Influence of incoming plate relief on overriding plate deformation and earthquake nucleation: Cocos Ridge subduction (Costa Rica)

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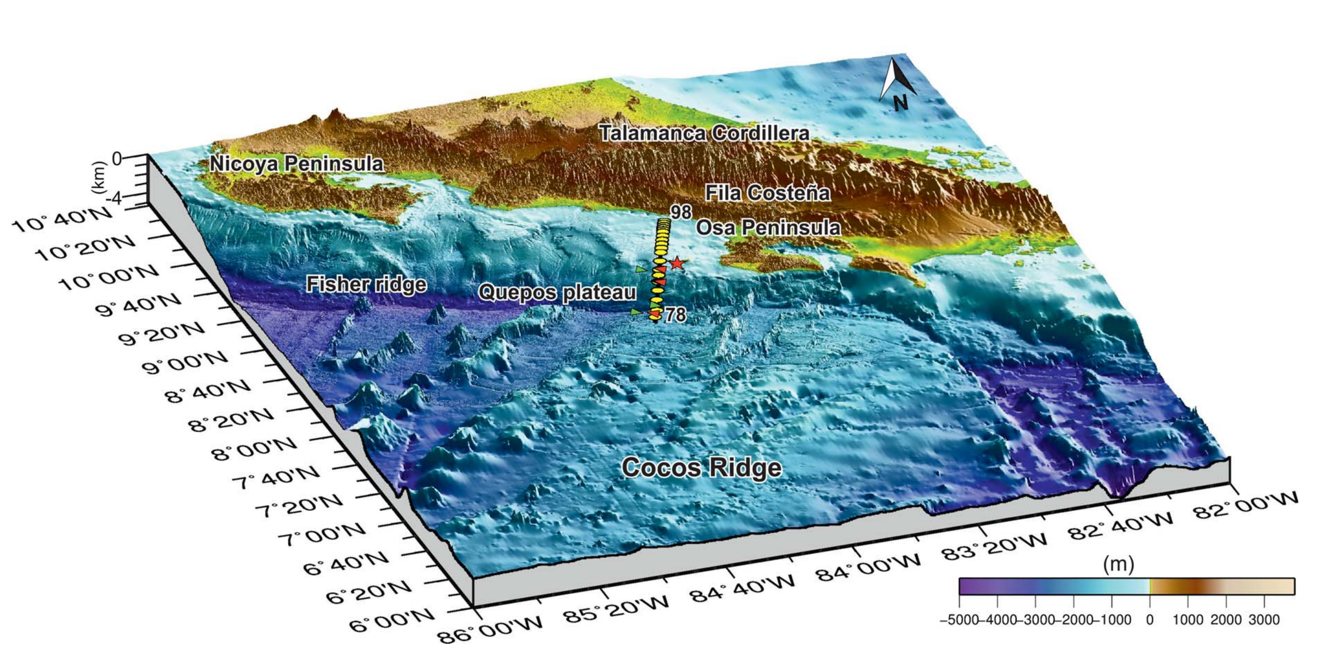
#EGU2020-2940 #Session SM2.5

Sara Martínez-Loriente[1*], Valentí Sallarès[1], César R. Ranero[1, 2], Jonas B. Ruh[3], Udo Barckhausen[4], Ingo Grevemeyer[5] and Nathan Bangs[6]

(1) Barcelona-CSI, Institut de Ciències del Mar - CSIC, Barcelona, Spain (*smartinez@icm.csic.es)
(2) ICREA, Barcelona, Spain
(3) Geological institute, ETH Zurich, Switzerland
(4) Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), Hannover, Germany
(5) GEOMAR-Helmholtz Centre for Ocean Research Kiel, Kiel, Germany
(6) Institute for Geophysics, University of texas at Austin, Austin, texas, USA

