Marine Geology 341 (2013) 29–45

Contents lists available at SciVerse ScienceDirect

Marine Geology

journal homepage: www.elsevier.com/locate/margeo

An insight into headland sand bypassing and wave climate variability from shoreface bathymetric change at Byron Bay, New South Wales, Australia

Ian D. Goodwin *, Rhaelene Freeman, Karen Blackmore

Marine Climate Risk Group and Department of Environment and Geography, Macquarie University, 2109 NSW, Australia

ARTICLE INFO

Article history:
Received 22 October 2012
Received in revised form 7 May 2013
Accepted 12 May 2013
Available online 19 May 2013

Communicated by J.T. Wells

Keywords:
shoreface bathymetric change
headland bypassing sand transport
multi-decadal wave climate
large scale coastal behaviour
headland bay-beach

ABSTRACT

The headland sand bypassing mechanisms in the Eastern Australian longshore sand transport system are investigated at Cape Byron, in response to wave climate variability. The mechanisms are interpreted from shoreface bathymetric change between surveys in 1883, 2002 and 2011 CE. They involve a split in the sand transport to follow a nearshore path along the inner bar and a cross-embayment path connecting the up-coast and down-coast outer bars. The relative magnitude of the net sand transported via the two pathways is controlled by a rotation in directional wave conditions. Two bypassing mechanisms were interpreted: (i) a predominantly cross embayment transport during unimodal east–southeast wave climate such as those interpreted for the period prior to 1883; and, (ii) a split transport between the inner nearshore and cross-embayment paths during a bimodal dominant south–south-easterly and sub-dominant east–north-easterly wave climate such as in the 2000s. The net sand transport bypassing Cape Byron was dominated by a connected outer bar system prior to 1883 and conversely, a stronger inner bar system during the 1960s to 2000s. This is manifest in the 10° rotation in seabed morphology and shoreline planforms. These changes are in accordance with decadal climate variability described by the Interdecadal Pacific Oscillation (IPO). The switching between headland sand bypassing mechanisms on interannual to decadal timescales determines the geometry of the bypass strand with the downcoast littoral zone and has important implications for understanding the shoreline rotation and the application of the headland-bay beach concept to predicting planform curvature in open compartments.

1. Introduction

1.1. Headland bypassing mechanisms

The headland bypassing mechanism is a crucial component to understand decadal scale shoreline change on open, obliquely-oriented coasts, yet there is meager literature on the topic, often related to engineering projects (e.g. the Tweed River Entrance Sand Bypassing Project, (Acworth and Lawson, 2012), global examples are discussed in Boswood and Murray, 2001). Sediment flow has been widely observed to bypass obstacles that interrupt longshore transport at low and high-angles, such as reefs, ebb tidal deltas, groins and breakwaters (Silvester and Hsu, 1997). There is a general view based on modelling that along the northern New South Wales (NSW) coast of Australia, at least 80% of longshore transport and headland bypassing occurs in water depths <4 m (Hyder, Consulting Pty Ltd, et al., 1997), which we refer to as the 'nearshore pathway'.

However, headland-bypassing processes that permit the exchange or leakage of sediment between deeply embayed compartments on longer time frames or in deeper water are largely un-documented. The observed and hypothetical mechanisms can be summarized as follows: (i) headland-attached bar bypassing (HAB) along obliquely aligned coasts (Zenkovich, 1967; Short, 1999; Silveira et al. 2010; Acworth and Lawson, 2012); (ii) shoreface strand-bypassing (SS) along obliquely aligned coasts (Smith, 2001); and, (iii) headland-attached, rip-head leakage bypassing (HAR) between swash-aligned embayments (Short, 1999).

