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# Geophysical constraints on the structure and tectonics of the North Chile erosional convergent margin at 23°30'S

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**Abstract**

Subduction erosion has dominated the evolution of the north Chile convergent continental margin since at least the Mesozoic. We investigate the structure of the Antofagasta sector of this margin (23° S) using coincident wide-angle and near-vertical seismic profiling and gravity data collected along a geophysical transect. A 2-D velocity model together with the inter-plate geometry has been obtained using joint refraction and reflection travel time tomography. A velocity-derived density distribution was used to model marine gravity data and substantiate the velocity model. Gravity and velocity models support that the overriding plate of the margin is mainly made of arc-type igneous basement. The upper plate is made of two main rock-bodies separated by a subhorizontal body (~7-9 km deep) defined by a velocity inversion, the top coincident with a prominent reflection in near-vertical seismic images. The seismic boundary is interpreted as a detachment separating an upper extended domain with large-scale normal faulting from a lower domain apparently undergoing a different type of deformation. Velocity-derived porosity indicates that the front of the margin is probably disaggregated and water-saturated favoring frontal erosion. Fluids carried into the subduction channel within slope debris filling subducted grabens reduce basal friction and probably induce hydrofracturing and basal erosion along the underside of the overriding plate. At depth greater than ~24 km porosity values indicate that most fluids have been exhausted and that the upper plate is structurally coherent and little fractured. This change in physical properties leads to increased mechanical coupling along the plate boundary and is coincident with the aftershock sequence of the 1995 Antofagasta earthquake ($M_w$ = 8.0), indicating that it may be ruptured during great earthquakes.

**Introduction**

Subduction erosion dominates tectonics at least at 50% of all convergent margins [von Huene and Scholl, 1991]. This tectonic process removes material from the overriding plate and inputs it into the subduction channel, the material is transported into the subducting zone and recycled into the mantle along with oceanic lithosphere. Material removal may occur by frontal erosion, when topographic features on the incoming oceanic plate collide with the apex of the margin and breach the slope toe, or by basal erosion, when material is removed along the underside of the upper plate. Subduction erosion thins the upper plate, leading to large-scale, long-term margin subsidence with steepening of the continental slope, to a progressive landward migration of the trench axis and to a similar migration of the volcanic arc. Despite the widespread occurrence of basal erosion, the mechanisms driving the process are poorly understood.

The northern Chilean margin has been long recognized as dominated by subduction erosion [e.g. Kulm et al., 1977; von Huene and Lallemand, 1990]. Tectonic erosion has been active here since the late Jurassic, as inferred from the progressive eastward migration of the volcanic arc during the past ~140 m.y. [e.g. Rutland, 1971]. The Jurassic arc crops out along the coastal areas and the location of the current arc indicates a total eastward migration of ~200 km. I In this work, we have used data from profile SO104-401 recorded with 15 OBHs (IFM-GEOMAR) and 4 PDAS land stations (GFZ-Postdam) deployed along a ~225 km-long transect extending from the outer rise of the oceanic plate to the western segment of the emerged forearc, across the trench axis and continental slope, together with coincident marine gravity data to obtain the velocity and density structure of the margin offshore Antofagasta (23.5° S). The geophysical models are used to infer the nature of the margin rocks, their porosity and the fluid distribution. The distribution of physical properties has been integrated with the tectonic structure from coincident seismic reflection images [von Huene and Ranero, 2003] to investigate how material properties and fluid distribution influence subduction erosion processes and the long-term tectonic evolution of the margin. Furthermore, changes in physical properties with depth are found to correlate with the transition along the plate boundary from aseismic creep to the stick-slip behaviour of the seismogenic zone defined by the aftershocks of the 1995 Antofagasta Mw 8.0 earthquake [Husen et al., 1999].

