Continental Shelf Research 110 (2015) 108–123

Contents lists available at ScienceDirect

Continental Shelf Research

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

Event-to-seasonal sediment dispersal on the Waipaoa River Shelf, New Zealand: A numerical modeling study

Julia M. Moriarty [a,*], Courtney K. Harris [a], Mark G. Hadfield [b]

[a] Virginia Institute of Marine Science, The College of William & Mary, P.O. Box 1346, Gloucester Point, VA 23062, USA
[b] National Institute of Water and Atmospheric Research, 301 Evans Bay Parade, Hataitai, Private Bag 14 901, Wellington 6021, New Zealand

ARTICLE INFO

Article history:
Received 29 August 2014
Received in revised form
23 September 2015
Accepted 8 October 2015
Available online 14 October 2015

Keywords:
Sediment transport
Numerical model
Flood deposit
River dispersal
Wave resuspension
Waipaoa shelf
New Zealand

ABSTRACT

The formation of the geologic record offshore of small mountainous rivers is event-driven and, more so than many other environments, can result in relatively complete sequences. One such river, the Waipaoa in New Zealand, has been studied from its terrestrial source to its oceanic sink over timescales spanning storms, seasons, and the Holocene. This study focused on the formation of riverine deposits on the Waipaoa Shelf during episodic flood and wave events, contrasting deposition during short-lived events to accumulation patterns created over thirteen months. Sediment fluxes and fate were estimated using the numerical hydrodynamic and sediment transport model ROMS, the Regional Ocean Modeling System, using CSTMS, the Community Sediment Transport Modeling System. During the study period (January 2010–February 2011), the model indicated that initial flood deposition generally occurred near the river mouth and along the coast in water shallower than 40 m, and that deposition during any one event was sensitive to variations in shelf currents and wave energy. Also, the sedimentation due to plume settling and suspended transport during these relatively short flood and wave events were not aligned with longer time-scale accumulation patterns (months or greater) previously reported for the Waipaoa shelf. In the days to months following a flood pulse, waves episodically reworked this initial deposit, resuspending centimeter-scale layers of sediment during energetic periods. Frequent and intense resuspension occurred in shallow areas where bed stresses were high. This encouraged redistribution of material toward deeper areas having lower near-bed wave stresses, including continental shelf depocenters and offshore areas. While fast settling material was preferentially retained near the river mouth, currents dispersed slower settling sediment farther before deposition. Overall, accumulation depended on characteristics of oceanographic transport (wave energy, current velocities), not just source characteristics (flood size, sediment size distribution).

1. Motivation

The marine geologic record is incomplete, complicating interpretation of seabed observations (e.g. Sadler, 1981; Orpin et al., 2010). Flood deposits, for instance, comprise significant components of the geologic record on river-dominated margins, but are often reworked by physical and biological processes following initial emplacement (e.g. Wheatcroft et al., 2007). The resuspension and redistribution of fluvial sediment, the focus of this paper, can erase flood deposits from the stratigraphic record and likely impacts their significance as carbon sinks (Wheatcroft and Drake, 2003; Blair et al., 2004).

Wright and Nittrouer (1995) partition the dispersal of terrestrial material from rivers into four general dispersal stages: (I) supply of material via plumes; (II) initial deposition; (III) resuspension and transport by marine processes; and (IV) long-term net accumulation. In some situations, multiple stages may coincide. For example, initial deposition may occur during periods of supply via plumes and/or while energetic waves resuspend seabed material. In this paper, Stage I refers to the movement of the river plume and the associated fluxes of material. Stage II includes the location and characteristics of the deposit formed by the flood. Stage III refers to a period of seabed reworking and redistribution of material that begins after the flood-associated storm conditions have waned and flood sediments have had sufficient time to settle. For the Waipaoa Shelf this often begins within about 2 weeks after the flood, but can last for some years. Stage IV refers to deposition over decadal or longer timescales.

