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Seamount subduction at the North-Ecuadorian convergent margin: Effects on structures, inter-seismic coupling and seismogenesis

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ABSTRACT

At the North-Ecuadorian convergent margin (1°S–1.5°N), the subduction of the rough Nazca oceanic plate leads to tectonic erosion of the upper plate and complex seismogenic behavior of the megathrust. We used three selected pre-stack depth migrated, multi-channel seismic reflection lines collected during the SISTEUR cruise to investigate the margin structure and decipher the impact of the subducted Atacames seamounts on tectonic erosion, interseismic coupling, and seismogenesis in the region of the 1942 Mw7.8 earthquake.

This dataset highlights a subducted ~30 × 40 km, double-peak seamount that belongs to the Atacames seamount chain and that is associated with a deep morphologic re-entrant containing mass transport deposits.

The seamount subduction uplifted the margin basement by ~1.6 km and pervasively broke the margin by deep and intense reverse faulting ahead of the seamount, a process that is likely to weaken considerably the margin. In the seamount wake, the basement reverse fault system rotated counter-clockwise. This faulted basement is overlain with slope sediment sliding along listric normal faults that sole out onto the BSR. This superposition of deep tectonic contraction within the basement and shallow gravitational extension deformation within the sediment highlights the key role of gas hydrate on outer slope erosion. In addition to long-term regional basal erosion, the margin basement has thinned locally by an extra 0.8–1 km in response to the subduction of the Atacames seamount chain and hydrofracturing by overpressured fluids at the margin toe. This pervasively and deeply fractured margin segment is associated with a seismically quiet and GPS-modeled low interseismic coupling corridor that terminates downdip near the 1942 epicenter and locked zone. We suggest that the deeply buried double-peak Atacames seamount triggered the 1942 earthquake ahead of its leading flank. This result supports previous studies proposing that subducted seamounts provide unfavorable conditions for locking the updip segment of the plate boundary limiting the updip extent of seismogenic zones, but may favor large subduction earthquakes at greater depths.

1. Introduction

Seamount subduction impacts the seismic activity at convergent margins. Models and field studies propose that seamounts act as seismic asperities capable of triggering great subduction earthquakes (Cloos, 1992; Scholz and Small, 1997) or as seismic barriers that inhibit seismic rupture propagation (Aki, 1979; Kodaira et al., 2000) by increasing the normal stress to the plate interface. In contrast, other studies argue that subducted seamounts create a complex stress and structure environment (Wang and Bilek, 2011) by activating or reactivating fracture networks in the upper plate (Collot et al., 1992; Dominguez et al., 1998) so that seamounts would subduct predominantly aseismically, producing only small and moderate-size earthquakes. Moreover, upward ex-

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pulsion of overpressured fluids from within the fractured subducting crust and fluid-rich sediments in the subduction channel around subducted seamounts tend to decrease the interplate seismic coupling (Moreno et al., 2014). Mochizuki et al. (2008) reported that a sequence of Mw7.0 earthquakes occurred down-dip of a subducted seamount since the 1920s, while the seamount remained aseismic. The authors suggested that the seamount kept creeping during this time period to allow renewing stress for the Mw7.0 earthquakes to produce. In addition, numerical models by Yang et al. (2012) show that under specific conditions a subducted seamount may generate or stop megathrust ruptures. These models and observations raise the question of the role of subducted seamounts onto interplate seismic coupling and large earthquake generation.

Subduction of topographic-highs (e.g. Dominguez et al., 1998; Hampel et al., 2004) and hydrofracturing by overpressured fluids (e.g. von Huene et al., 2004) are frequently invoked as major causes for subduction erosion and deformation that affect more than 50% of worldwide convergent margins (e.g. Clift and Vannucchi, 2004). At long-term erosive margins, topographic-high subduction leads to short-lived indentation, steepening of the outer slope, a temporal sequence of fore-arc uplift and subsidence (Collot et al., 1992; Hampel et al., 2004), pervasive fracturing (Dominguez et al., 1998) and moderate basal erosion of the margin basement (Bangs et al., 2006; Ranero and von Huene, 2000). The results of basal erosion have rarely been imaged with seismic data because of the poor penetration of seismic energy through highly attenuating acoustic basement.

Using three multi-channel seismic reflection lines from the SISTEUR cruise (Collot et al., 2002) migrated to depth, we investigate the structural pattern of a segment of the erosive (Sage et al., 2006) and seismogenic North-Ecuadorian (1°S–1.5°N) subduction zone (Fig. 1) that is undergoing seamount subduction, adjacent to the epicenter of the 1942 Mw7.8 subduction earthquake. We analyze the influence of this seamount onto the subduction erosion, interseismic locking and coseismic slip.