The HAB bypassing mechanism involves the procession of seaward rotation of the beach and upper shoreface that results in the continuation of the inner bar along the headland coast. Moderate to high oblique wave energy results in sand bypassing the headland coast to initially form a subaqueous shoal or bar downdrift of the headland. This shoal or bar typically migrates downdrift in the surf zone as a sand wave to form an elongate spit, before eventually welding to the downdrift shoreline (referred to as nearshore transport). In contrast, hypothetical sand bypassing via the SS bypassing mechanism is transported across the shoreface in the downdrift embayment following a strand at an angle of ~60° to the downdrift

* Corresponding author. Tel.: +61 2 9850 8354; fax: +61 2 9850 8420.
E-mail address: ian.goodwin@mq.edu.au (I.D. Goodwin).

http://dx.doi.org/10.1016/j.margeo.2013.05.005

shoreline (referred to as cross-embayment transport). Major storm wave events are a key driver of HAR bypassing by allowing sand to be transported to near the depth of closure and outside of the headland position (Short, 1999). The HAB mechanism has been observed to operate in shallow curvature planforms, such as, natural open coasts and engineered coasts with shore normal breakwaters and groins. The SS mechanism is hypothetically confined to deeply embayed and open compartments and requires shoreward transport across the embayment from near the upper–lower shoreface boundary, but there have been no coastal process or marine geological studies into this mechanism. The hypothetical SS pathway lies along the control line for the equilibrium headland bay–beach model, between the headland diffraction point and the downcoast limit of the embayed coastline.

In this paper, we investigate: the interaction of modal wave climate and headlands acting as sand bypassing valves; the nature and relative net sand bypassing rates; and, efficiency of the independent nearshore sand transport (HAB) and cross-embayment transport (SS) mechanism downdrift. We use a sediment budget approach to detect and resolve the shoreface sand supply and headland sand bypassing history for Byron Bay (Australia's most easterly point, Fig. 1) based on historical shoreface bathymetric changes since 1883 CE (the earliest survey available).

1.2. Geomorphic setting and approach

Shoreface processes can be discriminated on two time scales and geometries along the eastern Australian coast. These are: (i) the upper shoreface which extends from the shoreline to water depths of 12–15 m (nominally defined as the annual depth of closure for New South Wales coasts, (Short, 1999)) and the distribution of sand varies at the event to annual scale without vertical profile change (Nicholls et al., 1998); and, (ii) the lower shoreface which extends from 15 to 60 m water depths and sand transport can occur on interannual to centennial timescales, with vertical profile evolution on longer time scales (Nicholls et al., 1998). On regional, obliquely-oriented coastlines like the northern NSW and south-east Queensland (QLD) coasts (Fig. 1), where the prevailing moderate (south-east, 120–160°) wave energy drives a longshore sand transport system (Boyd et al., 2008) from south to north, headland sand bypassing is an intrinsic control on upper shoreface sand supply and distribution. Significant shoreward exchange of sand between the lower and upper shoreface is thought to operate on time-scales of decades to centuries based on sedimentological zonation (Roy and Stephens, 1980) where the sand is mobilized by orbital wave motion during large swell wave and storm wave events and high energetic wave climates sustained on time scales of decades or longer.

The eastern Australian coast is characterized by drift-aligned, long sand barriers with a composite Pleistocene–Holocene age such as the 34.5 km section from Cape Byron to Hastings Point (Roy and Thom, 1981). The shoreline planform geometry and compartment accommodation space are controlled by the relative shoreline obliquity to the modal wave direction and associated longshore sand supply bypassing the bedrock headland control points (Fig. 1). Recent research has demonstrated that NSW and south-eastern Queensland (SEQ) coastal behaviour (including shoreline rotation and position, longshore sand bypassing rates, upper shoreface profiles, and estuarine/lagoon inlet location) is intrinsically linked to wave climate and sea-level fluctuations associated with the major modes of Southern Hemispheric climate variability; the quasi-biennial El Niño Southern Oscillation (ENSO); and, the Interdecadal Pacific Oscillation (IPO) (Ranasinghe et al., 2004; Goodwin, 2005; Goodwin et al., 2006). The southern hook of the planform at Byron Bay (BB), conforms to the geometry predicted by the equilibrium headland-bay beach (HBB) concept (Hsu and Evans, 1989). The BB planform geometry is sensitive to nearshore wave direction variability on decadal to multi-decadal timescales and has experienced alignment rotation of the planform as detected in historical surveys and photogrammetry e.g. 1883 to 1913, 1942 to 1980, and 1980 to 2005 (Goodwin, 2006). The stability of the shoreline is principally dependent upon the frequency of upcoast headland sand bypassing, the resulting downcoast longshore sand supply, and the presence or absence of a cross-shore sand supply transported from the lower shoreface, within the compartment. The shoreline is located hundreds of metres seaward of the static equilibrium bay model, since shoreline processes are dominated by significant longshore sand transport differentials.