The relative importance of each dispersal stage varies among margins, but Wright and Nittrouer (1995) hypothesized that rapid initial deposition is especially dominant for small mountainous

* Corresponding author.
E-mail addresses: moriarty@vims.edu (J.M. Moriarty), ckharris@vims.edu (C.K. Harris), mark.hadfield@niwa.co.nz (M.G. Hadfield).

http://dx.doi.org/10.1016/j.csr.2015.10.005

rivers. Recent studies have shown that geologic records offshore of small mountainous rivers may have relatively good fidelity, meaning that deposits formed by specific events can be preserved in the marine sedimentary record (e.g. Sommerfield and Nittrouer, 1999; Wheatcroft et al., 2007; Blair et al., 2004; Brackley et al., 2010; Selvaraj et al., 2015). Certain characteristics of these river-dominated active margins, e.g. the rivers' small drainage basins, high sediment yield, and steep slopes, encourage this fidelity by helping to deliver signals from terrestrial flood events to the coastal ocean in coherence with the storm conditions that caused the rain and associated high discharge (Milliman and Syvitski, 1992; Wheatcroft, 2000). Upon reaching the continental shelf, steep slopes, combined with energetic waves and currents associated with the storm, may help sediment transit quickly to deeper sites where wave resuspension is less likely, enhancing preservation of flood deposits (Wright and Friedrichs, 2006; Wiberg, 2000; Warrick and Milliman, 2003). Although this paradigm fits many small mountainous rivers (e.g. the Eel River: Traykovski et al., 2000; Harris et al., 2005; the Gaoping River: Selvaraj et al., 2015; the Santa Clara River: Warrick et al., 2008), recent field data and model results for the Waipaoa River shelf have implied that event layer formation is not necessarily coherent with flood conditions. Instead, the Waipaoa shelf record reflects reworking by oceanographic transport mechanisms, and only the largest floods and storms would leave a preservable event bed there (Walsh et al., 2014; Bever and Harris, 2014; Rose, 2012).

Despite the relatively good fidelity and notable terrestrial influence expected offshore of small mountainous rivers, physical and biological processes are known to rework deposits on river-dominated margins (Wright and Nittrouer, 1985's Dispersal Stage III). On continental shelves, the impact of reworking on event layer preservation varies with depth into the seabed and water depth. For instance, both biological and physical processes act primarily on near-surface sediments, so rapid burial of event layers enhances the preservation of distinct beds in the geologic record (Wheatcroft, 1990; Bentley and Nittrouer, 2003; Wheatcroft and Drake, 2003). Similarly, wave orbital velocities attenuate with water depth, so waves more effectively resuspend sediment in shallow water (e.g. Harris and Wiberg, 2002). However, the temporal and spatial variability of these processes complicates efforts to estimate the likelihood of preservation for a given event deposit. Here, we investigated the role of physical reworking on the formation and preservation of continental shelf flood deposits and how patterns of fluvial accumulation, or net deposition, change on timescales of days to months.

This study focused on the Waipaoa River continental shelf, New Zealand, as part of the Waipaoa Source-to-Sink Studies. The National Science Foundation's (NSF) MARGINS program chose the Waipaoa as a Source-to-Sink focus site because it has a high sediment yield, interesting marine geologic record, and offshore anticlines that were thought to favor preservation of a relatively complete geologic record (see Fig. 1, Carter et al., 2010; Foster and Carter, 1997; Gomez et al., 2004; Hicks et al., 2000; Milliman and Farnsworth, 2011; Griffiths and Glasby, 1985; Hicks et al., 2004; Walling and Webb, 1996). However, previous studies, summarized in Kuehl et al. (2015), have indicated that physical processes (e.g. resuspension by waves, gravity-driven transport) likely affected variations (e.g. grain size, carbon signature) within the Waipaoa shelf geologic record (Bever, 2010; Brackley et al., 2010; Carter et al., 2010; Hale et al., 2014a). In spite of earlier studies, questions have remained about the role that transport processes play in sedimentation and event layer preservation on the shelf, and how short-term deposition differs from long-term accumulation. This numerical modeling study addressed these questions by estimating sediment fluxes and deposition over the entire shelf for a thirteen-month period that coincided with a field experiment (described below) and included two floods and multiple wave events.