2. Regional settings

2.1. Structure and tectonic pattern

The Neogene Nazca plate underthrusts the Ecuadorian fore-arc with a convergence vector of 4.7 cm/yr in a N83°E direction (Nocquet et al., 2014) (Fig. 1A). The Carnegie ridge, up to 2-km-high, shows a maximum crustal thickness of 14 km (Graindorge et al., 2004) to 19 km (Sallares et al., 2005) at the ridge apex, 1°S–1°20′S, decreasing northward to less-than-10 km at 0° (Sallares et al., 2005). The Atacames seamounts chain, 0°25′–0°55′N, which stands immediately north of the Carnegie ridge, is a N–S-trending line of four 1 to 1.5-km-high seamounts. The southernmost Atacames seamount is located in the trench, facing the Atacames re-entrant in the margin (Collot et al., 2005). N20°-trending, landward-facing, bending fault scarps in the trench outer wall bound narrow and thin trench basins, which contain 0.5 km of turbidite/hemipelagite fill overlying ∼0.5 km of Carnegie ridge draping (Ratzov et al., 2010). Multi-kilometer scale depressions, up to 400-m-deep, are widely distributed along the mid-slope of the northern and southern flanks of the ridge (Michaud et al., 2005). These morphologic heterogeneities together with the thin trench fill roughen the surface of the oceanic plate.

The 15 to 35-km-wide margin outer slope is indented by gullies, scarps and re-entrants (Collot et al., 2009) and fronted by mass transport deposits reworked in frontal prisms indicating a non-accretionary and/or erosive frontal tectonic regime (Collot et al., 2002). 40-km-wide semi-circular re-entrants *R1*, *R2* and *R3* separated by shallow spurs impinge the upper margin without affecting the deformation front (Fig. 1A). The re-entrants formed long before 25 kyr, the age of the oldest hemipelagic sediment recovered in the sediment pile deposited in re-entrant *R1* (Ratzov et al., 2010). In contrast, a series of 5-km-wide indentations forms the 20-km-wide Atacames re-entrant and steep scarp *S*, incises the deformation front and is associated with a mass transport unit whose youngest deposits are ∼3040 ± 60 yr old (Ratzov et al., 2010). Steep scarp *S* is bounded landward by shallow spur *P* between re-entrants *R1* and *R2*.

2.2. Seismicity and subduction earthquakes

The 1942 Mw7.8 subduction earthquake ruptured an interplate area of 100 × 200 km that extended northward to the Esmeraldas Platform and southward to the area of the Carnegie ridge crest subduction (Kanamori and McNally, 1982; Swenson and Beck, 1996) (Fig. 1B). The rupture zone purportedly extended as far west as the trench but no tsunami was reported suggesting a small or insignificant seafloor deformation near the trench (Swenson and Beck, 1996). Most 1942 aftershocks (white circles in Fig. 1B) were located in the trench or beneath the continental shelf and very few beneath the margin slope (Mendoza and Dewey, 1984). The CMT Harvard catalog indicates that the earthquakes with thrust focal mechanism (red beach-balls in Fig. 1B) are located at depth beneath the continental shelf. 33 additional focal mechanisms (blue beach-balls in Fig. 1B) of well-located crustal earthquakes (Mw > 4) recorded since 1988 by the local Ecuador seismic network (RENSIG) indicate a more complex distribution of rupture types including normal faulting, oblique thrusting and strike-slip deformation (Alvarado, 2012).

The micro-seismicity from 1994 to 2007 (colored circles in Fig. 1B) is heterogeneously distributed (Font et al., 2013). The shallow Galera and Jama clusters (Fig. 1C and E) extend trenchward to 18–20 km from the deformation front and are interpreted as interplate or upper plate events (Font et al., 2013). In contrast, within the study area in between, micro-seismicity is markedly absent beneath the outer-margin wedge and diffusely distributed at greater depth, near and landward of the 1942 epicenter (Fig. 1D). Font et al. (2013) indicate that earthquake locations are based on a 3D georealistic P-velocity model that integrates all published information on structures and velocities along the Ecuadorean margin, including the results from several OBS experiments. They conclude that the average location uncertainties dx, dy and dz are ±2.1 km, ±1.9 km and ±1.4 km. This excellent location accuracy clearly supports the seismic quiescence of the study area.

3. Seismic data and method

During the SISTEUR cruise (Collot et al., 2002) we recorded multi-channel seismic data with a 45-fold coverage, using a 360-channel, 4.5-km-long hydrophone streamer and a source formed of 45-L air gun tuned in a single bubble mode. Seismic pre-processing performed with Geocluster includes time variant band-pass filters, minimum phase conversion of the signal, external and internal mutes, multiple attenuation in the frequency-wave number (FK) domain and deconvolution. The pre-processed data, sorted in Common-Depth Point, is stacked and time migrated using a Kirchoff migration. The pre-processed data are migrated to depth with a preserved amplitude Pre-Stack Depth Migration (PSDM) approach (Lambaré et al., 2003; Operto et al., 2003; Thierry et al., 1999) performed in the angle domain. The accuracy of the migrated image is obtained by iterative correction of the background velocity model (Al-Yahya, 1989) to avoid problems associated with misfocusing and under/over estimation of amplitude of seismic reflectors.