Number One Reef: An overstepped segmented lagoon complex on the KwaZulu-Natal continental shelf

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This study of the bathymetry of the mid-shelf of the Durban Bight, KwaZulu-Natal revealed a series of previously undocumented seafloor features. These features were mapped using a high-resolution multibeam bathymetric echosounder and a detailed map of the seafloor topography was produced. We recognised several features that closely resemble features of contemporary segmented lagoon and lake systems: semicircular seafloor depressions, arcuate ridges, cuspate spits and prograding submerged barriers. Based on the striking similarity in morphology to Kosi Bay – a segmented lagoon system from the sandy northern KwaZulu-Natal coastal plain – a similar evolutionary model is proposed. This model is of an incised valley formed following a sea level lowering to the Last Glacial Maximum at about 18 000 BP. Thereafter, continued transgressive infilling occurred to a point where an extensive lagoon and back-barrier system was established. At this point, sea levels remained static, causing the net segmentation of the system and the slow closure of the tidal basins or circular depressions. This type of seafloor topography is rarely preserved and is the result of fortuitous cementation after deposition and the later removal of sediment that would ordinarily bury such features.

Introduction

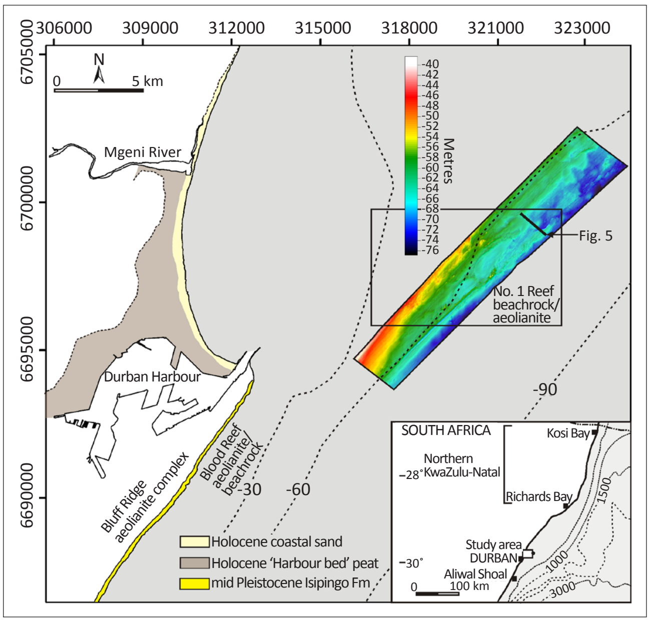
Despite several investigations,[1,2,3,4] the seafloor morphology of many areas off KwaZulu-Natal is poorly resolved or often completely unknown. Many of the bathymetry charts in use today are based on very simple echosounding,[5] in which complex seafloor morphology is often not revealed as a result of the poor resolution of the data. Recently collected multibeam bathymetric data from the Durban Bight in KwaZulu-Natal reveal an unprecedented glimpse of Number One Reef, a drowned calcarenite barrier complex[3] offshore of Durban Harbour (Figure 1). Our observations reveal a set of relict seafloor features, previously undocumented in the literature, concerning shallow seafloor geomorphology. These features appear to have been stranded by sea level rise as the shoreline transgressed the palaeocoastal plain of the Durban area.

There are three theoretical responses of barrier systems to such sea level rise.[6] The first is erosion, whereby rising sea levels erode the drowning coastline via wave erosion. The second is translation and rollover, whereby coastal landforms keep step with sea level rise and are shifted landward and up the depositional profile, and the third is overstepping, where the entire coastline is rapidly drowned and stranded. Here we present an extremely rare example of an overstepped series of coastal barriers preserved in the mid-shelf of KwaZulu-Natal.

