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Characterization of a flood-associated deposit on the Waipaoa River shelf using radioisotopes and terrigenous organic matter abundance and composition

Tara A. Kniskern [a,*], Siddhartha Mitra [b], Alan R. Orpin [c], Courtney K. Harris [a], J.P. Walsh [b,d], D.R. Corbett [b,d]

[a] Virginia Institute of Marine Science, Gloucester Point, VA, USA
[b] East Carolina University, Greenville, NC, USA
[c] National Institute of Water and Atmospheric Research, Wellington, New Zealand
[d] UNC Coastal Studies Institute, Wanchese, NC, USA

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ABSTRACT

An ephemeral oceanic-flood deposit adjacent to a well-studied small mountainous river (SMR), the Waipaoa River in northeastern New Zealand, was characterized using multiple proxies, including radioisotopes (^{234}Th, ^{7}Be, and ^{210}Pb), bulk organic carbon abundance and isotopic signature (%OC, δ^{13}C), as well as a biomarker of terrigenous organic matter (lignin). Field sampling was conducted within two weeks after a 1-in-8 year flood that occurred between January 30 and February 6, 2010. Geochemical analyses indicated that initial deposition of fresh riverine material extended alongshore to the north and south from the river mouth. A comparison of prior- and post-flood ^{7}Be inventories revealed that flood sediments were widely dispersed between 20 and 70 m water depth, accounting for 50–80% of the estimated flood load. Surface (0–2 cm) isotopic carbon values increased with distance from Poverty Bay, positively correlating with total ^{210}Pb activities, potentially reflecting increasing marine influence with water depth. Abundances of sedimentary organic carbon (OC) were 0.18–0.76% dry weight, and the total nitrogen varied from 0.02 to 0.13%. Stable isotope signatures of carbon ($\delta^{13}C_{OC}$), nitrogen (δ^{15}N), and lignin abundances (λ_6) throughout the study area ranged from −23.6 to −27.7‰, 1.9 to 5.3‰, and 0.93 to 9.0 mg 100 mg OC^{-1}, respectively. The spatial distribution pattern of terrigenous organic matter (OM) abundance and interclass ratios (indicative of freshness of organic matter) varied along and across-shelf. Lignin abundances were high and interclass ratios were low in the southern depocenter and inner shelf areas, suggesting that this zone had recently received vascular-plant enriched OM, minimally altered by shelf-bed mixing processes. In contrast, sediments in the northern depocenter and outer shelf also contained elevated amounts of terrigenous sedimentary OM, but this material was generally lower in lignin abundance and had higher interclass ratios (greater degradation). Collectively, these results suggest that the flood-derived sediment and fresh terrigenous OM were mostly constrained between 20 and 70 m water depth, with enhanced deposition overlapping the tectonic-controlled depocenters located to the northeast and southeast of Poverty Bay.

1. Introduction

Rivers provide an important conduit for the transfer of terrigenous sediments and organic matter to continental margins (Schlesinger and Melack, 1981; Milliman, 1991; De Haas et al., 2002; Lyons et al., 2002; Gomez et al., 2003; Eglinton, 2008). Disproportionate to their global catchment area, small rivers with mountainous catchments (SMRs) collectively produce over half of the estimated 1.8 Gt of terrestrial sediment delivered to the ocean annually (Milliman and Syvitski, 1992; Milliman et al., 1999; Milliman and Farnsworth, 2013). Additionally, this class of rivers accounts for nearly half of the global organic carbon (OC) annual load to the sea, carrying both ancient, rock-derived OC and modern terrestrial OC (Lyons et al., 2002; Leithold et al., 2006). SMR watersheds are primarily located on collision margins, are characteristically smaller than 20,000 km^2, have high relief, and have relatively high sediment yields due to fractured and easily-erodible uplifted lithologies (Milliman and Syvitski, 1992; Farnsworth and Milliman, 2003; Wheatcroft et al., 2010). Deforestation and river damming (e.g. Gomez et al., 2004; Kasai et al., 2005; Syvitski et al., 2005; Warrick et al., 2013) as well as natural disturbances (Major et al., 2000; Hovius et al., 2011) have profoundly affected catchment

* Corresponding author.
E-mail address: knista@vims.edu (T.A. Kniskern).

