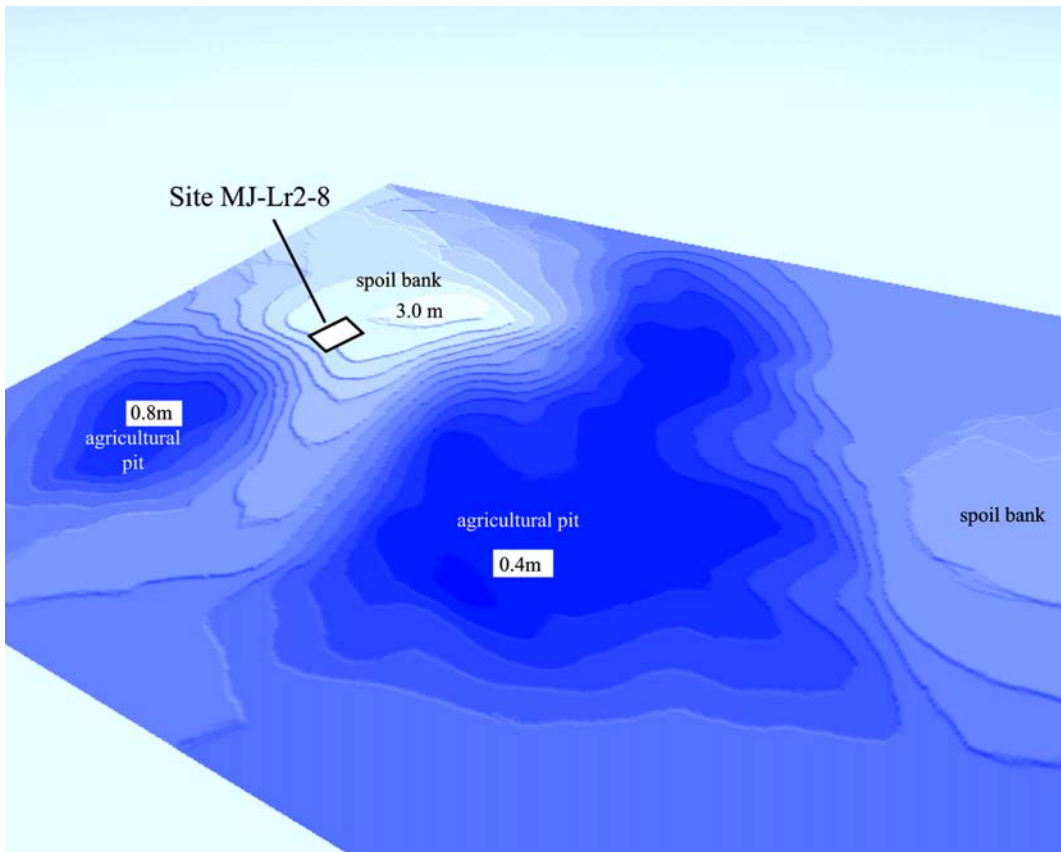


FIGURE 5. Schematic 3-D topography of an agricultural complex and location of site MJ-Lr2-8.

cavated to an approximate depth of 150 cm, and intact stratified deposits were encountered, composing roughly three strata excluding surface humus (Figure 6). These included the following:

(1) The lowest stratum (Layer 7) was a very pale brown (10YR7/3), naturally accumulated sand deposit consisting of sand-size fragments of coral, coralline algae, mollusks, and abundant large benthic Foraminifera (mostly *Calcarina* spp.).

(2) The second stratum (Layer 6), lying just on top of the natural stratum, contained dark gray sand (10YR4/1) and charcoal flecks and appears to be the earliest buried A horizon. The shallow pit of an earth oven (U1-Fe6) along the eastern profile contained a large abundance of burned coral pebbles

and charcoal flecks, probably monocotyledon trunk and coconut endocarp, which dated to 2,010 years B.P.

(3) The third stratum (Layer 2 to U1/Fe5) consisted of gray sand layers (10YR4/1–6/1) and earth ovens containing burned coral pebbles and charcoal flecks. The components of these layers bear a resemblance to those of soil in the adjacent pits. Dolphin (probably *Peponocephala electra*) vertebrae and turtle remains were retrieved along with bones of pelagic, benthic, and reef fishes from the sediments of ovens as well as the spoil layers, which were roughly sifted through 10 mm and 5 mm screens (Yamaguchi et al. 2005:31). We also obtained five associated radiocarbon ages from charcoal flecks of Pacific rosewood and Chinese lantern, all of which

