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Generation of talc in the mantle wedge and its role in subduction dynamics in central Mexico

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ABSTRACT

Geophysical evidence shows the presence of low-seismic velocity material at the surface of slabs in subduction zones. In the central Mexican subduction zone this appears as a thin (∼4 km) low-velocity zone that absorbs nearly all of the strain. The P-to-S velocity ratio as a function of S wave velocity distinguishes among the various candidate hydrous (low-strength) minerals; the thin layer in the flat-slab region is most consistent with a layer showing enrichment in talc overlying normal MORB-like gabbro. Based on available thermodynamic data for equilibria for talc, its generation at the trench is nearly impossible, and hence we propose it originates from the mantle wedge during the slab flattening process coupled with trench rollback. The evolution of this low-strength zone has important implications for the dynamics of the slab-flattening process as well as the geochemistry of the mantle wedge and arc in central Mexico.

1. Introduction

The presence of low-velocity material that extends to depths of ∼150 km with a thickness of 2–8 km along the slab–mantle interface has been detected in a number of modern subduction zones using teleseisms (Abers, 2000, 2005; Abers et al., 2003). Such low-velocity layers have been interpreted as either hydrated oceanic crust due to subduction of hydrous materials and subsequent up-dip fluid transport (Abers, 2000), or mélange material composed dominantly of chlorite and talc on top of the subducting oceanic crust (Marschall and Schumacher, 2012). The strength of the slab–mantle interface greatly influences interplate frictional behavior and may thus control the extent to which convergent motions between the slab and the overriding plate are accommodated by earthquake slip, post-seismic deformation, or interseismic creep (Lay and Bilek, 2007).

Recent imaging based on the teleseismic converted phase in Cascadia have been able to resolve a few km thick low-velocity, high P-to-S velocity ratio (V_p/V_s) channel at the upper portion of subducted crust (Audet et al., 2009; Hansen et al., 2012). Reported high V_p/V_s values (2.3–2.8) have been used to argue for fluid-filled porosity of 2.7–4.0% with the fluid under near-lithostatic pressure at a depth of less than 35 km (Audet et al., 2009; Peacock et al., 2011). Also, in Nankai, southwestern Japan, a zone of high V_p/V_s (1.9–1.95) is imaged beneath the plate boundary at a depth of ∼25–30 km (Kodaira et al., 2004; Shelly et al., 2006). The high pore fluid pressures appear to be an important and necessary factor, which can explain low seismic velocities, and the promotion of slow slip earthquakes and tremors, both observed in shallow subduction environments such as Cascadia (Audet et al., 2009; Peacock et al., 2011), Nankai (Kodaira et al., 2004; Shelly et al., 2006), and also in central Mexico (Song et al., 2009; Kim et al., 2010; Song and Kim, 2012). However, at deeper depths anhydrous minerals may play a role in reducing the strength of the interface.

Central Mexico is an ideal place to examine seismic velocity variations along the crust–slab and slab–mantle interfaces and within subducting oceanic crust because: first, there is an available high-quality dense-array dataset (Middle American Subduction Experiment, MASE (MASE, 2007); Fig. 1; Perez-Campos et al., 2008) oriented along the subduction direction (Fig. 1). Second, the top of the oceanic Cocos plate beneath Mexico is cooler because of the lack of a thick insulating sedimentary cover (Currie et al., 2002). Third, a single down-dip profile in our study region (black solid line, Fig. 1) exhibits shallow-flat-steep progression of slab dip angles (Fig. 2A; Perez-Campos et al., 2008; Kim et al., 2010) with progression in slip behavior distributed with depth (Kostoglodov et al., 2010). Fourth, the subducting Cocos plate horizontally underplates the North American plate for ∼325 km from the trench

