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PART C: NATURAL HISTORY

CHAPTER 18

LANDSCAPE HISTORY AT BULBUL, GELAM'S HOMELAND

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Mapping and particle size analyses undertaken on samples collected at Bulbul, northeast Mua (Moa Island), indicate a series of beach ridges interpreted in the broadest sense to include both wave-built and wind-built coastal ridges. Using the advantages and limitations of a deductive historical sciences approach, a history of the ridges and surrounding landscape is compiled which outlines environmental changes from the time of sea level transgression into Bulbul to the time of marked human presence. Interpretations of scientific interest include confirmation of the conclusions by Woodroffe et al. (2000) that sea level in the Torres Strait stabilised before 2300 years BP, in this case by approximately 2900 calendric years BP at Mua; that an environmental transition occurred here in the very late Holocene with evidence for increased reworking of beach ridge sediments by wind, culminating in the formation of a coastal dune; and that the last c.800 years have been marked by apparent increased burning and disturbance, resulting in artefact burial. ❐ *Torres Strait, Mua island, Holocene, Quaternary, geomorphology*.

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Our understanding of the landscape history of an area depends on the way in which the information is obtained and what we do with that information. Oral traditions themselves contain time-honoured knowledge of past events handed down through the generations to community members; knowledge is here often gained through direct observation of local events and processes, such as the recent burial of Gelam's footprint by beach sands in the northern end of Bulbul (Bruno David, pers. comm., 2007). Historical science is another means of documenting landscape change, sometimes over periods of time extending beyond individual and community memories. Here past landscape events have not been observed directly and they are instead interpreted from various intermediary sources, such as sediments and landforms. The sizes of sand and finer sediments, for instance, have been found from observations and experiments to reflect the way they were deposited by water, gravity or wind; landforms are believed, from observing current processes, to inherit shapes that reflect various actions of erosion and deposition. Historical earth and environmental scientists use such observations of present environments from studies previously conducted and apply them to landforms and sediments that developed in the past. They are in effect travellers to different regions who apply their acquired knowledge of other areas in order to interpret the clues they recognise in the terrain being studied.

The approach should not be characterised though as the way to gain absolute truths about landscape history. Frodeman (1995) argued that not only are historical scientists seldom in possession of all the data needed to make a decision, but further, that it is not always clear that the data (and arguably also the interpretations based on them) are free from bias or subjectivity. Stories of landscape history usually evolve with further investigations, due to the type of information collected, the addition of detail and improvements of technology applied to the studies. The changes may mean simply refinement of the earlier stories, or a substantial change in interpretation.

At Bulbul there have been no previous published scientific studies of landscape history (but see Barham, 1983). It is a coastal low relief terrain adjacent to, and constrained by, steep slopes developed on granitic bedrock. This terrain does contain clues to at least some of its environmental history that can be used to reconstruct events that might have occurred here. The low relief surface has coastal ridges next to and parallel to the shoreline, made of sands that by their size and nature might contain information on how they were deposited by water or wind. Well-sorted fine and medium sized sands, for instance, might indicate that the sediment was sorted by wind; coarser sands and gravels across a broader range of sizes might indicate that the sediments were deposited by water in higher energy conditions. As the build-up of sediments can force the shoreline to retreat seaward, the landward ridges are often thought to be older and contain information about earlier environments and the seaward ridges are usually younger and contain information about environments closer in time to the present. Behind the ridges is a plain of weathered rock and water-deposited sediments; these sediments are deposited in a vertical sequence so that those at depth might contain information about earlier environments and the sediments nearer to the surface relate to subsequent environmental events.

These sediments and landforms are used in this study to interpret parts of Bulbul's environmental history. A range of information gained from other regions may be relevant to these interpretations, particularly in the form of sea level histories, understanding of coastal beach ridge and dune development and histories of climatic and environmental change. Palaeoenvironmental information gained from the Torres Strait and Gulf of Carpentaria regions is used as background and the context for the basic investigation undertaken in this study.

THE SETTING OF BULBUL IN THE TORRES STRAIT

Bulbul (10°08'S, 142°18.2'E) is a coastal terrain located in north eastern Mua in the narrow Torres Strait shelf region between Australia and Papua New Guinea. Mua and several other Torres Strait islands contain hilly outcrops of Palaeozoic granitic rock rising above an otherwise gently undulating plain submerged by shallow sea. The islands are located in a tropical low wave energy environment, which regionally experience a moderate mean spring tidal range of 3.6m (Brander et al., 2004). Climate is characterised by a summer wet season and a winter dry season associated with the north Australian monsoon. Winds during the dry season (April to November inclusive) are predominantly from the southeast and east; winds during the peak of the wet season (January and February) are from the west and northwest (Australian Bureau of Meteorology, data from Thursday Island).

CLIMATE CHANGE AND REGIONAL PALAEOENVIRONMENTAL STUDIES

The Australian monsoon is a dominant climatic influence on the Torres Strait and northern Australian regions. The most recent fully active phase of the Australian monsoon is believed from sediment records in north western Australia to have begun 14,000 years ago and to have become less intense over the last 5000 years (Wyrwoll & Miller, 2001). Changes to forest assemblages and their extent, lake salinities and fire frequency in the northern regions from China to India also indicate reductions in monsoon activity over the last 5000 years (Hope et al., 2004). Drawing on a range of studies conducted in northern Australia, Shulmeister (1999) argued that reduced effective precipitation and increased climatic variability occurred after 3700 years before present (BP) due particularly to the shared influence of sea surface temperature on the North Australian monsoon and the Walker Circulation over the Pacific Ocean.