A major uncertainty in understanding both, past and future large-scale coastal behaviours (LSCB) is that natural wave climate and shoreface sand supply variability is under-determined. Specifically, we do not have an adequate knowledge of associated processes that control the connectivity of longshore sand transport between compartments, their time scales of operation, shoreface depth limits, and lags between observed shoreline translation and rotation and shoreface sand supply.

The HAB bypassing process at prominent headlands along the eastern Australian coast is complicated with a component of sand transported offshore from the littoral zone, to nourish headland-attached shelf-sand lobes (SSL) on the inner shelf (40–60 m water depth, Ferland, 1990). The hypothesised processes that drive such a sand loss are: the episodic bifurcation of the northward flowing longshore current due to either storm-driven downwelling currents, ebb tidal currents, and/or interaction with the southward flowing Pacific western boundary current, known as the East Australian Current, that impinges onto the middle to inner shelf (Roy, 1998). The accretion of the SSLs along the NSW shelf was estimated by Roy et al. (1994) to have evolved during the mid–late Holocene highstand on underfit shelf segments. The Cape Byron SSL located on the inner shelf is shown in Fig. 2, together with the Byron Inner Nearshore Lobe, that has evolved contemporaneously since the middle Holocene, from probable headland sand bypassing. Gordon et al. (1978) estimated the annual rate of sand loss to the Cape Byron shelf sand lobe was ~50,000 m^3/yr, assuming that the SSL had been accreting for 6000 years. Similar SSLs that are comprised of physical sediment properties indistinguishable from littoral sand, known as Inner Nearshore Sand (Roy and Stephens, 1980; Ferland, 1990; Roy, 2001) have been discovered off major headlands along the northern NSW and south-eastern Queensland coast, (Roy, 1998). Hence, the prominent headlands such as Cape Byron act as valves for sand transport, either downdrift in the littoral zone, or seaward onto the lower shoreface and inner shelf. The temporal variability of the sand valve and headland bypassing process and its relationship to wave climate is unknown, and is the subject of this paper.

We develop a conceptual model to explain the shoreface depth and morphological changes as part of the LSCB response to time-varying sand supply and wave climate. The results in this study are applicable to: (i) reconciling decadal scale shoreline and shoreface changes; and, (ii) interpreting the temporal variability of the headland-bay beach planform, on widespread sections of the south-east Australian coast, and to all obliquely-oriented, sand barrier coasts in passive continental margin settings.

2. Overview of wave climate

Directional waverider buoy data are available for the mid-shelf (90 m depth) off Byron Bay from 1999. These wave data indicate that the average monthly observed mean wave direction (MWD) for 1999 to 2007 at Byron Bay is 128.5°T, with an extreme monthly range from 85° to 160° (January and July) (Kulmar et al., 2005). This variability is produced by synoptic patterns ranging from subtropical, anticyclonic intensification forcing a more easterly component, and extratropical, southern Tasman Lows forcing a more southerly component. The synoptic variability also controls fluctuations in wave spectra between a statistically skewed unimodal SE wave climate,