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Antecedent geologic control on nearshore morphological development: The wave dominated, high sediment supply shoreface of southern Namibia

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ABSTRACT

The inner continental shelf, nearshore zone and adjacent onland coastal strip of southern Namibia has been mapped using airborne electromagnetic and magnetic techniques, providing, for the first time in the area, a continuous onshore-offshore geophysical dataset. In addition, the inner continental shelf and nearshore zones of this vigorous, wave-dominated coastline were mapped, inshore of a pervasive acoustic blanketing layer, using multibeam bathymetry, singlebeam bathymetry and boomer sub-bottom profiling systems in water depths between -3 and -55 m. We use an integrated, iterative approach to the interpretation of these brand new datasets to map the structural framework of the Late Proterozoic -age bedrock of the area beneath thick Holocene sand cover and show how, despite the vigorous wave regime and high sediment supply from the Orange River, this framework acts as a recurring primary control to the area's geomorphic evolution.

The bedrock morphology is divided into three main zones that are constrained by NNW-striking and coast-parallel faults. A southern zone, characterised by both relatively shallow bedrock depth and shallow bedrock slope is bounded in the north by a dextral strike-slip fault system. This basement promontory is the primary control on the shallow, low gradient seafloor in the southern zone. Strike-slip movement on the fault shifted the bedrock to the north both down and inshore relative to the shallow basement promontory to the south. However, in this central zone, both the seafloor and seafloor gradient remain shallow. Sediment accumulation in this area is explained by two processes. Firstly, the relative downward movement of the bedrock has resulted in the creation of relatively more accommodation space and sediment delivery begins to overprint the underlying bedrock framework, smoothing the general seafloor gradient in the central zone. Secondly, this central zone, directly north of the basement promontory has existed in a swell shadow as long-lived SW directed wave energy has continually been refracted around the palaeo-promontory, promoting natural accretion of sediment within the lee of this feature. A fault-related inflection point on the modern coastline marks a change in coastline orientation from NW to slightly more north striking, and the start of the northernmost bedrock zone. Here the shallow, wide, low-relief seafloor zone transitions to a wider nearshore high-relief zone that mimics the underlying uniformly steepening nearshore bedrock profile. The combination of the uniform, coast-normal basement gradient with the fault-related inflection changes the nearshore response to incoming wave energy. In the northern zone, waves approach at a slightly more oblique angle due to the fault-controlled coastline orientation, and reinforce an already vigorous longshore drift regime that is responsible for the steeper and deeper nearshore profile, underpinned by the underlying steep basement topography. The steep antecedent topography also limits the amount by which the seafloor can aggrade and subsequently adjust its slope; an imbalance between the sediment supply and the large volume of accommodation space thus exists that cannot be overcome given the context of the vigorous longshore drift. The continual inheritance of the underlying bedrock slope in the nearshore is further revealed with the unchanging slope of the reflectors that match the present-day nearshore seafloor gradient. We suggest that the geologic framework control remains a critical factor in nearshore-beach system development, even in an area of high sediment supply and high wave energy conditions.

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1. Introduction

Inherited geological framework has been recognised as a first order control on the morphology of nearshore and beach environments. Jackson et al. (2005) have shown how beach-state models often fail to predict actual beach morphology, a factor they ascribe to antecedent geological conditioning. In particular, when these areas are juxtaposed with a limited supply of sediment, the underlying geological framework is increasingly likely to control their contemporary morphodynamic functioning. The same should be true for the seaward continuum of the system though the shallow subtidal into the shoreface. In their classic study on the shorefaces of North Carolina, Riggs et al. (1995) showed how subsurface geology influenced shoreface morphology, with the primary distinction being between shorefaces underlain by relict headlands (interfluves or positive relief features) or incised valleys. They noted (p.213) that "*stratigraphically-controlled bathymetric features on the inner shelf modify waves and currents and thereby effect patterns of sediment erosion, transport, and deposition on the adjacent shoreface*". Where bedrock actually crops out, wave energy is dissipated, topographic rips are produced and accommodation space further constrained (McNinch, 2004; Aleman et al., 2015). Thieler et al. (2001, p 958) go on to state: "*The lithology of the underlying units exerts a primary control on the distribution, texture, and composition of surficial sediments, as well as inner-shelf bathymetry*". Thieler et al. (2014), Mallinson et al. (2005) and Mallinson et al. (2010) further show how the shallow geologic framework of the inner shelf can inform the evolutionary pathway of coastal features like barrier island segments, where the underlying sandy substrate is scavenged by the barrier as the shoreface migrates landwards. Lastly, prominent outcrop, such as bluffs, capes or headlands further create sedimentary boundaries and strongly compartmentalised beaches and surfzones of varying form (e.g. Loureiro et al., 2012; Klein and Menezez, 2001; Vieira de Silva et al., 2016).

