Holocene sea-level change and human response in Pacific Islands

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Holocene sea levels and coastal change, southwest Viti Levu Island, Fiji

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Abstract

For the first time, a sediment core spanning the entire Holocene has been analysed from Fiji. The 6-m core was obtained from the floor of an ancient coastal lagoon (palaeolagoon) adjacent to Bourewa, the site of the earliest-known human settlement in this island group. The basal sediments, just above bedrock, date from 11,470 cal BP. A major transition occurs around 8000 cal BP where marine influences on palaeolagoon sedimentation increase sharply. Full shallow-water marine conditions are attained around 4630 cal BP and last until 3480 cal BP after which there is a regressive phase lasting until 2025 cal BP.

The results agree with the area-specific predictions of sea level in the ICE-4G model, particularly in the timing of the highstand. In addition, the results support the ideas (a) that early human colonization of Fiji occurred during the late Holocene regression, (b) that the first inhabitants of Bourewa utilized both nearshore marine (reefal) and brackish lagoon food sources, and (c) that the abrupt human abandonment of the area around 2500 cal BP was probably driven by a reduction in these resources associated with sea-level fall.

Keywords

Core

Sediment analysis

Sea-level change

Holocene

42 Fiji

43 Lagoon (coastal)

Introduction

Holocene (postglacial) sea-level changes produced a succession of coastal-environmental changes that transformed both marine and terrestrial ecosystems and sometimes profoundly influenced the development of human societies. Most studies of the links between sea-level change and environmental development have been along continental coasts where there are generally greater rewards in terms of understanding ecosystem complexity and human-societal responses to extraneous forcing (Pavlopoulos et al., 2007; Nienhuis, 2008; Titus, 2009).

There have been fewer such studies on oceanic islands although there has been an upsurge of interest in such research in the past two decades, particularly on Pacific Islands. Part of this is attributable to the demonstration that Holocene palaeoenvironmental reconstructions across this vast region have much to contribute to the understanding of subjects as diverse as earth rheology, island habitability and future coastal management (Calhoun and Fletcher, 1996; Dickinson et al., 1994; Kayanne et al., 2002; Dickinson, 2003; Gray and Hein, 2005; Moriwaki et al., 2006; Nunn, 2007a,b; Nunn and Heorake, 2009).

This paper reports the results of core-sediment and faunal analyses from a former coastal lagoon (palaeolagoon) in Fiji which encompass the entire Holocene. For the first time from this part of the world, empirical data are available on the course of Holocene sea-level change and the ways that it transformed coastal environments. The palaeolagoon studied adjoins what is regarded as the earliest human settlement (named Bourewa) in Fiji where Holocene sea-level change first rendered the coastline attractive to (human) marine foragers and later forced them elsewhere to develop alternative livelihoods (Nunn, 2009).

Holocene sea levels and environmental change in the southwest Pacific Ocean

It is now widely accepted that sea level rose above its present level in the Pacific during the middle Holocene, reaching a maximum elevation of perhaps 2.1 m in Fiji around 4200 cal BP (Grossman et al., 1998; Dickinson, 2001; Nunn, 2001; Nunn and Peltier, 2001). Of particular relevance to this study is the work of Nunn and Peltier (2001) that compared all available data on Holocene sea levels in the Fiji archipelago and plotted them against site-specific predictions of the ICE-4G model. The close comparison found between predictions and empirical data suggests that the model was valid for Fiji and comparable far-field sites. Late Holocene sea level attained its present level around 1200 cal BP and subsequently exhibited variations that were comparatively minor in amplitude yet probably had profound effects on Pacific Island societies (Nunn, 2007a, 2007b).

Owing to its tropical oceanic location, particularly in the region where there is a strong ENSO climate signal, the Fiji Islands have received some attention from palaeoclimatologists (Bagnato et al., 2005). Of particular interest has been the evolution of reef-bordered and barrier coasts (Shepherd, 1990) as well as, more specifically, the nature of coastal environments first occupied by humans around 3100 cal BP (Nunn, 2005).

