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Climate Change and Cultural Dynamics: A Global Perspective on Mid-Holocene Transitions
David G. Anderson, Kirk A. Maasch and Daniel H. Sandweiss (Editors)

Chapter 8

Mid-Holocene cultural dynamics and climatic change in the Western Pacific

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Abstract

Human settlement in the Southwest Pacific began 40,000 or more years ago, but until about 3000 cal yr BP it was restricted to the region of Near Oceania that consists primarily of Australia and New Guinea. In Australia, there was a set of cultural changes during the mid- to late Holocene, which included the introduction of the dingo, the florescence of an assemblage of composite tools, movement of residential settlement into new environments, and a significant and sustained increase in the occupancy of archeological sites. These changes have been attributed most often to demographic and social factors, but some of them might be responses to relative resource scarcity induced by mid-Holocene climatic changes. Evidence from across the Western Pacific region indicates that significant climatic changes occurred during the mid-Holocene. These changes were neither all uniform nor simple but they appear to reflect generally strengthened circulation systems, including the onset of modern ENSO periodicities about 500 yr BP. In New Guinea, the Holocene development of agriculture in the Highlands is generally attributed to endogenous processes, but climatic change, particularly in relation to ENSO conditions, might have been influential. A relationship between climatic and cultural change is therefore plausible in several cases, but further investigation of these propositions will need much better comparative data on demographic trends that, it can be assumed, were also significant in mid-Holocene cultural dynamics.

1. Introduction

The Western Pacific is a region of dramatic contrasts in human history. On the ancient and geologically stable continent of Australia there has been habitation for

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more than 40,000 years (Allen and O'Connell, 2003) and archeological remains of similar antiquity occur in New Guinea and its nearest offshore islands – New Britain and New Ireland. On outlying islands, such as Manus, settlement could have only occurred through open sea crossings of greater than 150 km, accomplished more than 20,000 years ago. Yet that early promise in maritime capability was not widely fulfilled until very much later (Anderson, 2000, 2003). There were probably people in the Southeast Solomons by the late Pleistocene but there is no evidence of human settlement any further to the north, east, or Southeast in Oceania until the late Holocene, about 3000 cal yr BP. The Pacific divides, therefore, into two broad regions: "Near Oceania" and "Remote Oceania", with the dividing line at the eastern-end of the larger Solomon islands (Fig. 8.1). This paper focuses upon Near Oceania where cultural sequences span the mid-Holocene, but before discussing all those, it is worth outlining the spread of Neolithic cultures across both regions during the late Holocene because that, too, might have been initiated in some way by mid-Holocene climatic changes.

Older, aceramic cultures of coastal and insular Near Oceania were largely replaced about 3200–3300 cal yr BP by a material culture that included red-slipped, dentate-stamped pottery known as Lapita ware (Specht and Gosden, 1997). Lapita expanded rapidly eastward, reaching New Caledonia by about 3000 cal yr BP, and Fiji, Tonga, and Samoa by 2800–2900 cal yr BP (Anderson, 2001a). Other

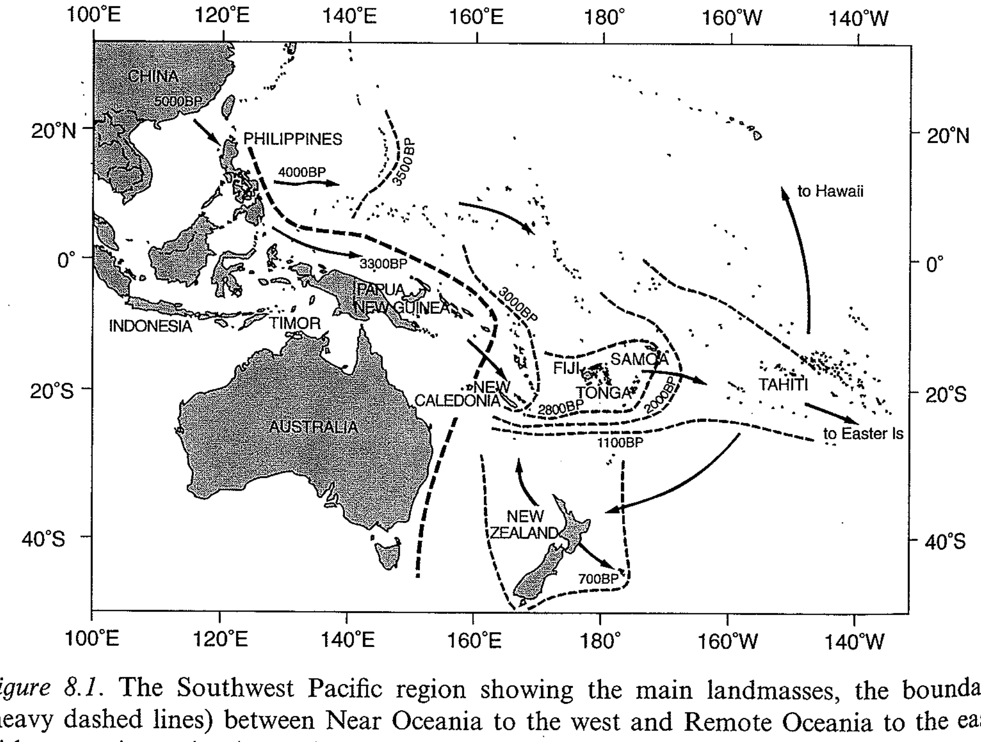

Figure 8.1. The Southwest Pacific region showing the main landmasses, the boundary (heavy dashed lines) between Near Oceania to the west and Remote Oceania to the east, with approximate isochrons (narrow dashed lines) of initial island colonization.

red-slipped ceramics, polished stone adzes and chisels, slate and shell tools, and ornaments and fish hooks, sometimes associated with remains of pigs, dogs, and chickens, are found in mid- to late-Holocene sites throughout island Southeast Asia. They probably reflect various mainland Southeast Asian sources but one route of dispersal was almost certainly through Taiwan. Corded-ware ceramics arrived there about 6000 cal yr BP from coastal south Chinese traditions dated to 7000–5000 cal yr BP, and the development of those in Yuanshan and other ceramic traditions after 4500 cal yr BP marks the point of rapid expansion toward Oceania (Spriggs, 1999). Neolithic culture reached the Philippines before 4000 cal yr BP, the Marianas by 3500 cal yr BP, and Western Melanesia, in the form of Lapita ware, by 3300 cal yr BP. There were some important changes along the way, notably the loss of rice agriculture that reached the Philippines but failed to penetrate any further to the southeast where taro, yams, and tree crops prevailed.

The spread of Neolithic culture into island Southeast Asia and Oceania during the period 5000–3000 cal yr BP raises the question of a climatic impetus, strengthening El Niño-Southern Oscillation (ENSO) conditions and some changes in monsoon circulation at about 5000 cal yr BP. One suggestion arises from Liu (2000), who attributes major population shifts and socio-political realignment concurrent with the collapse of Lungshan culture before 4000 cal yr BP to lower temperatures and increased flooding in Northeast China. Wu and Liu (2004) present a similar and more wide-ranging hypothesis which suggests that significantly wetter and cooler conditions in South China, beginning about 4500 cal yr BP led, as did drought elsewhere in China, to the widespread collapse of Neolithic cultures, 4200–4000 cal yr BP. One potential adjustment may have been increasing migration, and as the impact of ENSO increased during the late Holocene, then the strengthening frequency of offshore winds could have produced a significant increase in sea travel toward island Southeast Asia, perhaps accelerated in the 4th millennium BP by the addition of sails to watercraft (Anderson, 2000, 2004; McGrail, 2001, p. 356; Anderson et al., 2005).

Turning to Near Oceania, here including Australia, the mid-Holocene appears as a significant hinge in late Quaternary environmental and cultural history. Rising post-glacial sea levels severed the Sahul landmass into its three main constituents of New Guinea, Australia, and Tasmania, in the period 11,000–8000 cal yr BP, and by 5000 cal yr BP the loss of more than two million km^2 of late Pleistocene landmass had reduced the land area in the Southwest Pacific to its smallest extent within the last 100,000 years. Land areas and coastal complexity increased somewhat in the late Holocene as a result of a slight retreat from a post-glacial high sea-level, in some areas, after 4000 cal yr BP and the catch-up of coral reef growth as sea-levels stabilized (Dickinson, 2001). The mid-Holocene, therefore, was probably the least suitable period for island or coastal settlement in the Western Pacific since the last glacial era (Enright and Gosden, 1992). From an archeological point of view, sea level changes had an equally dramatic effect because they wiped out or concealed most of the potential evidence of coastal and insular settlement prior to the mid-Holocene. To consider the potential relationship of cultural dynamics to climatic change at that time, it is desirable therefore to review archeological data that are not wholly bound to coastal occupation.