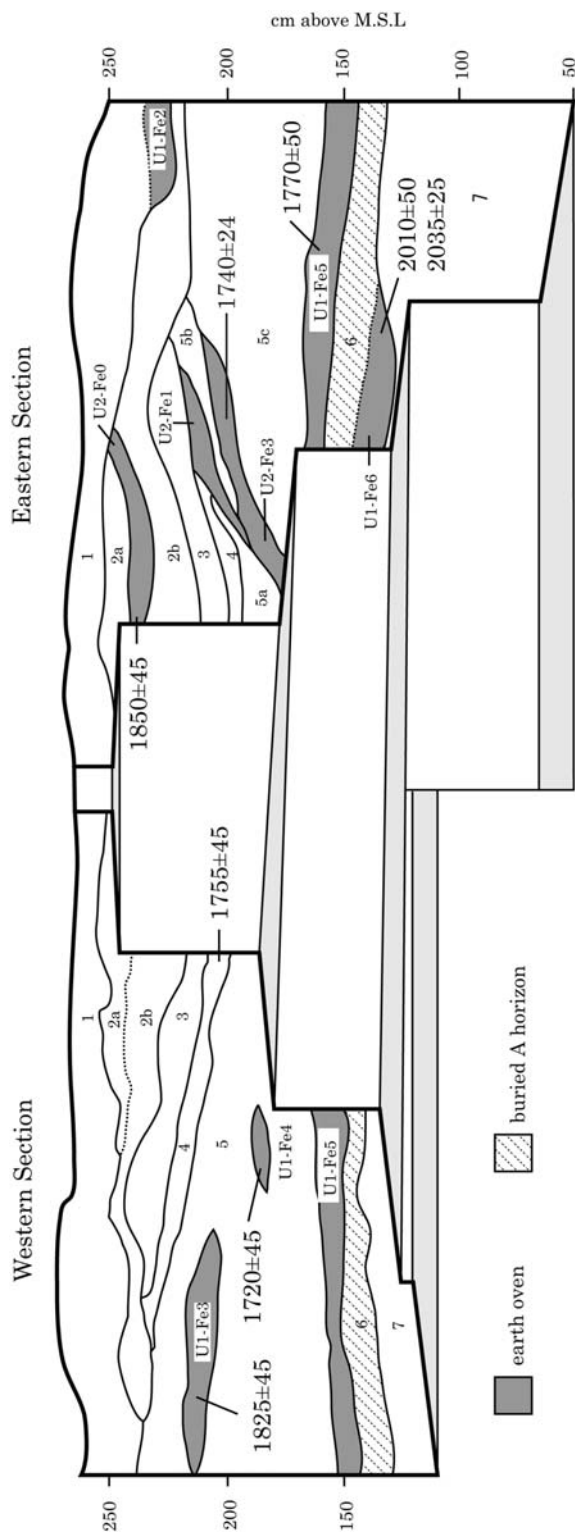


FIGURE 6. Schematic 3-D stratigraphy of site MJ-Lx2-8 showing both walls, western and eastern, and eight conventional ages from charcoal samples.

fell within a narrow range of 1,700–1,800 years B.P.

Early Settlement on Laura Relating to Its Geomorphological Formation

We excavated the same trench of site MJ-Lr2-8 in 2006 and collected charcoal flecks from the lowest earth oven (U1-Fe6). Although this rough reexcavation could have caused some younger samples to be redeposited in the lower layers, a charcoal fleck of *Cocos* spp. yielded $2,035 \pm 25$ years B.P. (PLD-6752), equivalent to the age of $2,010 \pm 50$ years B.P. (PLD-2790) obtained from the same feature in 2003 (Table 1). Recent archaeological studies of the Marshall Islands have revealed that the prehistoric human settlements on several atolls fall within the same range, and the preceding evidence from Laura reported by the Bishop Museum (Riley 1987) and Weisler (2000) also show a range of 1,800–2,000 years B.P. It is, therefore, almost certain that a group of oceanic islanders arrived at Majuro Atoll around the first century A.D.

In the mid-Holocene, the paleoreef had developed to the highstand sea level over the Pleistocene-aged limestone bedrock. It is estimated to have started to emerge sometime after about 2,000 years ago (Tracey and Ladd 1974, Buddemeier et al. 1975, Dickinson 2003), which is nearly contemporaneous with the earliest period of human habitation on Laura. We collected samples of *Calcarina* from the natural stratum at a trench for a geomorphological study that was parallel to the lowest layer (Layer 7) at site MJ-Lr2-8. As noted earlier, *Calcarina* samples preserving fresh spicules have recently been shown to be available for radiometric dating in geomorphological studies on coral sand sedimentation. Our two samples yielded dates of $2,380 \pm 40$ years B.P. From two earth ovens (U1-Fe5 and U2-Fe3) of the third stratum, we recovered several dolphin vertebrae, and premaxilla and maxilla of *Peponocephala electra* that were associated with charcoal samples. We are now using these materials to help estimate a local ΔR , which will enable us to better estimate the chronological relation-

ship between geomorphological formation of Laura and initial human colonization (H.K., T. Yasukochi, T.Y., H.Y., and M. Yoneda, unpubl. data).

Prehistoric Invention of Agricultural Pits

The third stratum at site MJ-Lr2-8 is interspersed with earth ovens that tend to descend to an agricultural pit in the same way as the spoil layers, except for the lowest oven (U1-Fe5), which is a large one more than 2 m in diameter (Figure 6). It can be speculated that the lowest oven in the third stratum was constructed before the excavation of the adjoining agricultural pit began, and the rest of the ovens were used in the process that created the spoils piled up around the pits.

Of particular interest is that the six radiocarbon ages associated with these earth ovens, including the lowest (U1-Fe5) and uppermost ones (U2-Fe0), fall within a narrow interval of around 1,700–1,800 years B.P. (1,600–1,800 cal. B.P.) (Table 1, Figure 7). This implies that the spoil bank was formed not gradually but over a short period and has remained largely unchanged. The charcoal samples also provide an indication of past vegetation. Identified charcoal flecks from the third stratum include Pacific rosewood (*Cordia* spp.) and Chinese lantern (*Hernandia* spp.) as well as pandanus and coconut trees. These species are commonly found in close proximity to agricultural pits, but no charcoal fleck of the breadfruit tree, another common species, was retrieved from this stratum. It is thus plausible that inhabitants on Laura also began to deliberately construct these agricultural pits not long after initial human colonization.

The development of the pit-agricultural landscape required not only the development of the freshwater lens but also knowledge to manipulate the hydromorphic terrain for tuber cultivation. Most languages spoken in Micronesia, including in the Marshall Islands, belong to Nuclear Micronesian, one of the Proto-Oceanic subgroups that is closely correlated with the eastward expansion of the Lapita cultural complex. Archaeological excavations on three high islands in central