To appreciate the disproportionate interest in the earliest (Lapita) period of human settlement in Fiji, it should be realized that the people involved crossed more than 1100 km of open ocean more than 3000 years ago with only stone-age technology at their disposal. This achievement, unparalleled elsewhere in the world, has led to investigations of many Lapita palaeoenvironments in Fiji and other western Pacific

Island groups that were colonized in the same period (Dickinson and Green, 1998; Burley and Dickinson, 2001). A similar interest explains the interest in the abrupt and possibly simultaneous end of the Lapita period about 2500 cal BP in western Pacific Island groups, an event that is most plausibly attributed to resource depletion associated with late Holocene sea-level fall (Carson, 2008; Nunn, 2009).

The study area: Bourewa, southwest Viti Levu Island, Fiji

Bourewa is located on the Rove Peninsula, a dry and waterless limestone promontory fringed along its western border by an uncommonly broad coral reef (Figure 1). The presence of such a broad fringing reef off the Bourewa coast means that it is very low-energy in character, only occasionally registering any signs of the large waves (storm surges or tsunami) which affect nearby areas. There are no signs of late Quaternary tectonic activity along the Rove Peninsula although it cannot be completely discounted as it is part of a forebulge in other parts of which recent tectonic activity is detectable (Hamburger and Everingham, 1986).

Bourewa is the site of the earliest and the most extensive Lapita-era (3100-2500 cal BP) settlement discovered on the Rove Peninsula (Figure 1). Likely to be the founder settlement in the Fiji group, the earliest settlement at Bourewa involved a stilt-platform occupation out across the broad fringing reef, probably an indication of the overwhelming importance of marine foraging for the first Fiji people (Nunn, 2007c). Such a location also gave the Lapita inhabitants of Bourewa access to the food resources of a brackish coastal lagoon, separated from the fringing reef by a sand spit.

A model has been developed involving initial occupation of the Rove Peninsula after the Holocene sea-level maximum when the fringing coral reef had “caught up” with the ocean surface. This was the time of optimal attractiveness of the site to marine foragers. Some 600 years later, rather than population pressure (small site, short time period, massive fringing reef), it is thought that late Holocene sea-level fall impacted reef ecology making it impossible for marine foragers to continue to obtain sufficient food from it (Nunn, 2009). At this point, about 2500 cal BP, the Bourewa Lapita settlement and all the others on the Rove Peninsula were abandoned. This area was largely eschewed for settlement after this time.

To test the validity of this model, several cores were taken from the surrounding palaeolagoon and nearby sinkholes. Only one core (Ram Lal 2) proved suitable for analysis, its location being 110 m from the northeast boundary of the reconstructed Bourewa settlement, in what was inferred to be one of the deepest parts of the adjoining palaeolagoon (location shown in Figure 1).

Coring of the Bourewa palaeolagoon

Coring was carried out using a hand corer in six one-metre sections with an open cylindrical end piece (Figure 2). Sediment samples were recovered in successive 10-cm sections which enabled penetration to a total of 6 m below surface (+2.92 m msl). At this depth, as inferred from the increase in limestone particles in the core sediments, the bedrock foundations of the palaeolagoon are close.

Core stratigraphy is shown in Figure 3A with ages for the different layers interpolated from radiocarbon determinations (Table 1). The basal age of the sediment core is 11,470 cal BP, around terminal Pleistocene or earliest Holocene times. Changes in sediment texture through the core are explainable by changes in depositional environment, the nature of which was clarified by other analyses. A few decades of non-mechanized ploughing of the palaeolagoon suggests that the top 20-30 cm of the core may have been disturbed for this reason.

