# Development and preservation of transgressive sandy versus rocky shorelines: Observations from the SE African shelf



**Published in:**
Geomorphology

**Publication Status:**
Accepted/In press: 08/10/2022

**Document Version**
Author Accepted version

Development and preservation of transgressive sandy versus rocky shorelines: observations from the SE African shelf

Sashan L. Manikam 1, Andrew N. Green1, 2, Andrew Cooper2,1, Gaynor Deacon3

1 Discipline of Geology, School of Agriculture, Earth and Environmental Science, University of KwaZulu-Natal, Durban, South Africa

2 Geography and Environmental Science, Ulster University, Coleraine BT52 ISA, Northern Ireland, UK

3 Amaza Survey Services, Plot 141, P65 Main Road, Albert Falls, 3220, South Africa

Abstract

## 1. Introduction

## 2. Regional setting

### 2.1. Physical setting

The Eastern Cape continental margin along the coast of southeast Africa is a sheared passive margin marking the separation between southern Africa and South America during the nascent opening of the South Atlantic (Scrutton and Du Plessis, 1973; Martin, 1984; Watkeys, 2006). Compared to the global average (~ 75 km), the shelf is significantly narrower (~ 15 km) and in places may narrow further where shelf-breaching canyon heads occur (Flemming, 1981). The shelf of the study area is intersected by up to 5 submarine canyons, that include the Mbotyi, Mzimvubu and St. Johns Canyons (Flemming, 1981; Birch, 1982). Shelf width varies between ~ 5 km and 23 km wide (Birch, 1982). The shelf break occurs at a depth of 100-120 m, slightly shallower than the global average (130 m) (Flemming, 1981). The shelf gradient is relatively steep along the inner to mid-shelf (2.9°) and becomes more gently inclined towards the outer shelf (~ 1.4°) (Dlamini, 2016).

The southeast African margin is a high-energy, wave-dominated environment that is exposed to predominantly south-westerly oriented swells. These swells range between 1 and 2 m in height, with a maximum recorded height of 9.3 m (Dixon et al., 2015). The region has a micro-tidal regime with spring and neap tidal ranges are between 1.59 and 2.0 m and 0.6 and 0.8 m respectively (HRU, 1968; SANHO, 2019). The Agulhas Current dominates along the mid- to outer shelf where it, as one of the fastest poleward flowing geostrophic, western boundary currents, can reach surface velocities in excess of 2.5 m/s (Pearce, 1978; Gründlingh, 1980). Multiple rivers enter the ocean along the coast and are sources of a significant supply of sediment to the shelf. The Mzimvubu, Great Kei and Great Fish Rivers supply 10.458 x 106 $m^3$, 11.48 x 106 $m^3$ and 11.134 x 106 $m^3$ respectively (Flemming, 1981). The annual sediment yields to the coast from these local sources ranges from 150 t/$km^2$ to 800 t/$km^2$ (Rooseboom, 1978).

The coast exhibits a strong bedrock control on the various erosional and depositional landforms that have developed. These features include coastal cliffs, lagoons, waterfalls (Knight and Grab, 2015) and numerous rivers which terminate at bedrock-bound microestuaries that may be open, barred or have fringing mangroves (Cooper, 2001). The coastline is mixed, with rocky headlands that separate broad, sand-rich embayments and sandy beaches. These tend to be backed by vegetated and headland bypass dunes (Tinley, 1985; Jackson et al., 2014; Knight, 2021) which are separated from one another by coast-perpendicular to coast-oblique d rocky headlands.

