Marine Geology 295–298 (2012) 51–76

Contents lists available at SciVerse ScienceDirect

Marine Geology

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

Postglacial (after 18 ka) deep-sea sedimentation along the Hikurangi subduction margin (New Zealand): Characterisation, timing and origin of turbidites

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ARTICLE INFO

Article history:
Received 7 July 2011
Received in revised form 6 November 2011
Accepted 7 November 2011
Available online 25 November 2011

Communicated by D.J.W. Piper

Keywords:
hyperpycnite
earthquake
debris avalanche
marine transgression
triggering mechanism
sediment cores

ABSTRACT

Recent sedimentation along the Hikurangi subduction margin off northeastern New Zealand is investigated using a series of piston cores collected between 2003 and 2008. The active Hikurangi Margin lies along the Pacific–Australia subduction plate boundary and contains a diverse range of geomorphologic settings. Slope basin stratigraphy is thick and complex, resulting from sustained high rates of sedimentation from adjacent muddy rivers throughout the Quaternary. Turbidites deposited since c. 18 ka in the Poverty, Ruatoria and Matakaoa re-entrants are central to this study in that they provide a detailed record of the past climatic conditions and tectonic activity. Here, alternating hemipelagite, turbidite, debrite and tephra layers reflect distinctive depositional modes of marine sedimentation, turbidity current, debris flow and volcanic eruption, respectively. Turbidites dominate the record, ranging in lithofacies from muddy to sandy turbidites, and include some basal-reverse graded turbidites inferred to be derived from hyperpycnal flows. Stacked turbidites are common and indicate multiple gravity-flows over short time periods. The chronology of turbidites is determined by collating an extremely dense set of radiocarbon ages and dated tephra, which facilitate sedimentation rate calculation and identification of the origin of turbidites. Sedimentation rates range from 285 cm/ka during late glacial time (18.5–17 ka) to 15 to 109 cm/ka during postglacial time (17–0 ka). Turbidite deposition is controlled by: (1) the emplacement of slope avalanches reorganising sediment pathways; (2) the postglacial marine transgression leading to a five-fold reduction in sediment supply to the slope due to disconnection of river mouths from the shelf edge, and (3) the Holocene/Pleistocene boundary climate warming resulting in a drastic decrease in the average turbidite grain-size. Flood-induced turbidites are scarce: nine hyperpycnites are recognised since 18 ka and the youngest is correlated to the largest ENSO-related storm event recorded onland (Lake Tutira). Other turbidites contain a benthic foraminiferal assemblage which is strictly reworked from the upper slope and which relates to large earthquakes over the last c. 7 ka. They yield a shorter return time (270–430 years) than the published coastal records for large earthquakes (c. 670 years), but the offshore record is likely to be more complete. The deep-sea sedimentation along the New Zealand active margin illustrates the complex interaction of tectonic and climate in turbidite generation. Climate warming and glacio-eustatic fluctuations are well recorded at a millennial timescale (18 ka), while tectonic deformation and earthquakes appear predominant in fostering turbidite production at a centennial timescale (270–430 years).

1. Introduction

Gravity-driven flows are ubiquitous and fundamental process that control sediment dispersal where steep bathymetric gradients, enhanced tectonic activity and voluminous terrigenous sediment supply prevail such as at active margins. They range from submarine avalanches, cohesive debris or grain flows, liquefied and fluidized flows and turbidity currents (Stow et al., 1996; Stow and Mayall, 2000). Such processes can generate complex sets of sedimentary structures from a variety of triggering mechanisms and scales including giant avalanches consisting of $>100\ \text{km}^3$ of lithified sediment (e.g. Collot et al., 2001; Canals et al., 2004), thick successions of density-variable turbidites (Bouma, 1962; Stow and Shanmugam, 1980; Lowe, 1982), to centimetre-thick hyperpycnites that can be linked to individual flood events (Mulder et al., 2003). As such, gravity flow deposits contain invaluable information about past stratigraphic, climatic and tectonic history (Adams, 1990; Goldfinger et al., 2003; St-Onge et al., 2004; Blumberg et al., 2008; Noda et al., 2008; Nakajima et al., 2009). However, due to the geomorphologic complexity of active margins lateral correlation of events is often

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doi:10.1016/j.margeo.2011.11.002

problematic, both in terms of dealing with the spatial variability of gravity events and recognising synchronous “event assemblages”.