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sensitivity and suspended load of SMRs over the last century. Furthermore, due to the compact size of SMRs, floods can occur within hours of storm-induced precipitation, discharging at the coast whilst energetic oceanographic conditions may persist offshore (Milliman and Syvitski, 1992; Wheatcroft, 2000; Blair et al., 2004; Wheatcroft et al., 2010, Kniskern et al., 2011).

Complex processes control the ultimate fate of the sediments and associated organic matter delivered by SMR systems. For example, upon delivery to the shelf, flood-derived material can undergo repeated deposition and resuspension, which are influenced by waves, currents, tidal energy, and physical and biological processes that may affect the critical threshold of resuspension (Hedges and Keil, 1995; Ogston et al., 2000; Wiberg, 2000; Wheatcroft and Drake, 2003). On some narrow continental shelves, cross-shelf gravity-driven sediment flows disperse a significant portion of the river load rapidly beyond the shelf break (Mullenbach et al., 2004; Addington et al., 2007; Alexander et al., 2010; Hale et al., 2012). Finally, stochastic events such as large storms may remove or rework previously delivered terrestrial organic matter. In order to understand the cycling and ultimate fate of the terrestrial organic matter from source to sink, it is important to characterize terrigenous OM deposition prior to reworking by physical and biological mixing processes that may augment or preclude carbon burial. In this study, we use a multiproxy approach (e.g. Mitra et al., 1999; Goñi et al., 2006; Kuzyk et al., 2008, 2009) to characterize an initial oceanic-flood deposit in the seabed adjacent to a SMR. Herein we use the term oceanic-flood deposit to denote recently-deposited shelf sediments associated with flood dispersal into the coastal ocean while storm conditions persist (Wheatcroft, 2000). Reworking and redistribution of an oceanic-flood deposit over time can influence an event layer.

Time-series studies investigating flood-associated bed deposition have indicated that the fate of sediment and carbon is dependent on a combination of initial transport processes and subsequent reworking and burial (e.g. Wheatcroft et al., 1996; Leithold and Hope, 1999; Sommerfield et al., 1999; Allison et al., 2000; Bentley and Nittrouer, 2003; Wheatcroft and Drake, 2003; Palinkas et al., 2005; Miserocchi et al., 2007; Tesi et al., 2008, 2012). However, due to the episodic nature of SMRs, few studies have had the opportunity to disentangle these complex relationships by sampling shelf depocenters immediately following a flood, identifying the flood-associated deposit, and relating the deposit to the conditions under which the sediments were dispersed (Wheatcroft et al., 1997; Sommerfield et al., 1999; Leithold and Hope, 1999; Bourrin et al., 2008; Hale et al., 2012). Because sedimentary organic matter preservation is directly related to burial efficiency, understanding the compositional characteristics of a flood deposit can offer clues towards how OC is ultimately sequestered in continental margins.

The Waipaoa Sedimentary System (WSS), composed of the river basin, Poverty Bay and adjacent shelf and slope, efficiently transfers terrestrial sediments and organic matter from land to sea (Fig. 1; Gomez et al., 2003; Hicks et al., 2003, 2004). Previous multidisciplinary work within the WSS (see Carter et al., 2010 and references therein) and a recent 15-month shelf study (Kiker, 2012, Moriarty, 2012; Hale et al., 2014; Walsh et al., in review) provided a framework for comparison to planned post-flood rapid-response sediment core collection. In January, 2010, rainfall associated with a storm system resulted in a 1-in-8-year flood (using the frequency–magnitude relationship described by Gomez et al., 1998) in the Waipaoa River. Because the seabed in this area had been characterized only weeks prior (January 14–20, 2010) by Kiker (2012) and Walsh et al. (in review), the rapid-response investigation of this study provided a rare opportunity to assess the impact of flood-associated sediment deposition and organic matter delivery to the seabed.