We will look at two cases, pitched at different geographical scales and representative of the fundamental cultural juxtaposition in the region: (1) the suite of cultural changes which occurred in hunter–gatherer societies during the mid- to late Holocene in Australia, and (2) those changes which appear to document the early history of agriculture in Highland New Guinea. Before examining these case studies, we briefly review the modern climate and inferred mid-Holocene climate changes.

2. Regional climatology

Three major zones of atmospheric circulation are represented in the Southwest Pacific region: the Monsoonal Belt (5–15°S), the Sub-tropical Anticyclonic Belt (20–35°S) with the southeast trade-winds on its northern flank, and the Westerly Belt (40–60°S). Because the Southern Hemisphere is dominated by oceans, zonal atmospheric circulation is less modified than in the Northern Hemisphere. As warm air rises at the equator, it generates very humid climates, especially where the uplift is accentuated by tall mountain ranges, as in New Guinea. Areas that receive this moisture for part of the year fall within the Monsoonal Belt. The air that rises over the equator travels to higher latitudes at high elevations and, in the Southern Hemisphere, it cools and sinks at about 30°S. Thus, in the Sub-tropical Anticyclonic Belt, where the air sinks, there is little surface air movement and little precipitation. The air that sinks at 30°S either flows southwards and is deflected by the spin of the earth into the westerly wind belt that dominates the mid-latitudes, or it turns northwards to be deflected into the southeast trade-wind belt. All of these zones are displaced southward in the Austral summer and move equatorward during the winter (Figs. 8.2 and 8.3).

In addition to the basic zonal pattern of atmospheric circulation, regional and local factors play a major role in controlling the distribution of rainfall. The Walker Circulation, a Pacific-wide zonal circulation in tropical latitudes, is thought to result primarily from strong atmospheric convection over the Western Pacific Warm Pool which drives air eastward at high altitude to sink in the East Pacific Dry Zone. The seasonal transit of the Intertropical Convergence Zone southwards from the Asian continent in the Austral spring and summer brings monsoonal rainfall to the tropical regions of the Southwest Pacific. Another feature of regional significance in terms of rainfall is the South Pacific Convergence Zone that connects the convective region over the Warm Pool with the higher latitudes of the southwestern Pacific (Allan et al., 1997). At higher latitudes, onshore winds crossing warm water on the eastern side of temperate Australia make that area much moister than equivalent latitudes in Western Australia. Mountain ranges, especially in New Guinea and New Zealand, also dramatically modify the local climates by blocking prevailing winds and concentrating rainfall on windward slopes.

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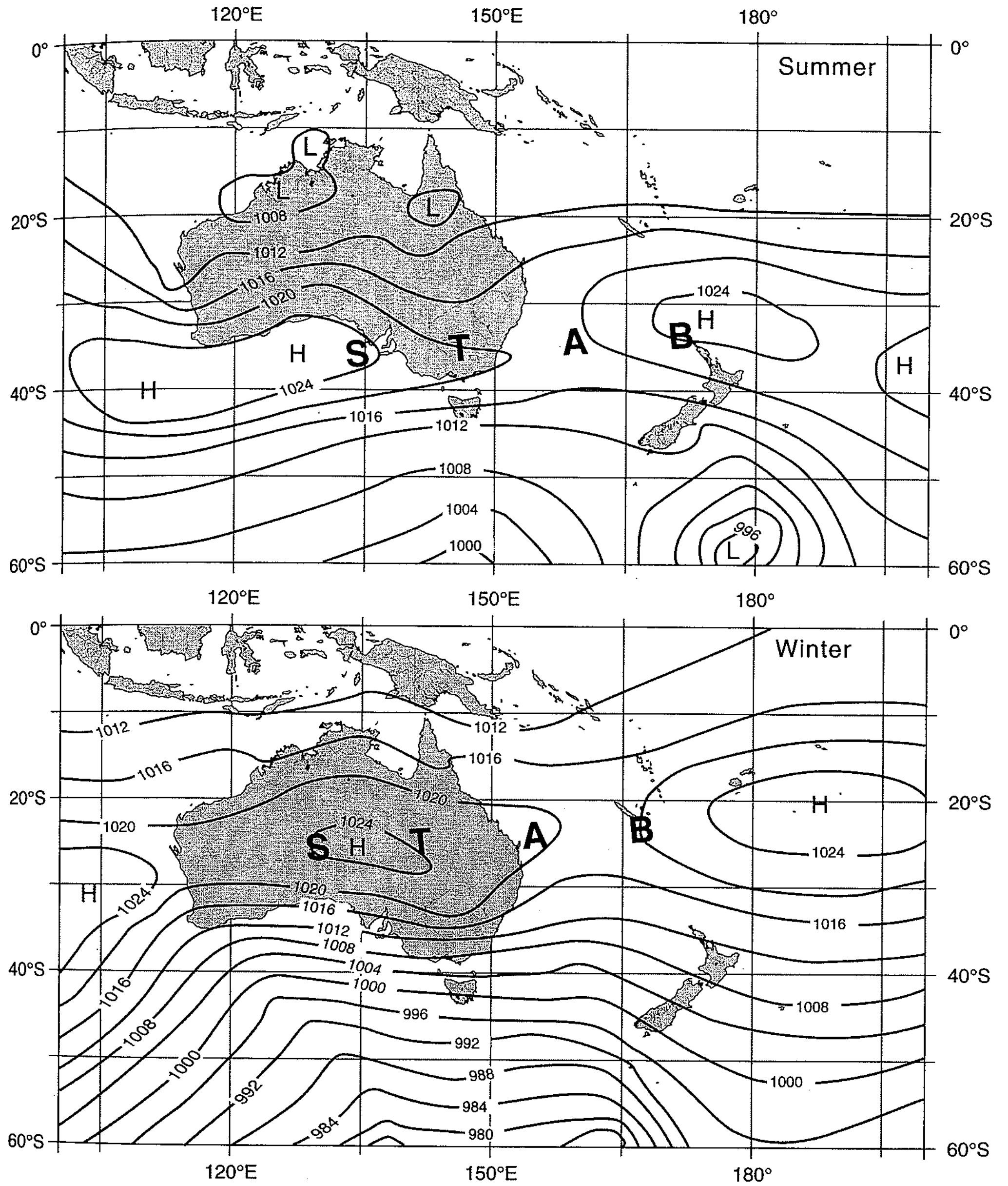
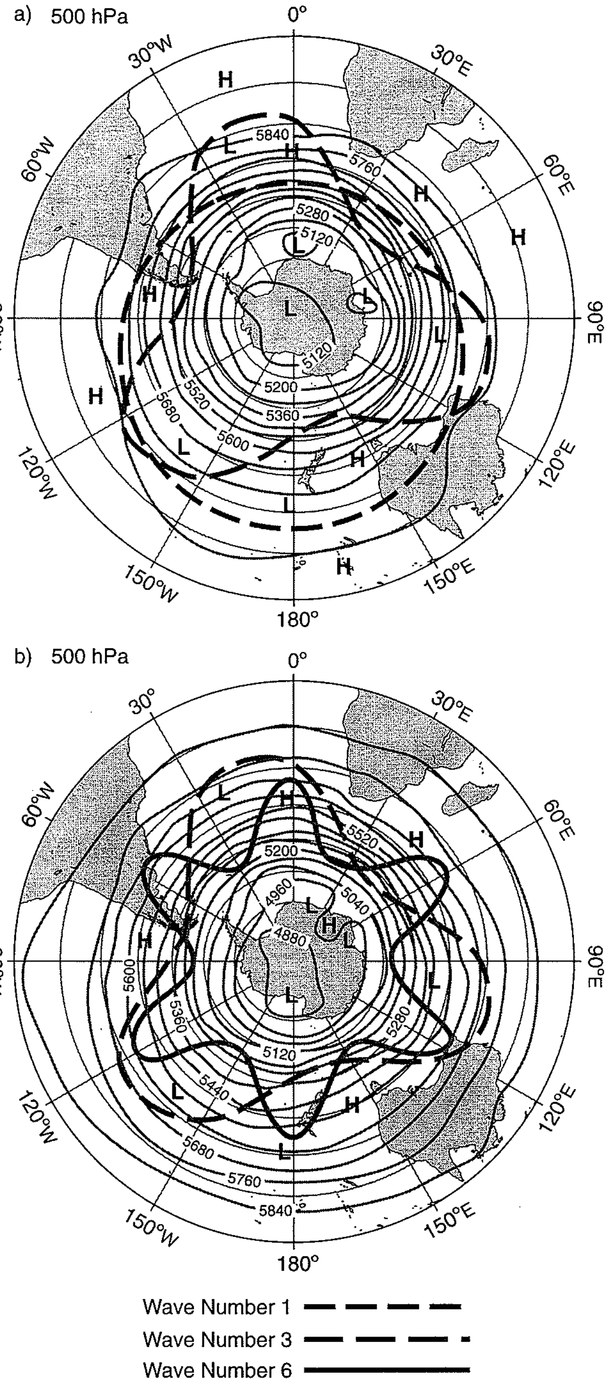


