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The Barrier Islands of Southern Mozambique

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ABSTRACT

Two barrier island systems from southern Mozambique (Inhaca and Bazaruto) are described. Both systems comprise a composite barrier island or barrier island chain that developed on a steep continental margin as a result of initial (Pleistocene) spit progradation. Continuing aeolian dune deposition against this initial core during subsequent sea-level highstands and lowstands has given rise to the highest dunes (120m) of any known barrier island. Wave reworking of the composite barrier island sediment during the past 6000 years of the Holocene sea-level highstand has resulted in the formation of spits, barriers, barrier islands and bluffs on the downdrift and bay side sections of the barrier island systems. The relative stability in position of the barrier systems at contemporary sea level is attributed to their large sediment volume and the development of equilibrium shoreline forms under swell waves. Beachrock and aeolianite outcrops provide anchor points for the development of contemporary shoreline forms.

ADDITIONALINDEXWORDS: *coastal evolution, east Africa, coastal dune.*

INTRODUCTION

Barrier islands are widely distributed around the world's coastline but show preferential development in certain locations. Barrier islands appear to form by a variety of processes and their morphology is strongly influenced by antecedent topography and sediment supply (Halsey, 1979). They exhibit a diversity of forms. Barrier islands are particularly abundant on the east coast of North America and for this reason much current understanding is based upon those systems. Recent studies of previously unstudied and in some cases previously unknown barriers (e.g. in Colombia, MARTINEZ *et al*., 1995), however, reveal much greater diversity in form and origin than was previously suspected. In this paper we describe the geology and sedimentary environments of little known barrier islands in southern Mozambique that exhibit several unusual characteristics.

We focus on the barrier island systems of Inhaca in the Bay of Maputo (26°00'S; 32°55'E) (Fig.1) and the Bazaruto Archipelago (21°30-22°10 S; 35°22'-35°30'E) (Fig.1). Both barrier island systems face the open Indian Ocean and are backed by extensive sheltered bays. The Inhaca system comprises the vegetated islands of Inhaca and Ilha dos Portugueses and a series of unvegetated and unnamed barrier islands (Fig.1). The Bazaruto archipelago comprises a barrier island chain (Bazaruto, Benguerua and Magaruque) and an individual island (Santa Carolina) in the back-barrier area (Fig.1).

ENVIRONMENTAL SETTING

The Quaternary sea-level history of Mozambique is poorly known although RAMSAY AND COOPER (2001) have recently summarised sea-level data for southern Africa and produced a sea-level curve (Fig.2) that is probably indicative of the situation in southern Mozambique. This curve indicates relative sea-level highstands during oxygen isotope stages (OIS) 7, 5e and 5c and during the mid-Holocene. The lowstand during the last glacial maximum (LGM) reached –130m MSL while minimum sea levels during previous glacial periods are not known.

Mean spring tidal range at Inhaca is 3.3m (MACNAE and KALK, 1969) and at Bazaruto is 3 m (DUTTON, 1990) which places both systems in the mesotidal range. Wave energy is high and the coastline is exposed to ocean swells. Deep water wave heights average about 1.5m. Dominant wave approach is from the SE, with a secondary peak in the wave distribution from the NE. Dominant wave-induced longshore drift is toward the north.