The region comprises a variety of igneous and sedimentary rocks ranging from Gondwana-age through to Quaternary age (Johnson et al., 1996; 2006). Sandstones and mudstones of the Natal

Group locally the area near Port St. Johns (Karpeta and Johnson, 1979). In the south, the coastline of Strachan's Bay, Folokwe and Mbashe comprises sandstones and mudstones of the Tarkastad Subgroup and Adelaide Subgroup (Johnson et al., 2006). The coastal plains, particularly between Folokwe and Mbashe and Mpama and Mgxotyeni are generally underlain by sandstones and siltstones of the Ecca Group. Numerous dolerite dykes and sills of the Karoo Large Igneous Province intrude these sedimentary lithologies (Duncan and Marsh, 2006). Rocky headlands between Folokwe and Mbashe comprise dolerites while headlands at Mpama and Mgxotyeni comprise tillites and sandstones of the Dwyka and Ecca Group respectively (Karpeta and Johnson, 1979).

Pleistocene to Holocene age beachrocks and aeolianites outcrop intermittently along the coastline and as discrete, shore-parallel ridges on the continental shelf (Martin and Flemming, 1987). On the shelf, aeolianite ridges mark former shoreline positions, particularly along the mid-shelf at depths between 60 to 85 m and outer shelf between 100 to 105 m respectively (Martin and Flemming, 1987; Green et al., 2020; Pretorius et al., 2019). These rest upon and are separated mainly by a scoured bedrock surface with intermittent and small accumulations of modern mobile shelf sediment.

## 3. Methodology

A combination of high-resolution multibeam bathymetry, backscatter, ultra-high-resolution seismic reflection and side scan sonar (SSS) data were collected in the study area from the inner to outer continental shelf. The high-resolution multibeam bathymetric data were collected using a Norbit iWBMS narrow beam multibeam echosounder with an integrated Applanix Wavemaster

II inertial navigation unit. The sound velocity in water was measured using an AML Base X system, and tides were corrected using a Real Time Kinematic GPS position. All data were processed in Hypack and the final product exported as a 1 × 1 grid. These data were subsequently incorporated into ArcGIS (v. 10.6.1) and Global Mapper for analysis and visualisation.

SSS data were collected with a Klein 3000 system via the Klein SonarPro software. The 500 kHz channel was used for the final mosaicking. All SSS data were similarly incorporated into ArcGIS (v. 10.6.1) and Global Mapper for visualisation and analysis. The final mosaic had a pixel resolution of 0.25 × 0.25 m.

Ultra-high resolution seismic reflection profiles were acquired using an Innomar SES2000 employing a secondary low frequency of 4 kHz. The system was triggered with a Ricker pulse at a pulse rate of 50 ms. The data were collected as SEGY and processed using Allworks GeoSuite where they were bottom tracked, bandpass filtered and swell filtered. Manual time varied gains were applied to all data. The final data resolve to ~ 20 cm in the vertical, though penetration was limited due to the sandy and overall gravelly nature of the seabed. A comprehensive seismic stratigraphy could not be constructed in this regard. Single channel sparker seismic reflection data, collected by the CSIR in the 1980's as part of a regional survey of the east coast of South Africa (Burg reference), were also used to constrain the stratigraphic relationships of various seabed features where the ultra-high resolution seismic could not penetrate. These data were scanned from the original paper records, then converted to SEGY format using the SEGY Transformer utility in Allworks GeoSuite. The seabed was digitised and the lines swell filtered in order to improve the image interpretability. These data resolve to ~ 2 m in the vertical.

Legacy seafloor dredge data (Kilburn and Herbert, 1994) were used to provide ground truth to the seabed geology (Table 1). In addition, satellite imagery (Google Earth) was used to compare the morphology of rocky outcrop along the coast to that of the seabed.

## 4. Results

### Seafloor morphology

The inner shelf gradient is relatively steep (1.72° to 2.2°) compared to the mid- to outer shelf (0.7 to 1.5°) where a topographic knickpoint marks a distinct change in the shelf slope at ~ - 60 m (Fig. 1). Various seafloor features are present (summarised in Table 2) and these are discussed further below.