TABLE 1
Radiocarbon Ages (AMS) from Our Excavations on Laura, Majuro Atoll

Lab. Code ^a	Provenance	Material	¹⁴ C Conventional	Delta ¹³ C	Cal. Yr (1σ)	Cal. Yr (2σ)
PLD-2016	MJ-Lr1-1 Fe 4	Unidentified	940 ± 25	-25.90	A.D. 1035– 1065 (32.6%) A.D. 1085– 1125 (46.1%) A.D. 1140– 1155 (21.3%)	
PLD-2017	MJ-Lr1-1 Layer 5 (lower)	Unidentified	1025 ± 25	-23.90	A.D. 995– 1025 (100%)	
PLD-6753	MJ-Lr2-9 Test Trench 1, Fe6	Monocotyledoneae	1605 ± 25	-23.76	A.D. 410– 450 (23.6%) A.D. 480– 540 (44.6%)	A.D. 410–540 (95.4%)
PLD-6754	MJ-Lr2-9 Test Trench 1, Fe7	<i>Cordia</i> spp.	1635 ± 25	-27.74	A.D. 380– 440 (62.7%) A.D. 490– 510 (5.5%)	A.D. 340–540 (95.4%)
PLD-6755	MJ-Lr2-9 Test Trench 2, Fe1	Monocotyledoneae	1005 ± 20	-24.14	A.D. 990– 1035 (68.2%)	A.D. 980– 1050 (87.4%) A.D. 1090– 1120 (6.6%) A.D. 1140– 1150 (1.4%)
PLD-6756	MJ-Lr2-9 Test Trench 2, Fe2	Monocotyledoneae	380 ± 25	-24.70	A.D. 1450– 1510 (54.1%) A.D. 1600– 1620 (14.1%)	A.D. 1440– 1530 (70.6%) A.D. 1570– 1630 (24.8%)
PLD-6757	MJ-Lr2-9 Main trench, Fe2	<i>Pemphis acidula</i>	405 ± 20	-26.33	A.D. 1440– 1480 (68.2%)	A.D. 1430– 1510 (88.7%) A.D. 1600– 1620 (6.7%)
PLD-2785 (MTC-04413)	MJ-Lr2-8 U2/Fe0	<i>Cordia</i>	1850 ± 45	-25.80	A.D. 125– 235 (97.0%)	
PLD-2786 (MTC-04414)	MJ-Lr2-8 Layer 4	<i>Pandanus</i> gen.	1755 ± 45	-28.10	A.D. 230– 345 (94.6%)	
PLD-2787 (MTC-04415)	MJ-Lr2-8 U1/Fe3	<i>Cocos</i> spp.?	1825 ± 45	-26.30	A.D. 130– 240 (100%)	

TABLE 1 (continued)

Lab. Code ^a	Provenance	Material	¹⁴ C Conventional	Delta ¹³ C	Cal. Yr (1σ)	Cal. Yr (2σ)
PLD-2788 (MTC-04416)	MJ-Lr2-8 U1/Fe4	<i>Pandanus</i> fruit	1720 ± 45	-25.40	A.D. 255– 300 (41.4%) A.D. 320– 385 (58.6%)	
PLD-5827	MJ-Lr2-8 U2/Fe3	Monocotyledoneae	1740 ± 24	-23.11	A.D. 250– 335 (68.2%)	A.D. 230–390 (95.4%)
PLD-2789 (MTC-04417)	MJ-Lr2-8 U1/Fe5	<i>Cordia</i> spp.	1770 ± 50	-25.70	A.D. 215– 340 (91.9%)	
PLD-2790 (MTC-04418)	MJ-Lr2-8 U1/Fe6	Monocotyledoneae	2010 ± 50	-27.80	50 B.C.–A.D. 60 (99.4%)	
PLD-6752	MJ-Lr2-8 U1/Fe6	<i>Cocos</i> spp.	2035 ± 25	-26.73	90 B.C.–75 B.C. (8.6%) 55 B.C.–A.D. 5 (59.6%)	160 B.C.–130 B.C. (2.4%) 120 B.C.–A.D. 30 (93.0%)
PLD-6758	MJ-Lr2-10 Layer 2	Monocotyledoneae	1910 ± 25	-24.67	A.D. 65– 125 (68.2%)	A.D. 20–140 (95.4%)
PLD-2791 (MTC-0441)	MJ-Lr2-6 Fe1	<i>Cocos</i> spp.?	1285 ± 45	-24.40	A.D. 680– 775 (100%)	
PLD-5828	MJ-Lr-S1 Fe1	Monocotyledoneae	488 ± 22	-26.13	A.D. 1415– 1440 (68.2%)	A.D. 1410– 1445 (95.4%)
PLD-5829	MJ-Lr-N2 Layer 4a	<i>Diospyros</i> cf. <i>ferrea</i> ?	1120 ± 25	-24.30	A.D. 890– 905 (9.7%) A.D. 910– 970 (58.5%)	A.D. 885–985 (95.4%)
PLD-6763	MJ-Lr-Seion Layer 9	Unknown broad- leaved tree	685 ± 25	-28.37	A.D. 1270– 1300 (57.9%) A.D. 1370– 1380 (10.3%)	A.D. 1270– 1310 (70.2%) A.D. 1360– 1390 (25.2%)

^a PLD refers to measurements by Paleo Labo Co., Ltd., a Japanese commercial laboratory; MTC refers to measurements made by MALT (Micro Analysis Laboratory Tandem Accelerator) requested through Paleo Labo.

Micronesia, namely, Chuuk, Pohnpei, and Kosrae, have revealed the sand-tempered plainware potsherds relating to the period around 2,000 years B.P. Their attributes bear a resemblance in form and technology to the late Lapita Plain Ware pottery tradition that extended from the Bismarks westward as far as the Reef-Santa Cruz Islands eastward after 2,500 years B.P. (Athens 1990:29).

Thus, linguistic and archaeological evidence strongly indicate that the Marshall Islands were colonized from the south, probably somewhere from the southeastern Solomon-Vanuatu region (see Blust 1988 [1984–1985]:58, Intoh 1997:22, Kirch 2000:175). A recent archaeological excavation on Nikunau, a reef island in Kiribati, has also revealed two early earth ovens dating from

