Earth and Planetary Science Letters 306 (2011) 299–305

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

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

Evidence for episodic aseismic slip across the subduction seismogenic zone off Costa Rica: CORK borehole pressure observations at the subduction prism toe

Earl Davis *, Martin Heesemann [1], Kelin Wang

Pacific Geoscience Centre, Geological Survey of Canada, 9860 West Saanich Rd., P.O. Box 6000, Sidney, B.C., Canada V8L 4B2

ARTICLE INFO

Article history:
Received 18 January 2011
Received in revised form 11 April 2011
Accepted 15 April 2011
Available online 8 May 2011

Editor: P. Shearer

Keywords:
subduction zones
accretionary prisms
aseismic fault slip
borehole observatories

ABSTRACT

Slow slip events, or "silent" earthquakes, may relieve a significant amount of stress at many subduction plate boundaries, both downdip of the limit of seismogenesis, and within the seismogenic zone itself in cases where seismic energy release accounts for only a fraction of the plate tectonic displacement rate (Schwartz and Rokosky, 2007). Slow slip has been identified in several instances downdip of the landward limit of the seismogenic zone and is often accompanied by seismic tremor or low-frequency earthquake activity along and above the plate interface (referred to as "episodic tremor and slip", or ETS). Little is known, however, about the spatial distribution and history of slip between great earthquakes along the seismogenic thrust interface itself which lies mostly offshore. In this article we present formation pressure transients observed in two deep-sea boreholes near the toe of the subduction prism off Nicoya Peninsula, Costa Rica, which followed ETS events observed on shore by 1–2 weeks. The signatures of the transients are consistent with local slip on the shallow part of the thrust interface, with the underthrusting plate experiencing relaxation and the outer prism experiencing contraction. The delay between the tremor activity and the pressure transients observed c. 100 km seaward at the prism toe suggests either slow propagation across the seismogenic zone or delayed deformation at the outer part of the prism triggered by the slip beneath Nicoya. Such slip may serve generally to relieve stress at subduction zones, but also to increase stress in parts of the plate boundary where interseismic slip does not occur.

1. Introduction

In 2002, two Ocean Drilling Program (ODP) boreholes were drilled at the toe of the subduction zone prism off the Nicoya Peninsula, Costa Rica, sealed, and instrumented with "CORK" (circulation obviation retrofit kit) hydrologic observatories for long-term monitoring of seafloor and formation pressures (Davis and Villinger, 2006; Jannasch et al., 2003). Hole 1253A intersects the underthrusting igneous oceanic crust 200 m seaward of where the subduction thrust fault outcrops at the seafloor, and Hole 1255A intersects the subduction prism above the thrust roughly 400 m landward of the fault outcrop (Fig. 1). Between November 2002 and February 2004, continuous records of formation pressure from these boreholes captured two transient events that were approximately concurrent with slow slip events beneath Nicoya Peninsula detected by a land-based GPS monitoring array (Davis and Villinger, 2006; Protti et al., 2004).

Since that time, an additional slip event in 2007 has been detected with continuing GPS observations (Outerbridge et al., 2010) and several episodes of low-frequency earthquakes or seismic tremor activity have been observed with a local network of broadband seismometers brought into service in July 2006 (Brown et al., 2009; Outerbridge et al., 2010). The most energetic of the tremor episodes was simultaneous with the 2007 slow slip event (Outerbridge et al., 2010). This association and the location of the events are similar to those of ETS events at the Nankai and Cascadia subduction zones (Brown et al., 2009; Kao et al., 2009; Obara et al., 2004; Rogers and Dragert, 2003; Schwartz and Rokosky, 2007), where episodic slow slip and seismic tremor are focused near the landward limit or some distance down-dip of the locked part of the "seismogenic zone", the part of the subduction plate interface that releases elastic strain energy suddenly during great thrust earthquakes. Beneath Nicoya Peninsula, the tremor and primary locus of GPS-estimated slow slip lies at a depth of about 30–40 km, 100–140 km landward of the toe of the subduction prism, landward of the locked portion of the subduction thrust, and near the down-dip limit of the seismic rupture areas of major thrust earthquakes in 1950 ($M_w = 7.7$) and 1978 ($M_w = 7.0$) (Brown et al., 2009; Norabuena et al., 2004; Outerbridge et al., 2010) (Fig. 1). In this paper we present the most recently downloaded ODP borehole observatory records spanning from February 2004 to February 2009, and compare them to the recently acquired history of ETS activity beneath the Peninsula.

* Corresponding author.
E-mail address: edavis@nrcan.gc.ca (E. Davis).
[1] NEPTUNE Canada, University of Victoria, P.O. Box 1700 STN CSC, Victoria, B.C., Canada V8W 2Y2.