### Low-relief rocky unit

A low-relief rocky unit occurs along the inner shelf, its surface texture marked by NNW-SSE to NW-SE trending lineaments, interpreted as joints. The unit crops out at least ~ 2 km from the coast between depths of ~11 to 30 m (Fig. 2; 3; Table 2) and maintains a consistent relief of ~ 1 m to 2 m (cross section A-A' in figure 3). Outcrop widths span at least 1.5 km (Fig. 2). Seismic reflection profiles reveal that the unit's undulatory surface has a high acoustic return with little to no penetration compared to the adjacent unconsolidated sediment (Fig. 2a). The low-relief rocky unit typically crops out in spatial association with a higher-relief rocky unit (Fig. 2; 3a).

### High-relief rocky unit

A second rocky unit with a higher relief occurs throughout the study area. It has a relief between ~ 3 m to 8 m (cross section A-A' of figure 3) and is characterised by extensive, complex jointing (Fig. 3). Multiple joint sets oriented roughly WNW-ESE to NNE-SSW can be observed from the multibeam bathymetry (Fig. 2; 3a). The unit crops out <500 m from the modern coastline, particularly offshore the area between Folokwe and Madakeni (Fig. 2; 3) and extends r seaward, to depths of -55 m. Outcrops are widest along coastal strike in the shallows and taper seaward, where they narrow sharply (Fig. 2; 3). Morphologically, the unit appears blocky, particularly at the intersections of joint sets where it may segment (Fig. 2; 3), This accounts for a wide variation in outcrop dimensions (Table 2).

High-relief irregular and pinnacled outcrops and ridges

An extensive system of ridges covers the seafloor between depths of ~ 70 m to 90 m (Fig. 1; 2b-d). The ridges are generally linear, orientated NNE-SSW to NE-SW, with and may be either pinnacled or flat topped (Fig. 2b, cross section A-A' and B-B'). Shallow ridges (~ 80 m or less) are generally narrower (less than 10 m wide with a maximum width of ~ 25 m) (Fig. 2d) when compared to ridges towards the shelf edge (greater than ~15 m with a maximum width of ~ 47 m).

The ridges on the outer shelf are arranged in a step-like fashion, are laterally persistent along strike, and are spaced between 10 m to 20 m apart (Fig. 2). They mostly appear linear and elongate (Fig. 2d) however some recurved or parabolic-shaped ridges (Fig. 2c) are also observed at depths between ~ 80 m to 85 m. The parabolic-shaped ridges reach up to 3.8 m in relief and comprise multiple continuous and discontinuous outcrops ~ 16 to 44 m wide, spaced between 30 m to 60 m (Fig. 2c). The recurved ridges form as splays off the seaward edge of the main parabolic-shaped ridges and rise to ~ 2.8 m high from the surrounding seabed, forming a stepped arrangement (Fig. 2c; Table 2).

## Subdued rocky unit

A unit with an irregular to mound-like morphology, crops out along the mid-shelf mainly between depths of ~ 50 m to 70 m (Fig. 2, 3). A unique case is observed where individual outcrops of the subdued unit resemble discontinuous seaward-pinching cuspate-like features (Fig. 2d). When compared to the high relief and low relief rocky unit (Fig. 2; 3), this unit lacks discernible lineaments like bedding or joint sets. The unit is not topographically prominent when compared to the low relief rock or high relief outcrop units, where it rises irregularly to ~ 0.5 m high from the seafloor (cross section C-C' in figure 2).