Palaeoenvironmental investigations regionally have been conducted southwest of the Torres Strait in the islands of the Gulf of Carpentaria, 2 to 6° to the south. These have implications for the climatic phenomena that influence the strait. Microfossil records from lake sediments on Vanderlin Island (Prebble et al., 2005) and sediment and palynological records from Groote Eylandt (Shulmeister, 1992; Shulmeister & Lees, 1995) indicate that the north Australian monsoon intensified in the period leading up to 5000 years BP with maximum effective precipitation occurring in the next 1000 to 1500 years. Changes to vegetation in the later Holocene, which could be interpreted as indicating greater climatic variability and reduced precipitation, might also or instead be a response to changes in local fire regimes (Prebble et al., 2005).

Fire had been an influence over this time on the vegetation of Vanderlin and Groote Eyelandt, as indicated by charcoal particle concentrations in sediments. For some time there has been uncertainty in interpreting the causes of increased burning, which may have been controlled by people, fire-promoting environmental conditions (such as extended dry seasons, reduced annual rainfall, increased cyclone frequency and intensity, the presence of sclerophyllous vegetation and organic debris build-up), or both (Prebble et al., 2005). Haberle and Ledru (2001) argued, from compiling charcoal records across Indonesia, Papua New Guinea and Central and South America, that fire is promoted during periods of rapid climate change and high climatic variability regardless of the absence or presence of people. The authors found that the strongest correlations in fire history between the regions occurred after 5000 years BP, when increased burning apparently corresponded with increasing El Niño-related climatic variability.

Studies of past environmental changes need to consider not only broader climatic variations but changing sea levels and the associated shifts in shorelines. Sea level change has conceivably had a major effect on the local and regional landscapes of Torres Strait, involving the creation of islands. Studies of sea level changes have been undertaken in a number of coastal sites in Queensland, the Gulf of Carpentaria and Torres Strait itself. Before 9700 years BP the sea was absent from Torres Strait and the Gulf of Carpentaria; and the regional landscape, interpreted from pollen and other biotic remains preserved in sediments from that time, consisted of savannah grasslands surrounding a near-full Lake Carpentaria (Chivas et al., 2001). Torres Strait – more accurately, the Torres Plains – would then have had low relief plains with granite hill rises. Sea level in the Torres Strait is believed from reef development on Iama (Yam) and Hammond Island to have risen after this time until it was 0.8-1.0m higher than present about 5800 years BP, before falling gradually to its present level by about 2300 years BP (Woodroffe et al., 2000). Due to either this sea level history or to climate change, nearly half of the reefs in Torres Strait and Queensland stopped expanding after 4800 years BP and most had stopped by around 2500 years BP (Smithers et al., 2006).

The rise in sea level was associated with the development of coastal beach ridges and even dune-fields on the present islands in this region. Coastal dunes have been regarded as unusual features for the tropics, but dune-field development has been identified and described on Groote Eylandt in the Gulf of Carpentaria (Shulmeister & Lees, 1992; Shulmeister et al., 1993). The Holocene dunes are argued to have been activated by storm-induced vegetation destruction associated with marine transgression in the period leading up to sea level stabilisation, consistent with a pattern of dune-field formation across a number of locations in northern Australia that have sufficiently high onshore wind energies (Lees et al., 1993; Shulmeister et al., 1993).

LANDSCAPE HISTORY INVESTIGATION AT BULBUL

The broad approach to investigating landscape history at Bulbul is to identify the nature of its landforms and sediments through field observation, sample collection and measurement of sediment sizes; to determine the age of some of these sediments; and to use these ages to discern any changes through time in the landforms and the ways in which materials were being formed and deposited. Two biases are apparent here in the scope of the landscape history investigated. As information about sediment deposition is more easily ascertained and interpreted than the erosional processes that govern the shape of hills and rock formations, there is an emphasis on sediment sample collection and interpretation in this study. Second, sediment sampling is more intensive in the coastal ridge sequence largely because the results of previous studies suggest that shoreline changes would be the most obvious landscape change that might have occurred in the time of human presence. Despite the emphasis on beach ridge sampling, the scope of this study did not extend to investigating the morphodynamic significance of beach rock formation at Bulbul and this remains a potential area of further investigation.

In order to characterise the landscape of Bulbul, a surface survey of boundaries between major landforms was undertaken in the field with a handheld Global Positioning System (GPS). GPS locations were also recorded along the crests of the coastal ridges. These locations were plotted onto a basal 1:100,000 scale topographic map to produce a generalised landform map of Bulbul. A total of 115 GPS locations were recorded in the field in an approximate 800m by 600m area.

A surface survey of slope angles and heights of the coastal ridges relative to beach rock was undertaken in a transect using measuring tapes, clinometer and a compass adjusted for magnetic declination, in order to display height variations with distance from the shoreline. This is described as transect B below; sampled sites were recorded in the survey.

Soils and sediments were sampled from landforms where the nature of materials was clear from field observation (hill-slope soils on granitic bedrock, sand bars in stream bends, and present beach sands at the high tide mark) and from where the nature of the material needed to be more accurately identified (coastal ridge

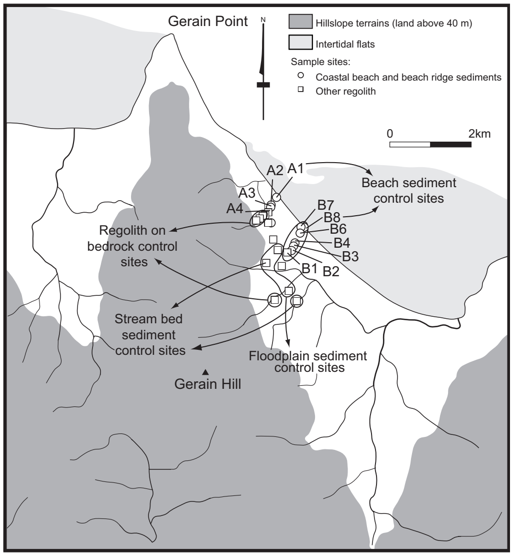

FIG. 1. The Bulbul landscape and the locations of sample sites.

sediments, regolith on the plains inland of the ridges, and sediments in the apparent alluvial and scoured zone northwest of the ridges). Stratified sampling was thus employed to gain information from each of the landscape components, but transect sampling was employed for the coastal ridge sequence to identify variations in sediments with distance from the present shoreline.