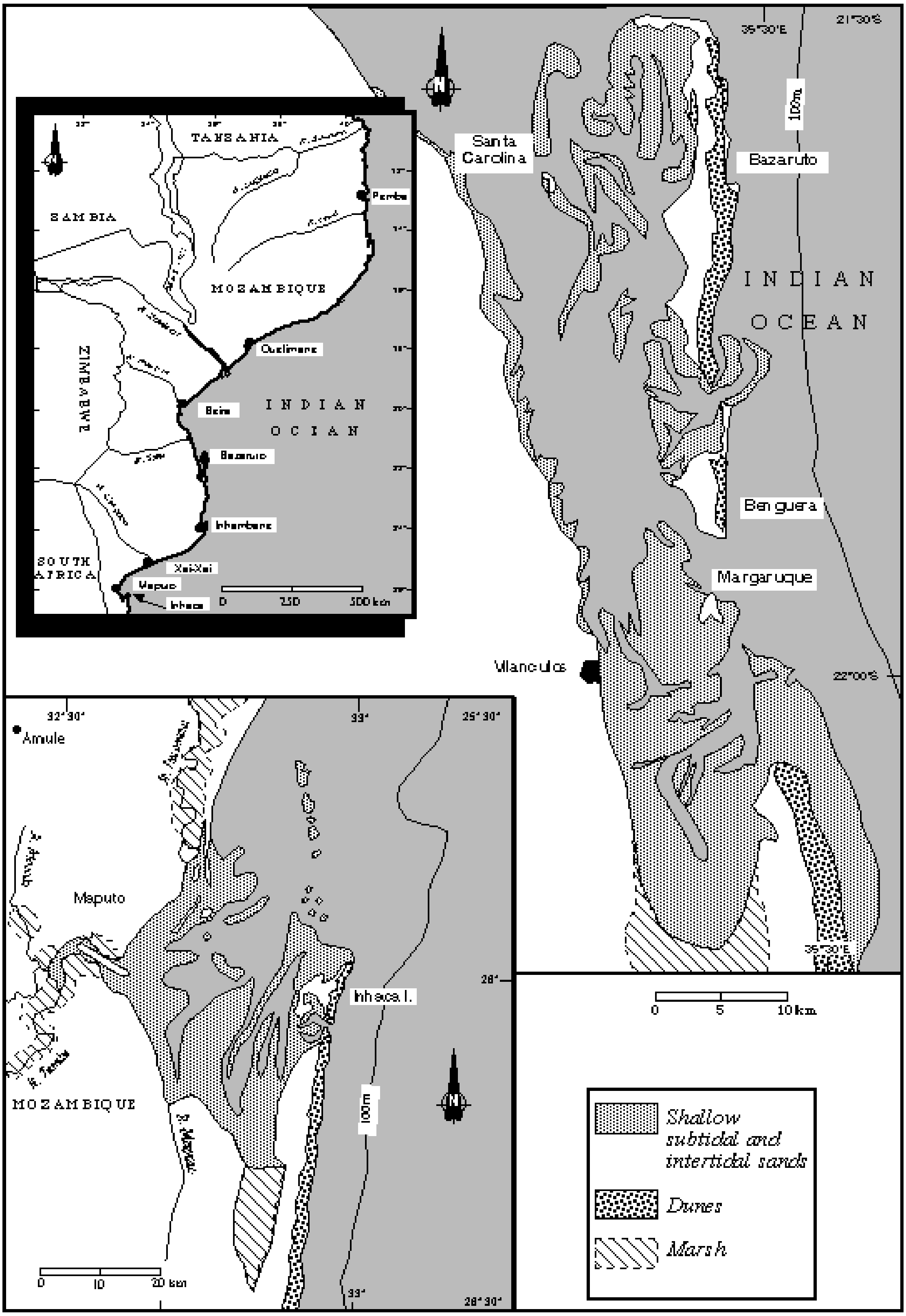

Figure 1. Locality map showing locality and setting of Bazaruto and Inhaca barrier island systems.

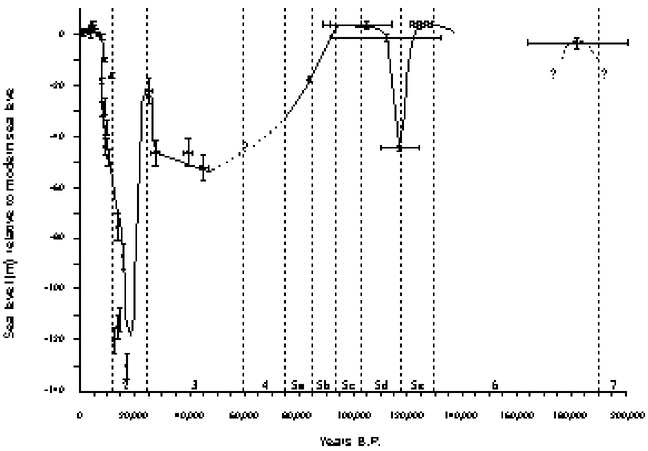

Figure 2. Sea-level curve for southern Africa (after RAMSAY and COOPER, 2002).

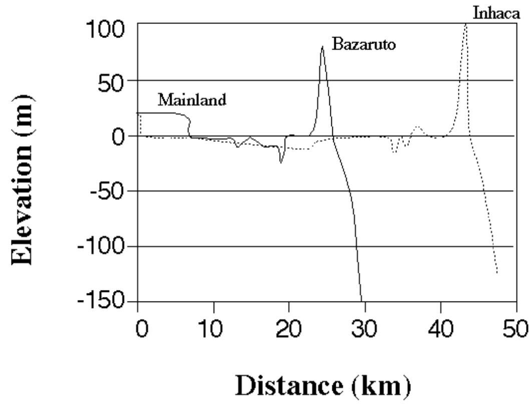

Figure 3. Cross-section of barrier island – mainland sector for Inhaca and Bazaruto. Note the steep and narrow continental shelf and the location of the barriers at the break in slope.