## Seabed channels

Bathymetric and SSS data reveal several channels that extend across the shelf (Fig. 2; 3; 4a). These form seafloor low-points that are orientated NNW-SSE like the joint orientations of the inshore outcrops. The seabed low-points are 0.5 to < 3 m deep below the adjacent rocky outcrops (cross section A-A' of figure 3), while channel widths vary between 20 to 120 m (Fig. 3; Table 2). Legacy seismic data reveal these to correlate with a series of partially filled incised valleys, XX m-wide and xx m-deep (Fig. )

## Seafloor backscatter characteristics and interpretation

Several acoustic facies occur in the study area and are related to the above morphological features; the relative locations of which are provided in figure 4 and insets a to f therein. These acoustic facies are summarised in figure 5. In combination with legacy dredge data (Table 1), the various acoustic facies are interpreted as follows:

Acoustic facies A has a smooth and predominantly even-toned low backscatter (Fig. 4a; 4d; 5a). It mostly occurs on the inner shelf as the flat and featureless seafloor, and forms the channel fill where the seabed channels cross the seafloor (Fig. 4a; 4d). Dredging reveals this to comprise fine to medium quartzose, sands (Table 1).

Acoustic facies B comprises linear to irregular shaped patches of smooth-toned, medium to high backscatter (Fig. 4b-c; 5b). This acoustic facies sometimes occurs interspersed with facies A (Fig. 4b-c; 5c-e). Dredges reveal acoustic facies B to comprise a mixture of coarse sands and bioclastic gravels (Table 1). The finer (facies A) and coarser (facies B) sediment arrange to form broad (Fig.4c; 5c) and narrow (Fig. 5d) low backscatter ribbons of sand, or sandy subaqueous dunes (Fig. 4b-c; 5e) interposed with bioclastic gravels in the dune troughs. These are most common along the mid- to outer shelf (Fig. 4c; 5e).

Acoustic facies C is characterised by high backscatter with an irregular tone and blocky to rugged texture (Fig. 4d; 5f). Acoustic facies C tends to occur in spatial association with acoustic facies D (see figure 4 locations in figure 5). Acoustic facies D comprises medium to high backscatter seafloor that is irregular, with moderate relief and a blocky texture (Fig. 5g).

In conjunction with overlapping multibeam bathymetry (Fig. 2) and onshore satellite photography, acoustic facies C is interpreted as outcrops of the blocky, topographically prominent, high relief rocky unit (Fig. 6a, inset i) which we interpret as dolerite on the basis of its similarity in morphology to dolerite outcrops onshore (Fig. 6a, inset ii). Acoustic facies D comprises outcrops of the low relief rocky unit (Fig. 6a, inset iii), where the distinct lineaments of the offshore outcrops can be traced landwards and reconciled with the onshore and coastal outcrops of Beaufort Group sandstone (most prominently between Folokwe and Madakeni) (Fig. 6a, inset iii and iv).

Acoustic facies E is characterised by an irregular toned and rugged textured, medium to high backscatter seafloor (Fig. 4b; 4d-e; 5h). This facies is common across the shelf, but most prominent on the inner to mid-shelf (Fig. 4b; 4d) with occasional occurrences on the outer shelf (Fig. 4e). Acoustic facies E matches the high relief irregular and pinnacled outcrops from overlapping bathymetry, dredges of which reveal this to comprise aeolianite (Table 1). ~~, and we link this to onshore aeolianite outcrops (e.g. the Knysna coastline of the southern Cape) (Fig. 6bii).~~

Acoustic facies F is characterised by a predominantly mottled, high backscatter seafloor (Fig. 4d, 4f; 5i; Table 1). Acoustic facies F forms irregular patches on the mid-shelf and sometimes linear patches on the outer shelf, in close spatial association with the aeolianite of acoustic facies E. The overlapping bathymetry (Fig. 2d; dotted lines in figure 4) reveals that acoustic facies F correlates with outcrops of the subdued rocky unit; the close relationship to the high relief aeolianite suggests this to be a subdued relief variation of the aeolianites.

Acoustic Facies G is characterised by a mottled, high backscatter with rippled patches of low to medium backscatter (Fig. 4b; 4e; 5j). The acoustic facies represents a flat, current-scoured gravel pavement as several dredges were retrieved empty or with occasional shell hash (Table 1).