In each 10-cm sample, counts were made of whole (98% marine) shells and foraminifera (Figure 3B). Layer 1 contained least, while Layer 3 contained most. In Layer 2, both shell and foraminifera numbers increase with decreasing depth, suggesting this layer represents a transition from Layer 1 to Layer 3 environments. Similarly, in Layer 4(i) there is a decrease in shell and foraminifera numbers suggesting that this layer represents a transition from Layer 3 to Layer 4 environments. Of the 1073 whole shells identified, the most common species are the shallow nearshore species *Nassarius* (59%) and *Cerithium* (12%); full details are in Lal (2010).

Loss-on-ignition in a muffle furnace at 555°C and 950°C allowed the calculation of organic and carbonate proportions in each 10-cm sample (Figure 3C). The results show that the organic fraction is highest in Layers 1 and 4 and around half of this amount in Layers 2-4(i). In contrast, carbonate content is very low in Layer 1 yet rises sharply in Layer 2 and remains high through the rest of the sequence.

Interpretation

These results indicate that Layer 1 represents sedimentation from largely terrestrial sources, plausibly when sea level was significantly lower than the bedrock floor of the palaeolagoon. The few marine shells and foraminifera found in Layer 1may have been deposited in the palaeolagoon during storms or introduced post-deposition by burrowing organisms. The high proportion of organic material and low proportion of carbonate in Layer 1 sediment also supports its interpretation as a terrigenous deposit. Various postglacial sea-level reconstructions for the tropical Pacific (reviewed above) suggest that sea level during the period to which Layer 1 is dated was about 40-3 m below present. If the bedrock floor of the palaeolagoon is around 3 m below present (see Figure 3), as inferred from coring, then the palaeolagoon would have been significantly above sea level for most of the time of Layer 1 sediment deposition. The slow rate of deposition of Layer 1 is also consistent with terrigenous sedimentation in limestone terrain.

Three abrupt changes at the base of Layer 2 signal the start of marine influences on palaeolagoon sedimentation: namely the introduction of sand to the deposit, the sharp rise in marine shell and foraminiferal inclusions, and the rapid rise in carbonate sediment (see Figure 3). This is consistent with sea level rising to within a few metres of the (sediment-filled) lagoon floor, allowing throughout the period of Layer 2 deposition an increasing influence on its composition.

Layer 3 is interpreted as a marine sediment, as supported by its distinctive lithology, high numbers of shell and foraminifera, and high carbonate (low organic) content. It represents a marine incursion into the palaeolagoon which was then perhaps simply another coastal embayment. If this were the case, then unknown amounts of Layer 3 sediment may have been lost, which may explain why it does not display a clear peak in foraminiferal abundance or carbonate percentage. It is plausible to suppose that Layer 3 was that deposited during the Holocene sea-level highstand in this area.

The lithology of Layer 4 (including 4(i)) is largely similar except for the olive colouration of 4(i). This and the high proportion of shells that it contains suggests that Layer 4(i) is a transitional layer marking the change from a wholly marine coastal embayment to a coastal lagoon. Yet both the high counts of foraminifera and high carbonate content of Layer 4(i) sediment show that it continued to be influenced by marine processes. It is probable that Layer 4(i) was formed at a time during the late Holocene when sea level had begun to fall from its maximum. The contrast between this transitional layer (Layer 4(i)) and the earlier (Layer 2) suggests that the latter was driven by a sea-level rise that was more rapid and monotonic compared to the former that was slower and more variable.

The main part of Layer 4 is dated to the late Holocene and has low numbers of shells and foraminifera that demonstrate a significantly reduced influence from the ocean yet not its total exclusion from palaeolagoon sedimentation. It is likely that sea level at the start of Layer 4 deposition 2025 cal BP was around 1 m higher than today so that occasional marine incursions would have been common. This interpretation is supported by the continuing high level of carbonate sediment and low level of organic sediment, although this has risen relative to Layer 4(i) and signals an increased terrigenous sediment contribution.

Holocene sea-level change and palaeogeography

The most detailed postglacial sea-level curves for Fiji, using the ICE-4G model constrained by abundant empirical data, were published by Nunn and Peltier (2001) and included one for southern Viti Levu Island. This is shown in Figure 4 for the past 9000 yr together with the various palaeoenvironmental changes at Bourewa interpreted from core analysis.