I. Abstract



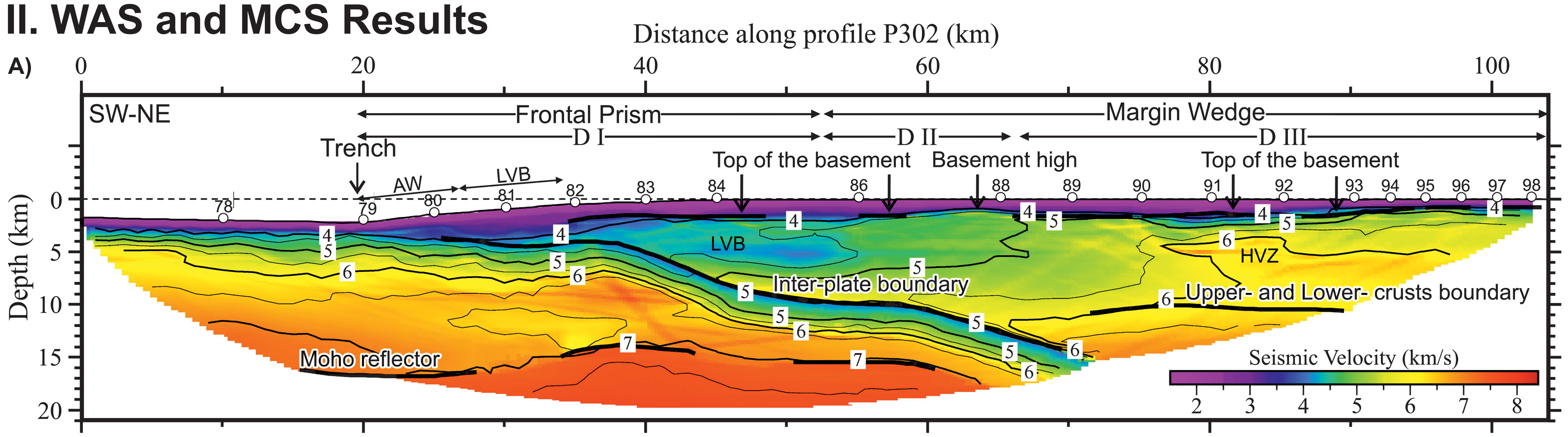
In 1995, a German-U.S. team carried out the TICOSECT refraction and wide-angle reflection seismic (WAS) survey off- and on-shore Costa Rica, onboard the R/V Maurice Ewing. The main objectives of the TICOSECT project were to investigate the crustal structure of the active continental margin and to understand the geodynamic processes within the subduction system.

In this work we present a 2D P-wave seismic velocity (Vp) model and a multichannel seismic (MCS) reflection profile along the same across-strike transect characterizing the structure of the southern Costa Rica margin and incoming Cocos Ridge, West of Osa Peninsula. The seismic profiles image the ocean and overriding plates from the trench across the entire offshore margin, including the structures involved in the 2002 Osa earthquake sequence.

We combine the Vp model and seismic image of the upper and subducting plates with stress and strain estimations obtained with 3D numerical modelling of subducting seamounts, and with earthquake locations to investigate: (1) the properties and structure of the Cocos plate and continental margin, (2) the influence of the incoming plate relief on stress and permanent deformation, and (3) the potential role of incoming plate relief on seismogenesis.

Figure 1.- 3D Bathymetric and topographic map of the study area. Black line shows location of the coincident wide-angle seismic (WAS) transect and multi-channel seismic (MCS) profile. Yellow dots display OBS/Hs deployed along the WAS profile. The Integrated Ocean Drilling Program (IODP) sites at Expeditions 334 and 344 are indicated with red and green triangles, respectively. Red star displays the 2002 Osa earthquake relocated by Arroyo et al. (2014a). Modified after *Martínez-Loriente et al. (in press).*