0012-821X/$ – see front matter.
doi:10.1016/j.epsl.2011.04.017

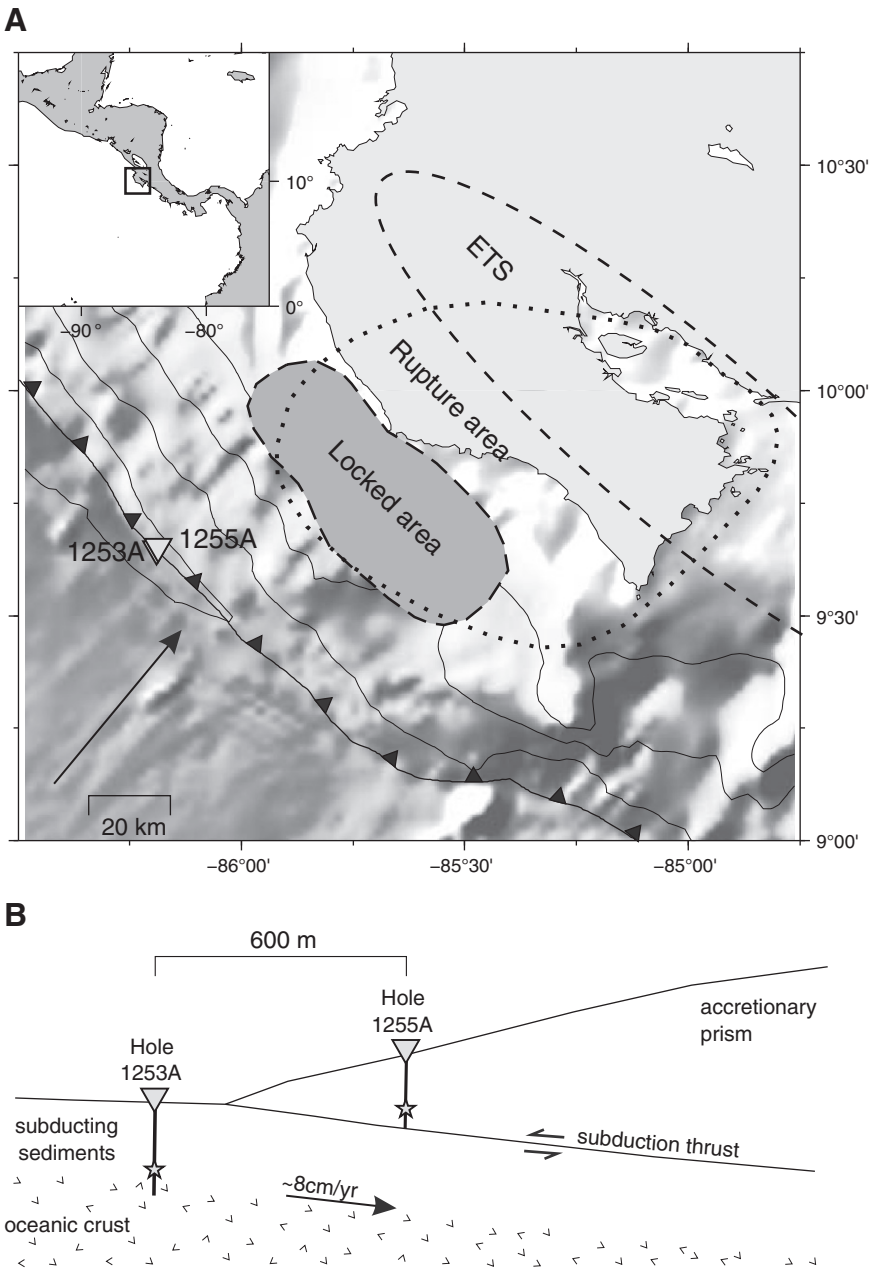

Fig. 1. Map of the Costa Rica subduction zone in the vicinity of the Nicoya Peninsula (A) and schematic section through the subduction prism toe where CORK hydrologic observatories in Holes 1253A and 1255A are located, with formation monitoring depths indicated with stars (B). At the prism toe off Nicoya Peninsula (barbed line in a), 24 Ma oceanic crust of the Cocos Plate subducts beneath the continental Caribbean Plate at a speed of roughly 85 mm yr^{-1}(arrow) (DeMets, 2001). Areas of seismic tremor (Brown et al., 2009) and slip (Outerbridge et al., 2010) activity in May 2007 beneath the Nicoya Peninsula (tremor locations enclosed by the dashed oval) lie 100 to140 km landward of the prism toe where ODP boreholes 1253 and 1255 are located (inverted triangles). Between large thrust earthquakes (estimated rupture area of the 1950 M_w 7.7 earthquake outlined by dotted line), the seismogenic zone in the vicinity of the Nicoya Peninsula is characterized by plate locking from roughly 40 to 70 km landward of the prism toe (offshore shaded area) as estimated from geodetic measurements (Norabuena et al., 2004).

2. New observations

At Hole 1253A pressures are monitored at the seafloor and at two screened filters positioned within sediment-buried igneous rocks below the bottom of solid steel casing at 413 m below the seafloor (mbsf) (see Jannasch et al., 2003, and Davis and Villinger, 2006, for details regarding this hole and Hole 1255A). Pressures at the two levels are nearly identical and only one of the records is shown here. At Hole 1255A pressures are monitored at the seafloor and at two levels in the underlying sediment section, one in the subduction thrust at 140 mbsf, the other within the overthrusting prism at a depth of 127 mbsf. A malfunctioning seal of a fluid sampling instrument at the bottom of this hole precludes use of the data from the deeper horizon. All pressure data were corrected for clock and sensor drift using intermittent clock checks and hydrostatic tests. Formation pressure signals caused by oceanographic loading were suppressed by using the cross correlation of the formation and seafloor pressure records. Remaining tidal constituents were removed by applying tidal harmonic analysis (Pawlowicz et al., 2002). Additional smoothing (black traces in Fig. 3) was done by applying a Gaussian filter with a window length of 12 h.

Fluid pressure measured in the prism sediments at Hole 1255A is super-hydrostatic by roughly 50 kPa and displays a secular trend of about +3.5 kPa/yr that may reflect slow interseismic contraction of