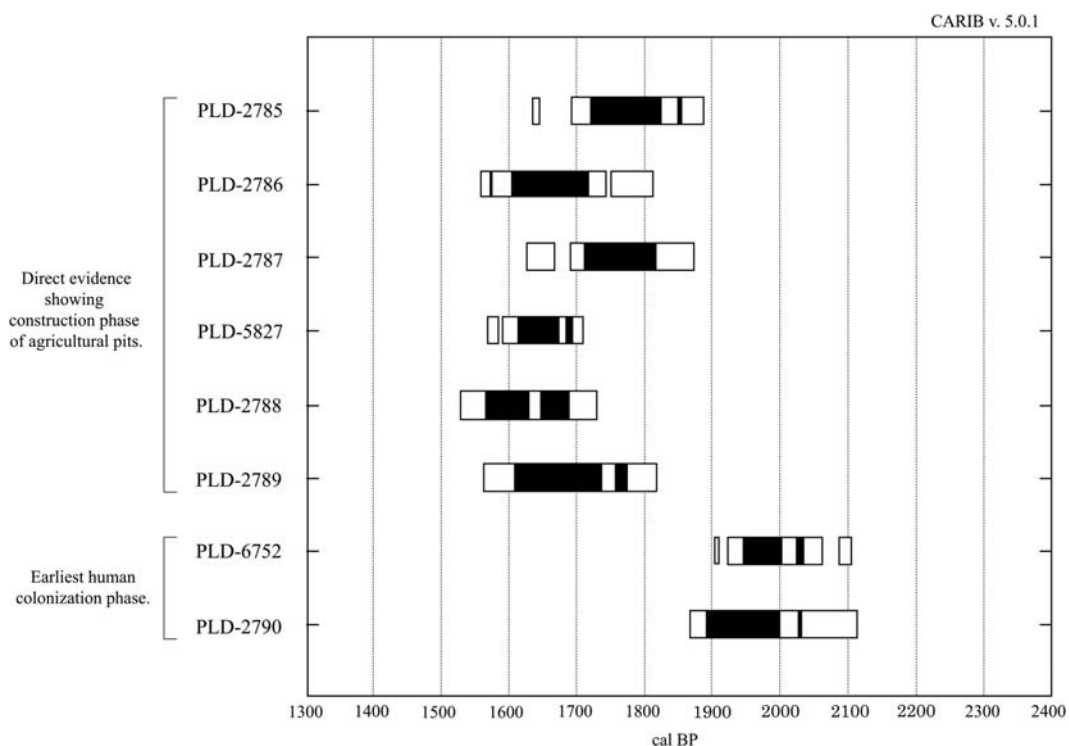


FIGURE 7. Calibrated ages (CALIB 5.0.1) of the earliest construction of agricultural pits, and the time difference with the earliest phase of human habitation.

about 2,000 years B.P. (Di Piazza 1999), which suggest an indirect route passing from the south through a chain of atolls and coral islands in Kiribati. Although it would be worthwhile to examine whether Lapita peoples had practiced distinctive irrigation in Melanesia, they probably cultivated both species of *Colocasia* and *Cyrtosperma* at least “in naturally swampy swales behind the beach terraces where they made their home” (Kirch 1997:211; see also Kirch and Lepofsky 1993). It seems possible that one of their groups, first encountering the strange environment of isolated atolls, brought with them to Laura seed tubers and the knowledge of cultivating swamp taro by utilizing the hydromorphic terrain, thereby reproducing part of their homeland landscape on this new islet.

This is, however, the first phase of Laura’s landscape history, which was followed later by phases associated with the expansion of

the pit-agricultural landscape and the expansion of habitation areas. Further excavations on Laura provide additional data on the sequence of landscape history, briefly discussed in the next section.

ARCHAEOLOGICAL SEQUENCE OF THE LANDSCAPE HISTORY OF PIT AGRICULTURE

As already noted, in the 1980s the U.S. Geological Survey carried out a hydrogeological survey on the underground water lens of Laura and reported estimated contour maps of the water table and depth of the freshwater lens (Hamlin and Anthony 1987: fig. 7, fig. 30). Although their base map was not perfectly overlain with IKONOS high-resolution satellite imagery and as such is not completely accurate, we can still estimate the spatial relationship between the freshwater lens and distribution of agricultural pits (Figure 8). Both

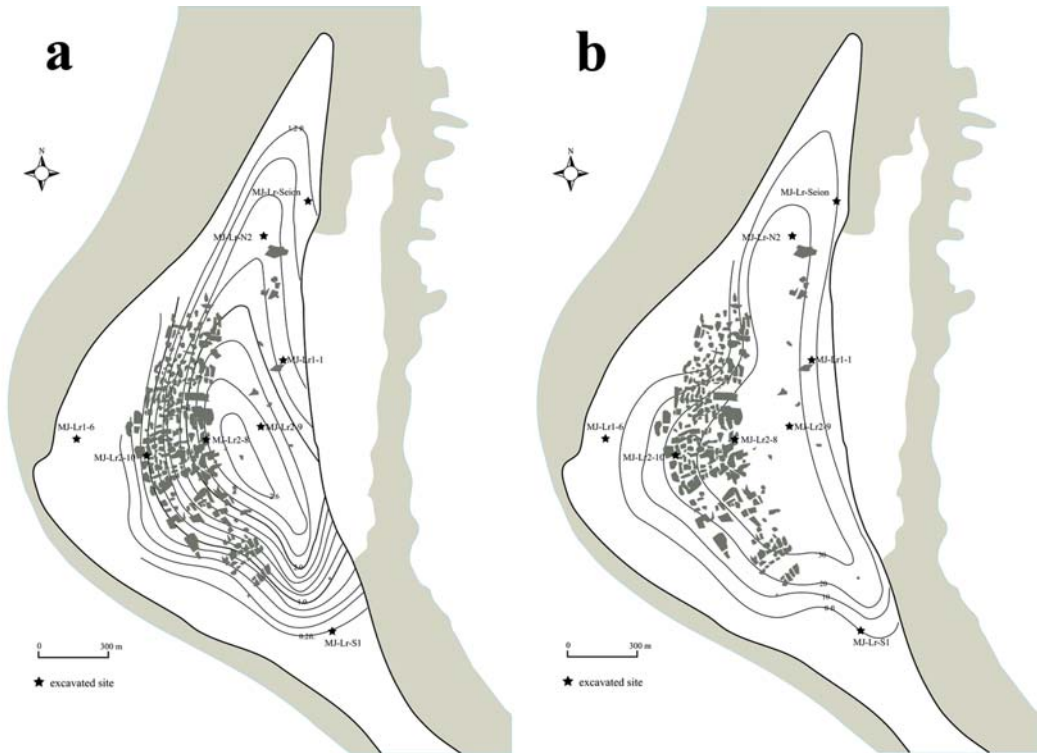


FIGURE 8. Spatial relationship of Laura's agricultural pits with (a) depth and (b) water table of freshwater lens. The contour maps are modified from Hamlin and Anthony (1987: fig. 7 and fig. 30).

maps indicate a subtle spatial difference of agricultural pits with the hydrogeological core of the current freshwater lens. Residential houses are now distributed around the core area, where the thickness of the lens is more than 30 ft (about 9 m) and the water table is more than 2 ft (about 60 cm). In addition, some agricultural pits are scattered just behind the lagoonside beach ridge. These distributional characteristics tempt us to envisage changes both of geomorphological condition and land utilization that have been involved in the historical construction of the current landscape. Four more excavated sites contributed to such an investigation; these are approximately located along a transect line in the vicinity of the widest portion between Laura's shorelines, lagoonward and oceanward: MJ-Lr2-6, MJ-Lr2-10, MJ-Lr2-9, and MJ-Lr1-1 (Figure 4, Table 1).