II. WAS and MCS Results



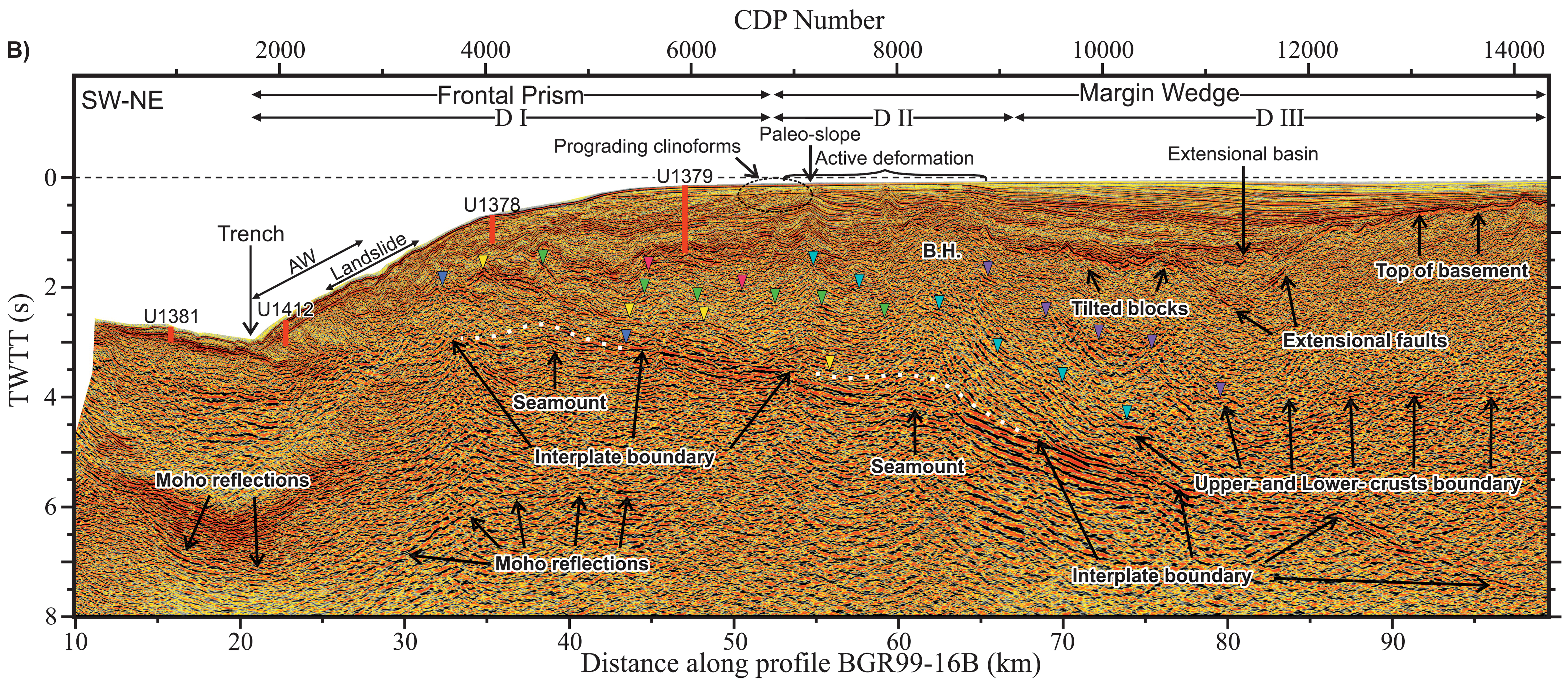


Figure 2.- A) The 2-D final velocity model obtained by joint refraction and reflection travel-time inversion of the whole data set. White circles indicate OBS/Hs locations. Velocity units are km/s. VE≈0.75; **B)** Post-stack time migrated MCS BGR99-16B profile acquired coincident with the WAS profile. Colored triangles label thrust fault traces. Red rectangles show location of the drill IODP sites projected along the MCS profile (Vannucchi et al., 2003). Seamounts morphology is indicated with white dots. AW: Accretionary wedge; B.H.: Basement High; D: Domain; HVZ: high-velocity zone; LVB: low-velocity body. See location in Figure 1. Modified after *Martínez-Loriente et al. (in press).*