Figure 8.2. Position of the sub-tropical anticyclonic belt (STAB) over the Southwest Pacific region in summer and winter. This belt separates the mid-latitude westerlies to the south from the intertropical convergence zone (ITCZ) to the north (modified from Sturman and Tapper, 1996).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Precipitation patterns in New Guinea are particularly complex due to the orographic effects of an east–west blocking range (the highest point, Mount Djaja, is 5029 m high) and the interactions of two major moisture sources. The most important of these moisture sources are monsoonal rains that occur during the austral summer (January–April). These are sourced from the northwest and while they provide significant rainfall to most areas, a rain shadow affects some lowland southeastern areas, such as the Fly River delta. Southeasterly trade winds, which flow during May to October, are modified as they pass over the Coral Sea, southeast of New Guinea, and provide substantial rainfall to parts of the southeast, notably the Fly River delta, and to the mountains, while a rain shadow occurs on the northwestern side of the island and in the southernmost lowlands. Mountain areas also generate much convective rainfall activity throughout the year. The Highlands of New Guinea consequently have high rainfalls with a fairly even distribution of rain throughout the year, but both sources of rainfall are highly vulnerable to circulation changes associated with an ENSO.

ENSO is embedded within the Walker Circulation, which is the most significant modifier of inter-annual climates in the southwestern Pacific. On a 2–7 year basis, the Walker Circulation weakens and the convective center over Indonesia moves eastward where it generates anomalous rainfall from the central equatorial Pacific to the Peruvian coast. This is an El Niño. The effects of El Niños are well known in the Southwest Pacific where droughts occur in Southeast and northern Australia, Papua New Guinea, and the far western portion of Oceania. An excellent review of the oceanic, atmospheric, and hydrologic responses to ENSO in the southwestern Pacific region can be found in Allan et al. (1997). By contrast, it is less well known that the impacts of ENSO are equally severe in New Zealand. In particular, El Niño years are associated with anomalously strong southwesterly flow over New Zealand (Gordon, 1985) and this pattern is linked to changes in the Southern Hemisphere polar-jet stream, which controls the angle of approach of Southern Ocean cyclonic systems on to New Zealand (Fig. 8.3).

A detailed analysis of historical climate records spanning the last century has produced a new view of the spatial patterns of ENSO variability through time (Allan et al., 1997). This analysis suggests that rainfall, sea-surface temperatures (SSTs), and wind-field patterns associated with ENSO differ strongly among events, and the centers of action also shift. The cause of these shifts is not clear; leading candidates include a change in the basic state of the tropical climate system (Federov and Philander, 2000) or a modulation of ENSO by decadal-scale

Figure 8.3. Idealized Rossby waves nos. 1 and 3 (Fig. 8.3a) and nos. 3 and 6 (Figure 8.3b) in the Southern Hemisphere, at 500 hPa elevation. Low-Rossby numbers are associated with zonal flow and high numbers with meridional flows. Unlike the Northern Hemisphere, where the polar-jet is anchored to the Rocky Mountains, the Southern Hemisphere polar-jet is less restrained and modification of the Rossby waves affects the track of cyclonic systems approaching New Zealand. The dominance of southwesterly flows over New Zealand during El Niño years may be related to shifts in position or wave number of the Rossby wave.

variability. There is increasing recognition of decadal oscillation signals in the Southwest Pacific (e.g., Salinger et al., 2001) which compound and/or confound ENSO signals. These signals do not, however, offer a complete explanation of variation.

3. Climatic and environmental change in the mid-Holocene

3.1. Terrestrial reconstructions

Before considering the archeological data for putative interactions between climate and culture, it is necessary to determine which climate changes occurred during the mid-Holocene in the Western Pacific. As might be expected in such a large area, these changes are not consistent across the region. In addition, one of the primary problems of examining pre-instrumental climate changes in areas of long-term human habitation is that many of the indicators that are used to identify climate change are also susceptible to anthropogenic modification. A classic example, and one that is noted again in the context of New Guinea, is fire. Increased burning, as evidenced by charcoal in soils, lake beds, and other sediments, may be the result of increasing aridity due to climate change, or of changes in human land use, either in type or intensity. To determine whether there were any climatic changes of consequence, it is necessary to consider a situation where anthropogenic landscape modification post-dates the mid-Holocene. In this context, the best paleoenvironmental records regionally come from New Zealand.

In New Zealand, the early part of the Holocene was somewhat warmer than the present day, with a climatic optimum at ca. 8000 cal yr BP (e.g., McGlone et al., 1993). After this time a gradual increase in frosts and droughts occurred. Although a number of vegetation changes occurred during the Holocene throughout New Zealand, McGlone (1988) and McGlone et al. (1993) have not ascribed these to any distinct changes in climate, except at about 3000 cal yr BP when southern New Zealand became wetter and cooler in response to enhanced westerly circulation. Shulmeister (1999) noted, however, that there is strong evidence from the resurgence of glacial activity in the Southern Alps (Gellatly et al., 1988) and from the reduction or elimination of frost intolerant taxa from sites in central New Zealand (McGlone and Moar, 1977) for a significant climatic change at ca. 5000 cal yr BP. Glacial advances at that time have been attributed also to strengthening westerly or southwesterly flows (Fitzharris et al., 1992; Shulmeister et al., 2004).

From these observations, we can deduce that the dominant climate signal in New Zealand is the gradual strengthening of westerly zonal circulation through the Holocene (Shulmeister et al., 2004). All the zonal circulations are linked and, in general, as one circulation strengthens or weakens, the others will respond in a similar manner. Thus, strengthening the westerlies in New Zealand should also mean increasing the southeast trades and the monsoon winds in the sub-tropics and tropics as the Holocene progressed. Shulmeister (1999) provides evidence that

ENSO is linked to this circulation change and that it was either absent or substantially reduced prior to about 5000 cal yr BP.

In northern Australia, analysis of fossil pollen assemblages in sediment cores indicates that after a gradual increase in moisture through the early Holocene, there appears to be an effective precipitation (EP) maximum between 5000 and about 3500 cal yr BP (e.g., Kershaw, 1983; Shulmeister and Lees, 1995). This period was up to 50% wetter than modern (Kershaw and Nix, 1989), whereas the EP maximum in Southeast Australia is inferred to be only 5–10% above modern values (Dodson, 1998) and occurred between about 7000 and 5000 cal yr BP. In Southeast Australia, an arid phase began after 5000 cal yr BP.

Holocene environmental change has been investigated also in Papua New Guinea. Analysis of pollen assemblages in sediment cores (below) suggests that rapid post-glacial warming had crossed into a regime slightly warmer and wetter than today by 9000 cal yr BP, and there is evidence that the treeline climbed from 2700 to 4000 m. In the period 8500–5000 cal yr BP, alpine ice fields disappeared from Mt. Wilhelm and the treeline was 100–200 m higher than at present. At the end of this "hypsithermal interval", the treeline retreated to its current position, temperatures cooled slightly, and from 3500 cal yr BP to the present there were at least four small glacial advances (Haberle, 1994, p. 178, 1996).

3.2. Ocean–atmosphere reconstructions

Documenting past changes in the Western Pacific Warm Pool (mean SST > 28°C) is particularly important for understanding Holocene climate change. The relatively warm, fresh, "skin" of buoyant Warm Pool water occupies only 0.05% of the total ocean-water mass, yet it plays a leading role in driving atmospheric circulation (Webster, 1994). Even small changes in tropical SST can lead to a marked increase in surface–ocean evaporation and water vapor in the atmosphere (Flohn et al., 1990). Thus, any change in the temperature, size, or positioning of the Warm Pool in the past would have had a profound effect on global climate (Cane and Clement, 1999).

Recent research has revealed new insights into the temperature, size, and variability of the Warm Pool since the Last Glacial Maximum (LGM). Studies of foraminiferal Mg/Ca and alkenones from deep-sea sediment cores provide long, continuous histories of changes in mean SST (Pelejero et al., 1999; Lea et al., 2000; Kienast et al., 2001; Koutavas et al., 2002; Stott et al., 2002; Rosenthal et al., 2003; Visser et al., 2003). These reconstructions generally agree that SSTs in the Warm Pool region during the LGM were ~2–4°C cooler than at present. In contrast, the tropical East Pacific exhibits a much smaller cooling of ~1°C during the LGM (Koutavas et al., 2002). Interestingly, records near the equator or in the Southern Hemisphere tropics show a rapid rise to SSTs 0–1°C higher than modern values during the early-middle Holocene (~10,000–4000 cal yr BP).