Oceanographically, the Durban Bight coastline is considered to be wave-dominated.[7] Offshore, sediment deposition and erosion is influenced by the Agulhas Current, a strong western boundary current that impinges on the mid-shelf.[8] There is general consensus that the Agulhas Current can reach velocities of up to 2 m/s.[8] This velocity is considered sufficient to entrain medium sand.[9] As a result, much of the outer shelf is characterised by a very thin veneer of Holocene sediment, a relict pavement of bioclastic debris[3] or an outcrop of Cretaceous material.[10] The inner continental shelf is characterised by thin (~5 m) drapes of Holocene sediment,[3,10] overlying several calcarenite complexes of which Number One Reef is the most prominent in outcrop.[3] These calcarenite complexes extend along both the north and south coasts of KwaZulu-Natal and usually comprise linear-type features, often with relatively flat relief.[1] The Aliwal Shoal to the south of Durban is a typical example (Figure 1), although its relief is of much greater scale.[2] These features are, on the whole, considered to be drowned coastline deposits, comprising sedimentary successions of beach and aeolian facies that were cemented in the coastal environment.[1,11] Previous authors consider these features to form during sea level stillstand or regression[1,11] and to typically overlie rocks of Cretaceous (Lower Santonian to Upper Maastrichtian) age.[10]

Methods

A 20-km^2 portion of seafloor was mapped using a Furuno 160-KHz WMB-160F multibeam-echosounding system (Furuno, Nishinomiya, Japan). Positions and attitude estimations were



Note: Northing and easting co-ordinates are in metres with UTM projection.

FIGURE 1: Locality map of the study area with new multibeam bathymetry of the Number One Reef and 30-m interval isobaths. The major river systems of the area include the Mgeni River to the north and the Durban harbour complex to the south. The inset image depicts the regional bathymetry[22] and the locality of the Aliwal Shoal.

provided by a Furuno SC30 system. All data were corrected to depth relative to Mean Sea Level (MSL) after reconciliation with sound-velocity profiles and tidal fluctuations. All data resolve to ~5 m in the horizontal domain.

Observations

Several unusual features are apparent from the survey data, the most striking of which are the laterally continuous high-relief ridges (Ridges 1-4) that form semicircular enclosures of relatively low-relief depressions within the seafloor (Figure 2). These ridges occur as seafloor protuberances that are ~50 m wide and 1 m – 2.5 m high. Each ridge forms a concentric pattern that steps progressively inwards from the landward margins of the study area. Cuspate features at the termination of each ridge are apparent. Smaller-scale in-stepping or prograding ridges are also apparent within these cuspate features (Figure 2) and terminate in Ridge 4, the most seaward ridge that marks the landward limit of the low-relief depressions. Seawards, these depressions terminate against the most prominent ridge, a laterally continuous feature that breaks up into patches of rugged seafloor relief. This ridge possesses a seafloor relief of ~10 m and attains a width of ~100 m. The point at which this ridge breaks up completely corresponds to the deepest portion of the seafloor imaged. Offshore of the deepest ridge, the seafloor appears featureless, with a seaward slope of 0.5°–1°.

Figure 3 shows a comparison between the contemporary Kosi Bay System of the northern KwaZulu-Natal coastal plain and the Number One Reef. Note the similarities in the arcuate ridges, the small wedge-shaped sedimentary bodies at the junction of each ridge and the overall concentric ring-like appearance. In particular, the enclosed depressions, occurring as lakes in the Kosi System and the featureless semicircular portions of the seafloor of Number One Reef appear very alike. Lastly, coast-parallel palaeoshorelines in the Kosi Bay System appear to have similar counterparts in the Number One Reef System, namely Ridges 1 and 2 (Figures 2 and 3).

Discussion

When compared to calcarenite ridges from other areas, notably the adjacent Blood Reef[4] and the continental shelf of northern KwaZulu-Natal,[12] the ridges observed in the Number One Reef System bear little similarity to these features. The only ridge that conforms to the generally linear, continuous type of morphology is the most seaward ridge mapped. Inshore of these, the ridges are notably curved and present an overall segmented morphology not recognised in the literature on continental shelves to date. These ridges, however, do bear a striking resemblance to segmented lake and lagoonal systems found in contemporary coastal plain settings.[13,14,15]

This segmented morphology is typically ascribed to the progressive segmentation of a shallow lagoon-type environment as the fringing shorelines have been reworked by wind-derived wave erosion.[16,17] Downdrift of this reworking, cuspate spits form that begin to enclose the lagoon basin. Such spits tend to become stranded, particularly by sea level fall, and can form the core of subsequent barriers that more fully isolate the sub-basins.[15] The development of several of these prograded ridges signifies a period of high sediment supply, coincident with high rates of shoreline erosion.[15]

