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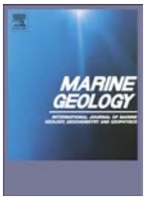

Erosional features as indicators of thrust fault activity (Nankai Trough, Japan)☆

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ABSTRACT

A submarine channel system and basal ramps of a Quaternary mass-transport deposit (MTD) are shown to represent thrust fault activity in the Nankai accretionary wedge. Variations in channel bed slope, height and width of submarine channels and gullies indicate uplift and sediment bypass seaward from a margin-dominating out-of-sequence thrust, the megasplay fault (MSF), at <1.67–1.46 Ma. Between ~1.05 and 0.85 Ma, a younger mass-transport deposit (MTD 6) was detached at different depths. Demonstrating the significant deformation observed in the study area, the direction of transport of MTD 6 differs 30°–45° from the strike of scarps and ramps at its base, which are parallel to the structural contours of thrust anticlines underneath. This character contrasts to the geometries frequently documented in frontally-emergent submarine landslides. Oblique basal ramps form significant boundaries between zones of MTD 6 with distinct acoustic and, suggestively, petrophysical properties. As a result of this study, we postulate that developed channel systems can erode the upper continental slope and lead to bypass of substantial volumes of sediment to distal parts of accretionary wedges. This process bears the potential of generating periods of more intense thrust-wedge deformation than those predicted by mathematical and physical models based on present-day taper geometries. On a regional scale, the observations in this paper are important as they indicate a more diffuse distribution of deformation in the Nankai accretionary wedge than previously assumed for the MSF region.

1. Introduction

The mechanics behind the deformation of accretionary wedges have been described by the Coulomb wedge theory, in which the outer wedge is considered at a critical state (i.e. the wedge is on the verge of failure) or reaching critical state after large earthquakes (Davis et al., 1983; Dahlen, 1984, 1990; Wang and Hu, 2006). In these conditions, rapid mass redistribution can occur throughout, or across, large regions of accretionary wedges (Beaumont et al., 1999; Dominguez et al., 2000; von Huene et al., 2005; Camerlenghi and Pini, 2009; Smit et al., 2010; Yamada et al., 2010, 2012). Yet, few examples of erosional features with impact on accretionary wedge geometry and growth have been documented (Berger and Johnson, 1980; Davis et al., 1983; Konstantinovskaya and Malavieille, 2005; Graveleau and Dominguez, 2008; Konstantinovskaya and Malavieille, 2011; Buiter, 2012; Kitamura and Yamamoto, 2012). This under-representation in the literature poses important limitations, as erosional features formed adjacently to active structures can be helpful markers of tectonic deformation on convergent margins (Bangs and Cande, 1997; Dominguez et al., 1998; Tsuru et al., 2000; Tamaki et al., 2009). In particular, to recognise enhanced periods of tectonic deformation on convergent margins is important because they are associated with: a) a relative increase in the activity of large-scale seismogenic faults; b) the generation of major fluid-flow paths extending from subducted slabs to the surface, and; c) the triggering of recurrent slope instability events (Lucente and Pini, 2008; Kitamura and Yamamoto, 2012; Ratzov et al., 2012).

Mass-transport deposits (MTDs) are primary features capable of imposing changes to the architecture of accretionary wedges (Ashi and Taira, 1992; Wang and He, 1999; Buiter, 2012). In such deposits, basal erosional features can be important to the recognition of tectonically active structures, similar to what is documented for sub-aerial landslides (Masek et al, 1994; Matsushi et al., 2006; Korup et al., 2007; Lavé and Avouac, 2011). A key character in basal erosional features of MTDs is that they resemble brittle structures (Gee et al., 2005; Ashabranner et al., 2010). Brittle structures reflect the loss of internal cohesion along specific surfaces when the elastic limit is exceeded under an applied stress (Hancock, 1985; Sibson, 1998).

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A second example of features with impact on the evolution of accretionary wedges comprises submarine channels generated during periods of enhanced tectonic uplift. On land, there are established scale-relationships between the rates of tectonic uplift and the evolution of specific landscape features (Mann et al., 1998; Humphrey and Konrad, 2000; Maruyama and Lin, 2000; Nakada et al., 2002; Finnegan et al., 2005; Matsushi et al., 2006; Kagohara et al., 2009). Similar relationships have been established for submarine channels, particularly in upper slope areas where downslope eroding sediment flows are known to promote headward erosion (Pratson et al., 1994; Pratson and Coakley, 1996; Mitchell, 2005). Incision rates of channels are generally assumed to be a function of their geometry, with the landscape evolving towards a steady state in which the lowering of topography by erosion is equal to uplift (Lague et al., 2003; Huyghe et al., 2004; Turowski et al., 2006; Heiniö and Davies, 2007; Turowski et al., 2008, 2009; Covault et al., 2011). As a result, three main parameters vary consistently in submarine channels, gullies and furrows as they do in their onshore counterparts: (1) channel/gully bed slope gradient increases with increasing tectonic uplift of the substrate, demonstrating a close relationship between erosion and seafloor deformation; (2) drainage basins with complex channel networks (orders 2–3) are installed after an initial phase showing relatively low rates of incision; (3) the width of erosional features decreases and the depth of incision increases proportionally to tectonic uplift (Orange, 1999; Mitchell, 2005; Turowski et al., 2006; Kolla, 2007; Covault et al., 2011; Turowski et al., 2008). Moreover, tectonic uplift on continental margins is frequently associated with seafloor faulting and gully erosion atop active anticlines (e.g. Mountjoy et al., 2009), a process further emphasised by climatic and oceanographic phenomena (Lewis et al., 1994; Micallef and Mountjoy, 2011).