III. Discussion & Conclusions

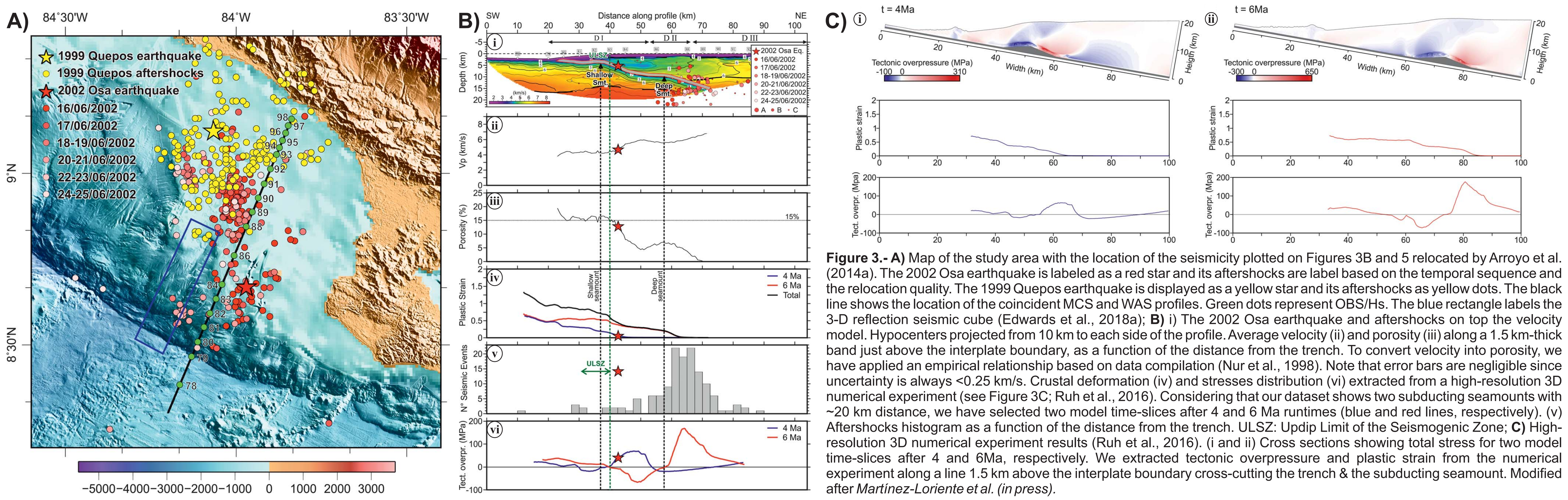


Figure 3.- A) Map of the study area with the location of the seismicity plotted on Figures 3B and 5 relocated by Arroyo et al. (2014a). The 2002 Osa earthquake is labeled as a red star and its aftershocks are label based on the temporal sequence and the relocation quality. The 1999 Quepos earthquake is displayed as a yellow star and its aftershocks as yellow dots. The black line shows the location of the coincident MCS and WAS profiles. Green dots represent OBS/Hs. The blue rectangle labels the 3-D reflection seismic cube (Edwards et al., 2018a); **B)** i) The 2002 Osa earthquake and aftershocks on top the velocity model. Hypocenters projected from 10 km to each side of the profile. Average velocity (ii) and porosity (iii) along a 1.5 km-thick band just above the interplate boundary, as a function of the distance from the trench. To convert velocity into porosity, we have applied an empirical relationship based on data compilation (Nur et al., 1998). Note that error bars are negligible since uncertainty is always <0.25 km/s. Crustal deformation (iv) and stresses distribution (vi) extracted from a high-resolution 3D numerical experiment (see Figure 3C; Ruh et al., 2016). Considering that our dataset shows two subducting seamounts with ~20 km distance, we have selected two model time-slices after 4 and 6 Ma runtimes (blue and red lines, respectively). (v) Aftershocks histogram as a function of the distance from the trench. ULSZ: Updip Limit of the Seismogenic Zone; **C)** High-resolution 3D numerical experiment results (Ruh et al., 2016). (i and ii) Cross sections showing total stress for two model time-slices after 4 and 6Ma, respectively. We extracted tectonic overpressure and plastic strain from the numerical experiment along a line 1.5 km above the interplate boundary cross-cutting the trench & the subducting seamount. Modified after *Martínez-Loriente et al. (in press).*

