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Sedimentation, bioturbation, and sedimentary fabric evolution on a modern mesotidal mudflat: A multi-tracer study of processes, rates, and scales

Samuel J. Bentley Sr. [a,*], Andrew Swales [b], Benjamin Pyenson [c], Justin Dawe [d]

[a] Coastal Studies Institute and Department of Geology and Geophysics, Louisiana State University, Baton Rouge, LA 70803, USA
[b] National Institute of Water and Atmospheric Research, Hamilton, New Zealand
[c] Haverford College, Haverford, PA, USA
[d] NALCOR, St. John's, Newfoundland and Labrador, Canada

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ABSTRACT

A study of muddy tidal-flat sedimentation and bioturbation was undertaken in the Waitetuna Arm of Raglan Harbor, New Zealand, to evaluate the physical and biological processes that control cycling of sediment between the intertidal seabed and sediment–water interface, and also the formation of tidal flat sedimentary fabric and fine-scale stratigraphy. Cores were collected along an intertidal transect, and analyzed for sedimentary fabric, ^{210}Pb and ^{7}Be radiochemical distributions, and grain size. At the same locations, a new approach for time-series core-X-radiography study was undertaken (spanning 191 days), using magnetite-rich sand as a tracer for sedimentation and bioturbation processes in shallow tidal flat sediments. Sedimentary fabric consists of a shallow stratified layer overlying a deeper zone of intensely bioturbated shelly mud. Bioadvection mixes the deeper zone and contributes fine sediment to the surface stratified layer, via biodeposition. Physical resuspension and deposition of surface muds by wave and tidal flow are also likely contributors to formation of the surficial stratified layer, but physical stratification is not observed below this depth. The deliberate tracer study allowed calculation of bioadvection rates that control strata formation, and can be used to model diagenetic processes. Results suggest that the upper $\sim$15 cm of seabed can be fully mixed over timescales $<$1.75 y. Such mixing will erase pre-existing sedimentary fabric and transport buried sediment and chemical compounds back to the tidal-flat surface. Shallow biodiffusion also exists, but produces much slower and shallower mass transport. Best fits for ^{210}Pb profiles using a diagenetic bioadvection/sedimentation model and independently measured tiered bioadvection rates suggest that sediment accumulation rates (SARs) on the tidal flat are $\sim$0.25 cm/y, near the low end of contemporary New Zealand muddy intertidal SARs. Frequent deposition and erosion of the surface layer demonstrates that long-term sediment accumulation captures only a small fraction of sediment deposited at any one time. Model results also suggest that our magnetite tracer method may slightly underestimate short-term shallow mixing rates (demonstrated by ^{7}Be profiles), and slightly overestimate longer-term, deeper bioturbation rates (demonstrated by ^{210}Pb profiles).

1. Introduction

Tidal flats constitute an important reservoir of sediments delivered from terrestrial to marine sedimentary environments. Much sediment accumulation in estuaries occurs at the transition from fluvial to marine-process dominance, due to downstream decrease in fluvial flow velocity, and upstream decrease in sediment transport from tides and waves (Johnson et al., 1982); tidal flats occupy the intertidal portion of this region (Dalrymple et al., 2012). These settings are proximal to the effects of changes in terrestrial sediment delivery, and are the first marine environments to receive anthropogenically influenced sediments, whether contaminated or not, from land. So, understanding transport and fate of sediments delivered to such coastal settings is important. Because sediment volumes accumulating in these proximal estuarine depocenters can be large, understanding formative processes is also instructive to understanding the history of many ancient sedimentary deposits (Dalrymple and Choi, 2006).

* Corresponding author.
E-mail address: sjb@lsu.edu (S.J. Bentley).

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The objective of this study is to evaluate the physical and biological processes, rates, and spatio-temporal scales that control sediment cycling between the intertidal seabed and sediment–water interface, and the formation of tidal-flat sedimentary fabric and fine-scale stratigraphy. The study area is a muddy intertidal flat complex in the Waitetuna Arm of Raglan (Whaingaroa) Harbor (Fig. 1) on New Zealand's North Island. The motivations are twofold. First, we aim to improve the understanding of processes controlling recycling and postdepositional alteration of intertidal sedimentary strata, with application to both modern transport and fate of terrestrially derived materials, and formation of the ancient sedimentary record. Second, we attempt to separate the competing effects of bioturbation and sedimentation on natural sediment radiotracer distributions, in order to better constrain SARs in the intertidal study area over the past several decades. To do this, we have developed and applied a new quantitative approach using a deliberate tracer of sediment mixing (native magnetite-rich sand) monitored using time-series collection and X-radiography of sediment cores.