The hill-slope soils were triplicate composite sampled at 0-5cm depths, the typical depth of the soil to granitic rock, in a short transect of three sites of 20m distance intervals from 8m vertical height above the slope base to the break of slope. These sites and one point sample of weathered granite on the plain are indicated as control sites for regolith on bedrock in Fig. 1. Sand bars of stream bends, in streams upstream of the beach ridges carrying quartz sand sourced from the hill-slopes, were triplicate composite sampled at two sites, shown in Fig. 1 as stream bed sediment control sites. Finer sediments overlying coarser sediments in a fining up sequence (two sites) and surface regolith away from identifiable near-surface weathered granite (one site) were used to characterise non-channel floodplain sediments. The present beach sands were triplicate composite sampled at 1-10cm depths from (a) the high tide level at the beach rock edge, and (b) from different nearby positions seaward and inland of this level at sites A1 and B8, used as beach sediment control sites. As the present formative environments at these locations could be easily identified, the characteristics of these sediments were used as a basis for interpreting the formative environments of older sediments with a similar character.

Those sediments and soils where the formative environment needed to be identified were sampled in a combination of transect, point and core sampling. The coastal ridge sequence for identification purposes was pit sampled from the most sheltered positions of the ridges to reduce the potential effects of surface deflation on particle size distributions, namely the lower inland slope of the ridges. Ridges were sampled in two transects, A and B, in order to identify any variations in deposition mode with distance from the shoreline, as the distances might be related to ridge age. Additional pit sampling of the ridges was undertaken in the swales (sites A4, B3) and on a ridge-top mound (site B7) in the transects. Pits were dug to 90-100cm deep and transect B pits were sampled at 20cm depth intervals. An extra ridge, an apparent dune, at the northwestern end of the sequence was sampled at 50cm depth intervals from a 2m-deep cutting facing the beach (site A2).

The regolith of the plains inland of the ridges was sampled by combined pit and augering to replicate core sampling in order to determine changes in the nature of materials with time. Site B1, on the immediate inland edge of the ridges, was sampled by this combined pit and augering; samples were taken at 20cm depth intervals in a 90cm deep pit and from further augering to a total depth of 330cm. Regolith of uncertain origin was point sampled at two sites on the plain located at different distances from stream channels in order to identify the nature of the materials there. An apparent erosional zone northwest of the ridges was sampled within the 0-35cm depth range from four sample locations at three sites on sediment lobes within the zone. The total of six sample locations at five sites point sampled for identification purposes are indicated as test sites in Fig. 1.

Investigation of the particle, or grain, size distribution of soils and sediments sampled in the area was undertaken in order to identify the nature of the materials that make up the landscape and to ascertain agents responsible for the transport of sediments. A Beckman Coulter LS100Q laser diffraction particle size analyser was used to estimate the volume percent of particles in 83 size classes between 0.4 and 948μm. The whole samples collected in the field were riffled down to approximately 1 to 2cm^2 in volume. Distilled water was added and the samples were placed for one minute in a vortex mixer before being placed in an end-over-end mixer. These samples were allowed to settle and not shaken, to avoid creating bubbles, before being poured through a 1mm sieve into the LS100Q particle size analyser. Laser diffraction particle size analysis is based on the principle that particles diffract light at angles according to their size, so that larger particles diffract light at smaller angles and vice versa. Laser beam light diffracted from the particles in the LS model is focused onto 126 detectors and the measurements used to estimate the particle sizes. In this study the Fraunhofer theory was used to calculate particle size from the detector measurements.

Samples with significant proportions of sands and gravels greater than 1mm in size were dry sieved to obtain further information on particle size distributions. These samples were riffled down to a weight of less than 30g unless they contained a significant proportion of gravels; the latter samples were minimally riffled. Floodplain samples with significant proportions of finer materials were also dry sieved to allow comparison of results. Five floodplain and bedrock regolith samples required gentle crushing with a mortar and pestle before dry sieving. Samples were then mechanically shaken through 2.0, 0.6 and 0.106mm sieves for a minimum of eight minutes each.

Charcoal fragments were retrieved from five site B1 and four beach ridge subsurface samples. These were submitted for accelerator mass spectrometry (AMS) radiocarbon dating at the Australian Nuclear Science and Technology Organisation (ANSTO) using the facility outlined by Fink et al. (2004). Ages relate to graphite derived from the fraction and they were rounded according to the guidelines of Stuiver and Polach (1977). Conventional ^{14}C ages were calibrated to calendric ages on Calib 5.0.2, with Southern Hemisphere option.