Figures 4 provides further high-resolution images of the morphological features identified from the bathymetry. This includes an exceptionally large, linear aeolianite ridge offshore Mpama (Fig. 4d) with greater dimensions than the ridges described previously. The ridge here is considerably wider (≤ 110 m). Multiple cuspate features adjoin the landward margin of the aeolianite at ~ 75 m depth and are surrounded by relatively flat seafloor. In addition, multiple smaller seabed channels are evident on the inner shelf (e.g. Fig. 2; 3) and converge seaward, forming single, more sinuous, isolated channels on the mid- to outer shelf that extend to the shelf edge (e.g., Fig. 4a). Their channel widths are relatively uniform (~ 120 to 180 m) (Fig. 4a; 4d).

The general seafloor geology and palaeo-drainage of the study area are depicted in figure 7. Dolerite and sandstone crop out extensively on the inner shelf between Mpama and Mbashe (Fig. 2; 3; 4d; 7). North of Mpama, sandstone crops out more frequently relative to dolerite. Outcrops and ridges of aeolianite and subdued aeolianite are distributed across the shelf, Subdued aeolianite crops out are more frequently on the inner to mid-shelf between Mpama and Mgxotyeni (Fig. 4f) and towards the outer shelf between Folokwe and Madakeni (Fig. 7). Five seabed channels extend from the conversion of smaller channels on the inner shelf towards the outer shelf (Fig. 2; 3; 7). Four channels trend roughly coast perpendicular while one channel, offshore Mpama, deviates to the southwest and extends coast-parallel (Fig. 4d; 7). Two seabed channels are observed near the shelf edge which could not be traced inshore.

## 5. Discussion

Outcrops along the seafloor reflect a variety of relict rock coast features which record significant palaeo-coastal change over the postglacial transgression. The various hard rock units observed have been reshaped into a variety of different landforms (Fig. 2; 3) which strongly resemble the morphology of (i) modern rocky shorelines (Fig. 6a) and (ii) depositional shoreline features that experienced early lithification)(Fig. 2; 3; 4b; 4d-e; 6b; 8a-b).

## Evidence for relict rocky shorelines

The morphology of the submerged dolerite and sandstone outcrops, particularly between Folokwe and Madakeni, resemble the headland-embayment morphology of the adjoining rock coast (Fig. 2; 3; 6a; 8c) and appear to comprise submerged extensions of the modern headlands.

The notched nature of the bedding-like lineaments cut into the face of the sandstone outcrops on the inner shelf between Mpama and Mgxotyeni (Fig. 8d) are interpreted as palaeo-cliff features at depths of ~ 40 m (Fig. 8d). The form and lineaments of the outcrops match those of the contemporary, subaerial cliffs immediately onshore (Fig. 8d). Similar features were identified by Cawthra et al. (2015) from the southern Cape shelf ~ 800 km to the SW.

## Aeolianite shorelines

The various aeolianite bodies on the shelf (Fig. 4b, 4d-e; 5h; 6b; 8a-b) are lithified remnants of coastal dunes, which have been observed and mapped at various locations on the southeast African shelf (Martin and Flemming, 1987; Salzmann et al., 2013; Green et al., 2013; Pretorius et al., 2016; 2019; Green et al., 2020). The majority of the aeolianite outcrop in the study area is manifest as parabolic-shaped ridges that span impressive along-coast lengths. The general ridge and trough morphology resembles the morphology of modern parabolic dunes (Short, 1988; Bailey and Bristow, 2004; Hesp, 2008; Jackson et al., 2014; Yan and Baas, 2015), aligned with the palaeo-wind transport direction (Carter et al., 1990; Hesp, 2002), and is indicative of a once sandy, dune-fringed shoreline that was lithified before transgression.