Southern Mozambique experiences a humid subtropical climate. Rainfall at Inhaca is 1000mm (MACNAE and KALK) and at Bazaruto 978mm (DUTTON, 1990). Both barrier island systems are exposed to SE Trade winds and most winds blow from that quadrant.

Both island systems are located on the edge of a platform at a marked break in slope (Fig.3) and are fronted by a narrow and steep continental shelf (gradient = 0.05). Landward, they are backed by broad, shallow bays that front the Mozambique coastal plain. Several major rivers (Incomati, Pongola, Limpopo, Save, Pungwe and Zambesi) which cross the coastal plain drain an extensive, weathered, cratonic hinterland.

BARRIER ISLAND MORPHOLOGY

BAZARUTO

The Bazaruto archipelago comprises a barrier island chain of three islands separated by tidal inlets and extending along strike from a mainland peninsula (Fig.1). Extensive flood-tidal deltas are developed landward of the inlets, particularly the most southerly, while ebb-tidal deltas are small as a result of high wave energy. The islands comprise a core of Pleistocene dunes that are exposed at several localities on the western (bay) margin of the islands as a weathered and largely structureless sand with an orange-red colouration. The main geomorphological features of Bazaruto Island are depicted in Figure 4. Unweathered yellow-white sand forms climbing dunes of Holocene and modern age along the ocean margin of the islands (Fig.5A). Their long axes exhibit a dominant SE-NW orientation, consistent with the dominant wind regime. In places the modern active dunes deposit large slip faces (Fig.5B) on barrier flats and freshwater ponds. The dune crests reach 90m elevation on Bazaruto and are sparsely vegetated. Along both the ocean and bay margins of the island are extensive outcrops of beachrock and aeolianite (Fig.5E), some of which is quarried for building purposes (Fig.5F). Beachrock is exposed both in the present intertidal zone and at elevations 1-2 m above the present high water mark where it probably relates to a mid Holocene sea-level highstand (Fig.2).

At the northern tip of Bazaruto and Benguerua are elongate sandspits. Intertidal flats are well developed toward the northern tip of Bazaruto in the lee of the sandspit and along its bayside margin. The bay margin of Bazaruto is characterised by a series of large-scale cuspate forelands (Fig.5D) and the formation of a series of barriers that enclose contemporary marshes (Fig. 5C) and straighten and smooth the formerly irregular shoreline.

The ocean margin of the islands has developed a series of zeta bays (Fig. 4) in which beachrock-aeolianite outcrops provide the anchor points on which the bay forms are stabilised. Offshore submerged aeolianite ridges occur along the ocean margin of Bazaruto (Fig.4) and mark former shoreline positions. In many instances these have been colonised by coral growth.

INHACA

Inhaca Island (Fig.6) is separated from the mainland by a tidal inlet to the south at which an extensive flood tidal delta is formed. The ebb-tidal delta in contrast is relatively small. The island comprises a core of Pleistocene dune ridges and three separate units have been identified (SENVANO *et al*., 1997). These Pleistocene ridges are typically reddish-orange in colour and exhibit various degrees of weathering. Modern aeolian deposition has formed climbing dunes over the core that reach elevations of over 120m (Fig.6). Contemporary active dunes show a strong SE-NW