(1) Site MJ-Lr2-10 (Figure 9a). This site, located at the oceanward edge of the main pit-agricultural area, was selected for an investigation into the spatial extent of earlier pits. We excavated a 4 by 2 m trench on a spoil bank, which was surrounded with three pits and approximately 80–100 cm higher than the current paved road extending north-south along the ocean coast of Laura. Although in the 1980s the bank was leveled and the upper layers of spoil were bulldozed, the lowest A horizon lying on natural Foraminifera-rich deposits still remains.

The stratigraphy of a section profile consisted of four layers. Layer 4 could be divided into three sublayers that had naturally accumulated: the lowest one (Layer 4c) comprised light brownish gray foraminiferal sand (10YR6/2) with a large amount of coral cobble more than 100 mm in diameter, the mid-

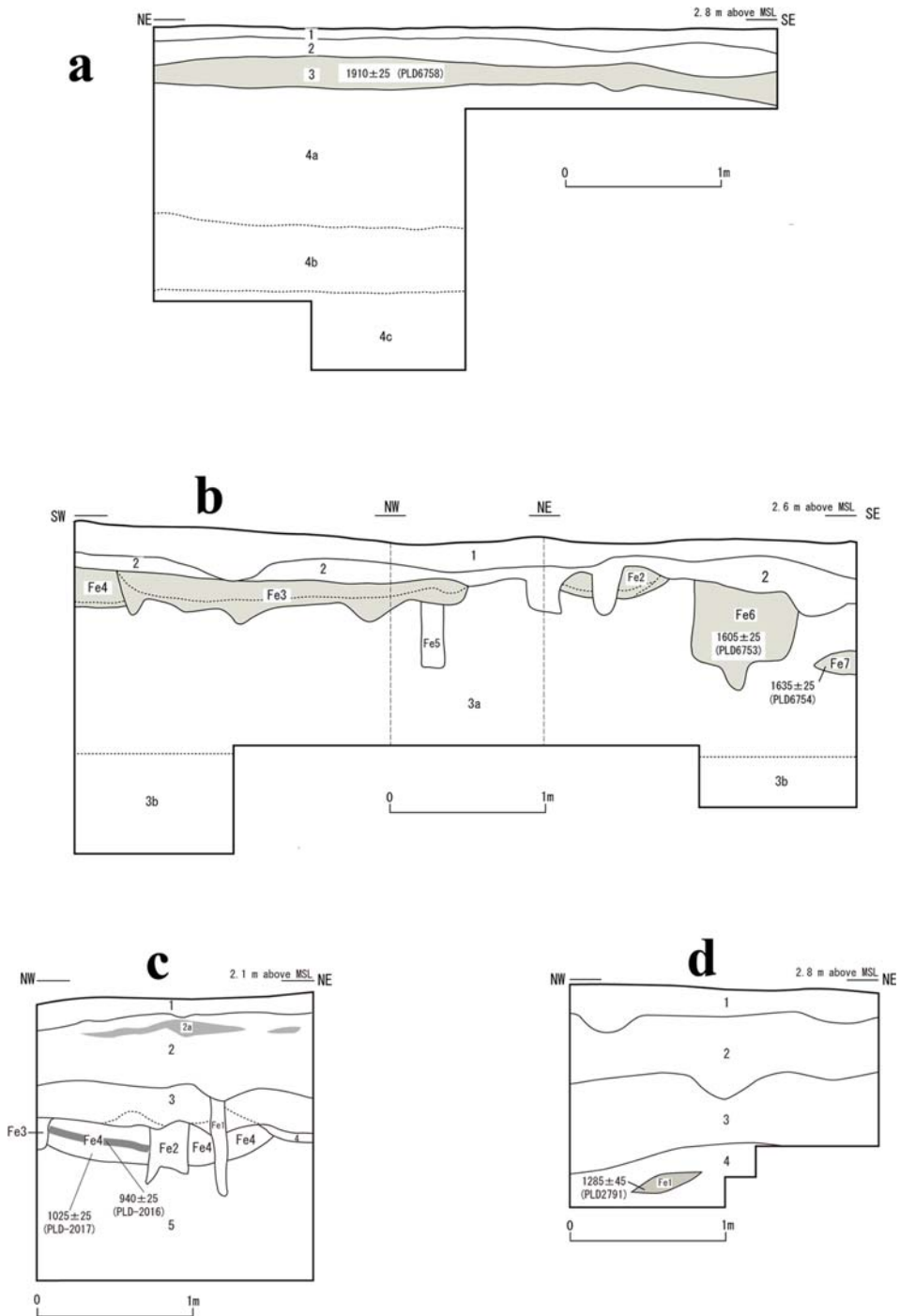


FIGURE 9. Profiles of four excavated trenches in Laura: (a) eastern section of Site MJ-Lr2-10, on a spoil bank at the oceanward edge of the main pit-agricultural area; (b) three sections of Site MJ-Lr2-9, a habitation site at the lagoonside front of Site MJ-Lr2-8; (c) northern section of Site MJ-Lr1-1, on the spoil bank of a detached agricultural pit behind the lagoonside beach ridge; (d) northern section of Site MJ-Lr2-6, probably a camp site behind the ocean ridge.

dle one (Layer 4b) consisted of slightly darker foraminiferal sand (10YR6/3) with a small amount of coral pebbles approximately 10 mm in diameter, and the upper one (Layer 4a) consisted of light gray fine sand (10YR7/2) containing foraminiferal tests with little coral gravel. Layer 3 was darker than Layer 2 and was mainly composed of gray sand (10YR5/1) in which many charred flecks were scattered with brittle coral fragments that could have been burned in an earth oven. One piece of these flecks was dated to $1,910 \pm 25$ years B.P. (PLD-6758). Thus this layer suggests that the earliest habitation occupied the area between MJ-Lr2-8 and MJ-Lr2-10 along the central transect line. Layer 2 mainly comprised pale brown sand (10YR6/3) and a large amount of coral pebbles approximately 10 mm in diameter. Most of the deposits were bulldozed, but these were probably spoils from the adjacent agricultural pits, suggesting that the inhabitants appropriated the habitation area around this site for farmland after 1,910 years B.P. Layer 1 was the current surface containing very dark grayish brown humus soil (10YR3/2) and pale brown sand (10YR6/3), which lay over the flattened Layer 2.