New coral Sr/Ca paleothermometry records from northern Australia and Indonesia are in good agreement with the foraminiferal Mg/Ca estimates of early-middle Holocene warming of tropical Western Pacific SSTs (Gagan et al., 2004). New coral records show that SSTs reached modern values by ~8500 cal yr BP. Mid-Holocene SSTs in southern Indonesia fall within 0.5°C of modern values, whereas corals from the inshore Great Barrier Reef, Australia, indicate SSTs ~1°C warmer than the present (Gagan et al., 1998). Taken together, the foraminiferal Mg/Ca and coral Sr/Ca records indicate a general cooling of SSTs since the early Holocene that has not reversed until the 20th century.

To improve our understanding of tropical ocean–atmosphere interactions in the past, the Mg/Ca and Sr/Ca paleothermometers have been used to remove the temperature component of the oxygen isotope signal in biogenic carbonates, and thereby reveal changes in seawater ^{18}O concentrations as a proxy for surface–ocean salinity (e.g., Gagan et al., 1998, 2000; Lea et al., 2000; Hendy et al., 2002; Stott et al., 2002; Rosenthal et al., 2003). In the tropics, changes in surface–ocean salinity primarily reflect changes in the balance between evaporation and precipitation at the ocean surface. An important new finding is that the foraminiferal and coral records both show significant freshening of the ocean surface in the tropical Western Pacific region since ~8000–6000 cal yr BP (Gagan et al., 1998; Stott et al., 2002).

In summary, the oceanic climate reconstructions indicate a semi-permanent La Niña-like state in tropical Pacific SSTs during the early-middle Holocene (Koutavas et al., 2002; Stott et al., 2002). A prolonged, westward-concentrated La Niña during the early-middle Holocene agrees with terrestrial paleoclimate records indicating warmer and wetter conditions in the tropical Western Pacific region, as discussed earlier. Moreover, the Holocene cooling to a more El Niño-like state in Pacific SSTs explains why Near Oceania became progressively drier in the late Holocene.

The climate-change scenario described above provides interesting possibilities for enhanced eastward-directed sea travel to Remote Oceania during the late Holocene. Geoarcheological evidence of the late Holocene emergence of habitable atolls, as the result of a 1–2 m drawdown in sea level, has been linked by Dickinson (2001) and Kerr (2003) to the pattern of human colonization. The impact of emerging atolls on migration patterns, however, was probably rather slight because most Oceanic atolls lie in Micronesia and the Tuamotus, well to the north of the main routes known, from archeological evidence, to have been used between archipelagos in Melanesia and Polynesia. Very few atolls emerged on those routes. There were none in the critical passage between the main Solomon Islands and the Reef Islands – the boundary between Near and Remote Oceania, very few between West and East Polynesia, and none between East and South Polynesia.

More persuasive is the potential impact of climatic change on wind systems that were critical for voyaging at a time when sailing technology probably did not permit passages against the wind (Anderson, 2000, 2001b). The transition to a more El Niño-like state in Pacific SSTs during the late Holocene would have reduced the average strength of the Pacific tradewinds, as indicated by climate models (Clement et al., 2000; Liu et al., 2000). Indeed, the frequency of "windows of opportunity" to travel east on frequent westerly wind reversals, against the prevailing southeasterly trades, would have increased as El Niño events became more common in the late Holocene. Anderson (2004) and Anderson et al. (2005) suggest that quasi-cyclic enhancement of westerlies at a millennial scale may have provided climatic forcing of eastward migration in Remote Oceania, especially around 3000 and 1000 cal yr BP.

The opposing changes of the surface–ocean and terrestrial freshwater balances during the Holocene are also intriguing. During the La Niña-like state of the early-middle Holocene, strong tradewinds and westward transport of moisture would have increased rainfall on land in Near Oceania, as indicated by the terrestrial paleoclimate records. In contrast, the freshening of the surface–ocean (and drying of Near Oceania) toward the late Holocene indicates that the focus for rainfall shifted eastward, toward the open ocean, as occurs during modern El Niño events.

Taken together, the paleoclimate evidence suggests that relatively weak and variable Pacific tradewinds, interspersed with frequent westerlies, could have promoted eastward sea travel to Remote Oceania during the late Holocene. It is possible that rainfall shifted toward Remote Oceania during the late Holocene, thereby increasing the survival rate of early seafarers, if not also providing an incentive for them to disperse from drought-prone western islands (Anderson, 2004). Such a possibility leads us to examine what is known about changes in the frequency of El Niño events during the Holocene, and any bearing that might have on human settlement patterns in the tropical Western Pacific.

3.3. Holocene evolution of ENSO

The most continuous, high-resolution record of ENSO for the early Holocene comes from laminated-clastic deposits in a high-altitude lake, Laguna Pallcacocha, in Ecuador (Rodbell et al., 1999; Moy et al., 2002). Today, these clastic laminae record anomalously high rainfall during El Niño events. Interestingly, the sedimentary record shows a clear suppression of ENSO variability, with periodicities of ~15 years, from 12,000 cal yr BP (the beginning of the record) to 7000 cal yr BP (Fig. 8.4). The result is in good agreement with pollen records from South America, New Zealand, and Australia, which indicate that early Holocene vegetation did not include types adapted to the periodic droughts associated with ENSO (McGlone et al., 1992; Markgraf and Diaz, 2000). By comparing early Holocene vegetation, lake level, and fire history records from these regions, McGlone et al. (1992) concluded that the circum-Pacific precipitation patterns, reduced environmental variability, and absence of fire all suggest the suppression of ENSO between 10,000 and 8000 cal yr BP. A coral record from Papua New Guinea also shows a suppression of ENSO variability at 6500 cal yr BP (Tudhope et al., 2001).

Several lines of paleoclimate evidence suggest that the onset of modern ENSO variability occurred between 7000 and 4000 cal yr BP. Spectral analysis of the

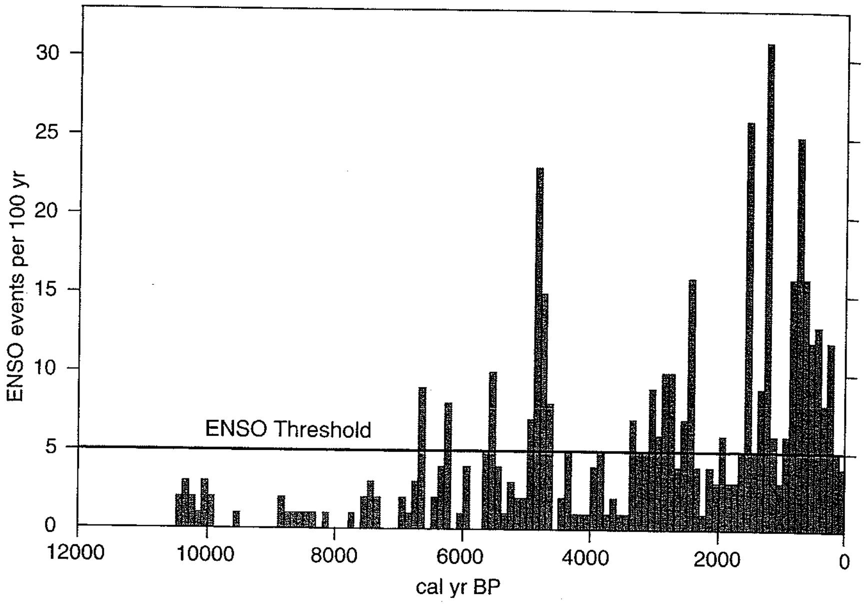

Figure 8.4. Summary of the number of moderate–strong El Niño events in 100-year windows since 12,000 cal yr BP, based on the analysis of clastic laminae in lake Laguna Pallcacocha, southern Ecuador (after Moy et al., 2002). The solid line indicates minimum number of events (~5) required to produce ENSO-band variance. Data available from the NOAA/NGDC Paleoclimatology Program website: http://www.ngdc.noaa.gov/paleo/pubs/moy2002.

15,000-year high-resolution record of storm-derived clastic sedimentation in Laguna Pallcacocha, Ecuador (Rodbell et al., 1999; Moy et al., 2002) shows that the transition to modern ENSO periodicities (2–8 yr) began ~7000–5000 cal yr BP (Fig. 8.4). Sandweiss et al. (1996) and Rollins et al. (1986) reached a similar conclusion based on their analysis of fossil mollusk and fish assemblages and other geoarcheological evidence from coastal Peru. On the western side of the Pacific basin, the first occurrence of drought-adapted pollen taxa in lake sediment cores from tropical northern Australia indicates ENSO onset at ~4000 cal yr BP (Shulmeister and Lees, 1995). A composite charcoal abundance record derived from 10 lake and wetland records from eastern Indonesia and Papua New Guinea reflects changes in the pattern of regional burning from the LGM to the present (Haberle et al., 2001). Higher charcoal concentrations from the mid- to late Holocene (5000 cal yr BP to the present) are interpreted to reflect higher precipitation variability associated with the onset of modern ENSO variability.