Aeolianite provides mostly a terrestrial limiting sea level index point as it can form at various elevations above sea level due to the precipitation from meteoric waters of calcium carbonate that binds the sandy sediment in the core of coastal dunes. Given the height of many of the dunes on the SE African coast (up to 100 m; Jackson et al., 2014), the cemented core of these dunes may rise significantly above mean sea level. However, where apparent, the basal contact and thus leading edge of the aeolianite, especially if resting on bedrock, can be used to infer an approximate shoreline position. Furthermore, other relatively small-scale morphological features formed in aeolianite may be used to discern a clearer relationship with palaeo-sea level and can aid in palaeo-shoreline reconstruction(see below).

Seabed channels (Fig. 2; 3; 4a; 4d; 7) are interpreted as submerged extensions of contemporary fluvial systems produced by incision during the Last Glacial Maximum (Pretorius et al., 2019; Green et al., 2020) . This is based on observations of these channels as they extend directly offshore the contemporary Xora (Fig. 2; 7), Mncwasa and Mpako Rivers (Fig.  7). towards the shelf break. Their underfilled nature reflects a negative balance between sedimentation and sea-level rise-related flooding during transgression with the.

Palaeo-shoreline reconstruction and transgressive evolution of the shelf

The seafloor features characterising the inner to mid-shelf can be compared to contemporary shoreline features along the southeast African coast (Fig. 8a-d).  and used to reconstruct past shoreline positions and track local changes in sea level over time.(e.g., Ota and Omura, 1991; Gardner, et al., 2007; Harris et al., 2013; Zecchin et al., 2015; Rovere et al., 2016; Brooke et al., 2017; Goff et al., 2018; Passos, et al., 2019; LeBrec et al., 2022). Figure 9 and insets depicts several key seafloor morphologies interpreted as equivalent to palaeo-shorelines from a variety of depths and table 3 contextualises the various palaeo-shoreline features, their depths, and lists shorelines of comparable depths from around the world.

## The -85 m and -75 m depositional sandy shorelines

The -85 m linear aeolianite ridges and recurved ridge features offshore Folokwe (Fig. 2c; 9a) represent a departure from the parabolic-shaped aeolianite that prevails elsewhere on the shelf. These ridge features occur directly seaward of a seabed channel that extends offshore the contemporary Xora River (Fig. 2; 7; 9a), and their morphology strongly resembles the geomorphology of contemporary inlet, spit and barrier features associated with the barrier and back-barrier of modern micro-tidal estuaries of the SE African coast (Cooper, 2001) (Fig. 8a). The linear aeolianite ridges extend north and slightly seaward of the recurved spit, along the same isobaths and are interpreted as remnants of the core of a formerly continuous barrier feature (Fig. 2c; 8a) adjacent to the palaeo-estuary.

The recurved ridges have a distinct seaward stepping nature and resemble a set of prograding spits, similar in form to those of modern drumstick barriers and are likely remnants of a developing drumstick or mixed energy barrier. Their presence implies conditions of high sediment supply, coupled with sea-level stability both o which enabled the development of planform morphological equilibrium. The leading edge of these features can thus be used as a good approximation of palaeo-sea level, especially as these barrier systems range in their vertical occurrence from the supra- to subtidal zone and thus comprise a terrestrial limiting point up to two metres above the high-water mark (Cooper, 2001; Cooper and Pilkey, 2002).

We interpret the main depression that fringes the edge of the drumstick barrier as the palaeo-inlet to a microtidal estuary/lagoon system (Fig. 8a;). Modern inlet depths in SE Africa can vary from 0.5 to 3.5 m below mean sea level (Cooper, 2001; Carr et al., 2010; Cooper and Green, 2021). The tongue-like seabed features to landward of the inlet and barrier have a similar morphology to contemporary flood tide deltas, and we interpret these as submerged and preserved equivalents accordingly (Fig. 2c; 8a). Flood tide deltas tend to occur in the intertidal to shallow subtidal zone but have been documented to occur up to 2 m below the mean low water mark (Hayes and Kana, 1977) and have been used to indicate former sea levels in SE Africa (Pretorius et al., 2016). The above depth constraints thus strongly suggest a sandy shoreline developed at ~ 85 m water depth (Table 3).