RESULTS AND INTERPRETATIONS. The general landform and regolith map of Bulbul is presented in Fig. 2. Identification of the nature of regolith in the beach ridges, supratidal erosion zone and plains behind the beach ridges was ascertained using particle size analysis results presented shortly. The locations of erosion scarps were identified from field observations. These erosion scarps are interpreted to be supratidal because of two apparent breach points in the

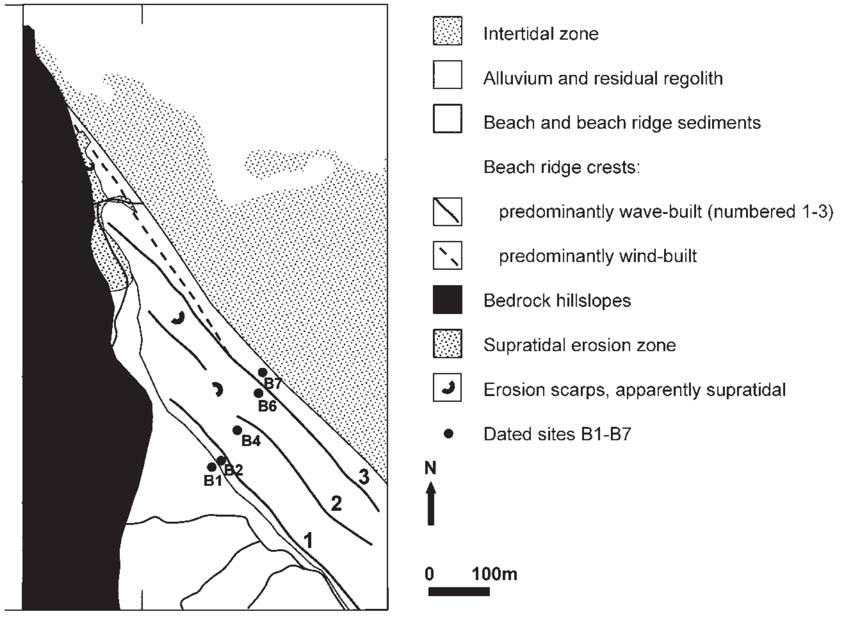

FIG. 2. General landform and regolith map of Bulbul based on the results of this study. The extent of the intertidal zone is derived from the Moa Island 1:100,000 scale topographic map (map no. 7377).

northwestern-most ridge and because erosion scarps occur in the swales of the beach ridges, which have no catchment areas for stream flow, suggesting tidal water encroachment and associated erosion.

Variation in coastal ridge height with distance along transect B is indicated in Fig. 3, which includes the locations of the sample sites of this transect. Beach ridges are numbered in order of decreasing expected age, with the landward ridge numbered 1 and the seaward ridge numbered 3. The beach ridge heights and shapes shown in Figure 3 suggest high but non-erosional wave impact on the beach ridges except for beach ridge 3, which is cliffed on the seaward side. Soil horizon depths are based on field observations and the A horizon depths include A2 horizon materials where present. Total soil profile depth, as expected from the theoretical increase in ridge age with distance from the shoreline, is deeper in the inland ridges and shallower at the seaward beach ridge 3. The soil profile at site B7 had the least horizon development with only incipient A horizon materials. At beach ridge 2 the profile indicated disturbance and redeposition of the beach ridge sediments with burial of an older soil profile and evidence of previous human occupation, as described in David et al. (this volume). The sequence indicated at site B1 includes alluvium and beach sediments at depth, which have been interpreted from particle size distribution results.

The volume of particle size distribution data generated from both the laser diffraction and dry sieving methods has been refined and reduced to three diagrams that aid interpretations relevant to understanding the origins of materials (Figs 4-6).

The first of these diagrams (Fig. 4) highlights the origins of the beach ridge materials. The particle size distributions of samples A1 and B8, collected from the present beach, are broadly similar to the sediments of beach ridges 1 to 3 as the dominant mode is located in the coarse sand fraction between 400 and 1000μm. As the present beach sediments were used as control samples this strongly suggests that the sediments of beach ridges 1 to 3 are primarily water-deposited. The fine to coarse sands of the beach ridge sediments are consistent with upper intertidal to supratidal wave-built deposits as reviewed and described by Otvos (2000), but not with gravel-boulder 'storm' ridges. Large swell waves generated from distant storms can contribute to the aggradation of high beach ridges (Otvos, 2000) such as these. However the beach ridge sediments differ from the present beach sediments in that there is increasing bimodality in the particle size distributions from beach ridge 1 to beach ridge 3, with a second mode occurring between 100 and 300μm and broadly around 185 μm.

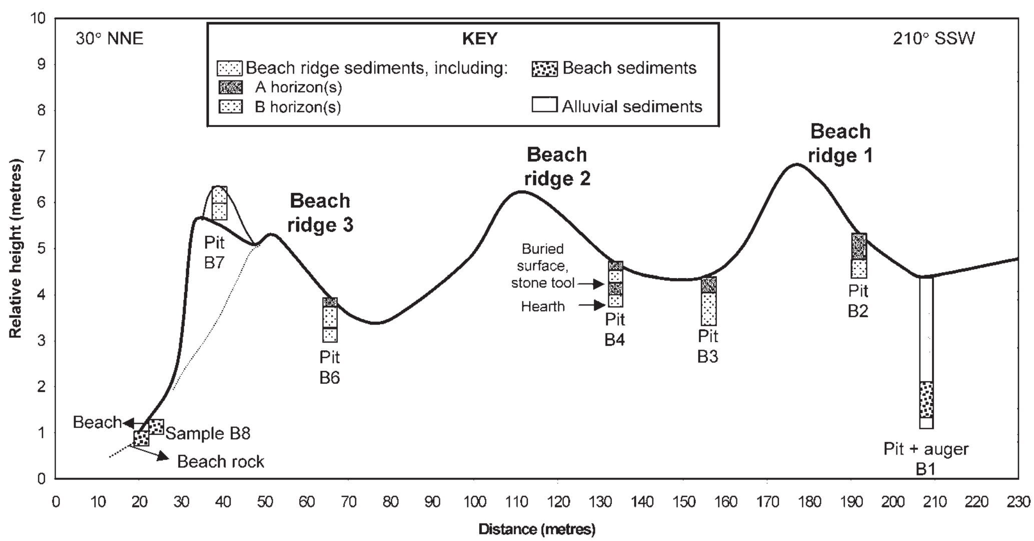

FIG. 3. Variations in coastal ridge height with distance along transect B, the positions of sampled sites (B1 to B8) and the nature of sediments at these sites interpreted on the basis of particle size analysis results.