Based on the similarity between the Kosi Bay System and the Number One Reef System, we propose a similar evolutionary model. We consider this system to have formed originally as the seaward extension of the adjacent onshore fluvial systems. This formation occurred as sea levels fell towards the 120 m depth of the Last Glacial Maximum[18] (Figure 4) and valleys were incised across the exposed shelf[10] (Figure 5). Thereafter, continual transgressive infilling occurred to the point that the system comprised an extensive lagoonal environment, separated from the ocean by a long barrier in the form of the most seaward ridge. A stillstand must have occurred at some point at a depth of ~60 m, whereby the gradual reworking of the lagoon margins, as described above, would then have taken place. This reworking caused the development of several back-barrier ridges (the equivalent of Kosi Bay's lagoonal barriers) that evolved to a concave planform[15] before being subsequently stranded. Slightly higher phases of shoreline reworking and thus sediment supply ensued, causing progradation of these ridges both landwards and seawards in towards the lagoonal basin.[15] This progradation is recognised by the successive stepping of the ridges imaged and the development of a concentric pattern in ridge orientation. The downdrift terminus of each sub-basin is marked by cuspate spits where this sediment was deposited. Large gaps in the most seaward ridge

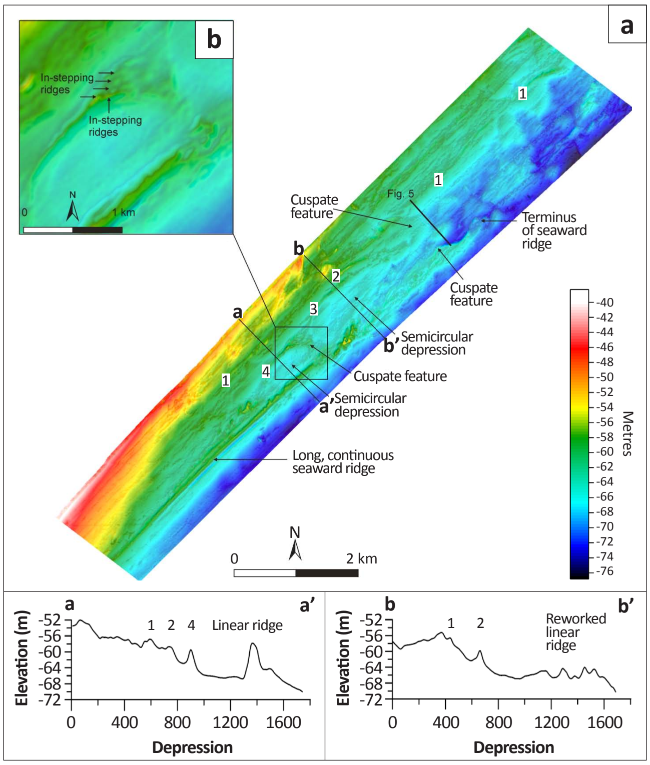