The picture emerging for the most recent 5000 cal yr of ENSO history indicates that it began to operate as it does now, but with variability on millennial timescales, and a peak in ENSO frequency and magnitude at ~1800–1200 cal yr BP (Fig. 8.4). The record of clastic sedimentation from Laguna Pallcacocha, Ecuador, shows that El Niño events became more frequent over the Holocene until about 1200 BP, and then declined toward the present (Moy et al., 2002). Superimposed on this long-term trend are periods of relatively high and low ENSO activity, alternating at a time scale of about 2000 years. Geoarcheological evidence from the coast of Peru indicates an increase in ENSO event frequency after 3200–2800 cal yr BP (Sandweiss et al., 2001). Isotope records from massive fossil coral microatolls at Christmas Island in the central equatorial Pacific also indicate that ENSO variability reached, or exceeded, modern values from 2500 to 1700 cal yr BP (Woodroffe and Gagan, 2000; Woodroffe et al., 2003).

In summary, the most continuous, high-resolution record of ENSO (Moy et al., 2002) indicates a significant suppression of El Niño during the early Holocene, with less than five moderate–strong events/century recorded (Fig. 8.4). In contrast, several different paleo-ENSO records indicate a maximum in ENSO magnitude and frequency during the late Holocene. The Moy et al. (2002) reconstruction indicates up to 30 moderate–strong events/century for several periods during the late Holocene, which is significantly more than were observed during the 20th century. Cultural developments during the mid- to late Holocene in Near Oceania can now be considered in relation to the long-term history of climatic and environmental change.

4. Cultural change in mid- to late Holocene Australia

Australia is so large and environmentally variable that it cannot be expected that a single set of cultural changes would occur in the mid- to late Holocene. Yet, leaving aside some regional contradictions and differences, a group of features with at least very broad distribution have been proposed (Williams, 1987; Bird and Frankel, 1991; Lourandos and Ross, 1994; Lourandos, 1997). These are as follows:

(1) The addition to long-established stone tool types, and their partial replacement by, a new assemblage known as the "small tool tradition" (mainland, but not Tasmania), referring essentially to small stone elements of various kinds that had been parts of composite or hafted tools. The most important of the newly-abundant tool types were backed artifacts, bifacial points, and tula adzes.

(2) Evidence of increasing site numbers and increasing intensity of site occupation, with inferred settlement patterns that include greater mobility in many areas, but also signs of logistically-organized habitation in large base camps, the increasing use of defined cemeteries, notably in the lower Murray valley, and an efflorescence in painted rock art which is also differentiated into regional styles.

(3) Expansion of settlement into new habitats including the sandridge deserts, subalpine areas, tropical rainforest, and offshore islands with concomitant changes in resource utilization including greater use of marine resources, the processing of toxic plants for food, and the specialized grinding of grass-seeds.

(4) The arrival of a domestic animal, the dog or dingo (excluding Tasmania), which drove its indigenous competitors on the mainland, *Thylacinus* sp. (Marsupial Tiger) and *Sarcophilis* sp. (Tasmanian Devil), into extinction.

Of the new tool types, the backed artifacts and bifacial points were already in existence but scarce by the early Holocene (Hiscock and Attenbrow, 1998) and there is evidence of occasional cycad processing and grass-seed grinding which dates to the late Pleistocene (Lourandos, 1997; Gorecki et al., 1997). But whether quantitatively or qualitatively, most of the inferred changes are dated to later than 4000 cal yr BP. There is no archeological evidence of the dingo earlier than about 3500 cal yr BP (Lourandos, 1997), systematic processing of toxic cycads may go back to about 4000 cal yr BP (Beaton, 1982), although the data are not as clear as might be wished (Hiscock, personal communications), and specialized grass-seed grinding to 3500 cal yr BP in the semi-arid zone. Data on site usage patterns suggest that the point of inflection toward more intensive occupation was generally at 2500–3500 cal yr BP.

The general similarity of these inferred cultural changes to events occurring during the early Holocene in many other parts of the world, where they have been characterized as the development of complex foraging, has not escaped notice, but whether, in Australia, they fit together as pieces of a single jigsaw puzzle, and to what they might be attributed, has been argued for more than 20 years. The null hypothesis, still not clearly rejected in most regions, is that with the exception of some newly-introduced elements, notably the dingo, the increasing diversity and frequency of mid- to late Holocene archeological remains presents an impression of change which is conveyed largely by the relative survivability of a greater range and quantity of material toward the present.

Many other explanations have invoked an hypothesis of land-use and resource procurement intensification, the general form of which is that, by the mid- to late Holocene, demographic imperatives, especially population growth, had begun to convert some mobile socio-economic strategies into more complex and sedentary systems. Changes in technology and social organization including more extensive exchange and kinship networks and more elaborate ceremonial behavior were associated with increased occupation of hitherto marginal environments, a broadening of the resource base, and sharpened differentiation of territoriality and associated behaviors such as the production of rock art. It is worth looking at this proposition and some alternatives in a little more detail by reference to one of the regional cases, Southeast Australia.

4.1. Southeast Australia

Modern vegetation patterns were re-established in Southeast Australia by the early Holocene, following late Pleistocene aridity. A maximum warming and moisture regime, with rainfall 5–10% higher and temperatures 1–2°C higher than today, was then attained in the period 8000–6000 cal yr BP (Dodson, 1998). Since 5000 cal yr BP there has been a small decrease in temperature and precipitation and some expansion of alpine grasslands from about 4000 cal yr BP. There was a period of drier conditions during which peat formation succeeded shallow lake environments in some catchments and in both inland and coastal lakes water levels declined substantially until about 2000 cal yr BP (Dodson et al., 1992).

Throughout Southeast Australia there is a slight increase in the rate of archeological site occupation during the early and mid Holocene with the frequency increasing dramatically after 4000 cal yr BP. While factors, such as the loss of mid-Holocene coastal sites by erosion, 6000–4000 cal yr BP, and the possibility that at least some of the variation reflects population re-distribution in the landscape, might have contributed to this pattern (Head, 1986); there seems little doubt that significant overall population growth had also occurred. The upward trend encompassed an expansion of settlement into environments not previously occupied to any extent. For example, from about 2500 cal yr BP, large earth mounds which served as foundations for settlements appear in the swamplands of southwestern Victoria (Williams, 1987), along with extensive drainage and fish trap systems. Habitation also expanded in the semi-arid mallee scrublands of northwest Victoria from about 2500 cal yr BP (Ross et al., 1992) and in the Southern Highlands. In Tasmania, isolated from the mainland for thousands of years, settlement expanded into the western forests from about 4000 cal yr BP, which might reflect the increasing efficiency of forest firing, and site occupancy generally and the use of coastal resources also increased noticeably.

The takeoff in archeological site occupancy at 4000 cal yr BP in Southeast Australia is not contemporary with the initiation of mid-Holocene climatic change, nor with the early stages of its impact on lake levels, especially in the coastal areas where most sites are located (Fig. 8.5). Proponents of intensification models argue, therefore, that this process had little, if anything, to do with climatic change; that not only is the chronology mismatched between climatic and cultural change, but also that if climate was an influential variable then there ought to have been significant increases in site occupation during the period of higher humidity and greater terrestrial bio-production in the early Holocene, not during the more stressful late Holocene (Lourandos, 1997).

In regard to the first argument, there is no reason to expect that cultural dynamics would necessarily track changes in climate. Lowered precipitation and temperatures could have had varied and unexpected impacts on sedimentary and biological systems, while to the inherent complexity of those reactions must be added the resilience and diversity of cultural behavior. In addition, the relationship of cultural to natural systems is mediated by other processes that, at some scales of analysis, may be regarded as independent of change in either, notably the timing and strength of population increase or of immigration. These various considerations may be regarded as "buffering" the relationship between climatic and cultural change and therefore as capable of delaying the manifestation of a cultural response in the archeological record.