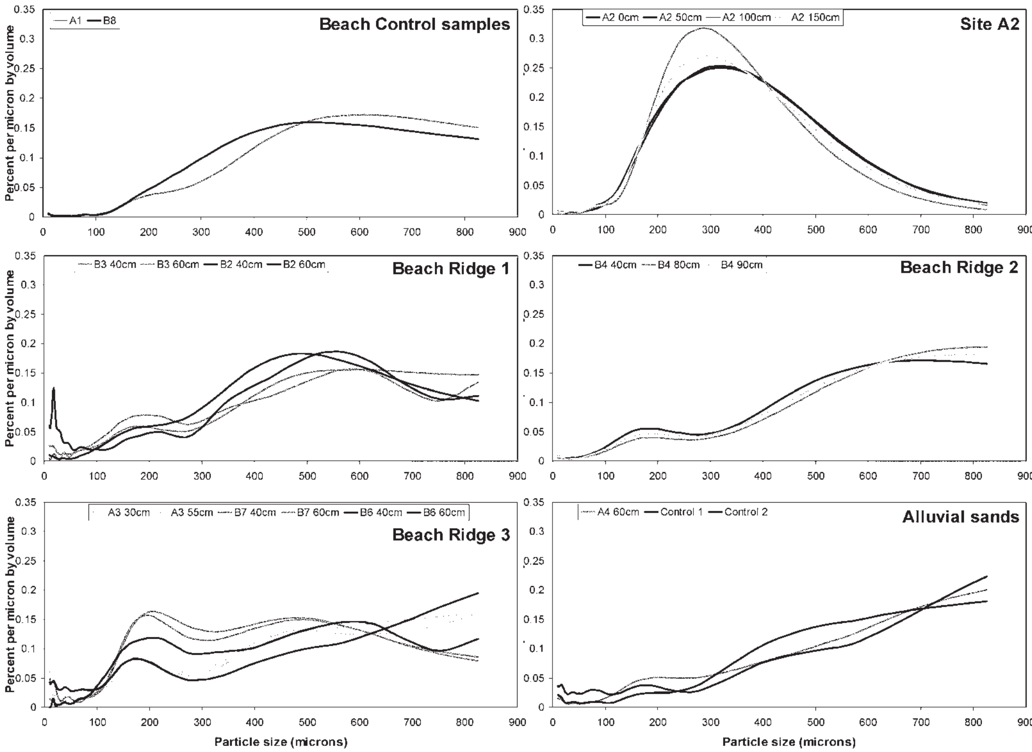

FIG. 4. Particle size distributions of beach sediment control samples and coastal ridge sediments determined by laser diffraction particle size analysis and displayed as percentages by volume (y axis) at each micron (micrometre) particle size (x axis). The percent volume for each size class in the Beckman Coulter S100Q model particle size analyser has been divided by the number of micrometres in each class to derive the 'percent per micron' results.

Fig. 4 indicates further that site A2, on the ridge to the northwest of and not present in transect B, has a very different particle size distribution to the beach sediments and beach ridges 1 to 3. The distributions indicate a well-sorted sandy sediment with a single mode between 200 and 400μm, which is within the saltation size range and very typical of dune sediments (Fig. 4). This ridge is interpreted to be a wind-blown coastal sand dune. Its origin is indicated on the landform map of Fig. 2 and it is the only sand dune discovered in this investigation. Finally, site A4, in the swale between beach ridges 3 and 2, had a particle size distribution that closely matched the control samples for alluvial sands (Fig. 4), in that the mode occurred beyond 1000μm and it contained significantly coarser sands than the beach ridge sediments. Alluvial sands are interpreted to be in the swale at this site near to the edge of the beach ridge sequence, and so the site is not used for beach ridge analysis. The location of alluvial sands at this site confirms that erosion has occurred in the swales below the erosion scarps indicated in Fig. 2, and in this case erosion of the beach ridge sediments reveals that alluvium underlies the beach ridges here.

Fig. 5 utilises dry sieving results to indicate the origins of sediments with depth at site B1, which is located immediately on the inland side of the beach ridges as shown in Fig. 3. Samples taken at 20cm depth intervals between 0cm and 120cm have contents of fine materials (less than 106 μm) and fine gravels (2 to 6mm) similar to the control samples for floodplain sediments and they are identified here as those sediments. The sample taken at 140cm has contents of these materials similar to the control samples for regolith on bedrock taken from the hill-slopes, which could mean either deposition of hill-slope sediments without sorting or, more likely, that the sample is a mixture of stream bed sediments and finer floodplain sediments taken across a boundary between these sediments at that level. Samples taken at 40cm depth intervals at and below 160cm indicate an origin consistent with the control samples for stream bed sediments, except that these samples include even coarser gravels that are not present in the control samples. The depth of samples used for dry sieving is modified between the field-observed sediment boundaries at 220 and 295cm, with three samples analysed at the depths of 245, 260 and 280cm in order to be located clearly within the sediment between the two boundaries. These sediments were tentatively interpreted in the field to be beach sediments, and the proportions of fines and fine gravels in the samples indicated are more consistent with beach sediments than stream bed sediments. On the basis of the particle size analysis results these are interpreted as beach sediments, given that potential decalcification of these sands render other forms of identification difficult. The lowermost beach sediment deposit is not appreciably higher in elevation than the upper level of the present beach rock material using the survey method employed; further and more detailed surveys would be required to determine any significant height difference. As the sediments occur at depth in the sequence, these sands may have been deposited during an earlier transgressive shoreline phase, while the higher beach ridge sediments were likely deposited during a later progradational, or regressive, phase in shoreline evolution. Below 295cm depth at site B1 are sediments again similar to the stream bed control samples, shown by the 320cm depth sample in Fig. 5.

