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Deep-sea sedimentation offshore eastern Taiwan: Facies and processes characterization

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ABSTRACT

Recent sedimentary facies and processes along the offshore slope of east Taiwan are investigated using a large set of geophysical and sedimentological data. The Taiwan orogen is often considered as one of the most tectonically active regions in the world and also suffers important climatic activity with an average of four typhoons per year. We have mapped in details the morphosedimentary features and characterized the sedimentary facies along offshore eastern Taiwan. There, we show that the slope is driven by a variety of erosional processes from mass wasting to turbidity current. Mass movements such as slides or mass transport deposits (MTDs) are ubiquitous and affect the whole east coast off Taiwan. Detailed core investigations, such as grain size analysis, chemical and mineralogical composition, revealed that turbidite facies range from thin fine-grained turbidites to thick massive turbidite facies. The detailed analysis of turbidite beds allow us to discuss the controlling factors of turbidity current generation. Turbidity currents represent an important sedimentary process that governs the slope morphology off east Taiwan. Triggering mechanisms likely range from slope instabilities related to earthquakes shaking to failure relative to climatic-controlled pulses of sediment supply. We propose that at least two end-members are characteristics in our turbidite records in term of controlling factor:

1) Turbidity currents likely generated by tectonic activity and earthquakes shaking in particular; and
2) Turbidity currents likely generated by climatic activity such as typhoon-induced floods.

1. Introduction

Along active margins, gravity flows represent the main erosional process that controls slope morphology and governs sediment dispersal in the oceanic realm (Masson et al., 2006). Gravity flows include massive debris avalanches (Collot et al., 2001), slide/slumps, cohesive debris flows, fluidized flows (Mulder and Cochonat, 1996; Mulder and Alexander, 2001) and turbulent flows such as turbidity currents (Bouma, 1962; Mulder and Alexander, 2001). These sedimentary processes result in a variety of deposits (slumps, MTDs, Turbidites) and are triggered or facilitated by a wide range of factors including tectonic forcing (uplift and slope oversteepening, earthquakes) and climatic forcing (catastrophic floods, sea-level variations, wave loading, storms, sediment overloading), or a combined effect of both (Einsele, 1996; Locat and Lee, 2002; Piper and Normark, 2009). Additionally, longshore currents may also locally rework, transport and accumulate shelf material or the one supplied by rivers (Romans et al., 2009; Covault and Graham, 2010). The Taiwan mountain belt, represents a peculiar place to investigate such sedimentary processes because it displays a variety of morphological settings, an intense tectonic and seismic activity, and high sedimentation rates (Huh et al., 2004, 2006). Since the last decades, the Taiwan area has been studied through abundant tectonic and geophysical investigations but it appears that only few studies focused on morphosedimentary processes (Huang et al., 1992; Dadson et al., 2005; Ramsey et al., 2006). Because of a lack of "ground-truth" data it is still uncertain to provide a clear assessment about the erosional processes that shape the seafloor offshore eastern Taiwan and their controlling factors. Using a compilation of a large pre-existing geophysical dataset and newly acquired sedimentological data, we aim to characterize the variability of sedimentary facies in such an active context. This work will provide new considerations on

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recent sedimentation and constrain the sedimentary processes. The results will give insights to the controlling factors of such sedimentary processes offshore eastern Taiwan. This work is important for future studies and geohazard assessment such as submarine landslides or hyperpycnal flows that may trigger tsunamis or telecommunication cables breakage (Hsu et al., 2008; Carter et al., 2012).

2. Regional settings

2.1. Geological context

The Taiwan mountain belt results from the rapid and oblique convergence of the Luzon arc carried by the Philippine Sea Plate (PSP), and the passive Chinese continental margin (CCM, Fig. 1A) (Biq, 1972; Suppe, 1984). Plate kinematics predicts about 80 mm/year of convergence between these two plates (Seno et al., 1993). The orogen links two subduction systems dipping with opposite vergence: to the South the Manila subduction zone and to the east the Ryukyu subduction zone (Fig. 1A). South of Taiwan, the South China Sea lithosphere is being subducted eastwards beneath the PSP, building an accretionary wedge progressively uplifted above the sea level. To the northeast, the PSP slab is retreating southwards beneath the Eurasian margin resulting on the opening of the Okinawa back-arc domain and the collapse of the northern part of the Taiwan mountain belt.

2.2. Regional climate, drainage systems and sediment discharge

Taiwan is positioned within the "Typhoon Alley" (Liu et al., 2008) and is impacted on average by three or four typhoons annually. Therefore, Taiwan receives not only abundant precipitation due to its southern Asian monsoon climate, but periodically heavy rains during typhoons (Wu et al., 1999; Lin et al., 2002; Galewsky et al., 2006; Liu et al., 2008). The Morakot Typhoon (2009) was the worst event of the last 50 years with a 2777 mm accumulated rainfall (Ge et al., 2010). It triggered 12,697 landslides (Tsou et al., 2011; Wu et al., 2011) and exceptional flooding in Southern Taiwan, and left 700 casualties and catastrophic damages. The east flank of the Central Range is drained by rivers, incising the geological units. The Coastal Range, elongating along the east coast of Taiwan, represents a dam and captures the rivers. The runoff collected along the Longitudinal Valley (Fig. 1B) is diverted around the northern and southern edges of the Coastal Range in the Hualien and Beinan rivers respectively. The Hsiukuluan river is the only drainage cutting through the Coastal Range. Northeast of Taiwan, the Hoping and the Liwu rivers (Fig. 1B) are the major rivers collecting the runoff from the Central Range. In Southeastern Taiwan, the Taimali River and smaller rivers (e.g Jinlun river, Nongxi river, Dawu river and Daren river, see Fig. 1B for location) accumulate most of the runoff from the Hengchun Peninsula (Fig. 1B). With high relief, steep gradients, important tectonic activity, heavy rainfall and frequent typhoons, Taiwan has the highest sediment production worldwide, and possesses 7 of the 10 global rivers with the highest sediment yield (Li, 1976; Milliman and Syvitski, 1992; Chen et al., 2004; Dadson et al., 2004; Liu et al., 2008). Taiwanese rivers presently annually discharge >300 Mt of sediments to the surrounding ocean and >30% of the total sediment from Taiwanese rivers is discharged at hyperpycnal concentrations (Dadson et al., 2005; Kao and Milliman, 2008; Liu et al., 2008). The river discharges on the east coast of Taiwan reaches about 150 Mt/year (Liu et al., 2008).