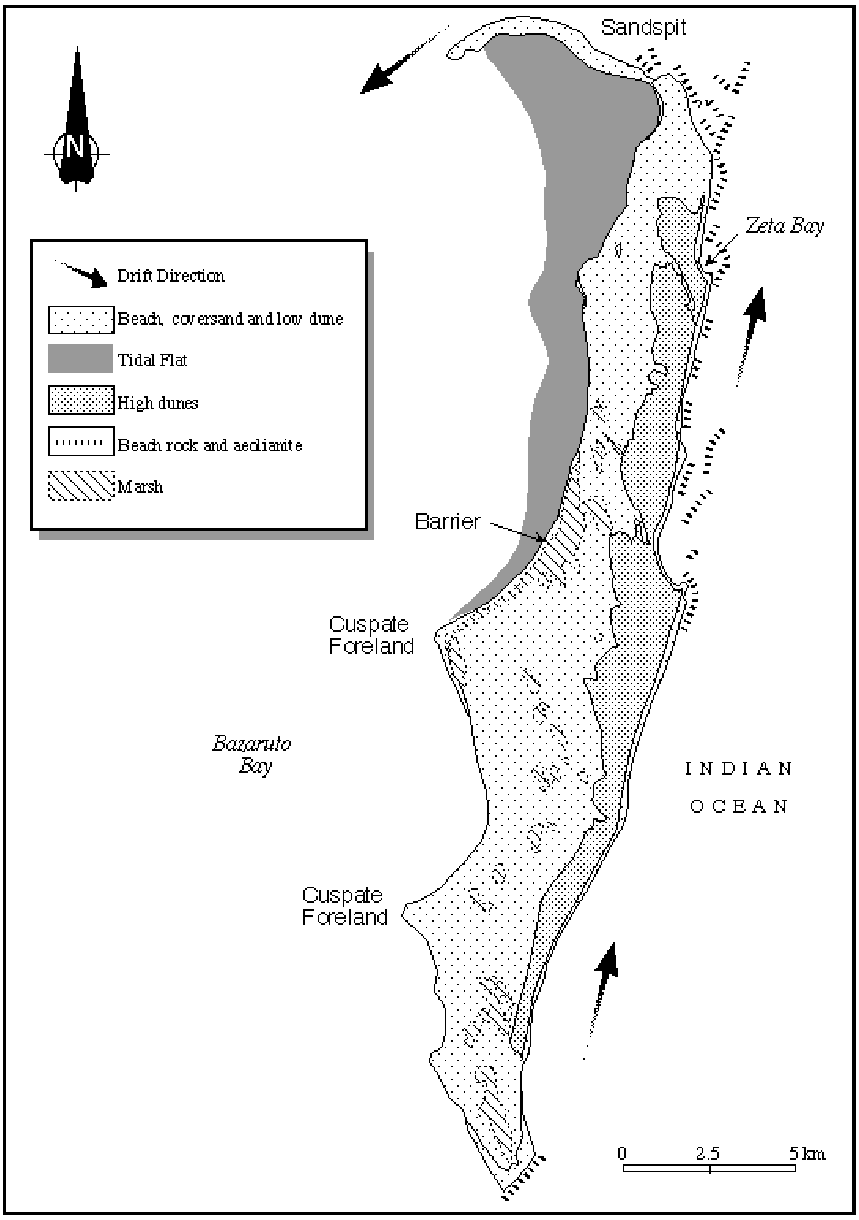

Figure 4. Main geomorphological features of Bazaruto Island

orientation with numerous blowouts and transgressive climbing dunes (Fig.7B). Beachrock is well developed around much of the island and forms a near-continuous intertidal exposure along its ocean margin (HOBDAY, 1977). At the northern tip of the island is an emergent outcrop of beachrock and aeolianite that probably relates to the mid Holocene sea-level highstand (SENVANO *et al*., 1997). The bay margin of the island exhibits an alternation of high bluffs cut into the Pleistocene dune (Fig. 7C) and depositional areas where eroded sand has accumulated to form barriers and beaches with smooth coastal planforms hinged on beachrock/aeolianite outcrops (Fig. 7D).

A series of contemporary barrier islands is developed that stretch west from the northern tip of Inhaca to Ilha dos Portugueses. These unvegetated islands (Fig.7A) are separated by shallow tidal channels with large flood-tidal deltas that merge with extensive intertidal flats (Fig.6). Comparison of satellite imagery, maps and field observations indicates that these barriers do change their form over time and that Ilha dos Portugueses has undergone various periods of beach ridge accumulation and erosion.