Though not displayed in Figs 4 and 5, similar analyses of particle size distributions were undertaken for sediments of the test sites in the apparent supratidal erosion zone and for unidentified materials on the plain. The sediments of all four sample locations in the erosion zone returned results consistent with the beach ridge sediments. Sediments of one of the two sites sampled on the plain for identification returned results strongly consistent with regolith on bedrock; the sediment of the other site returned results not consistent with any of the groupings shown in Fig. 5 and so its origin could not be identified using this method.

Fig. 6 is intended to highlight the change in the proportion of fine sands included in the beach ridge 1 to 3 sediments, corresponding to the noted

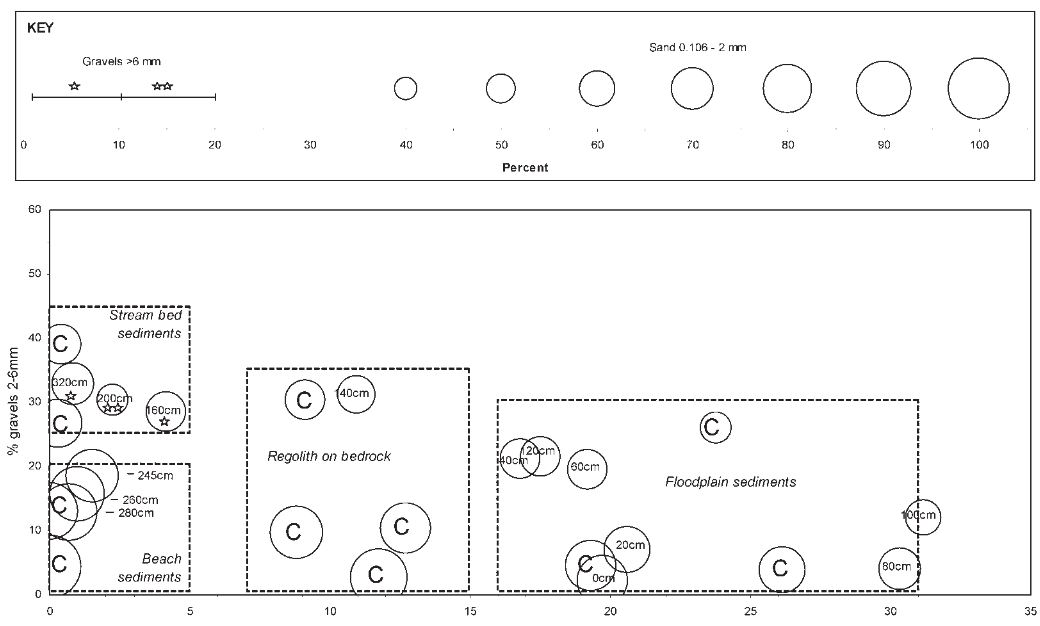

FIG. 5. Comparison of control (C) and site B1 (by depth) sample particle size distributions determined by dry sieving and expressed as percentages by weight. Percentages of fines less than 0.106mm and of gravels of 2 to 6mm in size are displayed on the x and y axes respectively. Bubble size is proportional to the content of sands in the 0.106 to 2mm size range. Stars indicate the presence of gravels larger than 6mm in size. Boxes indicate groupings used for ease of discussion.

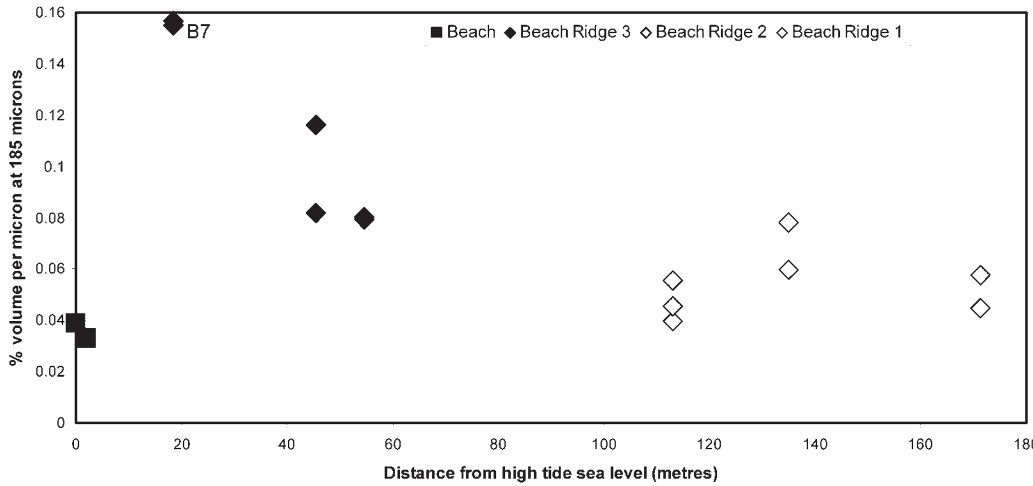

FIG. 6. Percent per micron (micrometre) values at 185 μm for the beach ridge (1-3) samples used in Fig. 4.