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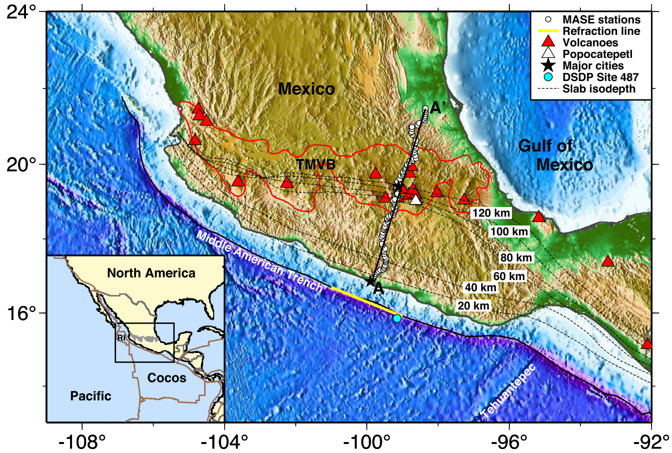

Fig. 1. Topographic-bathymetric map of the central Mexico subduction zone with 100 broadband seismic stations (open circles) used in the analysis. Lower-left inset illustrates the regional tectonic framework. Red line in the North American continent delineates Trans-Mexican Volcanic Belt (TMVB). Thin black dashed lines are slab depth isocontours at 20 km intervals based on Wadati-Benioff seismicity and receiver functions (Perez-Campos et al., 2008; Kim et al., 2010). The surface projection (A–A′; oriented 16° east of north) is shown as a black line in the North American continent. Two black stars indicate major cities located close to the MASE (Acapulco at the Pacific coast and Mexico City within the TMVB). A yellow line at the trench shows station locations from 1954 Acapulco Trench Expedition seismic-refraction survey (Shor and Fisher, 1961). DSDP Site 487 is located 10 km seaward of the axis of the trench off Mexico (Watkins et al., 1982).

with no intervening asthenosphere at a depth of ∼45 km (Fig. 2; Perez-Campos et al., 2008; Kim et al., 2010).

Of the flat subduction regions worldwide, the subduction system in central Mexico is unique because of the absence of the asthenosphere above the 250 km-long horizontal Cocos slab. Proposed mechanisms for the flat subduction are (1) the subduction of the young lithosphere or thickened crust in a form of an aseismic ridge due to buoyancy (Gutscher et al., 2000), (2) curvature of the margin (Gephart, 1994), (3) absolute motion of the overriding plate (Lallemand et al., 2005), and (4) structure of the overriding plate (Perez-Gussinye et al., 2008; Manea et al. 2013a, 2013b). There is no apparent cause such as the presence of oceanic impactor (Skinner and Clayton, 2010) or thickened continental (cratonic) lithosphere (Perez-Gussinye et al., 2008; Manea et al. 2013a, 2013b) that can influence the subduction angle in central Mexico.

Mode converted phases suggest the presence of a low-strength, low-velocity layer between the subducting oceanic lithosphere and the overriding plate, which completely decouples the overriding plate from the subducting oceanic lithosphere in the flat-slab region (Song et al., 2009; Kim et al., 2010). Numerical models require a low-viscosity channel atop the subducting crust to support the current flat-slab configuration (Manea and Gurnis, 2007), suggesting that the uppermost horizontal layer of the oceanic crust in central Mexico, observed to have notably low seismic velocity (Song et al., 2009; Kim et al., 2010; Song and Kim, 2012), provides the necessary low-viscosity channel.

Location of the low seismic velocities coincides with the observed slow-slip patch extending from Acapulco to ∼100 km inland along the MASE profile (Fig. 2A; Larson et al., 2007; Song et al., 2009). By modeling tangential-component receiver functions, a combination of clay minerals like talc and high pore fluid pressure in the layer is found to be necessary for the shallow part of the subduction system (Song and Kim, 2012). However, the influence of the pore pressure on seismic velocities is expected to decrease with depth (Christensen 1984; 1989) and is likely insignif-