(2) Site MJ-Lr2-9 (Figure 9b). This site, located in the lagoonside front of MJ-Lr2-8, is within the area where the current freshwater lens is thickest. In a 4 by 4 m excavated unit, we observed many earth ovens as well as postholes and found a burial feature of an adolescent. We also uncovered shell artifacts, including a *Cassia* chisel, a *Tridacna* spp. adze, and a *Pinctada* spp. fragment with a worked edge by dry sieving with 10 mm mesh. Six radiocarbon ages from this site range between 1,600 years B.P. and 400 years B.P. These features suggest the definite possibility of long-term habitation at this site. Here, we present a brief description of a section profile at Test Trench 1 located within the main excavated unit; a study presenting the details of this excavation including evidence of human skeletal remains is in preparation (S. Yoshida and T.Y., unpubl. data).

Layer 3, naturally accumulated, could be divided into two sublayers: the lower one (Layer 3b) comprised very pale brown coarse

sand (10YR8/3) including foraminiferal tests, and the upper one (Layer 3a) consisted of slightly darker fine sand (10YR7/3). Eight features including Fe3–Fe7 in Test Trench 1 penetrated into Layer 3, most of which consisted mainly of grayish sand (10YR4/1 to 10YR5/1) with blackish bands of charred grains (10YR2/1 to 10YR3/1). Some features, such as Fe6 in Test Trench 1, contained burnt coral fragments and therefore were identified as earth ovens. A charred fragment of Monocotyledon from Fe6 and another fragment of *Cordia* spp. were dated at $1,605 \pm 25$ years B.P. (PLD-6753) and $1,635 \pm 25$ years B.P. (PLD-6754), respectively. We also obtained three radiocarbon ages from two earth ovens in Test Trench 2: $1,005 \pm 20$ years B.P. (PLD-6755), $1,044 \pm 24$ years B.P. (PLD-9188), and $1,553 \pm 25$ years B.P. (PLD-9187). Layer 2, consisting of very dark gray sand (10YR3/1) and dark gray sand (10YR4/1), covered these eight features. Four features, including Fe1 and Fe2 in Test Trench 1, were dug down from Layer 2. A charcoal sample from this layer and another one from an earth oven observed at the southern section profile of the main excavated area were dated at 380 ± 25 years B.P. (PLD-6756) and 405 ± 20 years B.P. (PLD-6757).

(3) Site MJ-Lr1-1 (Figure 9c). This site is adjacent to a detached agricultural pit that was located behind the lagoonside beach ridge and close to Laura United Church. A 1.8 by 0.8 m test trench on the spoil bank covered with heavy bushes was excavated.

The lowest natural deposit of Layer 6 consisted of light gray sand (10YR7/1 to 10YR7/2), which was similar to the current beach sediment of the lagoonside coast. Layer 5 mainly consisted of very pale brown sand containing spots of gray (10YR5/1) sand, which was probably spoils piled up from the adjacent agricultural pit. A charcoal sample collected from the lower part of this layer was dated at $1,025 \pm 25$ years B.P. (PLD-2017). A thin band of gray sand (10YR5/1) was interspersed at the middle of Layer 5, and a charcoal sample was also dated at 940 ± 25 years B.P. (PLD-2016). These two ages indicate that inhabitants started to ex-

exploit new spaces for agricultural pits around the beginning of the second millennium. Layer 4 was of light yellowish brown sand (10YR6/4) without any charred flecks, the properties of which were indistinct. Two unidentified features (Fe2 and Fe3) recorded on the section profile were dug into Layer 5 and filled with dark gray sand (10YR4/1) along with some spots of very pale brown sand (10YR7/3). Layer 3a was characterized by a large amount of coral gravel 30 cm in diameter, which was heavily compacted with black soil grains (10YR1.7/1). Some parts (Layer 3b) of dark gray sand (10YR4/1) underlaid this level. A posthole approximately 70 cm long (Fe1), filled with dark gray sand (10YR4/1), was dug from the surface level of Layer 3a, and thus there is the high possibility that Layer 3 contained a house floor or a house platform. Layer 2a consisted of gray and dark gray sand (10YR5/1, 10YR4/1), in which some thin sediments of gray sand and black soil (10YR4/1, 10YR2/1) were interspersed. This layer was spoils dug from the agricultural pit. Layer 1, the surface soil, contained very dark grayish brown soil (10YR3/2) with a large amount of coral gravel approximately 30 mm in diameter.

(4) Site MJ-Lr2-6 (Figure 9d). This site is located just behind the ocean ridge. A 2 by 2 m trench was excavated by a geomorphologist in our group, who collected a sample of sediments. A cultural feature was found on the northern section profile, and thus the trench was also archaeologically investigated.

Layer 4 was the lowest level with natural sediment, composed of very pale brown sand (10YR7/3) with a small amount of coral gravel. Within this layer, we observed a thin deposit (Fe1) of dark gray sand (10YR4/1) that included a large amount of burnt coral gravel 40 mm in diameter and some fish bones. This suggests an earth oven; a charcoal sample, probably *Cocos* fragments, was dated at $1,285 \pm 45$ years B.P. (PLD-2791). Layer 3 consisted of coarser grains of very pale brown sand (10YR7/3) and a large amount of coral cobble approximately 10–60 mm in diameter. This layer was probably derived from a natural event such as a storm. Layer 2 comprised finer grains of very pale brown

sand (10YR7/3). Layer 1, covering natural sediments, was the surface humus of very dark gray soil (10YR3/1) with a large amount of coral gravel approximately 10–30 mm in diameter.