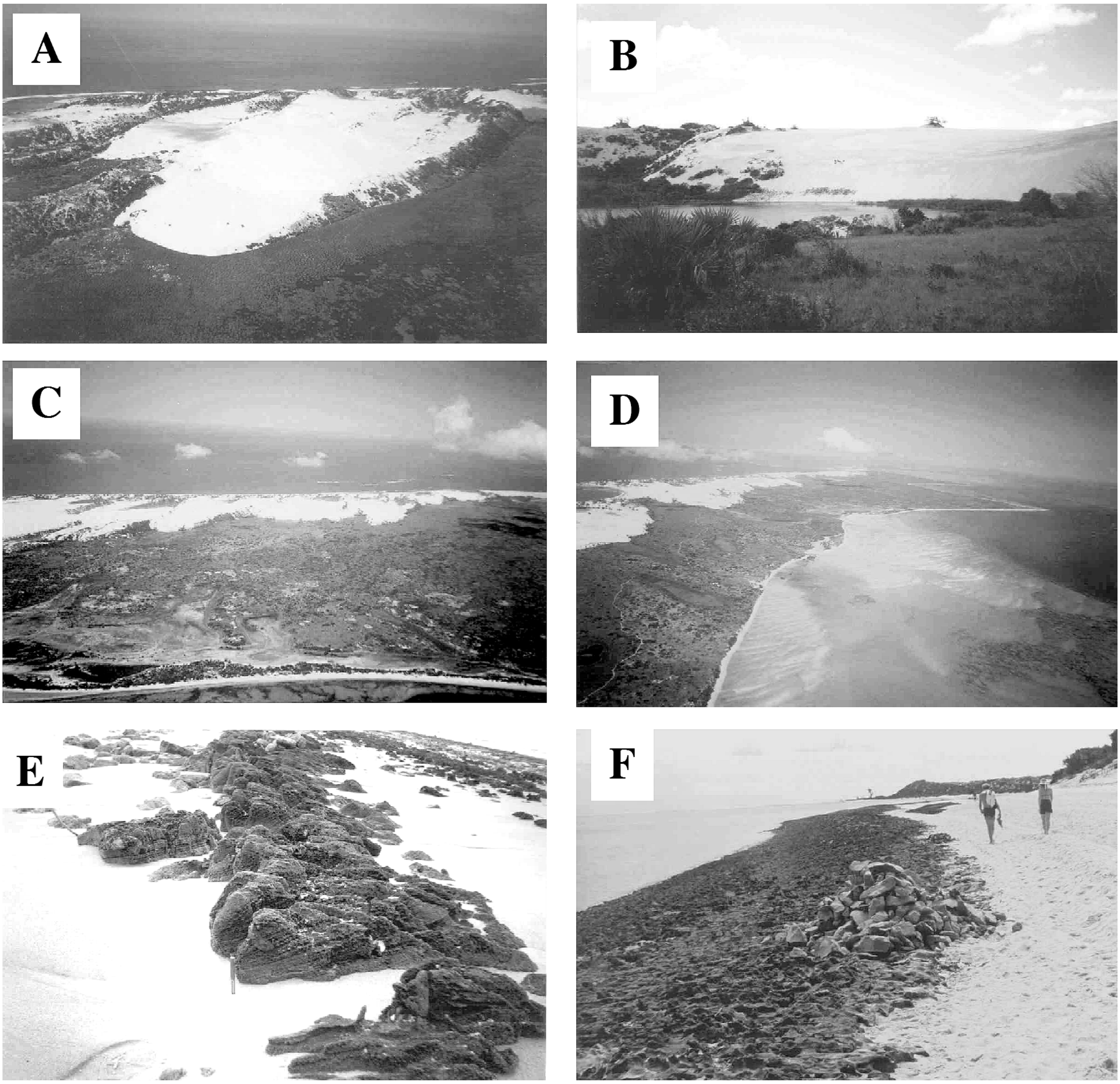

Figure 5. Geomorphological features of Bazaruto Island. A. Transgressive climbing dune. B. Dune slip face advancing into freshwater pond. C. Oblique aerial view of Bazaruto looking east, showing frontal dune, island surface and barrier on bay side of island. D. Oblique aerial view of Bazaruto looking southeast. Note intertidal flats and cuspate foreland on bay side of island. E. Beachrock exposure, Bazaruto. The beachrock forms two shore-parallel outcrops related to contemporary and mid-Holocene sea levels. F. Contemporary mining of beachrock and aeolianite outcrop, Bazaruto.