1.1. Waipaoa sedimentary system

The Waipaoa River, a small mountainous river with a highly erodible catchment, delivers sediment to the coastal ocean primarily during floods (Orpin et al., 2006; Hicks et al., 2000). The riverine load is primarily mud (D_{50}=8.5 μm during floods), although sands comprise about one percent of the fluvial load (Hicks et al., 2004; Orpin et al., 2006). This paper focuses on the period from January 2010–February 2011, which overlaps with associated field studies (i.e. Hale et al., 2014a; Walsh et al., 2014; Kniskern et al., 2014; Kiker, 2012; Fig. 1b). During this time, two large Waipaoa River floods occurred on January 31 and July 6, 2010 that represented the fifth and fourteenth largest discharges, respectively, in the 44-year record of Waipaoa River observations provided by the Gisborne District Council (GDC). Riverine sediment concentrations during the peaks of these floods were estimated to slightly exceed 40 g L^{-1} based on recent rating curves provided by

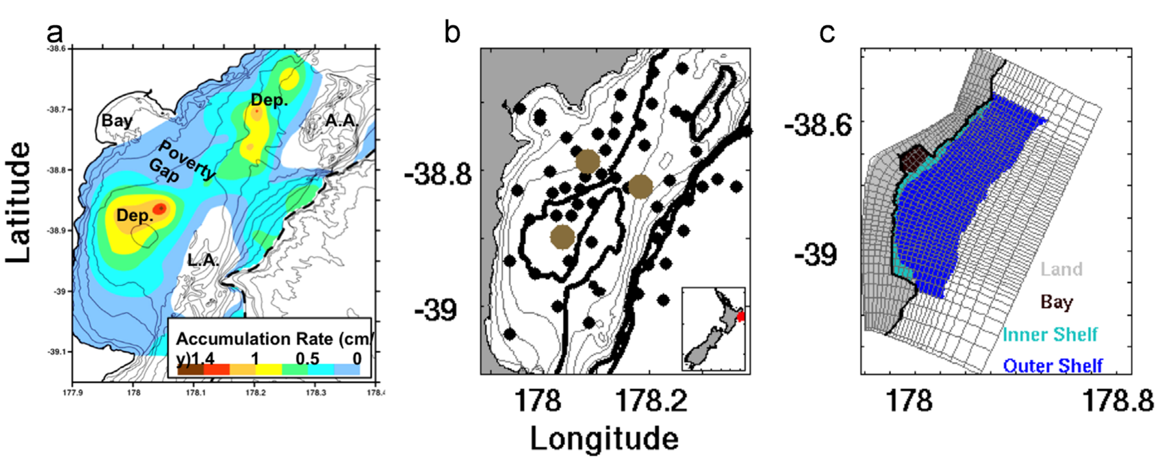

Fig. 1. Study site on North Island, New Zealand. (a) Adapted from Miller and Kuehl (2010). Spatial distribution of accumulation rates (cm y^{-1}) based on ^{210}Pb. Labels identify the Waipaoa River (red arrow), Poverty Bay (Bay), Poverty Gap, Lachlan Anticline (L.A.), Ariel Anticline (A.A.), and depocenters (Dep.). Bathymetric contours mark every 10 m (gray line) and the shelf break (black, dashed line). (b) Waipaoa Shelf map showing tripod locations (brown) and multi-core stations (black) from the January, 2010 research cruise. Inset shows location of study site in New Zealand. Bathymetric contours mark every 10 m (gray) and 50 m (black) depth intervals. (c) Waipaoa model grid. Boxes each encompass 25 grid cells. Colors (red, light blue, blue) indicate areas for sediment budgets discussed in Sections 4 and 5 (For interpretation of the references to color in this figure legend,the reader is referred to the web version of this article).