The second issue of why the strong increase in site occupancy, and presumably in population density, occurred during a period when there might have been greater resource stress than earlier is more difficult to answer but several potential explanations have been canvassed. As indicated above, one is simply that the initial

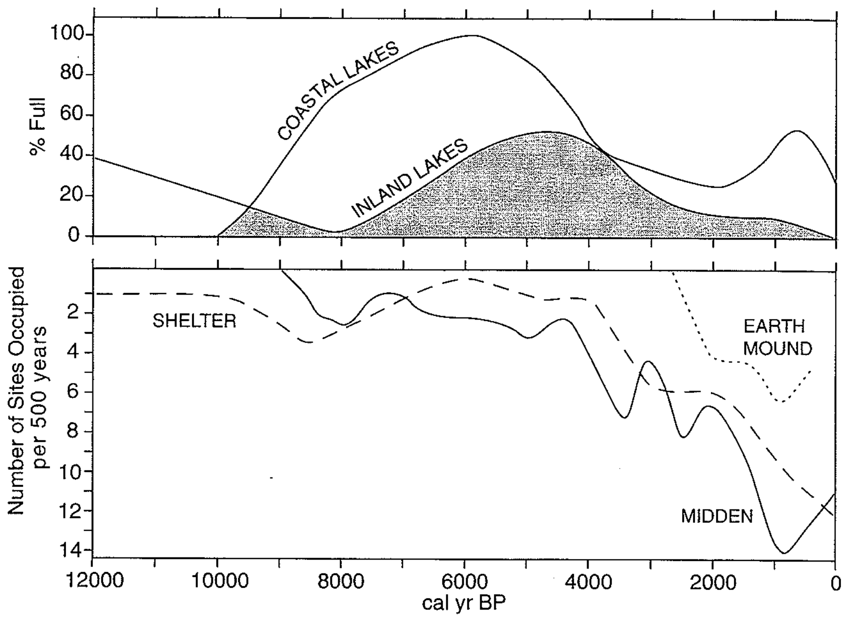

Figure 8.5. Variation in the level of coastal and inland lakes in Southeast Australia (above the time line) compared to the trends in occupancy of different sites in the same region (below the time line). Information from Dodson et al. (1992) and Lourandos and Ross (1994).

assumption may be invalid. Slightly cooler and drier conditions, and possibly greater climatic instability, might actually have produced greater rather than less access to economic resources. An opening up of the humid forest could have facilitated the use of fire to create richer, habitat mosaics, as seems evident from late-Holocene palynological profiles, while slightly lower late-Holocene sea levels seem, in fact, to have increased the extent of productive coastal freshwater wetlands in Southeast Australia (Head, 1986).

4.1.1. Climatically-induced stress

Other potential explanations have assumed the validity of increased stress on resources. Haberle and David (2004) argue that increased post-glacial population density by 6000 cal yr BP in northern Queensland, together with climatic change, led to a significant decline in bio-production which, in turn, resulted in a broadening of the diet spectrum and increasing territoriality and regionalization of material culture after 3700 cal yr BP.

Hiscock (1994) has developed an hypothesis which proposes that the mid-Holocene proliferation of small tools in mainland Australia generally, represents a solution to the economic risk of scheduling uncertainties in changing environments. Each of the main types was easily transportable. In addition, the bifaces combined the advantages of cores producing a consistent flake form, of being easily re-sharpened and of combining useful edges and points; tula adzes were also capable of multiple uses and extended use life, while backed artifacts appear to have been hafted as multiple points in spears and knives. This was a uniform, easily portable, reliable, and functionally flexible toolkit, which required relatively small quantities of raw material. It was especially suited to high residential mobility in environments where resource distributions were relatively unpredictable and foraging expeditions thus required reliable multi-purpose technologies to maximize extraction opportunities as these were encountered. Similar arguments regarding the use of multiple elements to increase redundancy and thereby lower the risk of implement failure, and other propositions about the relationship of composite tools to environmental uncertainty, have been raised in European, African, and American prehistory and continue under development in Australia (Rowland, 1999; Hiscock, 2002).

Given that the mid-Holocene was a period of climatic change which increased the relative uncertainty of many resource environments, then the emergence of the composite or small tool tradition, as well as the refinement of other technologies such as toxic nut and grass seed processing, made it possible to advance residential settlement into some of the least predictable environments in Australia, notably the sand-ridge deserts. By the late Holocene, when reduced mobility and increased population density is apparent in many coastal districts, the backed artifacts and points become less abundant and undifferentiated flake tools more prominent.

A similar kind of argument has been advanced to account for the noticeable increase in the use of marine resources, not only in the southern mainland of Australia, but also in Tasmania, after about 4000 cal yr BP. This is manifested both in the use of offshore islands, mainly from about 3000 cal yr BP (O'Connor, 1992), with implied developments in watercraft, and in the frequency of coastal middens. On the mainland there is evidence of extensive fishing and shellfishing. In Tasmania, fishing ceased, but it was replaced by intensive exploitation of other sub-tidal resources, notably abalone and crayfish, as well as culling of seal and muttonbird colonies. Since the same general trend appears on both sides of Bass Strait, it is difficult to explain it by reference to a coincidence in demographic or societal trends, unless population growth, for instance, was following the same post-glacial trajectory in each case, which is possible. The environmental hypothesis proposes that decreased precipitation and increased seasonality with frequent summer droughts and forest fires associated with the onset of intensive ENSO conditions led to increased stress on terrestrial resources and a re-orientation of the resource base toward a greater emphasis upon the large, reliable, year-round protein sources of the coast (Sim, 1998). That the climatic switch might have been quite severe locally is suggested by the extinction on Flinders Island, some time after about 4500 cal yr BP, of a human population that had survived there since 8000 cal yr BP. Sim (1998) argues that an already stressed population could not tolerate the increased incidence of drought and forest fires in the late Holocene and, having no means of reaching the Tasmanian mainland, must simply have perished, a fate probably coincident with the similar extinction of a long-established population on Kangaroo Island in South Australia. It should be acknowledged, however, that patterns of offshore island habitation in Holocene Australia are complex and enigmatic and no single explanation of them is apparent, particularly none of biogeographic origin (Bowdler, 1995).

The various explanations of mid- to late-Holocene cultural dynamics that have been advanced in Australian archeology find similar expression in the rather different circumstances of New Guinea, notably in the archeology of the Highlands.

5. Highland New Guinea agriculture

As part of the Pleistocene landmass known as Sahul, New Guinea has probably been occupied for as long as Australia. There are archeological remains, notably waisted blades recovered from the Huon peninsula, which probably date to about 40,000 cal yr BP. Holocene research on mainland New Guinea has concentrated on the great Highlands valleys in the central cordillera. These are located between 1300 and 2500 m above sea level and historically have been home to dense populations (up to 300 people per km^2) whose subsistence revolved around intensive gardening, notably of sweet potato (*Ipomoea batatas*, of American origin and introduced by the late 16th century AD) and pig husbandry (Golson and Gardner, 1990). The antiquity of Highlands habitation, and of agriculture there, has been the subject of considerable investigation.

There is little direct evidence of the early arrival of people in the New Guinea pollen records. An increasing frequency of the edible nut genus, *Pandanus*, in late Pleistocene to early Holocene spectra, and a second rise in its frequency from the mid-Holocene might reflect its intentional management at Highlands sites. More important as a potential cultural indicator is the frequency of sustained forest firing. Some swamp cores show that there was frequent or continuous forest firing during the late Pleistocene from about 30,000 cal yr BP and that this declined dramatically or ceased about 8000 cal yr BP (as in cores from Kosipe, Haeapugua, and Telefomin). The Holocene records are variable. At the lowland Hordorli site a continuous fire record exists from about 12,000 cal yr BP. In the Highlands at Kelela forest firing begins at about 7000 cal yr BP, at Telefomin it resumes at 5000 cal yr BP, at Noreikora it begins about 4500 cal yr BP, and at Sirunki at 4300 cal yr BP, but there is then reforestation and continuous clearance from 2000 cal yr BP (Haberle, 1993, 1994, 1995, 2000). Variable as these records are, and indicative of quite localized differences in cultural manipulation of forests across altitudes ranging from 500 to 3500 m, they disclose nonetheless evidence of a substantial increase in burning after 6000 cal yr BP and a tendency for peak Holocene charcoal counts to be attained within the period 4500–1000 cal yr BP (Haberle et al., 2001). It is reasonable to assume that this reflects both a greater incidence of firing by growing Highlands populations and a greater vulnerability to fire of late Holocene forests as a result, primarily, of ENSO-influenced climatic conditions. It is uncertain to what extent ENSO conditions may have distorted the fire signal, producing records that appear to be of cultural frequency and intensity, but the reduction of Highlands valleys to grassland in the mid-Holocene was probably mainly anthropogenic. Increased firing after 5000 cal yr BP can be inferred from an increase in grassland pollen and in accumulation of organic sediments in many Highlands valleys beginning at about 5000–4000 cal yr BP (Haberle, 1994, p. 191).