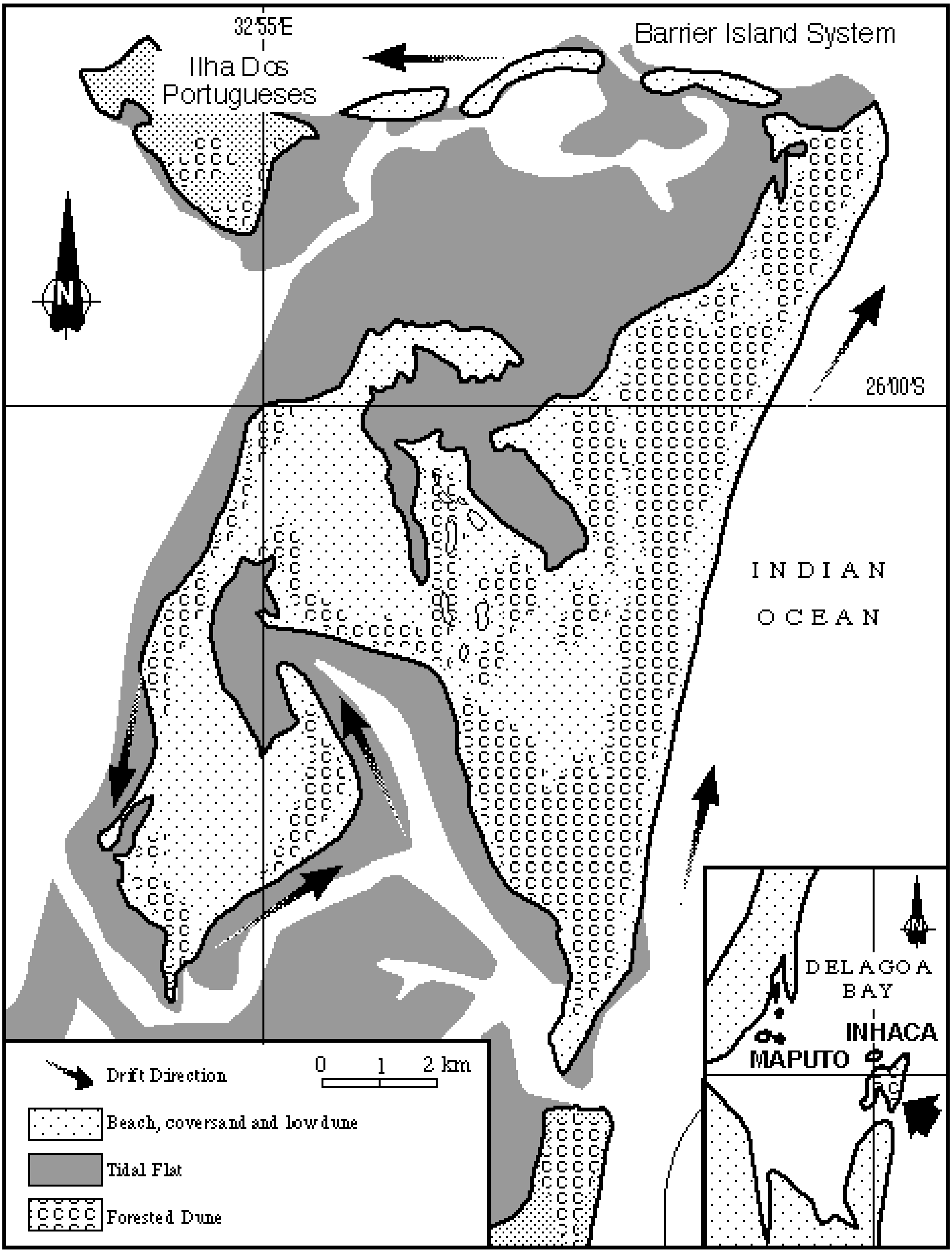

Figure 6. Main geomorphological features of Inhaca Island system. Modified after HOBDAY (1977).