The landward-pinching cuspate features of an exceptionally large aeolianite ridge offshore Mpama resemble the sandy back-barrier features that often enclose lagoons in the process of segmentation, such as at Kosi Bay on the northeastern coast of South Africa (Dladla et al., 2022) (Fig. 8b). The cuspate features on the seabed occur at a similar scale and with a similar morphology to the enclosing cuspate spits at Kosi Bay (Fig. 8b; 9b), the segmentation of which was considered as having occurred during a lengthy period of stillstand (Cooper et al., 2012). The submerged spits/barrier complex and barrier form at a depth of ~ 75 m (Fig. 9b), and correlate along strike with other, less well preserved, seaward-pinching cuspate ridges offshore Folokwe (Fig. 2d; 9c). The ridges off Folokwe are fringed on their seaward edge by multiple, linear, prograded ridges that front a small seafloor depression which is interpreted as a lagoonal basin (Fig. 2d). The ridges may represent a lagoonal shoreline that was subject to periods of erosion associated with a prolonged slowstand or stillstand (Cooper et al., 2012; Green et al., 2013) (Table 3). The above observations imply a strong sediment supply to a sandy coastline that is in stark contrast to the embayed and headland bound coast of today.

-60 m and -40 m erosional rocky shorelines

Several palaeo-headlands occur in water depths of ~ 60 m and unlike the aeolianite shorelines, reflect a morphology like the rock-bound contemporary shoreline (Fig. 2; 3; 6a; 9d-f). The extension of bedrock headlands, and the sculpting of these into erosional facets indicates a prolonged period of sea level stability at a depth of 60 m. On the Wild Coast, this reflects a change

From a depositional to overall erosional or sediment bypass coastal setting (Cattaneo and Steel, 2003). Similar palaeo-embayment features were observed ~ 60 km south on the East London shelf by Green et al. (2020) at the same depth. A -60 m shoreline has also been documented nearly continuously into southern Mozambique, where occasional planation surfaces, interpreted as wave-planed shore platforms, have been identified (Salzmann et al., 2013; Green et al., 2018; Engelbrecht et al., 2020).

Palaeo-headlands and a palaeo-cliff mark the position of a palaeo-shoreline at -40 m. (Fig. 9e-g). Birch (1982) described multiple ridge features on the seafloor at the same depths between Port St. Johns and Strachan's Bay, as well as a prominent ~ 10 m-high submerged cliff north of Port St. Johns.

The increasing emergence of rocky shoreline signatures preserved on the shelf implies an increase in bedrock control at this stage in the transgression and a switch from net deposition (the -85 and -75 shorelines) to increased rates of erosion and sediment bypass. The topographic knickpoint along the shelf at -60 m also marks the change to a steeper inner shelf gradient (Fig. 1); the ensuing reduction in accommodation space to landward of the knickpoint likely caused the switch to sediment bypass and higher rates of erosion (Cattaneo and Steel, 2003).

Competing preservation of sandy vs rocky shorelines in the geological record

Despite comprising 72% of modern shorelines (Nyberg and Howell, 2016), rocky shorelines are rarely recognised in the rock record. In a review on the apparent dearth of rocky shorelines in the geological record, Johnson (1988), identified several key factors responsible for their preservation, the first and most pressing of which is the tectonic regime; coastal uplift places rocky shorelines outside the erosional framework in which they formed and from which they can subsequently escape total breakdown. However, in areas of active tectonism such as island arcs, these can often be recycled quickly and their preservation is skewed towards the shorter term. Along trailing edge passive margins, such as that of the study area, at the point where thermal subsistence has commenced, conditions contribute to the longer-term preservation of rocky shorelines (Johnson, 1992).