Around 8000 cal BP, sea level was around 3 m below present, within perhaps 50 cm of the contemporary palaeolagoon floor and so just able to flood it at high tide. Prior to this time the palaeolagoon had been largely cut off from marine influences although these increase towards the end of Layer 1 deposition (see Figure 3B). The rise in carbonate sediment inputs to lagoon sediments are responsible for the change in their lithological character from Layers 1 to 2. During the time of Layer 2 sediment deposition, sea level in the area rose quickly (Figure 4) and the lagoon was flooded with increasing regularity.

It is significant that the timing of the sea-level maximum in the ICE-4G model shown in Figure 4 is coincident with the dating of Layer 3 at Bourewa (4630-3480 cal BP). This period marks a time when sea level was high enough (maximum +2.1 m) to permanently flood the former lagoon; terrigenous sediment inputs were minimal.

Since this time, the overall trend of sea level has been a falling one. From 3480-2025 cal BP, marine influences on the lagoon lessen, not only perhaps because of the regression but also because of the development of the sand spit that was part of the coastal landscape at the time (Nunn, 2007c). It is within this period that the human occupation of the Rove Peninsula took place and evidence from the shell midden suggests that at least for the first 200 years the Bourewa settlers were subsisting largely from shellfish foraging on both the fringing reef and the brackish coastal-lagoon. Some 200 years after initial arrival, there is evidence for the introduction of taro and yam, which were likely planted in the soft sediments around the fringe of the coastal lagoon (Horrocks and Nunn, 2007).

The final phase of palaeolagoon history determined from core analysis covers the last 2000 years and represents a time when the palaeolagoon was largely dry, subject largely to terrigenous sedimentation yet certainly not immune from marine influences. This is most strikingly shown by the continued high carbonate component of palaeolagoon sediment, although much of this may come from the re-deposition of marine sediments on the flanks of the palaeolagoon rather than primary marine deposition.

Conclusions

This study reports the results of the first palaeogeographical study for the Fiji Islands that is supported by core-sediment analysis. It was carried out in an area where appropriate equipment is generally lacking, where access is difficult, and yet which clearly has great potential. It would be encouraging if more research were carried out in this and similar areas.

The close correlation between palaeogeographical changes deduced from core-sediment analyses and the sea-level curve for southern Viti Levu Island is remarkable and adds weight to the assumptions that underlie both these separate processes.

In terms of the model of Holocene sea-level changes influencing the nature of Lapita-era settlement on the Rove Peninsula, several points are noted.

- Human settlement of Fiji (at Bourewa) did not occur until after the mid-Holocene highstand and may have coincided with the time at which coral reefs in this area caught up with sea level, their upgrowth having lagged behind its rise for much of the earlier Holocene.

- During the 600-year occupation of the Bourewa settlement site, sea level was falling and it therefore seems reasonable to propose that the changes in the nature of subsistence observed during this period – principally a reduction in emphasis on marine foraging and a concomitant increase in horticulture – may indeed be a result of this.
- The abrupt abandonment of the Bourewa settlement around 2500 cal BP occurred at a time when sea-level fall would have affected fringing-reef resources but also, as this study shows, would have caused the coastal-lagoon to have become much drier than earlier, rendering it unsuitable for either shellfish collection or aroid cultivation.

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Figure captions

Figure 1. Location of the study site within the Fiji archipelago.

Figure 2. Photograph of coring at site Ram Lal 2.

Figure 3. Results of coring. A – Core stratigraphy showing depths, relationship to current sea level, lithology and interpolated radiocarbon ages. B – Counts of shells and foraminifera in particular 10-cm samples. C – Percentages of organic and carbonate in each 10-cm sample.

Figure 4. Environmental changes at the study site interpreted from core analysis plotted against Holocene sea-level changes for the south coast of Viti Levu Island from the ICE-4G model (Nunn and Peltier, 2001).