increase in bimodality of particle size distributions in beach ridge 3. The percent volume of particles at each micron (micrometre), where results for each size class are averaged over the size class interval, is displayed for the results at 185μm, close to the mode in each of the bimodal distributions. Beach sediments have low amounts (≤0.04%) of 185μm sized sands and beach ridge 1 and 2 sediments have slightly higher amounts (0.04 to 0.079%). Beach ridge 3 sediments have volumes of between 0.08 and 0.16% sands of 185μm size, and in site B7 the amount of 185 μm sized sand is higher than the amount of sand at the second mode of 470μm. The presence of a discrete mode of fine sand in this environmental setting suggests a component of wind deposited material; if this interpretation is correct then deposition by wind would have to occur concomitantly with the period of beach sedimentation for the fine sands to be present at the current depths of 40 to 60cm in the sediment profiles. The times at which the increase in fine sand materials occurred in this landscape are potentially revealed by AMS radiocarbon dating of charcoal in the beach ridge sediments.

AMS radiocarbon dating results derived from charcoal particles in sediments of sites B1 to B7 are presented in Table 1. The dates determined are all less than 3000 calendric years BP, with the majority of dates less than c.800 cal. years BP. Two dates are within the range of c.1810 to 1560 cal. years BP and a single date lies is c.2800-2900 years BP. Apparent age reversals in site B1 are likely due to contamination of the lower sediments sampled during augering through that part of the sedimentary sequence. The ages are still included for interpretation, without depth specification, as the charcoal could have only been obtained from the higher levels of the sedimentary sequence at that site.

Calendric AMS radiocarbon dates are plotted against distance from high tide sea level in Fig. 7 to facilitate interpretations of beach ridge ages. As there are fewer controls on the interpretation of the age distributions than there are for the particle size analysis results, the following discussion is presented as a suggested interpretation that is open to scrutiny and further argument. Sediments that have accumulated behind the beach ridges at site B1 include the oldest charcoal of up to 2900 cal. years BP in age as well as younger charcoal c.1600 and c.800-700 cal. years BP. At 47cm depth, pit-sampled charcoal returned an age of 1685±57 cal. years BP, which might be close to the time of the end of sedimentation behind this part of beach ridge 1. Beach ridge 2 at site B4 is old enough to contain charcoal c.1700 cal. years BP at 40-45cm depth in the uppermost soil profile. Beach ridge 3 at sites B6 and B7 contain only younger charcoal, in this case less than c.650 cal. years BP.

The ages of the oldest charcoal dated at each of sites B7, B4 and B1 form a linear relationship with distance from the shoreline ($y = 13.289x + 353.21$, $r^2 = 0.9968$). Only three ages define this relationship and so the r^2 value is not accepted as realistic, but it is interpreted as providing acceptable absolute minimum dates for the

TABLE 1. AMS radiocarbon ages and calibrated ages on single pieces of charcoal, Bulbul (calibrations using Calib 5.0.2, with Southern Hemisphere option).

14C laboratory #	Sample code	Sampling method	δ13C ‰	% Modern	14C age (years BP)	Calibrated age BP, 1 sigma 68.3% probability (probability)	Calibrated age BP, 2 sigma 95.4% probability (probability)
OZH251	B1 47cm	Pit			1765±40	1560-1630 (.663) 1653-1691 (.337)	1528-1713 (1.000)
OZH252	B1 100-102cm	Auger			910±50	726-803 (.828) 873-899 (.172)	682-848 (.817) 860-907 (.183)
OZH253	B1 140-145cm	Auger			2780±60	2760-2870 (1.000)	2743-2961 (1.000)
OZH254	B1 160-165cm	Auger			840±60	671-749 (.943) 753-761 (.057)	573-587 (.013) 646-807 (.950) 870-901 (.037)
OZH255	B1 195-200cm	Auger			'Modern'	<200	<200
OZH256	B2 40-45cm	Pit			585±40	517-559 (.964) 617-621 (.036)	505-567 (.782) 597-632 (.218)
OZH258	B4 40-45cm	Pit			1840±40	1625-1670 (.324) 1689-1741 (.442) 1755-1780 (.154) 1795-1810 (.080)	1570-1583 (.018) 1595-1822 (.982)
OZH259	B6 40-45cm	Pit			330±120	153-172 (.057) 178-189 (.030) 192-207 (.045) 278-492 (.868)	0-34 (.037) 57-123 (.069) 133-518 (.894)
OZH260	B7 20-25cm	Pit			690±60	560-609 (.587) 625-658 (.413)	537-681 (1.000)

stabilisation of the ridges and the establishment of vegetation substantial enough to provide material for burning. On this basis the oldest ridge formed and caused alluvial sedimentation behind it, before the burning of established vegetation by c.2800-2900 cal. years BP. Ridge 2 was stabilised and vegetated by c.1700 cal. years BP, and this dated section of the landward side was remobilised in a mass movement event in the last c.650 years (see David et al., this volume). Ridge 3 was stabilised and vegetated before c.650 cal. years BP, and the charcoal dated to this time was included in reworked ridge-top sediments at site B7.

The majority of the ages determined date to the last c.800 years regardless of distance from the shoreline. This grouping of charcoal ages may suggest increased burning over this time due to changes in environmental conditions or because of burning by people. However because beach ridge 3 may have stabilised in this time, the apparent increased burning coincides with indications of increased reworking of the beach ridge sediments by wind; it coincides also with the formation of a coastal sand dune next to the present beach. The increase in sediment remobilisation by wind could result from longer vegetation establishment times, perhaps caused by drier conditions, increased wind activity, or both; the coastal dune establishment suggests increased wind activity for this landscape. The increased burning in this time, increased sediment remobilisation by wind and burial of a surface containing an artefact and hearth at site B4 all suggest a shift in environmental conditions that was either caused by people or had occurred in the time of human presence at Bulbul, likely influencing their activities there.