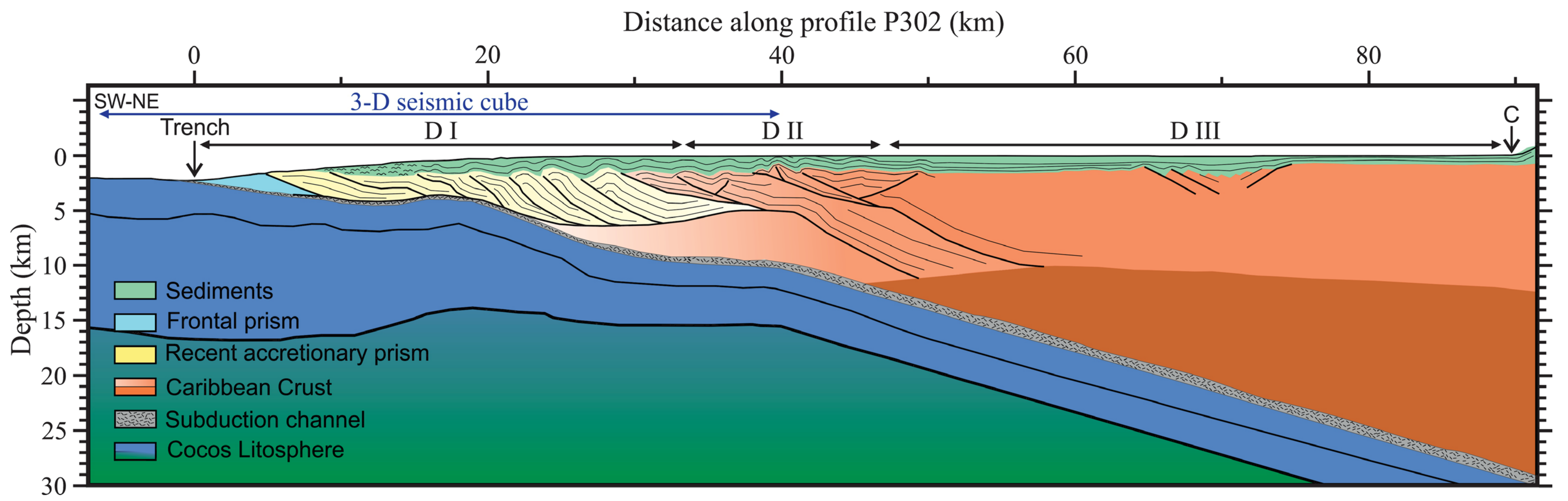


Figure 4.- Long term geological evolution model showing the units that make up the margin of southern Costa Rica. C: coastline; D: Domain; Smt.: Seamount. Blue arrow shows projection of the 3-D seismic cube location (Bangs et al., 2016). VE≈0.75. Modified after *Martínez-Loriente et al. (in press).*

The distribution of seismic velocity, internal geometry of the different units and tectonic structure define three domains in the overriding plate:

-D I: a ~33 km-wide zone including an 8 km-wide imbricated sediment frontal prism and thin-skinned deformation of an imbricated-thrust system probably made of clastic rocks with pervasive fault deformation. Vp typically increases landwards from ~1.8 to <4.5 km/s indicating ongoing sediment compaction.

-D II: a sector of indurated rocks (Vp 4.5-5-5 km/s) with >15 km-long landward-dipping reflection packages possibly indicating intra-basement large-scale thrust faulting that projects updip to a folded and faulted shelf sediment cover with uplifted strata truncated at the seafloor.

-D III: a >9 km-thick and 40 km-wide upper plate sector with velocity >5 km/s across most of it. The domain does not show recent brittle deformation and appears dominated by regional tilting and possibly elastic deformation. Thick-skinned tectonics of Domain II may cause the uplift of Domain III.

The oceanic plate shows crustal thickness variations from ~14 km at the trench (Cocos Ridge) to 6-7 km beneath the shelf. The crustal-seismic structure shows an upper layer 2 characterized by high velocity gradients and constant thickness and a lower layer 3 with more uniform velocities that mainly accommodates the thickening of the crust.

The 2002 Osa sequence nucleated at the leading flank of subducting seamounts in the area of highest tectonic overpressure. Both estimated rock fracturing and modelled brittle strain steadily increase from the leading flank of the subducting seamounts to their top, reflecting the progressive damage caused by the seamount. These analyses support the conclusion that the seismicity and the structural-mechanical evolution of the upper plate reflects the downward propagation of the leading edge of subducting plate roughness.

