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Does subduction of mass transport deposits (MTDs) control seismic behavior of shallow–level megathrusts at convergent margins?

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ABSTRACT

We present a critical appraisal of the role of subducted, medium (10–1000 km^2) to giant (≥1000 km^2) and heterogeneous, mud-rich mass transport deposits (MTDs) in seismic behavior and mechanisms of shallow earthquakes along subduction plate interfaces (or subduction channels) at convergent margins. Our observations from exhumed ancient subduction complexes around the world show that incorporation of mud-rich MTDs with a "chaotic" internal fabric (i.e., sedimentary mélanges or olistostromes) into subduction zones strongly modifies the structural architecture of a subduction plate interface and the physical properties of subducted material. The size and distribution of subducted MTDs with respect to the thickness of a subduction plate interface are critical factors influencing seismic behavior at convergent margins. Heterogeneous fabric and compositions of subducted MTDs may diminish the effectiveness of seismic ruptures considerably through the redistribution of overpressured fluids and accumulated strain. This phenomenon possibly favors the slow end-member of the spectrum of fault slip behavior (e.g., Slow Slip Events, Very Low Frequency Earthquakes, Non-Volcanic Tremors, creeping) compared to regular earthquakes, particularly in the shallow parts ($T < 250$ °C) of a subduction plate interface.

1. Introduction

Most large magnitude earthquakes (Mw ≥ 8.5) that occurred in the past are shown to have taken place along the frictional interface between two converging plates at subduction zones (e.g., Byrne et al., 1988; Scholz, 2002; Heuret et al., 2012; Scholl et al., 2015). Several interlinked geological, physical and mechanical factors have been proposed to explain different seismic behaviors of subduction plate interface, such as the coupling strength (e.g., Lay and Kanamori, 1981; see also Uyeda and Kanamori, 1979; Scholz and Campos, 2012; Doglioni et al., 2007), slab retreat (e.g., Doglioni et al., 2007), upper plate motion and the related-stress regime (Peterson and Seno, 1984; Scholz and Campos, 1995; Heuret et al., 2012), down-dip width of a seismogenic zone (e.g., Kelleher et al., 1974; Corbi et al., 2017), megathrust curvature (Bletery et al., 2016), and trench migration velocity (Schellart and Rawlinson, 2013). Among these factors, subduction of thick piles of trench sediments (i.e., thickness ≥ 1 km) appears to play a critical role in facilitating seismic rupture propagation and high-magnitude earthquake occurrences (Mw ≥ 8.5), by smoothing out lateral relief gradient and strength-coupling asperities at a subduction plate interface (Ruff, 1989; Heuret et al., 2012; Scholl et al., 2015; Seno, 2017; Brizzi et al., 2018). However, the occurrence of giant earthquakes (Fig. 1) at convergent plate boundaries, which are characterized by both sediment-flooded (e.g., Sumatra, Central-South Chile, Alaska/Aleutians) and sediment-poor trenches (e.g., Kamchatka, Northern Chile, Northern Peru, Northern Japan) (see, e.g., Kopp, 2013), suggests that some other factors such as the internal architecture and the mechanical properties of subducted material (e.g., composition, friction and strength properties, permeability, stiffness, fracture toughness; Fagereng and Sibson, 2010 and reference therein), as well as the thickness of a subduction plate interface (Rowe et al., 2013), may play a more significant role than sediment supply rates in influencing the seismic behavior at shallow depths in subduction zones. Particularly, subduction of heterogeneous material characterized by strong internal contrast in competence that is typical of mélanges and shear zones has been reported as a significant factor affecting seismic style within a subduction plate interface or in a subduction channel shear zone (e.g., Cloos, 1982; Raymond, 1984; Cowan, 1985; Festa et al., 2010; Codegone et al., 2012; Dilek et al., 2012). Mixing of competent blocks of oceanic crust with