LANDSCAPE HISTORY OF BULBUL. Using this part-deductive and part-interpretative approach a sequence of environmental events can be compiled. At some time before c.2900 cal. years BP sea level had reached a lateral distance of at least 210m inland of its present position. A beach would have existed there and deposited coarse sandy sediment over the original stream sediments on the plain. The shoreline migrated northwards until the (now) most landward coastal ridge formed from the accumulation of beach sediments. Stabilisation of the shoreline at that level would have allowed this volume of sediments to accumulate in ridge form and no earlier beach ridge is discernible in the present landscape. The ridge development, which arguably caused sediment containing charcoal of c.2800-2900 cal. years BP in age to accumulate behind it, indicates the time when sea level approached stabilisation. If the charcoal relates to the sediment age then it is slightly earlier than the estimated latest time of 2300 years BP for sea level stabilisation at Iama and Hammond Island in Torres Strait, as determined by Woodroffe et al.

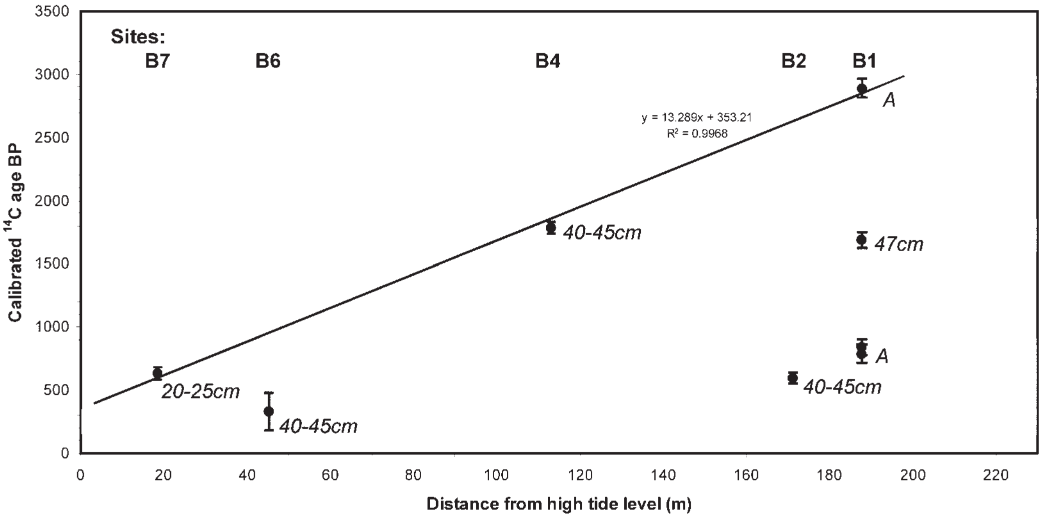

FIG. 7. Plot of calendric AMS radiocarbon ages with distance from the present high tide sea level, and interpreted age groupings.

(2000). Very little sediment was sorted by wind before the ridge stabilised. The shoreline at this stage was on the northern side of the ridge.

Initially, fine stream gravels and sand were deposited along the inland edge of this first ridge at site B1 until the stream migrated away from this location. After this time slightly finer but sandy floodplain sediments continued to accumulate behind the ridge as channels on the plain flooded. These sediments have likely filled in depressions on the plain so that both stream sediments and higher rises of weathered granite make up the plain surface, indicated by the materials recovered by point sampling on the plain. Behind the coastal ridges the sedimentation occurred particularly before c.1600-1700 cal. years BP, the age of pit-sampled charcoal at 47cm depth at site B1, while stream erosion and sedimentation after this time would have been concentrated closer to the present stream lines.

The second beach ridge was established and vegetated by c.1700 cal. years BP, again with minimal sorting of sediment by wind before stabilisation. The shoreline continued to migrate seaward as the beach ridge sediments accumulated. The third beach ridge was established by c.600 cal. years BP, but there were indications of increased sediment remobilisation by wind before stabilisation of this ridge. People were present in the beach ridge landscape at this time, as indicated by the presence of a hearth and an artefact at the level of charcoal that dates to a calibrated age of 1298-1413 AD (640±40 radiocarbon years BP; David et al., this volume). A sand dune developed next to the beach, suggesting increased wind activity unusual for this landscape, and fire may have become more frequent in the beach ridges. Sediments of beach ridge 2 were destabilised in at least one location after 600 cal. years BP, resulting in the burial of the earlier hearth and artefact.

Increased burning in the last c.800 years may well have disturbed vegetation cover and created an opportunity for mobilisation of sediment by wind and for soil destabilisation. But it is the youngest beach ridge which shows greater reworking than that of the other beach ridges, suggesting wind energy was sufficient to partially sort the sediments before the ridge was stabilised. If indications of increased burning can indeed be related regionally to increased climatic variability regardless of the presence or absence of humans, as Haberle and Ledru (2001) argue, then the effects of burning may have become more pronounced during a time of drying or increased wind energy concomitantly affecting sediment deposition. It is likely that the creation of a coastal sand dune indicates the development of sufficient wind energy regardless of the presence of fire; indeed this landscape does not record any earlier Holocene dune development, as described elsewhere in the Gulf of Carpentaria and northern Australia, presumably because it had insufficient onshore wind energy before this time. Given the proximity of the 'monsoon shear line' to the southeast of Torres Strait, which separates high summer rainfall areas from the drier easterly wind regime to the south (Wyrwoll & Miller, 2001), the late stage development of climate change on Mua might reflect the regional influence of an encroachment of the Southeast Trade winds on the islands.

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