In order to discuss these changes in relation to cultural dynamics, we need to examine the sedimentary and structural sequence at the Kuk site, situated at 1580 m altitude in the Wahgi Valley (Fig. 8.6). This shows that at about 10,000 cal yr BP, a channel and associated depressions and holes (Phase 1) were formed on the surface of a dark gray, slightly organic clay. Whether some of these can be distinguished convincingly from natural features, especially of fluvial origin, is uncertain and it is important to resist the temptation of a retrospective credibility being afforded by later and indisputable agricultural features having been constructed at higher levels in the same place. Denham et al. (2003) note that starch grains and raphides of *Colocasia*, cf. *esculenta* (taro) occur on the worked edge of a stone tool from Phase 1 and that there are also microfossils of *Musa* spp. (banana) in early Holocene contexts. It is not clear that either of these plants were domesticated, indeed *Eumusa* (wild banana) seeds in Phase 1 suggest it was not, and the situation is uncertain in regard to taro (Haberle personal communications). At the same time, however, the abundance of *Pandanus* (edible nut) and Musaceae which developed in the local environment during the early to mid-Holocene might suggest that some encouragement of preferred plants was by then underway.

An inorganic brown-gray clay was deposited upon the Phase 1 surface, and this clay continued to accumulate through the period 9000–6000 cal yr BP. Phase 2 begins in the period 7000–6400 cal yr BP (whether ditches were constructed immediately on the Phase 2 surface is not clear, according to Denham, personal communications) and Phase 3 about 4300–3800 cal yr BP, both within a partly organic dark brown to black clay (Denham et al., 2003). At about 3000 cal yr BP, another drainage system was established (Phase 4), and there were also later phases of structural construction and refurbishment.

The early drainage features in general have been interpreted as representing wetland garden systems of various kinds, often associated with dryland forest-fallow gardening, but some might be natural waterways, especially in Phase 1. Formal ditch construction is not evident until about the fifth millennium BP. The main crops may have been bananas (Musaceae), sugar cane (*Saccharum officinarum*), yams (*Dioscorea alata*), and especially taro (*Colocasia esculenta*), varieties of which, amongst other crops (e.g., Pacific almond, *Canarium* sp., betel nut, *Areca catechu*, and sago palm, *Metroxylon* spp.), might have been domesticated within New Guinea (Golson, 1991a, 1991b; Yen, 1991; Haberle, 1995; Hope and Golson, 1995). Bananas are represented by phytoliths throughout the archeological record at Kuk and, by some stage, at least some taxa were probably domesticates. Taro

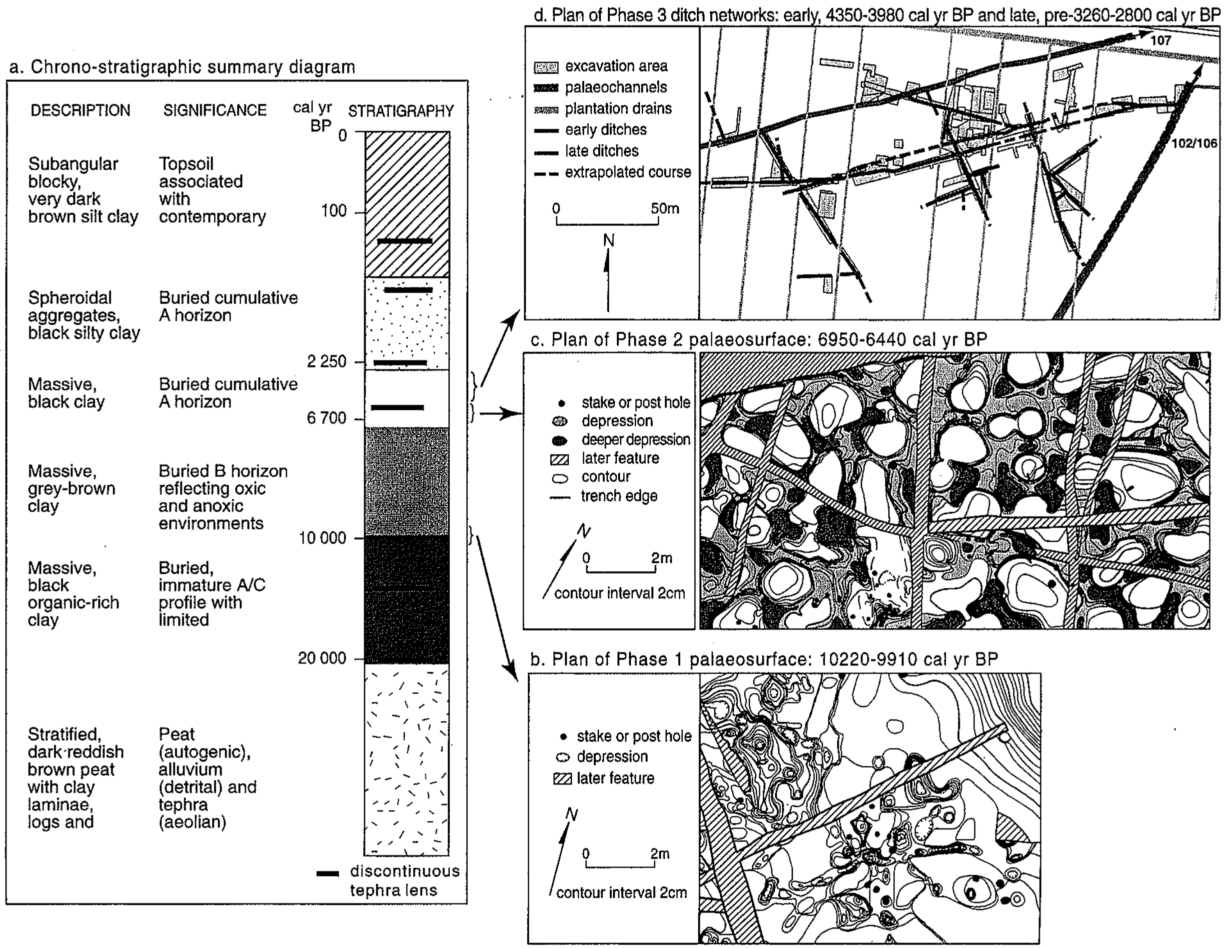

Figure 8.6. Archeo-stratigraphic representation of Phases 1, 2, 3 at Kuk (Reprinted with permission from Denham et al., 2003; Copyright 2003 AAAS).

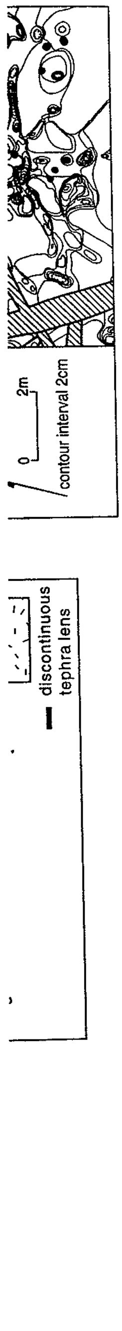

Figure 8.6. Archeo-stratigraphic representation of Phases 1, 2, 3 at Kuk (Reprinted with permission from Denham et al., 2003; Copyright 2003 AAAS).

and yams are also native to New Guinea. Yen (1995) suggested that their local domestication was no more strongly supported than is the introduction of cultivars from Asia during the Holocene, but Lebot (1999) has reviewed biomolecular data indicating that cultivars of taro, yam, sugarcane, breadfruit, plantain, and banana may have local origins in New Guinea. When and where they became domesticated, however, remains uncertain.

The sequence of subsistence development which has been constructed for the Wahgi Valley, and more generally for Highland New Guinea, begins with encouragement of useful forest taxa, notably *Pandanus*, as early as 30,000 cal yr BP (evidenced at Kosipe, but not yet in the Wahgi valley). It is argued that by the early Holocene there was construction of informal drainage features, possibly associated with incipient development of Highlands agriculture. The data, though, might be interpreted equally as re-orientation of non-agricultural settlement patterns and harvesting activities associated with environmental changes during the Holocene transition. Haberle and David (2004) suggest that taro, sugarcane, and gourd had dispersed naturally from lowlands to Highland valleys by the early Holocene and that there was no significant forest clearance until after about 8000 cal yr BP. From a wider review of palaeoecological sites from Highland valleys, Haberle (2003) concluded that either the Phase 1 agriculture argued to exist at Kuk was highly localized, or the antiquity of early agriculture in New Guinea needs re-assessment. Denham (2003), in fact, has rejected earlier claims that the Kuk wetlands were modified for agricultural purposes in Phase 1, although he accepts that the archeological evidence supports plant exploitation practices at that time. As Ballard (2003) emphasizes, however, there is no ultimate truth to be sought here, rather more, and more illuminating, archeological narratives. For example, the almost exclusive emphasis on plants in the discussion of Highlands subsistence development during the Holocene ignores the likelihood that swamplands in forested country, being relatively open and rich in herbs and invertebrates, were also highly attractive to game and their hunters; human activities on swamp surfaces might just as often have resulted from those practices, now no longer represented by bone which would not survive long in acidic soils. Indeed, the modified Phase 1 surface, with pits, post-holes, and a scatter of stone artifacts, some evidently used to cut or scrape plants, is reminiscent of inland hunter-gatherer camps in southern New Zealand, which lay at all times beyond the range of agriculture (Anderson, 1989).

