Toward a Unified Theory of Silent Seismicity in Mexico

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Abstract

Slow slip transients in the Mexican subduction zone have been first observed in 1998 (Kostoglodov et al., GRL, 2003). Since then, GPS records show that approximately every four years the phenomenon repeats itself (Cotte et al., EOS, 2009). Whether these quasi-static deformations processes in the lithosphere play a critical role in large subduction earthquakes remains a debate. Besides this observation, Non Volcanic Tremors (NVT) have been detected in the same regions where the Slow Slip Events (SSE) take place (Payero et al., GRL, 2008; Kostoglodov et al., GRL, 2010). Several studies in Mexico and worldwide have associated both phenomena to the same deep processes, interpreting them as two different manifestations of frictional mechanisms at the plates interface (e.g. Rogers and Dragert, Science, 2003). However, evidence from different subduction zones suggests that the NVT hypocentral region is rather a spread out locus on the deep and intermediate crust away from the SSE slipping surface (e.g. Kao et al., Nature, 2005; Kostoglodov et al., GRL, 2010).

During the 2006 SSE in the Guerrero province, Mexico, a seismic profile of 100 broadband stations (MASE array) was partly deployed right above the slipping interface. Detached from this seismological network, three additional observations were made: 1) From the analysis of converted phases in the subducted slab (Song et al., Science, 2009), a ultra-slow velocity layer confined to the uppermost part of the slab (i.e. with 3 to 5 km thick, and Vs from 2 to 2.7 km/s) has been inferred and coincide with the slow slipping zone; 2) from receiver function analysis (Kim et al., JGR, 2010), high Poisson's and Vp/Vs ratios have been determined within the upper part of the horizontal segment of the slab, which is a strong indicator of high-pressurized water content; and 3) from ambient noise correlation techniques (Rivet et al., GRL, 2011) an amazing and so far unknown phenomenon has been observed as well: the quasi-static slow-slip process produces a transient reduction of surface waves velocity in the deep and middle crust of about 0.2%.

Fluid release from the water-saturated subducted slab and diffusion into the overriding continental plate have been suggested in Guerrero (Jodicke et al., JGR, 2006; Song et al., Science, 2009; Manea and Manea, PAGEOPH, 2011). In particular, anomalous high Vp/Vs ratios within the top layer of the slab (Vp/Vs ~ 2.1; Kim et al., JGR, 2010) have strong implications in terms of porosity and water contents along metamorphic and igneous rocks in subduction tectonic settings (Peackock et al., Geology, 2011). Laboratory studies shown that such velocity-ratio values are best

explained by properties of fluid-saturated crystalline rocks with fluids near lithostatic pressures (Audet et al., Nature, 2009). By inputting the slip history of the 2006 SSE recently inverted from GPS data (Radiguet et al., submitted 2010) into a 3D viscoelastic finite difference code we show that the silent earthquake induces a widespread decrease of confining pressure (Pc) above the horizontal segment of the plate interface, as well as a localized and spatially evolving Pc reduction within the fluid saturated slab (60 to <120 km from the coast). By approximating the pore pressure as Pp = B*Pc, determining the associated Skempton coefficient (0 < B < 1) from tomographically constrained Lamé constants (Iglesias et al., JGR, 2010; Song et al., Science, 2009), and solving the fluid diffusion flow equations in the model, we find that the effective pressure, Pe = Pc – Pp, decreases as a function of time in the overriding plate, and that the affected region matches the locus of the NVTs hypocenter region determined by Payero et al. (GRL, 2008). However, if we assume a fluid seal along the horizontal plate interface due to sheared metamorphic rocks and minerals precipitation due to migrating fluids, as suggested in Cascadia by several authors (Audet et al., Nature, 2009; Peackock et al., Geology, 2011), an interesting phenomenon arises within the Guerrero's oceanic slab: time-dependent migration (velocity) of confined fluids in the ultra-slow slab layer is first upward everywhere and then reorganizes by pointing two 'attraction' poles (i.e. low-pressure slab segments), the first one ~90 km away the coast, and a second one around 150 km from the coast. By superimposing the occurrence of NVTs hypocentral locations over the evolving Pp lithospheric cross-section, a surprisingly good spatial and temporal correlation appears between those poles and the NVT segmentation reported by Payero et al. (GRL, 2008). A more detailed and complete NVT location catalog with hypocenters depths constrained to the plate interface (Husker et al., in preparation, 2011) confirms such spatio-temporal correlation.

Two critical questions are detached from the above analysis: do the slab fluids may migrate during successive SSE into the continental crust? and, if so, which implications would be in terms of NVT triggering? The transient velocity change in the crust observed during the 2006 SSE (Rivet al a., GRL, 2011) is a strong evidence of non-linear processes taking place in deep regions of the structure. Experimental studies with rocks have revealed that transient reduction of the shear modulus (i.e. material strength) arises as a consequence of anomalous nonlinear responses of rocks in their elastic regime (Johnson and Jia, Nature, 2005). Such behavior, that promotes shear failure, is strongly enhanced for low effective pressures (Pe) and start happening from deformation thresholds of about 10^{-6}, which we show were clearly overcome during the 2006 SSE above the plates interface. This phenomenon may play an important role in NVT triggering, especially if water content is present in the deep crust. In this study and based on our modeling results we analyze the possibility of hydrofracturing along the interface seal as a mechanism to allow fluid diffusion into the upper plate in terms of volumetric strain changes during the SSE.

Reliable evidence of NVT hypocentral locations above the plates interface (i.e. within the deep and intermediate continental crust) would be critical to constrain and support a given model. Then, to complete our analysis we present preliminary NVT relocations with a new and promising technique (Cruz-Atienza and Legrand, in preparation, 2011). This technique is based on NVT energy-like and waveform correlation measurements in the three ground motion components. By means of a source-scanning grid search, and a large database of both synthetic seismograms and theoretical arrival times computed with ray tracing, the algorithm looks for the hypocentral locations that minimize an error function between observed and synthetic energy-like profiles, and both P- and S-waveform correlations. We test the algorithm by locating finite-difference synthetic NVTs (Cruz-Atienza, 2010).