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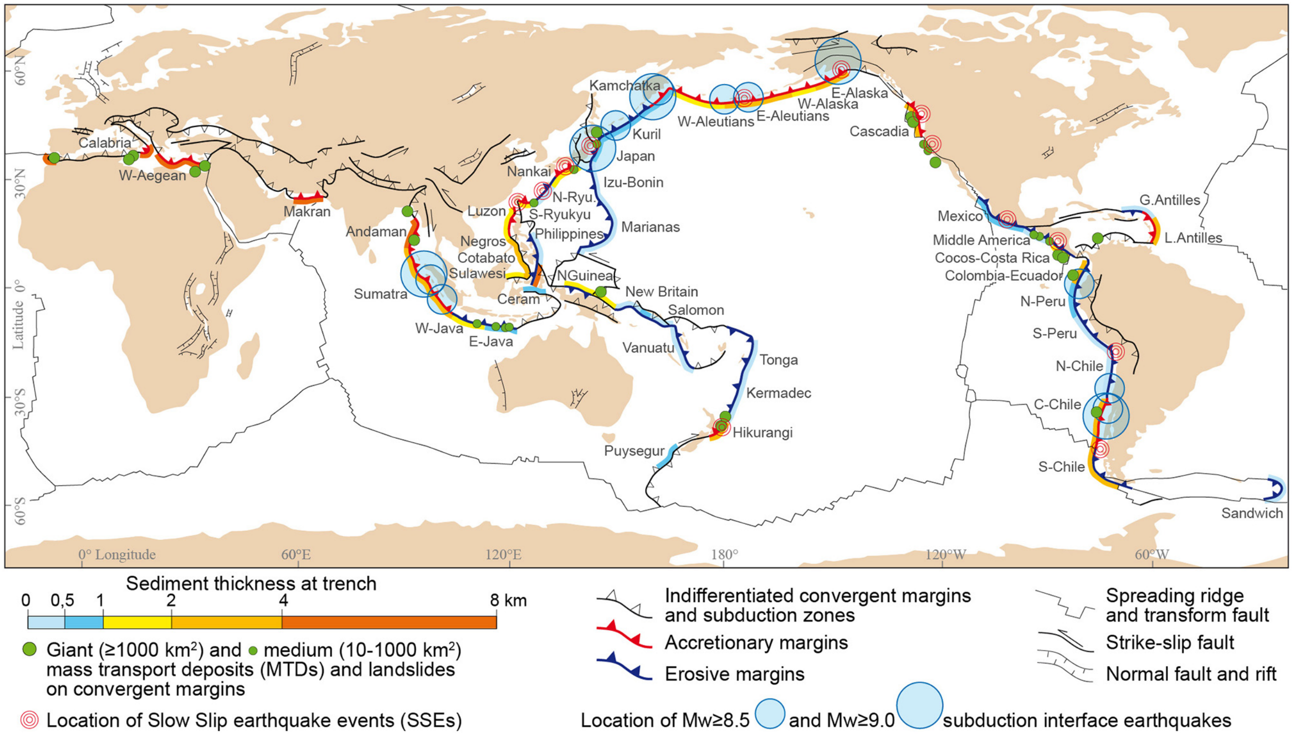

Fig. 1. Global distribution of accretional and erosional subduction zones (modified from Clift and Vannucchi, 2004; Scholl and von Huene, 2009) and the distribution of subduction interface earthquakes with magnitudes >8.5 (from Heuret et al., 2012; Scholl et al., 2015). The color bar shows sediment thickness variations in different trenches (modified from Clift and Vannucchi, 2004; Heuret et al., 2012; Scholl et al., 2015). Also shown on this map are slow slip earthquake events (SSEs; from Obara and Kato, 2016), and medium (area 10–1000 km^2) to giant (area > 1000 km^2) mass transport deposits (from von Huene et al., 2004; Urgeles and Camerlenghi, 2013; Festa et al., 2016; Moscardelli and Woods, 2016).

incompetent fluid-saturated trench-fill sediments and big differences in the proportion between competent blocks and weak matrix material create the highest competence gradient (Fagereng and Sibson, 2010).