More convincing evidence of agricultural practice occurs in Phase 2 at Kuk and also at Kana in the Highlands (Muke and Mandui, 2003) where it is argued that some features are contemporary with Kuk Phase 2. With extensive forest clearance from 7000 cal yr BP, possibly reflected in an increasing prominence of ground-stone axe-adzes (Denham, 2003), phases of wetland agriculture became more frequent. It is not yet clear that the number of Highlands archeological sites had increased significantly by the mid-Holocene, and therefore whether there occurred a similar vulnerability, through implied population density, to the impacts of climatic change that have been identified in Australian cases (above).

Drainage ditches and intervening gardening structures became progressively patterned and formal from Phase 2 onward and by about 3000 cal yr BP (also in the Baliem valley), forest-fallow gardening had largely collapsed. The valley bottoms were mostly in grassland, and by 2500 cal yr BP, agriculture was dominated by soil tillage with intensive, rotational gardening in wetter areas (involving systematic fallowing to clear out taro beetle (*Papuana* spp.) infestations), established by Phase 4 (Golson, 1990, 1991a, 1991b, 1997; Golson and Gardner, 1990; Bayliss-Smith and Golson, 1992; Bayliss-Smith, 1996).

The gathering diversity and complexity of Highlands agriculture from about the mid-Holocene is probably marked in other ways. There are the stone axe-adzes, and after 2500 cal yr BP, regional exchange networks emerged involving specialized production of high-quality stone implements and other products. There are examples of specialized agricultural implements from late-Holocene swamps, including a ditching spade dated 4564–4130 cal yr BP (ANU-2282: Golson, 1996). There is evidence of significantly declining diversity in wild fauna from about 5000 cal yr BP, and the pig (*Sus scrofa*) may have been husbanded in the Highlands by the mid-Holocene. That matter, however, is very uncertain and vigorously debated. Neither dog nor chicken remains are found in Highlands sites until after about 2000 cal yr BP, although the former, together with pig bone, is argued to occur in coastal middens from 6000 cal yr BP (Bulmer, 1998; Spriggs, 1999).

5.1. Relevance of climatic change

To what extent is climatic change implicated in this process of adopting agriculture, if at all? Golson and his colleagues (Golson, 1977; Golson and Gardner, 1990; Bayliss-Smith and Golson, 1992) thought that the interaction of cultural dynamics and environmental change in Highland New Guinea's prehistory reflected alternate innovations in dryland and wetland agriculture, each of which had environmental consequences. Thus, the 9000–6000 cal yr BP gray-clay unit at Kuk, which accumulated at a rate indicative of increasing erosion of open ground under agricultural conditions, was suggested as representing a dryland forest environment in which soil structures and fertility declined under repeated firing and forest-fallow cultivation. In turn, this land-use pattern produced costs of agricultural efficiency that eventually exceeded those of the labor-intensive construction and maintenance of large-scale wetland systems. Preference for the latter then increased as grassland came to dominate the landscape of Highland valleys and wetland agriculture intensified into a soil tillage and pig husbandry complex. There are alternative explanations of the prehistoric sequence of Highlands agriculture (e.g., by Kelly (1988) who emphasizes the increasing needs of pig rearing and by Gorecki (1986) who suggests mobile use and re-use of swamps), with population growth, as well as increasing pig production, becoming major considerations by the late Holocene. However, the common basis of all of these explanations is that none see mid-Holocene change in climatic variables as essential to explanation.

Nevertheless, Golson and Gardner (1990) conceded the potential significance of Brookfield's (1989) observation that the gray-clay unit corresponded fairly precisely with the hypsithermal interval and that sedimentary and cultural changes following this period might have reflected, to some extent, mid-Holocene climatic changes, notably an increasing impact under ENSO conditions of drought and frost on swamp management. Haberle and Chepstow-Lusty (2000) have elaborated on this suggestion. They point out that the upper margins of the probable natural ranges of the main cultigens extended into the Highlands and that initial domestication may have been a response to periodic environmental stress on these plants. Similarly, when ENSO conditions set in by the mid-Holocene, those may have stimulated further human action. One response might have been to move from drier ground on to swamp surfaces where a water supply was more assured. Another may have been closer control of water management systems. The earliest plausible evidence of agriculture, represented by ditch construction in Phase 2 at Kuk, dates to after about 7000 cal yr BP. How long after is unknown, except that it must have been before about 4300 cal yr BP when Phase 3 constructions began. That interval encompasses the period when El Niño activity first became elevated during the Holocene.

Golson (1990, p. 145) had noted of the Phase 1–3 systems that "their structural features are not linear and uniform but consist in part of small basins and interconnecting runnels which can admit and circulate water, as well as dispose of its excess." He thought that this system indicated broadly-based mixed gardening involving irrigation as well as drainage which, in Phases 4–6, was progressively replaced with staple cropping, initially of taro, in carefully-gridded ditch and raised-bed systems. This process culminated in the adoption of sweet potato cultivation, that cultigen becoming available and having superior qualities of production at the time of the Little Ice Age, when severe El Niño events may have occurred frequently (Haberle, 2000).

Adaptive water management is, at least, a plausible argument in the light of the known impact of ENSO climatic variability, and especially of El Niño conditions, on modern, indigenous agriculture in the New Guinea Highlands. Bourke's (2000) analysis of the 1997 El Niño event shows that in Papua New Guinea generally, 1.2 million people, about 40% of the total rural population, were suffering a severe, and in places life-threatening, food shortage, and that 400,000 had a grossly inadequate water supply by December 1997. The impact was greatest on small islands, where drought devastated the food crops and so weakened the populations that the effort of open sea fishing became too great. In the Highlands valleys, frosts were experienced down to 1450 m in altitude (in the 1972 El Niño they were so severe that forest and grassland as well as crops were damaged, Waddell, 1989) and there was prolonged drought often associated with bushfires (see also Johns, 1989). In addition to crop failure, the dry conditions affected hunting success for wild game. People turned to traditional famine foods and there was substantial migration out of the Highlands valleys to lower altitudes and to urban areas. Health declined significantly with increasing incidence of diarrhea, dysentery, malaria, pneumonia, typhoid, and skin diseases, and death rates by burning or starvation increased significantly, at least 500 attributed to the drought. In Irian Jaya (West Papua), too, about 700 deaths were attributed to the 1997 drought, many of them in the Baliem valley. It is not difficult to imagine that if El Niño conditions had begun to occur after 5000 cal yr BP with anything like the frequency of the recent past: 1956, 1964–1965, 1972, 1982, 1987, and 1997, or with the greater frequency now documented (Fig. 8.4), then there might have been a powerful incentive toward measures of risk aversion. However, it should also be noted that significant famines and episodes of crop failure have occurred in years without El Niño drought, in fact at times of excessive rainfall.

Perhaps the essential point here is that it is not so much the one case or the other as the unpredictable instability of ENSO conditions as a whole which may have constituted an imperative for ameliorating cultural measures. Chappell (2001) makes a more general case for linking the ultimate development of agriculture in New Guinea to declining frequency and magnitude of environmental disturbance at the Holocene transition, and the general significance of stability to agricultural development is a point well taken. An increasing emphasis on wetland gardening in systems which attempted to stabilize the management of agricultural water through periods of climatic instability would have been one appropriate response. Dewar's (2003) recent hypothesis about the significance of rainfall variability is pertinent here; his emphasis was geographical but it might just as easily have referred to the age-frequency distribution of ENSO effects. Whether the cultural changes in prehistory were actually impelled in this implied way remains, however, beyond our current ability to determine.

6. Some conclusions

For both Australia and New Guinea, it is possible to construct plausible propositions that link mid- to late-Holocene climatic changes to cultural dynamics, largely through the mechanisms of technological and subsistence pattern responses to increased uncertainty about access to or control of critical resources. There are several alternatives, however, that remain potentially significant. One is the possibility that cultural change in the mid- to late Holocene was generated significantly by new technologies and associated items arriving from Southeast or southern Asia. This looks especially likely in the case of Australia. Introduction of the dog and of new plant technologies might reflect the wider Neolithic dispersal in the region after 4000 cal yr BP, and some backed artifacts and microliths are similar to contemporary Indonesian industries such as the Toalian (Bellwood, 1997, p. 191). Agriculture in Highland New Guinea is older, dating fairly clearly to Phase 2 at Kuk, and as such it precedes the Southeast Asian agricultural dispersal, although it might have been influenced after 4000–3000 cal yr BP by contact with agricultural systems of Southeast Asian origin.