This paper explores a section of the tectonically active Nankai accretionary wedge offshore Japan to elucidate the importance of erosional features as proxies to recognise the margin's tectono-morphological development (Fig. 1). This approach led us to postulate that enhanced periods of erosion, as the incision of submarine channel systems, affected the balance of the critical taper offshore Nankai after 1.67 Ma. This imbalance precluded the onset of a feedback loop favouring further fault propagation, seismic activity and slope instability as a part of a process that ultimately resulted in the deposition of a Quaternary mass-transport deposit (MTD 6, Expedition 333 Scientists, 2011).

The timings and rates of uplift of structures offshore Nankai are here related to the evolution of submarine channel systems and basal scarps of MTDs. This is achieved by compiling morphological data such as width, height and orientation of seafloor erosional features. For this purpose, we use 3D seismic and borehole data to analyse the progressive incision of submarine channels adjacently to thrust faults (named S1 and S2 in this paper), and associated anticlines (A1 to A5) located downslope from a large out-of sequence thrust, the megasplay fault (MSF, Expedition 333 Scientists, 2011) (Figs. 2 and 3). Later in this paper a Quaternary MTD is investigated (MTD 6, Expedition 333 Scientists, 2011), the source area of which has been interpreted to coincide with the active MSF zone (Strasser et al., 2011) (Fig. 2a).

In summary, the scientific objectives of this paper are:

- To document the incision of a channel system over uplifting thrust anticlines located downslope from the MSF;
- To investigate how the geometry of ramps and flats below a Quaternary MTD relates to active thrust faults and associated anticlines;
- To understand why basal ramps mark zones of MTDs with distinct internal seismic characters;
- To assess statistical parameters associated with the progressive development of the studied channel system, and how these relate to seafloor uplift, splay fault activity and, ultimately, to the stability of critical tapers of convergent margins.

This work concludes on the progressive development of erosional features on the Nankai slope between 1.67 and 0.85 Ma, and their use as proxies for the recognition of active fault structures in accretionary wedges.

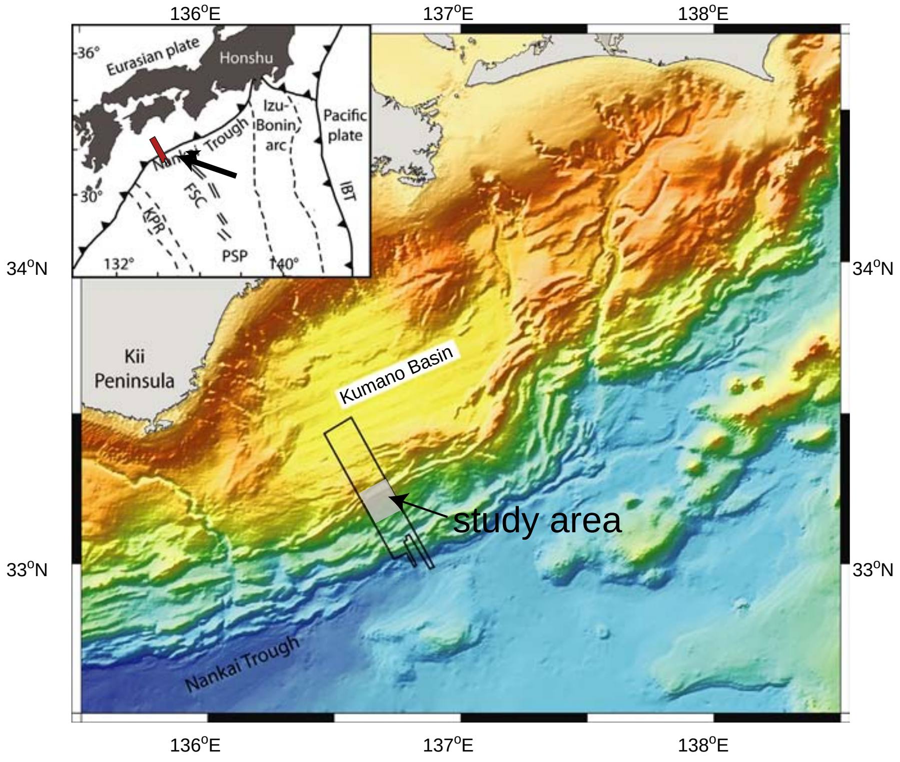

Fig. 1. Location of the study area and Kumano Transect across the Nankai Trough accretionary wedge. Arrow in inset indicates the position of the interpreted 3D seismic volume in SE Japan. IBT-Izu-Bonin Trench; KRP-Kyushu-Palau Ridge; FSC-Fossil Spreading Centre; PSP-Philippine Sea Plate.

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