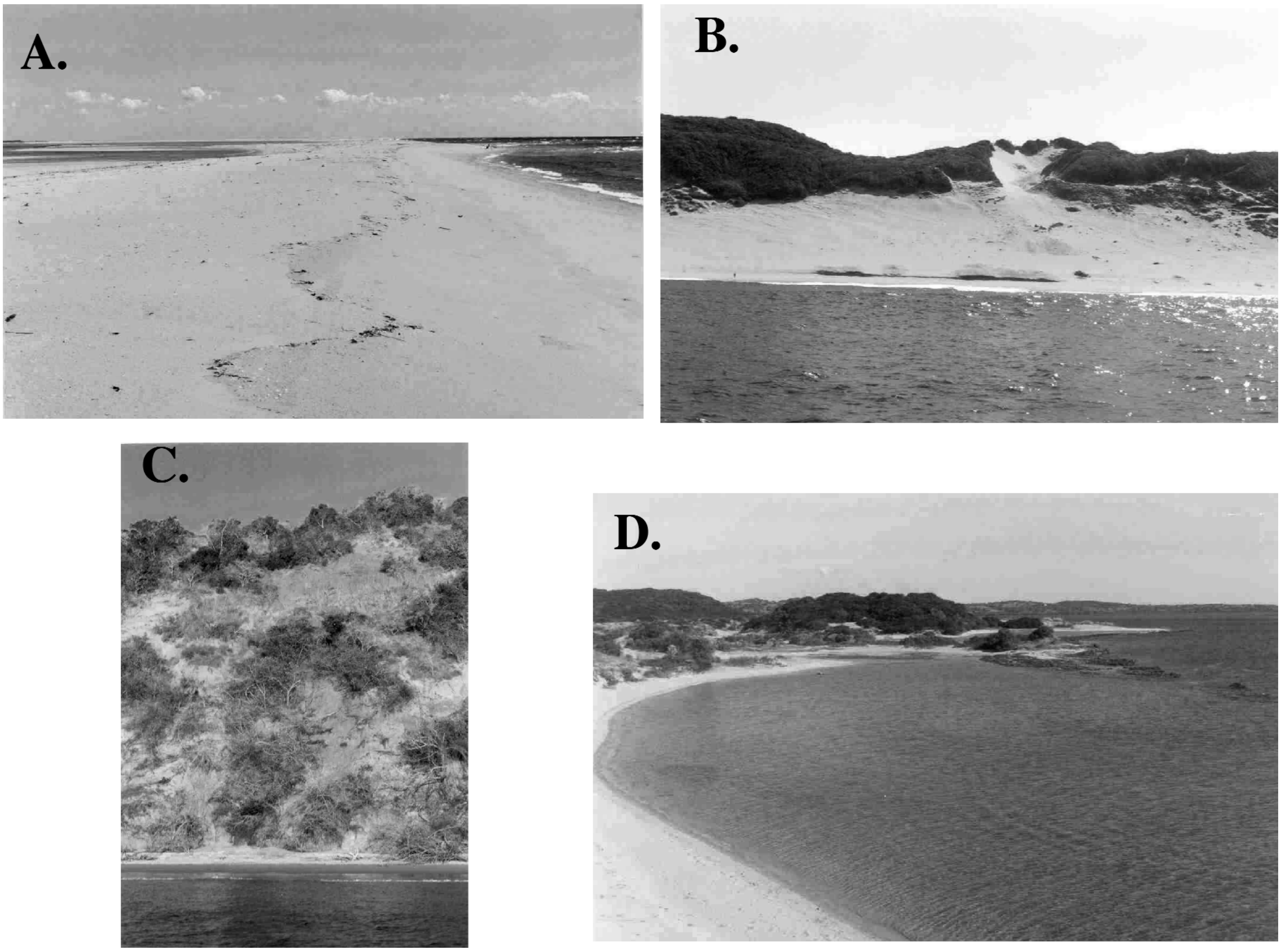

Figure 7. Geomorphological features of Inhaca Island. A. Contemporary barrier island viewed in cross-section, north of Inhaca Island. B. Transgressive dunes and blowout on ocean margin, Inhaca Island. C. Eroding bluff, bayside of Inhaca. D. Contemporary coastal barrier on bay side of Inhaca Island.

GEOMORPHOLOGICAL EVOLUTION

Both island systems show a similar overall pattern of evolution. During a Pleistocene highstand of sea level, growth of spits under wave action took place toward the north across coastal re-entrants (Maputo Bay and Vilanculos Bay). Breaches probably formed in the spits under low sediment supply conditions of sea-level highstands and the systems broke down into discrete cells, thereby creating tidal inlets where sediment volume was low. During subsequent regression and sea-level lowstands, adjacent rivers became incised along the tidal inlet channels and fresh sediment was delivered to the coastal zone to be incorporated into beaches and dunes. Weathering (leaching and reddening) of former coastal deposits also during lowstands. During subsequent transgressions, sand was reworked landward and accumulated against the pre-existing barriers and augmented the sediment volume. At Inhaca a relatively flat basement permitted the formation of a distinct spatial separation of two Pleistocene dune systems which is not evident at Bazaruto where the Pleistocene dunes appear to be vertically stacked. The relatively short distance between the lowstand and highstand shorelines (Fig.2) may point to continuing aeolian deposition on top of the pre-existing spit complex during lowstand conditions as suggested by SENVANO *et al.* (1997) at Inhaca. The absolute ages of the initial spit progradation is not known, but by reference to the sea-level curve (Fig.2) it probably belong to OIS 7, or 5e given that the islands contain at least two subsequent dune deposits.

During the Holocene transgression wave reworking of shelf sand promoted accumulation against the pre-existing spit remnant and its aeolian sand veneer, causing continued accretion of the barrier island system. During the 6000 years during which sea level has been close to present establishment of tidal deltas and tidal flats has taken place. Beachrock formation appears to have occurred during both a minor Holocene sea-level highstand of 2-3m and at present sea level. Earlier aeolianite and beachrock formation may have occurred but is now either buried under more recent deposits or de-cemented through weathering. The beachrock has played an important role in providing stable headlands and hinge points for barrier development during the present sea-level highstand (COOPER, 1991). The fall of sea level in the mid Holocene probably prompted reduction in the volume of the ebb and flood-tidal deltas which may in turn have liberated a fresh sand supply that is now incorporated as the transgressive climbing dunes. It is also possible that this may have enabled the growth of spits to the north of Inhaca, Benguerua and Bazaruto as the tidal inlet reduced in response to reduced tidal prism.

The sandspits at the northern end of both Bazaruto and Benguerua are prominent features formed by refracted ocean waves. At Bazaruto a 6km-long sandspit extends WNW into the back-barrier area. The spit is occasionally overwashed as evidenced by several washover fans on its bayside margin. A spit on the northern margin of Benguerua is 5 km long and parallels the long axis of the island. On the northern margin of Inhaca the series of contemporary barrier islands occurs in a similar setting to the spits on Bazaruto and Benguerua. These barriers occur in a line that runs at nearly 90 degrees to the ocean margin of Inhaca Island and form a discontinuous link with Ilha dos Portugueses.