Complex interplay between all these geological, physical and mechanical factors constitutes a major cause for a wide range of slip behaviors observed at a large number of subduction plate interfaces around the world. Slip rates may range from plate convergence rates (1–10 $cm \cdot year^{-1}$) during aseismic creep to slip rates of ~1 $m \cdot s^{-1}$ during earthquake propagation (e.g., Fagereng and den Hartog, 2016 and reference therein). In between these end members, different types of slow-slip events (SSEs) and low-frequency earthquakes (LFEs) show an intermediate range of slip rates with durations of days or years, representing a transitional seismic state between stable sliding (i.e., steady aseismic creep) and earthquake rupturing (e.g., Ide et al., 2007; Schwartz and Rokosky, 2007; Peng and Gomberg, 2010; Obara and Kato, 2016).

In this paper, we examine heterogeneous, mud-rich mass transport deposits (MTDs hereafter) subducted along subduction plate interfaces, and discuss how they may affect the seismic behavior at convergent margins by strongly modifying the internal architecture and the mechanical – physical properties of subducted material. We suggest that the heterogeneous fabric and compositions of subducted MTDs may diminish the effectiveness of seismic ruptures, favoring mixed continuous-discontinuous shearing. Because it is highly difficult to decipher the internal architecture and composition of modern subduction plate interfaces through seismic reflection and tomography studies, our observations and interpretations presented here are largely based on on–land analogues of megathrust shear zones in ancient subduction complexes exposed in the Northern Apennines (Italy), the *peri*–Mediterranean region, the Appalachians, and the circum–Pacific region where the existence of fossil submarine MTDs is well documented. These exhumed, ancient MTDs show strong similarities in size, distribution, recurrence interval, and run-out distance with modern submarine slide deposits in active continental margins (e.g., Camerlenghi and Pini, 2009; Urgeles and Camerlenghi, 2013; Ogata et al., 2014a, 2014b; Festa et al., 2014, 2016; Moscardelli and Woods, 2016).

2. Temporal and spatial recurrence of MTDs in subduction-accretion complexes

MTDs represent earth material that has been redeposited on the seafloor following its remobilization and transportation as a result of slope failure, gravitational deformation and/or tectonic activities (Lamarche et al., 2008, and references therein). Although submarine MTDs may develop in various tectonic settings, they commonly occur on continental slopes at convergent margins where high fluid pressures, high-magnitude seismic events, high sedimentation rates, rapid crustal uplift, tectonic erosion, and swift critical taper adjustments contribute to slope instability (Coleman and Prior, 1988; McAdoo et al., 2000; Collot et al., 2001). These chaotic deposits are, therefore, significant components of subduction complexes. In this section, we first discuss the occurrence and distribution of MTDs in both modern and ancient subduction complexes, and then examine the fate of subducted MTDs.

2.1. Modern subduction-accretion complexes

High-resolution multibeam echosounding surveys (e.g., von Huene et al., 1989, 2004) at modern convergent margins have helped documenting a wide spectrum of MTDs (Fig. 1), ranging from slumps to slides (e.g., Japan Trough, see Strasser et al., 2013 and reference therein) and debris-blocky flows (e.g., the Ruatoria MTD in Hikurangi margin, see Collot et al., 2001) with km-size megablocks embedded in a mud-rich to debrite matrix (see also, e.g., Moscardelli and Woods, 2008; Geersen et al., 2011; Urgeles and Camerlenghi, 2013; Ogata et al., 2014a; Ortiz-Karpf et al., 2016). Medium (10–1000 km^2) to giant (≥1000 km^2) MTDs that are composed mainly of debris-blocky flows occur in both erosional and accretionary convergent margins (Figs. 1, 2A), independently of the thickness of trench-fill sediments