The objectives of this study were to use multiple radioisotopic and geochemical proxies to track the spatial distribution of the oceanic-flood deposit on the shelf seabed adjacent to the Waipaoa River mouth, assess the preservation potential of the deposit, and compare these findings with centennial shelf depositional patterns.

2. The Waipaoa coastal system

The Waipaoa River, a SMR along the northeast coastline of the North Island of New Zealand, drains actively uplifting ranges and margin sequences within its 2150 km^2 catchment that are part of the deforming backstop and forearc basin of the Hikurangi subduction zone (Walcott, 1984; Ota et al., 1988; Lewis and Pettinga, 1993; Brown, 1995; Fig. 1). European colonization and subsequent clearing have led to the loss of 97.5% of the old-growth native forests for pasture since the 19th century, which has greatly increased erosion rates, accelerated gullying of fractured bedrock, and, during exceptional rainfall events, initiated landslides (DeRose et al., 1993, 1998; Kelliher et al., 1995; Wilmhurst, 1997; Tate et al., 2000; Reid and Page, 2002; Glade, 2003; Gomez et al., 2004; Kasai et al., 2005; Kettner et al., 2007). The triumvirate of easily erodible lithologies, deforestation, and high rainfall rates (ranging from 1 to 2.5 m $year^{-1}$) contributes to the high sediment yield of the Waipaoa River, which averages $\sim$6800 t km^{-2} yr^{-1} and produces a riverine suspended load of 15 Mt yr^{-1} (ranging from 2.5 to 32 Mt yr^{-1}, with a standard deviation of 6.7 Mt yr^{-1}) (Griffiths, 1982; Hicks et al., 2000, 2004). In addition, the Waipaoa River annually delivers an estimated $\sim$130 Kt of particulate OC to the coastal ocean (Gomez et al., 2003).

Although floods most commonly occurred between the austral autumn and winter months of May–August over the last several decades (Fig. 2), some of the largest floods were also observed during austral summer months, January–March. Flood records from the 20th century indicated that “major” floods of the Waipaoa River have peak discharges that exceed 1900 m^3 s^{-1} (Reid, 1998). During major floods, which are often associated with slow-moving tropical and subtropical depressions and extra-tropical cyclones (Sinclair, 1993; Page et al., 1994a, b; Foster and Carter, 1997), Waipaoa River sediments and associated chemical and organic constituents are dispersed into energetic coastal waters via multiple transport mechanisms. Estimates by Hicks et al. (2004) indicated that fluvial suspended sediment concentrations in the Waipaoa River probably exceed the threshold for hyperpycnal plume formation only every 40 years, such that muddy discharges most often enter Poverty Bay as a buoyant plume. The plume and wind-driven currents drive counter-clockwise circulation within Poverty Bay (Healy et al., 1998; Stephens et al., 2001; Bever et al., 2011), potentially trapping the plume and facilitating ephemeral deposition within the bay that may be resuspended during subsequent wave events (Bever and Harris, 2014). As the plume exits Poverty Bay, its direction may be influenced by a northeast flowing Wairarapa coastal current and/or cyclonic eddy (Chiswell, 2000, 2003), overprinted by wind-driven waves, currents, and longer-period swell from the Southern Ocean (Foster and Carter, 1997; Stephens et al., 2001; Gorman et al., 2003; Bever et al., 2011). Wave- and current-supported gravity flows have been inferred to transport sediment across the shelf to deeper waters during periods of elevated fluvial dispersal and/or resuspension (Alexander et al., 2010, Moriarty, 2012; Hale et al., 2014). Although centennial shelf depocenter accumulation rates are relatively high (0.75–1.5 cm yr^{-1}), biological activity in the seabed is sufficient to modify the majority of beds beyond $\sim$40 m water depth (Miller and Kuehl, 2010; Rose and Kuehl, 2010). An outer-shelf pathway through the Poverty Gap, that lies between the emergent Ariel and Lachlan anticlinal ridges, provides a potential bypass route for sediment and terrestrial carbon from the mid-shelf to deeper waters (Orpin et al., 2006; Alexander et al., 2010; Brackley et al., 2010; Gerber et al., 2010; Fig. 1).