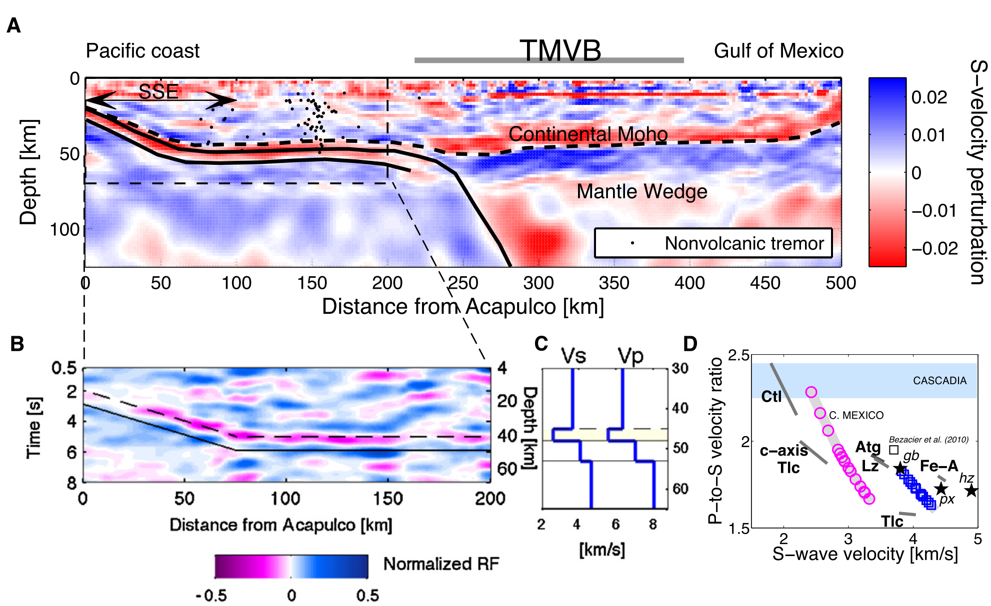

Fig. 2. Seismic observations and candidate mineral phases. (A) Migrated scattered-wave dV_s/V_s image for 500 km transect (A-A′ in Fig. 1; modified from Kim et al., 2012a; method details are presented in Kim et al., 2012a). Red to blue color scale represents slower to faster V_s perturbations relative to the 1-D model. The top and bottom interfaces of the oceanic crust are shown as black lines. Relocated seismicity (Pardo and Suárez, 1995), non-volcanic tremors (Payero et al., 2008) and the extent of the 2006 slow slip event (SSE; Kostoglodov et al., 2010) are also plotted. (B) Receiver function image from Acapulco to a point 200 km from the coast, showing the shallow-to-flat oceanic crust (modified from Kim et al., 2010; method details are in Kim et al., 2010). The negative and positive receiver function conversions at the bottom interfaces of the fore-arc crust and oceanic crust are shown as dashed and solid lines, respectively. (C) V_p and V_s profiles for the flat-slab region down to a depth of 70 km with the same line scheme as A and B. The layer with anomalously low-velocities is highlighted in light yellow. (D) Calculated V_p/V_s ratio versus V_s at the depth of the flat slab and a range of likely temperatures (500–800 °C) for candidate hydrated phases (gray lines) and rock types (black stars) (modified from Kim et al., 2010). The data points near the plate interface are shown as magenta circles for central Mexico. For comparison, the data points for Cascadia (Peacock et al., 2011) are also plotted and shown as light blue. The points for randomly oriented talc and *c*-axis oriented talc are from Mainprice et al. (2008), and those for different rock types from Christensen and Salisbury (1975). The points for antigorite are taken from 30° incident to basal plane. Abbreviation of rock names: gb – gabbro, px – pyroxenite, hz – harzburgite. Abbreviation of mineral phases: Ctl – chrysotile, Tlc – talc, Atg – antigorite (Bezacier et al., 2010), Lz – lizardite, Fe-A – Fe-bearing phase A. The data point shown as a square indicated a value computed for S-wave velocity at a 30° incidence angle between the seismic ray path and foliation plane of Cuba serpentinite at room P and T (Bezacier et al., 2010).