In contrast, areas of high sediment supply, or those areas subject to particularly high-energy waves or tidal currents, are considered as controlled more so by the allocyclic conditions of the local environment. For example, the beaches of the north and northwest coast of Ireland, where sediment forms a cover of several meters over pre-Holocene sediments, are derived from wave reworking during the Holocene transgression of continental shelf sand (Carter, 1991; Cooper et al., 2002) and have modified and evolved as sea level has risen during the Holocene. A substantial time has elapsed for the contemporary shoreface to evolve; and this in combination with the sediment thickness, means limited geological control has been exerted on the evolution of the shoreface profile (Jackson et al., 2005). In the case of wave-dominated coasts, Roy et al. (1994) examined the influence of regional substrate slopes and the extent to which the coast is laterally bounded by headlands. They recognised three general coastal types. These encompassed low-lying coastal plain coasts (inherited from low-gradient, sandy antecedents), more irregular embayed coasts (influenced by bedrock) and relatively steep, cliffed or protruding sectors of coasts (dominated by bedrock).

Despite the above-mentioned examples, relatively few studies exist regarding the shallow offshore environment encompassing the shallow subtidal to lower shoreface zones (Aagaard et al., 2013). We identify a crucial gap in the literature concerning how these nearshore zones interact with the underlying bedrock, the prevailing sediment supply, and the ambient oceanographic conditions. It is in this context that we examine the wave-dominated southern Namibian coastline. The area presents a unique situation in the context of geological control on shoreface, nearshore and beach morphology, as it is by contrast, a sediment-rich setting, located adjacent to southwestern Africa's largest fluvial debouchment, the Orange River. There are no bedrock outcrops along the coast, and it is characterised by a thick sediment cover that extends from the lower shoreface into the littoral. Sediment supply is considered to have been long-lived and abundant, and has produced an extreme example of a wave-dominated sediment dispersal system (Bluck et al., 2007). This paper documents the influence geologic control and framework have on the nearshore morphology of the area. We employ new airborne geophysical datasets spanning the onshore and the offshore, complimented by nearshore sub-bottom profile and bathymetric data to assess the relationship between the underlying subsurface geology and geomorphology and the contemporary nearshore coastal configuration and geomorphology.

2. Regional setting

2.1. Bathymetry and regional stratigraphy

On the coast of southwestern Namibia, from the Orange River Mouth north some 100 km up the coast, Late Proterozoic Gariep Belt siliciclastic rocks of the Oranjemund Formation (Jacob et al., 2006) form a rugged, high-relief nearshore basement. Seismic data (De Decker, 1987) show that the bedrock extends to between 2 and 5 km offshore and is onlapped by drift succession rocks of Cretaceous age (Stevenson and McMillan, 2004). The Cretaceous succession forms a gently sloping middle shelf region (Dingle, 1973; Stevenson and McMillan, 2004) which extends to 150 m water depth offshore Namibia (Rogers, 1977), followed by an initial shelf break, situated between 70 and 150 km offshore (Dingle, 1973). This break-in-slope separates the middle shelf from an outer shelf region that extends to the continental shelf edge at an approximate water depth of 500 m (Stevenson and McMillan, 2004). The shallow shelf has been combed by repeated regressions and transgressions since the Eocene, driven by relative sea-level fluctuations (Siesser and Dingle, 1981; Bluck et al., 2007); Tertiary and Pleistocene aged deposits therefore occur as a thin diamondiferous condensed horizon that unconformably overlies the Proterozoic basement. Holocene marine sediments directly overlie the diamondiferous horizon and comprise a seaward-thickening and northward-thinning wedge of sandy and muddy sediment up to 60 m thick in places (Fig. 1). This layer is associated with widespread acoustic blanking caused by gas-charged sediment.

2.2. Sediment supply and coastal regime

The Orange River, the principal conduit of coarse sediments and diamonds to the west coast of southern Africa, was established by the Early Cretaceous (Dingle and Scrutton, 1974). The outfall of the Late-Cretaceous precursor Orange River was a finer-grained system that fed into a large, long-lived palaeo-delta offshore of the present Orange River Mouth (Aizawa et al., 2000; Ward and Bluck, 1997; Wickens and McLachlan, 1990). Late to End Cretaceous regional subcontinental uplift initiated fluvial incision, which continued intermittently through much of the Cainozoic (Spaggiari et al., 2006) and shifted the deposition at the mouth from fine- (silt and clay) to coarse-grained (gravel and sand) sediment (Spaggiari et al., 2006). Since this time, the Orange River has carried sediment of up to boulder sizes to the coast (Bluck et al., 2007).

The modern Orange River has a wave-dominated delta that is subjected to vigorous northward longshore drift under the prevailing southerly swell, wind and wave regime (Fig. 1, De Decker, 1988; Rogers, 1977). Long period swells (average swell height > 3 m), originating in the Southern Atlantic Ocean are incident on the coast from the south-southwest. Wave data show that median wave heights range from 1.5 m in summer to 1.9 m in winter with wave heights exceeding 4.75 m common throughout the year. The median wave period lies between 10.5 s in summer and 12.5 s in winter. Superimposed on this long period swell are shorter period waves that are a response to the persistent SW wind (Fig. 1), generated by the South Atlantic Anticyclone system. 90% of the shorter period waves have a height falling between 0.75 and 3.25 m (De Decker, 1988) and wave base is thought to be at a depth of ~40 water depth, although semi-submersible dives indicate wave base can be considerably deeper at ~110 m water depth