Based on excavation of these four units, in conjunction with data recovered from site MJ-Lr2-8 (Figure 10), we can begin to construct a tentative sequence of landscape modification. The first phase (ca. 2,000–1,900 years B.P.) is that in which the earliest islanders, who discovered the emergent atoll islet, established their habitation in the middle of its current landform between site MJ-Lr2-8 and site MJ-Lr2-10. Here they likely cultivated wet taro that they had transported from their homeland. The second phase (ca. 1,800–1,600 years B.P.) is that in which agricultural pits were excavated within the earliest habitation space, which was then moved to the lagoonside around site MJ-Lr2-9. The third phase (ca. 1,300–1,000 years B.P.) is that during which the habitation space expanded lagoonward, and the back space of the ocean ridge was used for temporary fishing camps on the broad reef flat where fish traps, or stone-walled fish weirs, still remain (U.S. Army Corps of Engineers 1989:21). The fourth phase (ca. 1,000 years B.P.) is that in which inhabitants exploited new agricultural pits in front of their main habitations. They would also have extended their habitation space to the north and the south along the lagoon shore in the third and the fourth phases. While our examination of additional excavated sites (MJ-Lr-N2, MJ-Lr4-1, MJ-Lr-S1 in Figure 4) in the northern and southern parts of Laura was in progress, we obtained three conventional ages falling within the range of the later phases from the lowest cultural layers, respectively: $1,120 \pm 25$ years B.P. (PLD-5829), 685 ± 25 years B.P. (PLD-6763), and 488 ± 22 years B.P. (PLD-5828) (Table 1). These archaeological results strongly indicate that the space of human activities has increasingly expanded in both aspects of habitation and agricultural pits.

Advancing geomorphological and sedimentological studies provide information concerning the process of Laura's formation when contextualized with radiometric ages of

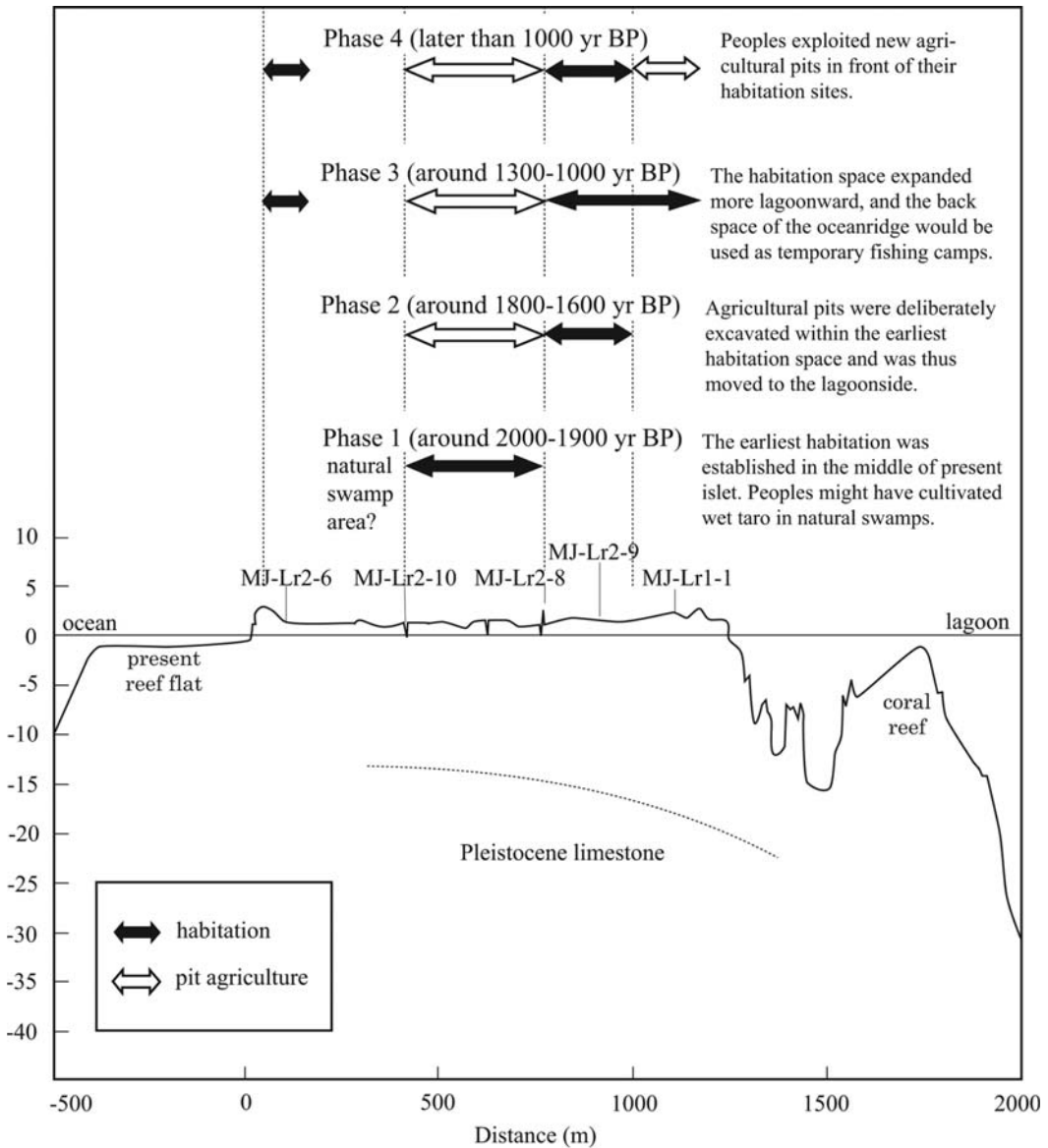


FIGURE 10. Tentative sequence of the landscape history of Laura's pit agriculture.

foraminiferal sand samples (Yasukochi et al. 2007; H.K., T. Yasukochi, T.Y., H.Y., and Yoneda, unpubl. data). The beginning of the late-Holocene sea-level drop enlarged the foraminiferal habitat and increased the volume of sediment on the reef flat, which rapidly formed the narrow core of the Laura islet

stretching along the north-south axis around 2,300 years B.P.; the islet then extended its subaerial landform to both sides of its northern and southern edges by 1,800 years B.P. The islet would have accreted both oceanward and lagoonward equally, and the current shorelines of Laura were formed by 1,200

and 1,000 years B.P., respectively. The accretion probably contributed to the enlargement of the volume of the freshwater lens, spatially moving its thickest portion into the lagoonside where finer and less-permeable sand sediments had accumulated. This appears to be the main reason for the spatial difference between the hydrogeological core of the current freshwater lens and the main distribution of agricultural pits that had been excavated in the earlier phases.