Although both composite barrier island chains appear to have been stable at the macro scale for a considerable period, due perhaps to the stabilisation imparted by beachrock formation, a number of features indicate reworking of sediments at present sea level. The zeta bays that have formed on the ocean margin of Bazaruto in the lee of beachrock/aeolianite outcrops is suggestive of static equilibrium, a situation that is consistent with a contemporary low sediment supply and refraction of long period swell waves. The stability of the ocean margin of Inhaca is similarly controlled by beachrock formation, although in this case it forms a semi-continuous linear outcrop at the toe of the modern beach.

Reworking of the bayside margins of Bazaruto is evident in the large scale cuspate forelands that are present. These low-lying features resemble the cusps noted by ZENKOVICH (1959) that contribute in some instances to lagoonal segmentation and are attributed to opposing wind wave regimes. On Inhaca Island, bayside reworking of the barrier island is evident in that eroding bluffs in the Pleistocene dune systems are flanked by contemporary spits and beaches with smooth planforms that are hinged to beachrock/aeolianite outcrops. In some instances. localised concentrations of rhizoliths from the eroding dunes has led to the development of gravel beaches composed of partially reworked rhizolith fragments.

DISCUSSION

The most striking feature of both barrier island systems is the height of the dune ridges. On Bazaruto dune crests reach 90m elevation and on Inhaca they extend to 120m. These, to our knowledge are the highest dunes on any barrier island. The height of the dunes may be attributed to several factors including the location of the system, sea-level change and sediment supply. The barrier islands are located at a pronounced break in slope which places them within 5 km of the shoreline even during maximum sea-level lowstands. This enables sand to accumulate during both highstand and lowstand conditions, probably since OIS 7 and certainly since OIS 5. We surmise that spit progradation took place during one of these highstands into the present Maputo Bay and Bazaruto Bay. These spits formed a core against which aeolian sand accumulation took place during sea-level lowstands of the late Pleistocene. During sea-level highstands, wave reworking of the sediment across the narrow shelf and continuing aeolian deposition may have enhanced the height of the dunes on the pre-existing core while wave processes may have reworked the littoral sediments into spits, barriers and a variety of coastal plan forms such as are evident at present sea level. The dunes thus appear to have been within the potential reach of aeolian sand deposition for most of the Pleistocene including the 90% or so of the late Pleistocene and Holocene period when sea levels were lower than present (Fig.2). Sediment for dune building would have been readily available from incised rivers (Incomati, and Pongola/Maputo at Inhaca and Rio Save at Bazaruto) which drain steep, weathered, cratonic hinterlands.

Reworking of barrier sediment during sea-level highstands such as the present has been accomplished by wave and tidal current action. The early formation of beachrock and of pre-existing aeolianite has provided solid anchor points against which a variety of shoreline forms have developed. The zeta bays for example, on Bazaruto are hinged on updrift rocky headlands of beachrock and aeolianite, whereas the linear ocean-facing shoreline of Inhaca might be attributed to the near continuous beachrock/aeolianite outcrop. Refracted wave action has formed the extensive spits on the northern (downdrift) margins of Bazaruto and Benguerua. At Inhaca, the series of barrier islands in the same setting points to their development from the same mechanism. The variability in position of these barrier islands in maps and satellite images, together with field observations of alternating accretion and erosion suggests that they form a longshore transport system that links Inhaca to Ilha dos Portugueses.

CONCLUSIONS

1. The barrier island systems of southern Mozambique have been potentially active depositional environments continuously since their formation during OIS 7 or 5 (Fig.2). This has led to very large barrier island sediment volume and high dunes

2. Sediment accumulation takes place both during regression and transgression when fluvial sediment is discharged to the coast and reworked.

3. Sediment reworking occurs during sea-level highstands when sediment supply is low. This results in the development of secondary coastal forms.

4. Contemporary reworking on the ocean margin under swell waves leads to the development of static shoreline equilibrium forms that are hinged on beachrock/aeolianite headlands. The high dunes and large sediment volume prevents overwashing and impedes landward barrier migration.

5. Contemporary reworking of the bayside margin under wind waves is marked and has led to formation of a series of barriers, barrier islands, sandspits, forelands, beaches and tidal flat systems.

6. Cannibalisation of the composite barrier island sediments at present sea level provides sediment for formation of contemporary barrier islands on the lagoon side.

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