The active Hikurangi convergent margin, New Zealand is an excellent locality for the study of gravity-driven events because of the diversity of geomorphological settings, the intense tectonic activity (e.g., Lewis and Pettinga, 1993; Collot et al., 1996) and the high rates of sedimentation that produce an expanded stratigraphic record at an exceptional resolution. As the Hikurangi Margin lies along the Pacific–Australia subduction plate boundary, it is subjected to intense seismic activity. Here, a well documented upper-plate earthquake record exists for magnitude $M_w < 7.8$ (Reyners, 1998; Webb and Anderson, 1998) but only a poorly documented record of inferred plate interface ruptures capable of generating $\sim M_w$ 8.8 earthquakes (Reyners, 1998; Reyners and McGinty, 1999; Cochran et al., 2006; Wallace et al., 2009). At the northern extent of the margin, intense mass wasting and margin-collapse activity are manifested as large morphological re-entrants in the continental slope (Collot et al., 2001; Lamarche et al., 2008a; Pedley et al., 2010). Due to the vigorous maritime climate, floods are a common feature of northeastern New Zealand (Hicks and Shankar, 2003; Hicks et al, 2004). Some prehistoric catastrophic floods have been inferred from river flood-plains and continental shelf sediments (Brown, 1995; Gomez et al., 2007; Brackley et al., 2010) which might be capable of rapidly transporting sediment directly from the coast to slope basins via hyperpycnal flows. The occurrence of numerous tephra originating from the Central Volcanic Zone (Fig. 1) provides excellent chronological control in the offshore stratigraphic record (e.g. Carter et al., 2002). The northern Hikurangi Margin was intensely studied over the last 20 years, and contributed to a robust understanding of long- and short-time scale tectonic deformation (Collot et al., 1996; Reyners, 1998; Reyners and McGinty, 1999), sedimentary processes and stratigraphy (Foster and Carter, 1997; Orpin, 2004; Gomez et al., 2007; Paquet et al., 2009; Joanne et al., 2010; Kniskern et al., 2010) and Holocene sediment budgets (Orpin et al., 2006; Alexander et al., 2010; Gerber et al., 2010; Paquet et al., 2011). But the thick and complex suite of Quaternary turbidites that infill the slope basins remains largely understudied and their event stratigraphy underutilised.

In this paper, we use a series of sediment cores collected in the Poverty, Ruatoria and Matakaoa re-entrants along the northern Hikurangi Margin to identify and characterise a complete and comprehensive series of turbidite events. We generate a chronology of catastrophic sedimentation over the last 20,000 years for the northeastern Hikurangi Margin, and detailed characterisation of turbidites is used to compare and contrast depositional patterns. The excellent chronological control afforded by tephra and radiocarbon dating allows us to develop a methodology for investigating turbidite origin, and determine the relative contribution of trigger and controlling mechanisms. The balance of these processes is likely to be applicable to active margins globally. The study suggests that large earthquakes, catastrophic floods and volcanic eruptions are the principal triggering mechanisms of turbidites in the deep water sedimentary systems, and that over the past 20 ka, turbidite systems activity was primarily controlled by glacio-eustatic fluctuations and basin morphology.

2. Geological and sedimentological settings

2.1. Geomorphology

The Hikurangi Margin marks the region where the oceanic crust of the Pacific Plate is being subducted obliquely beneath the Raukumara Peninsula (Fig. 1). The zone of active deformation covers from east to west, the Hikurangi Trough, the continental slope and shelf and the east coast of the North Island of New Zealand (Lewis, 1980; Lewis and Pettinga, 1993; Collot et al., 1996). Subduction-related underplating beneath the Raukumara Peninsula is actively uplifting the axial ranges at an estimated maximum rate of 3 mm/a (e.g. Reyners and McGinty, 1999). A narrow accretionary prism forms locally at the toe of the slope. To the west lies the rhyolitic Central Volcanic Zone which is a prolific source of geochemically-distinct tephra that punctuate the terrestrial and offshore stratigraphic record throughout the Quaternary (Lowe et al., 2008).