Furthermore, the geological record of rocky shorelines is typically manifested as an unconformity surface, either as an angular unconformity or non-conformity, and is often associated with fossil evidence for rocky shore habitat (Johnson, 1992). There is accordingly little evidence of landform-scale preservation of the rock shoreline, especially in three dimensions.  The degree to which this unconformity is established is related to the bedrock competency and the energy of the local setting. Harder bedrock will produce a stronger signature with greater relief and contrast with respect to differential erosion, and higher energy conditions will promote the development of a single-flat erosional surface with little preservation of the smaller facets of the rock platform (Johnson, 1992).

On the Wild Coast shelf, a variety of submerged landforms are found, each of which mark former palaeo-shoreline positions and provide insight into their form and structure. Their arrangement underpins a systematic change over the last postglacial transgression, from deeper aeolianite palaeo-shorelines to shallower rocky coastlines, the effect of increasing levels of bedrock control on sedimentation and erosion as the shore migrated landward. The aeolianite examples, specifically the barrier-lagoon and inlet associated facies, provide a high-resolution reference for palaeo-sea level and palaeo-environmental reconstructions from the rock record (e.g. Mulhern et al., 2021).

The majority of the aeolianites, especially those that correspond to the lithified large parabolic dune fields, were likely to have formed during sea level stillstands at MIS3 and MIS1 (Cawthra et al., 2018; Green et al., 2020), or possibly during MIS4 or 5 (Cawthra et al., 2018; 2022). By virtue of their calcium carbonate cements, these aeolianite palaeo-shorelines are predisposed to chemical and mechanical weathering, especially in the subtropical climate of the study area (e.g. Green and Cooper, 2016; Green et al., 2018; Cooper et al., 2019). Their overall preservation potential on the shelf is thus limited, especially as they are subaerially exposed for large periods of time during lowstands. Over time, the subtle variations in morphology are likely to be overprinted by chemical dissolution and block collapse (Cooper and Green, 2016), not only reducing their preservation potential, but also limiting the efficacy of these as detailed archives of palaeo-coastal change. Its is thus likely these will eventually provide only an unconformity surface as a record of rocky coastline occupation over time, though these are rarely reported on for limestones (Johnson, 1992).

In comparison, the remnants of cliff lines and headlands comprising sandstones and dolerites provide a more resistant rock type to subaerial weathering and mechanical breakdown processes (Johnson, 1992; Knight and Burningham, 2020). Though they provide less detailed information on relative sea level and coastal processes, these have the likely potential for preservation over far longer time scales, and to retain some form of three dimensional information on the palaeo-coastline. In their comprehensive study of ancient rocky shores, Johnson (1992) confirmed a bias towards these more competent rock types, as opposed to limestones and other karst-prone materials. To date, and as far as can be established, no three-dimensional rocky palaeo-shorelines have been documented from the geological record beyond the Pleistocene.

Regardless of their composition, all palaeo-shorelines must escape transgressive marine erosion to be preserved. It is important to note that the study area is tectonically stable; the coastal uplift considered necessary for preservation by Johnson (1988) is thus not pertinent and we rather consider the requirements for short-term transgressive preservation in the context of shoreline overstepping, where the palaeo-shoreline is stranded on the shelf after sea-level rise (cf. Carter, 1988). Given the high energy coastal setting of the study area, this overstepping is strongly linked to rapid rises in sea level; prolonged slowstands reduce the rocky palaeo-shorelines to a single ravinement unconformity. These rapid rises in sea level are termed meltwater pulses (MWPs), many of which have been linked to the abrupt submergence of coastlines from around the world. For example, Zecchin et al. (2010) show a situation where palaeo-cliff lines have been overstepped by MWP1A and 1B, strongly analogous to the stranding of headlands and cliffs in the study area. The presence of three dimensional palaeo-rocky coastlines in the rock record may thus reflect ancient meltwater pulses acting on ancient coastlines.