1.1. Physical characteristics of the study area

Raglan Harbor is a mesotidal estuary with an intertidal and subtidal area of 30 km^2, ~70% of which is intertidal and mostly unvegetated (Sherwood and Nelson, 1979). The Waitetuna Arm has an area of 5 km^2, and mostly consists of muddy intertidal flats with a small network of deeper channels (Fig. 1), within a drowned river valley that has been modified substantially by marine erosion. Recent sediments constitute an unconsolidated veneer of variable thickness overlying eroded soft (mudstone) bedrock platforms bordered by low cliffs (Sherwood and Nelson, 1979). Local tides are semi-diurnal with neap-spring range of 1.8–2.8 m (McKergow et al., 2010). Virtually all waves in the Waitetuna Arm are locally generated, owing to a narrow bedrock connection with the seaward body of the estuary (Fig. 1). Nevertheless, with fetch up to 2 km, wind-generated waves are apparently sufficient to drive cliff retreat and resuspend sediment when the Arm is flooded (Sherwood and Nelson, 1979; Pritchard and Green, 2008; McKergow et al., 2010). This physical mixing is similar to the effective resuspension

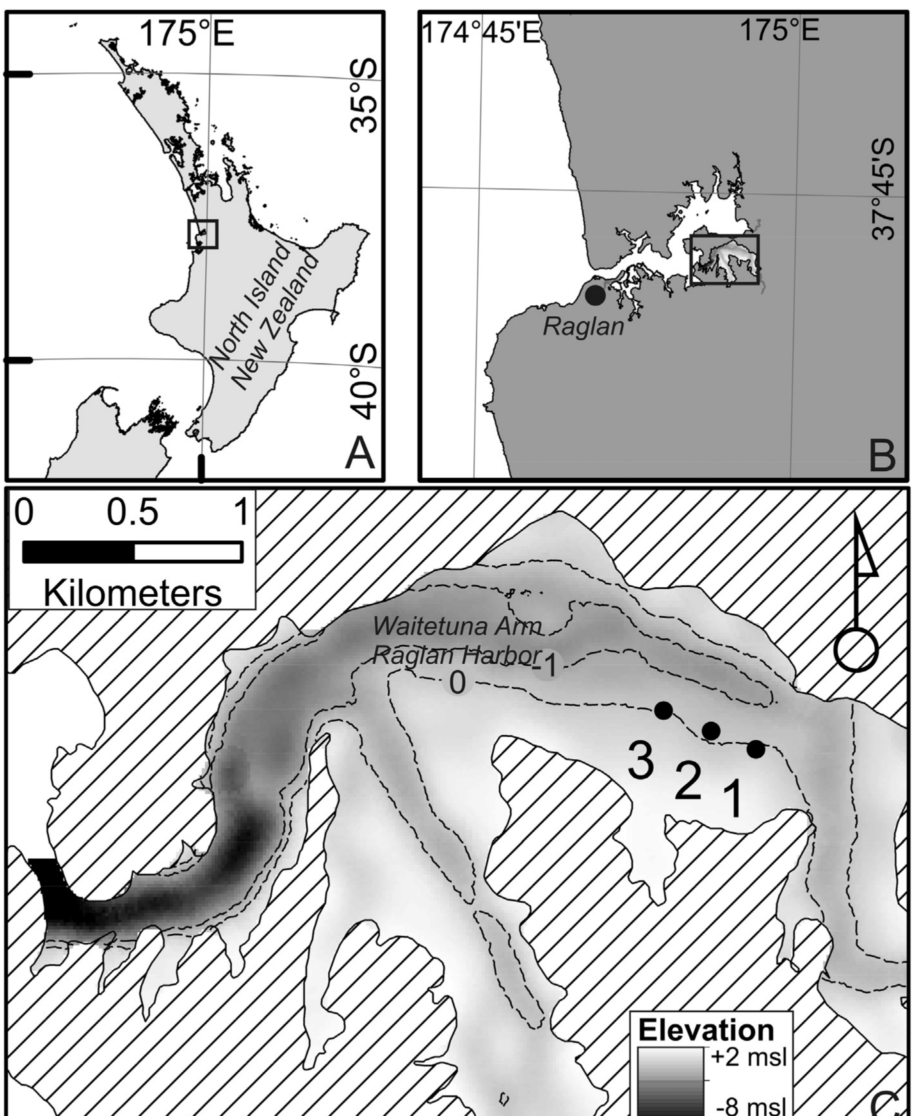

Fig. 1. (A) Location of Raglan Harbor, North Island, New Zealand. (B) Location of Waitetuna Arm of Raglan Harbor, New Zealand; (C) bathymetry and station locations in Waitetuna Arm of Raglan Harbor; white regions are water outside the study area, hatched area is dry land, and shaded region is harbor bathymetry from Pritchard and Green (2008).