These conventional ages from foraminiferal samples are not yet corrected with the local marine reservoir effect, but ongoing geoarchaeological analyses should elucidate the details on how the historical interactions between human agency and natural processes produced the current landscape of Laura, including pit-agricultural complexes.

CONCLUSIONS

During the mid-Holocene period, the paleoreef had grown up to reach the highstand sea level over the bedrock of Pleistocene limestone. It is estimated that the Holocene reef began to emerge sometime after around 2,000 years B.P. (Tracey and Ladd 1974, Buddemeier et al. 1975) and was fully exposed when the subsequent sea-level decline first carried its high-tide level below the mid-Holocene low-tide level. This “crossover” date is estimated to be around A.D. 1100 for the Marshall Islands (Dickinson 2003). Our geoarchaeological evidence, however, indicates that sediment buildup from wave action rapidly formed the subaerial core of Laura on Majuro Atoll, on which the earliest islanders established habitations beginning around 2,000 years B.P. Monocotyledonous trees such as *Cocos* and *Pandanus* probably would have established themselves on the emergent landform. Colonizing groups, who appear to have moved northward from Melanesia, may have cultivated wet taro, probably *Cyrtosperma*, in low-lying natural swamps based on their knowledge derived from the late Lapita cultural tradition. Some centuries later, they deliberately excavated agricultural pits to exploit the freshwater resource and probably planted tall trees of Pacific rose-

wood (*Cordia* spp.) and Chinese lantern (*Hernandia* spp.) on the spoil banks, as well as pandanus and coconut trees. The resulting organic matter would have been an ideal fertilizer. It should be noted, however, that there is no evidence currently that breadfruit trees existed there in that period.

The subsequent relative sea-level drop in the late Holocene probably enlarged the foraminiferal sediment, and the islet then extended its landform both oceanward and lagoonward as well as along its north-south axis (Yasukochi et al. 2007; see also Tracey and Ladd 1974, Dickinson 2003). The land accretion caused its inhabitants to increasingly extend their activity space and readjust areas for habitation. It would also have enlarged the volume of the freshwater lens, and thus the thickest portion of the lens moved lagoonward. The enlargement of the freshwater lens enabled additional construction of agricultural pits even in the area just behind the lagoonside beach ridge. The current landscape of Laura would have been formed by around 1,000 years B.P. Detailed geoarchaeological synthesis can more precisely elucidate the chronological relationship between islet accretion and expansion of human activities.

This synthesis is not, however, a complete reconstruction of the islet's landscape history. For example, some agricultural pits are not utilized today, and we observed in 2006 that the area of fully controlled pits for *Cyrtosperma* cultivation was only 17% of the total area of 195 pits (Figure 2b). Many pits (45%) in which only small patches of cultivated *Cyrtosperma* remain (Figure 2c) included a species of false elderberry (*Premna obtusifolia*), and other abandoned pits (35%) are completely covered with this competitive species (Figure 2d). This condition, which is in constant flux, must be examined in association with not only recent climatic fluctuation such as El Niño but also socioeconomic changes such as the introduction of cash crops, the growing dependence on imported foods, and population movements in the colonial and postcolonial periods (cf. Catala 1957, Luomala 1974, Geddes 1983, Lawrence 1983, Watters and Banibati 1984, Kazama 2002).

Earlier studies of insular societies from a

cultural ecological perspective have tended to discuss social and cultural diversity in terms of adaptive radiation to distinctive ecosystems such as high islands, raised atolls, and coral atolls. However, there is no doubt that oceanic islanders were in frequent contact between islands. In East Polynesia, for example, a network of long-distance interaction was established from the tenth to fifteenth centuries A.D. (Weisler 1997). Through this network, *Pinctada* shells, a superior material for making fishhooks, were transported from atolls to high islands and basalt adzes in the other direction. A fragment of basalt adze, although a surface collection, was found in the 2006 field survey of Majuro Atoll, an indication of the importance that exotic goods had in these populations.

Transported species such as pigs, dogs, chickens, taro, breadfruit, bananas, and others, collectively termed “portmanteau biota” (Crosby 1986, McNeill 1994), also accompanied prehistoric human migrations, although there is as yet no archaeological evidence of pigs and chickens in the Marshall Islands. Prehistoric exploitation also caused the extinction or extirpation of endemic species, particularly flightless birds such as rails (e.g., Steadman 1997). It is also well known from studies of various high islands in Oceania that agricultural activities on inland slopes led to increased soil erosion. This soil, in turn, accumulated within river mouths to form alluvial plains that choked coral reef systems but that subsequently supported the development of sophisticated irrigation systems (e.g., Spriggs 1986, 1997). From such a process, a concept of “transported landscape” has consequently stood out: the reiteration of similar processes on newly colonized islands (Kirch 1984:135–139, Gosden and Head 1994:114). Pit-agricultural complexes observed in atoll islets might also be viewed as another case of a transported and anthropogenically altered landscape.

Archaeologists in Oceania have scrutinized the interactions between two kinds of agency, human and natural, that produce the insular ecosystems and landscapes currently seen. It cannot be denied, however, that archaeology has stressed common and general processes

of interactions discernible on many islands. To elucidate and describe dynamic interactions between the two kinds of agency from a historical viewpoint, we must incorporate the particularity of each island in our geoarchaeological studies of landscape history. The entanglement with historical anthropology, as well as field sciences, is a prospective method toward achieving this aim; our continued interdisciplinary effort on oceanic atolls should provide numerous clues to these processes.

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