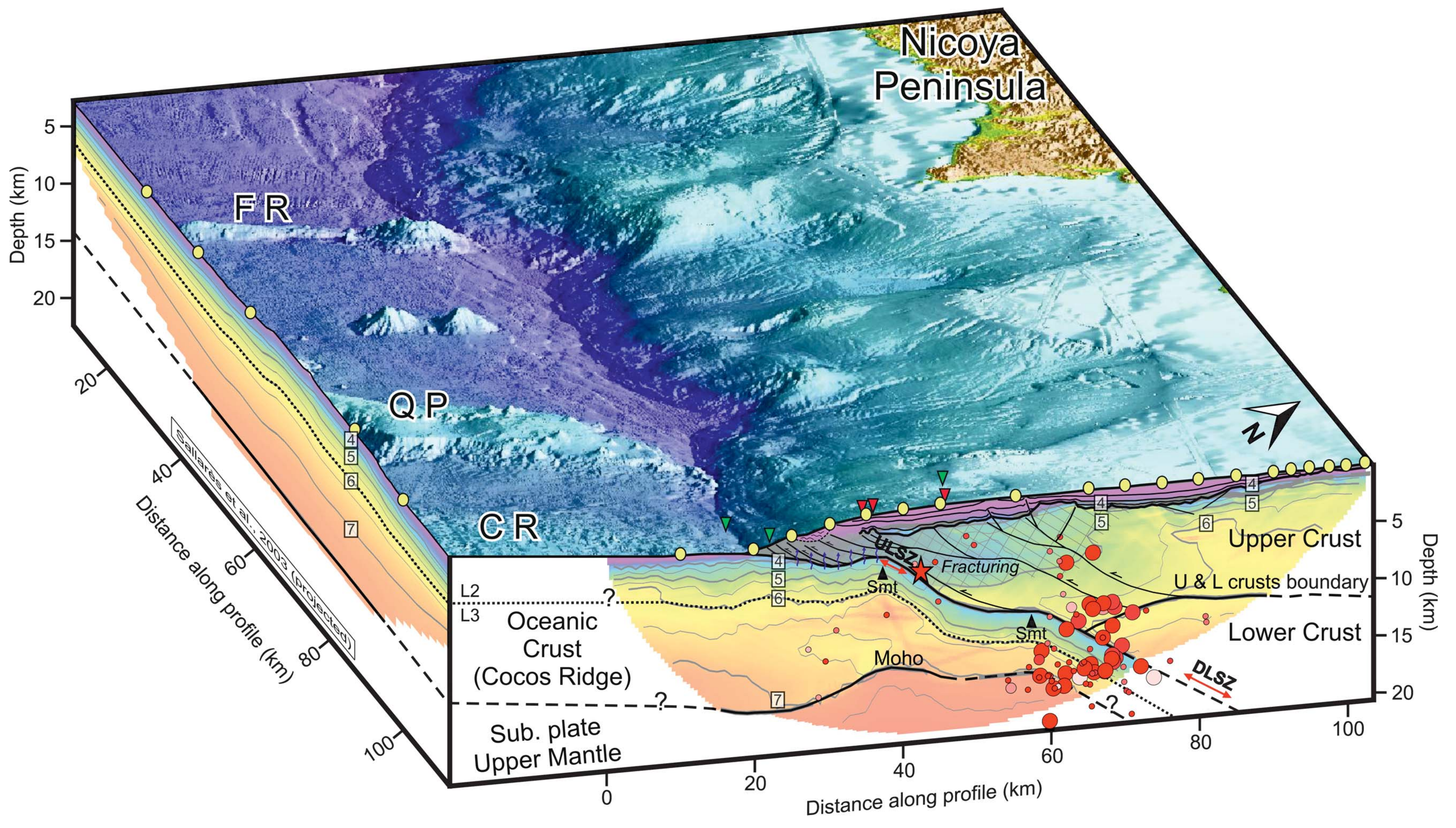


Figure 5.- Interpretative cross section of the tectonic and seismic structure along the WAS and MCS profiles at the southern Costa Rica margin, correlated with the bathymetry. Location of the 2002 Osa earthquake (red star) and aftershocks from Arroyo et al. (2014a) (see legend in Figures 3A, 3B). Blue arrows represent fluid migration from the subduction interface to the seafloor. A portion of the along-strike profile 2 (Figure 5) published by Sallarès et al. (2003) acquired close to our profiles is projected for reference. Note the excellent fit between both velocity models and inverted reflectors (i.e., L2-L3 and Moho boundaries). CR: Cocos Ridge; FR: Fisher Ridge; QP: Quepos Plateau; Smt: Seamount. VE≈0.75. Modified after *Martínez-Loriente et al. (in press).*

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