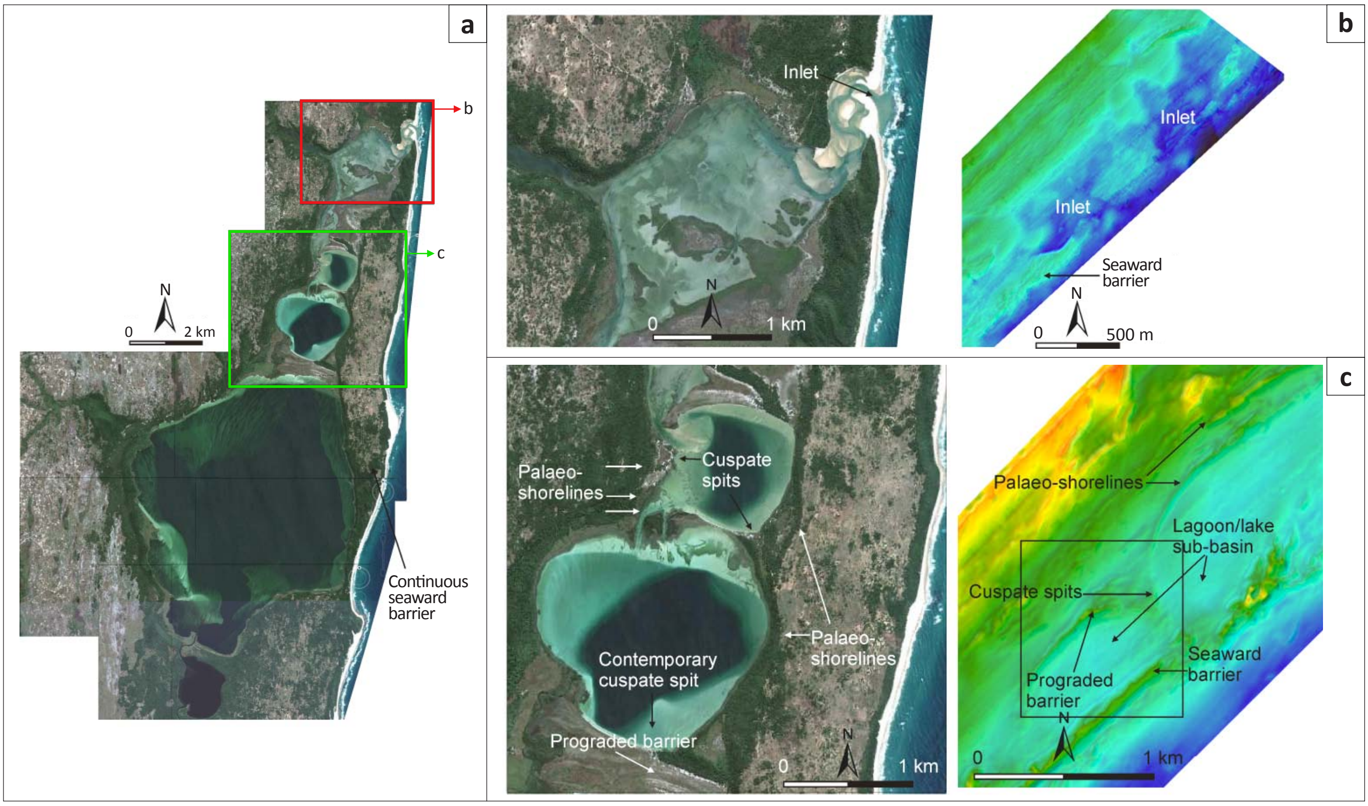
FIGURE 2: (a) Sunshaded multibeam bathymetric map of the study area. Arcuate ridges are delineated by numbers 1-4 on both map and depth cross sections a-a' and b-b'. Note the semicircular seafloor depressions, the cuspate features separating these depressions from each other and the linear seaward ridge. (b) Enlarged sunshaded bathymetric map detailing a semicircular depression, a cuspate feature and the associated in-stepping or prograding ridges.

are considered to represent palaeo-inlets to the lagoon.[14] Preliminary seismic studies[10] indicate that these inlets are underlain by palaeofluvial courses which would likely foster the later occupation by transgressive river mouths at a later stage of evolution.[13] Here a departure may exist from the Kosi Bay example – these incised valleys may have experienced significant infilling, whereas Kosi Bay was dominated more by shoreline-modification processes.

Post-stillstand, the entire system was then drowned by transgression to the current MSL and almost fully preserved during overstepping of the barrier system. Overall, this type of overstepping is rare and is unusual for a sandy system, being more common in gravel-dominated barrier systems where relaxation times (i.e. periods needed for a change in morphology) would typically be longer.[5]

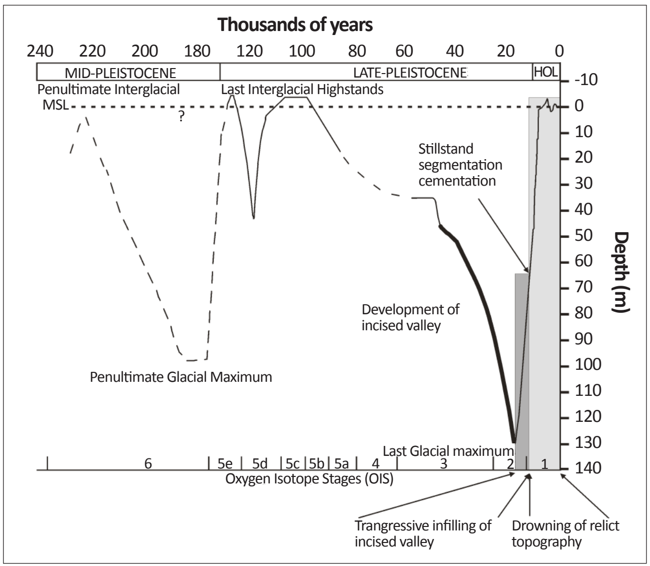
The important preservation factors for such relict seafloor topography are thus surmised as:

1. The availability of high amounts of calcium carbonate during the successive stages of ridge or barrier development. This availability would have ensured the rapid cementation of the successive ridges and would have increased the preservation potential accordingly.[19] Only isolated examples of such systems exist, notably in the north-eastern Gulf of Mexico.[20] Cementation of the Number One Reef System would have had to occur prior to transgressive drowning as wave ravinement or erosion



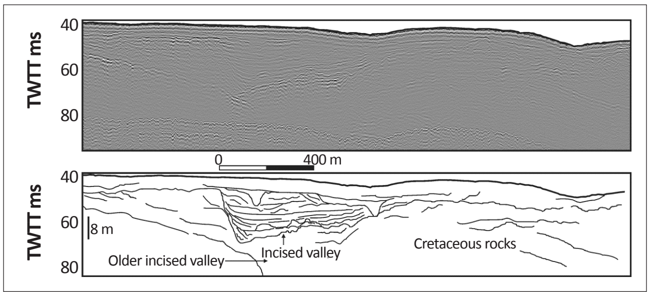
Source: Satellite imagery obtained from Google Earth™.

FIGURE 3: (a) Kosi Bay on the northern KwaZulu-Natal coastal plain. A comparison between the (b and c) contemporary Kosi Bay segmented lake or lagoon and the Number One Reef System. The similarity in morphology is striking: both systems exhibit segmented basins, cuspate spits, prograded barriers, inward-stepping palaeoshorelines and discontinuities in the barrier marking the position of inlets.



Source: Ramsay and Cooper[18]
MSL, Mean Sea Level.

FIGURE 4: Mid-Pleistocene to Holocene (HOL) sea level curve for KwaZulu-Natal. We propose the development of an incised valley during the regression to the Last Glacial Maximum of ~18 000 BP. This valley was later drowned during the transgression of Oxygen Isotope Stage 1 (Holocene) and infilled, creating an extensive back-barrier lagoon system. A stillstand, corresponding to a water depth of ~60 m, occurred, causing the system to segment into isolated sub-basins as apparent from Figures 2 and 3. This segmentation was followed by rapid cementation, before the valley was completely drowned by the ensuing Holocene transgression.



TWTT, two-way travel time.

FIGURE 5: Seismic data and line interpretation detailing an incised valley associated with the overstepped segmented lagoon complex. Profile location is depicted in Figure 1.

during sea level rise would have removed considerable portions of any unconsolidated material present.[21]

2. The present sweeping of the shelf by the Agulhas Current, which limited the burial of the system by the modern unconsolidated sediment wedge. In effect, relict material remained exposed as outcrops on the modern seafloor. Only isolated pockets of modern unconsolidated sediment remain, which are the remnants of the transgressive shoreface material expected to cap the estuarine or lagoon facies of such an incised valley fill.[21]

Conclusions

We have presented a set of relict seafloor features on the mid-shelf of Durban Bight that show a remarkable similarity to lagoonal and lacustrine systems of the northern KwaZulu-Natal coastal plain. Based on such similarity, we consider the Number One Reef System to represent a relict segmented lagoon. The incised valley system within which this lagoon was situated never achieved complete infilling. The subsequent capping of the fill by shoreface sands is absent. No other such observations have been reported in the literature. We thus consider such preservation of a relict lagoon system on the mid-shelf to be particularly unusual. This preservation is the product of vigorous current stripping in the mid-shelf portions of the study area and the possible fortuitous cementation of these features prior to drowning and ravinement.

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Competing interests

We declare that we have no financial or personal relationships which may have inappropriately influenced us in writing this article.

Authors' contributions

A.G. wrote the manuscript; R.L. and Z.T. collected and processed the data and were responsible for the project design; and G.V. assisted in accessing project funding and contributed to the data collection.

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