The northern Hikurangi Margin includes a flat, 20–30 km-wide continental shelf, a steep sediment-starved slope, and a 3500 m-deep subduction trough (Fig. 1). Tectonic erosion has produced three large slope avalanches: the 30–50 km-wide, Poverty re-entrant (Pedley et al., 2010); the 30–40 km Ruatoria re-entrant (Collot et al., 2001); and landward of the trench wall and immediately north of the Raukumara Peninsula, the Matakaoa passive margin contains the 50 km-wide Matakaoa re-entrant (Lamarche et al., 2008a). Elsewhere smaller debris slides, slumps and head-wall scarps are abundant, indicating ongoing slope instability (e.g. Lewis et al., 1998). The current study focuses on sediment cores within the Poverty, Ruatoria, and Matakoa re-entrants. The 1500 km^2 Poverty re-entrant is a major continental margin depression resulting from successive margin collapses since 1500 ± 500 ka (Pedley et al., 2010). The bathymetry of the Poverty re-entrant is complex and comprises several basic morphologic components (Orpin, 2004) including: a heavily gullied upper slope; the beheaded Poverty Canyon System; the gently sloping mid-slope Paritu Trough; margin-parallel North and South Paritu Ridges that are cross-cut by a small canyon feeding into the Lower Paritu Basin (Fig. 2). The Paritu Trough is filled with the Poverty Debris Avalanche (PDA), which is blanketed by sediments. Although the PDA is undated, the surface of the avalanche is rough and hummocky following a giant debris avalanche 170 ± 40 ka ago (Collot et al., 2001). The re-entrant consists of a gullied upper slope, a vast highly chaotic debris avalanche composed of individual blocks of several cubic kilometres in size, and the subduction trough (Fig. 3). The 1000 km^2 Matakaoa re-entrant resulted from multiple mass transport events, which occurred between 1300 and 35 ka ago (Carter, 2001; Lamarche et al., 2008a; Joanne et al., 2010) (Fig. 4). The eastern half of the re-entrant is infilled by the Matakaoa Turbidite System (MTS), which developed subsequently to the Matakaoa Debris Avalanche, 600 ± 150 ka ago (Joanne et al., 2010). The MTS is a classical channelised turbidite system with a canyon incising into the shelf break, a well-developed channel/levee turbidite plain and a fan growing in the Raukumara Plain.

In the Hikurangi Trough, the 2000 km-long Hikurangi Channel drains large turbidity currents parallel to the North Island East Coast (Lewis et al., 1994; 1998; Lewis and Pantin, 2002) (Fig. 1). At the latitude of the Poverty re-entrant, the channel is redirected sharply eastward (Fig. 1). There, well developed overbank sediment waves grew over the last 2 Ma, due to the combined effect of centrifugal and southern hemisphere Coriolis force. Sediment waves in the channel axis are comprised of stacked coarse turbidites overlain by a hemipelagic drape, suggesting limited activity during interglacial periods with episodic flows contained into the channel.

2.2. Sedimentology

Up to a kilometre of Quaternary sediment fill accumulates in ponded basins along the northern Hikurangi Margin continental shelf (Lewis et al., 2004) and slope (Orpin, 2004; Orpin et al., 2006; Paquet et al., 2009) as well as in the Hikurangi Trough (Lewis and Pettinga, 1993) and Raukumara basin (Kohn and Glasby, 1978) (Fig. 1). The mass accumulation rate along the margin is generally high over the last 1 My (4 Mt/a in Hawkes Bay), with millennial variations over glacio-eustatic cycles (Carter and Manighetti, 2006; Paquet et al., 2009). Over the last 30 ka, the highest rates were recorded during last-glacial lowstand through to the early highstand stage (30–7 ka). The Holocene highstand period (7–0 ka) shows a declining flux to the lower continental slope as more sediment is retained in subsiding shelf basins (Gerber et al., 2010) and baffled in intra-slope basins bounded by imbricate thrust ridges (Lewis