2.3. Submarine morphology

The morphology off eastern Taiwan displays a complex interaction between onshore and offshore processes in a context of high tectonic activity and extreme tropical rainfalls. From latitude 22°N to 24.5°N, the margin includes a flat narrow shelf, a steep incised slope, oceanic basins and sedimentary ridges such as the Huatung ridge and the Hsincheng ridge (Fig. 1B). The shelf is <10 km-wide, with a slope break at ~100 m water-depth. The slope displays steep slope gradients (15 to 20°) and is deeply incised by gullies and canyons (Fig. 1B). Downslope, they merge to form a dendritic channel pattern transferring sediments to deep oceanic basins (Ramsey et al., 2006). The slope also

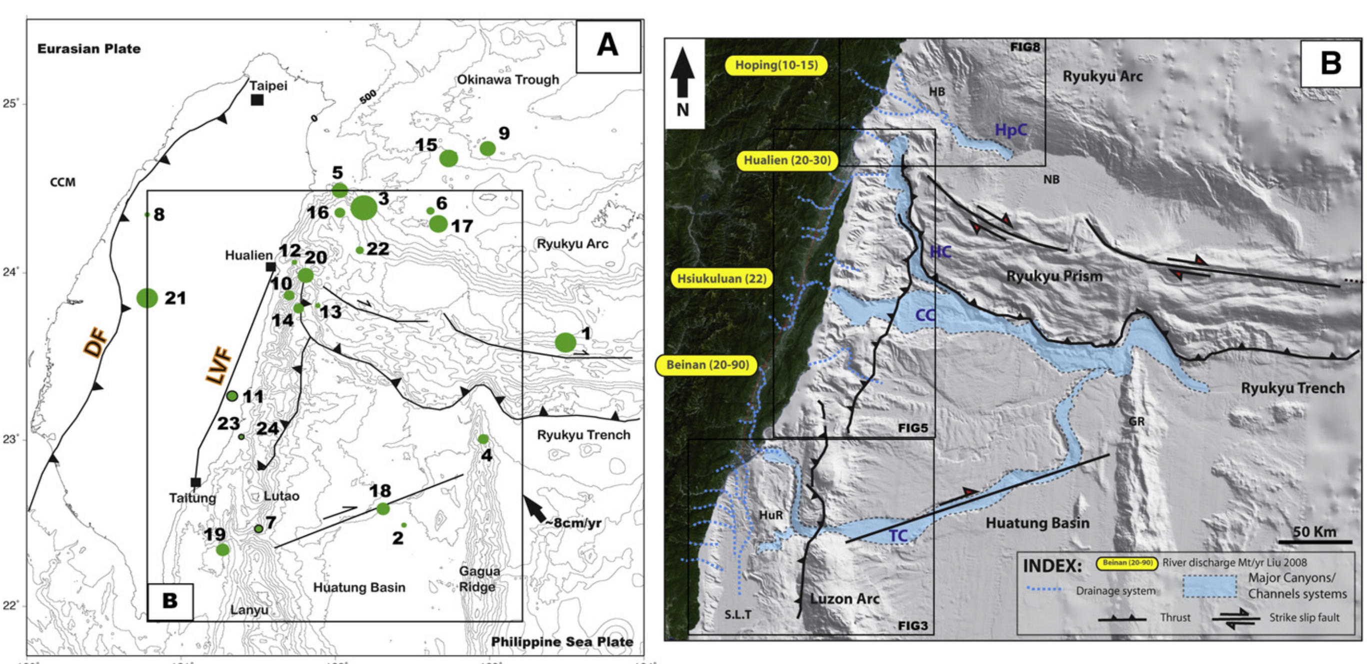

Fig. 1. A: Geodynamic context of Taiwan and plate boundaries, the box represents a zoom on the study area shown in B. CCM = Chinese continental margin, DF = Deformation Front, LVF = Longitudinal Valley Fault. The green circles represent the major earthquakes (Mw > 6.8) that struck the Taiwan island during the 20th century. Bathymetry is represented with contour line every 500 m and derived from the ACT96 survey; B: Recent sedimentary systems offshore eastern Taiwan showing the main active canyons and the actual drainage system. In yellow boxes are represented the river discharge in Mt/year after Liu et al. (2008). HB = Hoping Basin, NB = Nanao Basin, SLT = Southern Longitudinal Trough, HuR= Huatung Ridge, TC= Taitung Canyon, CC= Chimei Canyon, HC= Hualien Canyon, HpC= Hoping Canyon.