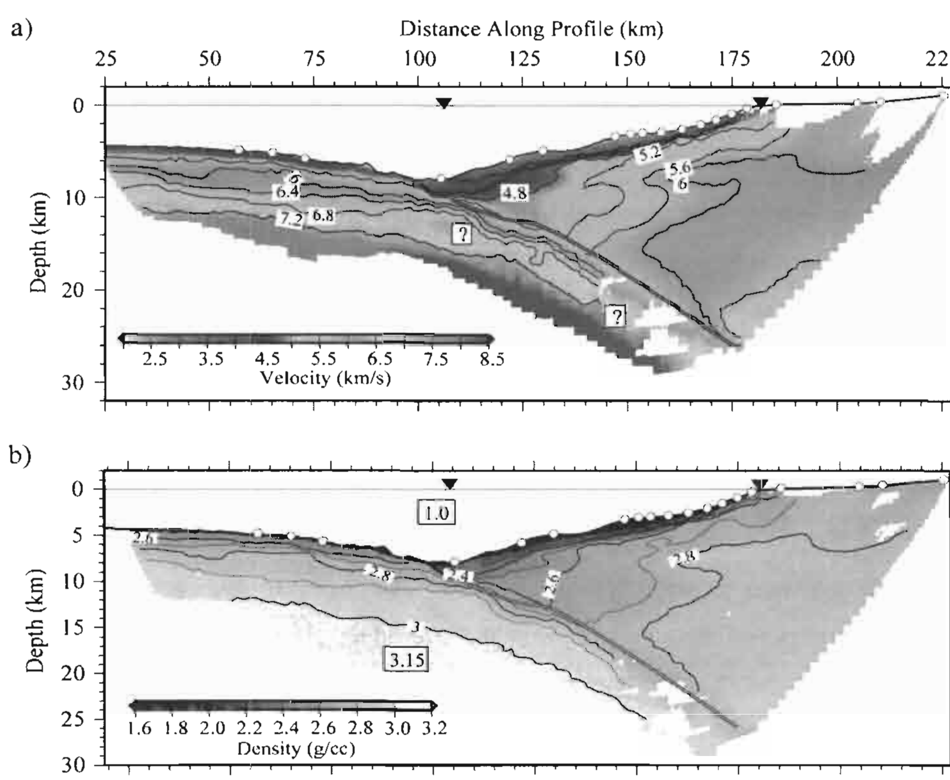


**Figure 1.-** (a) Final velocity model with isovelocity contours. Thick white line shows location of the inter-plate boundary. White circles indicate OBH and landstations locations. Arrows show the location of the trench and the coast line. (b) Density model along the transect derived from the velocity model displayed in panel a. Arrows show the location of the trench and the coast line.

**Results**

The velocity and density structure of the margin (Figure 1) indicate that the margin is mainly formed by igneous rocks representing a probably pre-Jurassic magmatic arc, composed by two rock bodies undergoing different deformation styles [Sallarès and Ranero, 2005]. The comparison of the velocity structure with pre-stack depth migrated images shows the correspondence of the main seismic boundaries detected with the two methods and the relation between tectonic structure and velocity distribution (Figure 2). The velocity model displays a well-defined low-velocity zone few km beneath the top of the basement that extends from beneath the coastal area to the middle slope, whose top corresponds to a subhorizontal event in the seismic reflection images, interpreted as a detachment surface where block-bounding faults cutting from the seafloor into the upper plate sole out (Figure 3). The detachment at the top of the low-velocity zone could represent either a rheological boundary formed along a pre-faulting contact between two rock bodies of different nature or a zone of low strength related to the presence of permeating fluids expelled from the subduction channel, a process previously inferred from temporal variations of P-wave to S-wave ratio following the 1995 Antofagasta earthquake [Husen and Kissling, 2001]. Expelled fluids may gradually collect beneath the detachment to form a low-velocity zone. Above the detachment, the size of fault-bounded basement blocks and the fault spacing decreases seaward, indicating progressively increasing extension, thinning and dismembering of the upper plate.

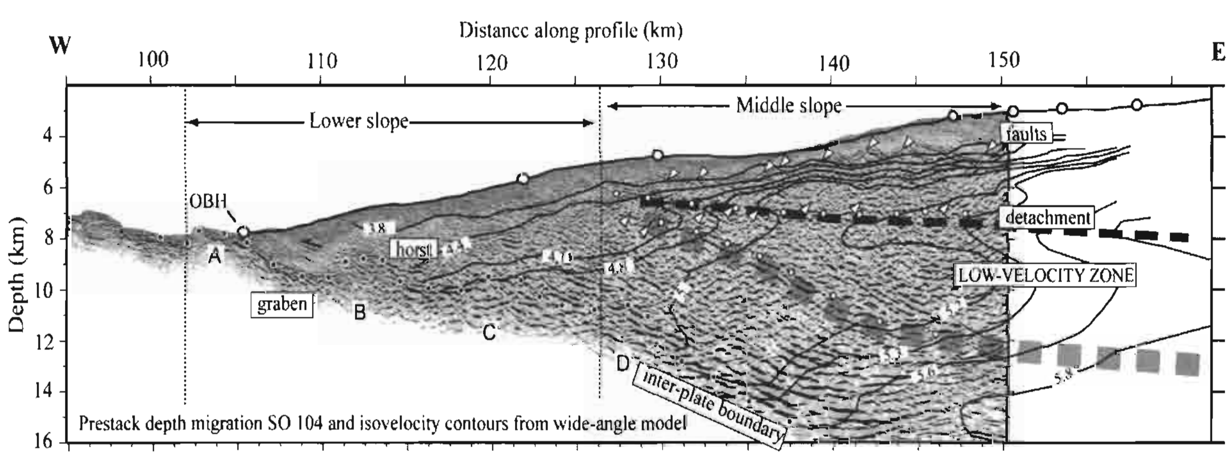


**Figure 2.-** Pre-stack depth migration image with tectonic interpretation superimposed with wide-angle velocity model shown as selected isovelocity contours. White dots show intra-basement detachment and a landward-dipping reflection at the base of the low-velocity zone. Arrows display block-bounding faults cutting from the seafloor into the upper plate. Black dots delineate the top of the subducting plate. Capital letters correspond to subducting horsts. Dashed lines correspond to the bounds of the low-velocity zone.

A velocity-derived porosity model shows that the upper part of the overriding plate, as well as the frontal part of the margin, are probably made of highly disaggregated and fluid-saturated material. Consistently, seismic images show that the frontal ~20 km of the overriding plate seem to be highly disrupted with pervasive deformation distributed across the plate rather than localized on individual large faults. Also, this frontal area displays along the ~200 km covered by multibeam bathymetry a series of low ridges and valleys that parallel the trend of subducting horst and graben topography of the oceanic plate. This morphological mimicking supports that the upper plate material lacks strength riffling over the subducting topography. The margin front is sufficiently thin to fracture and disaggregate due to repeated thrusting over subducting horsts and subsequent collapse into intervening grabens. At the toe of the margin, a <5 km wide sediment prism, formed of slope debris deposited in the trench, is thursted and subsequently carried into the subduction channel (Figure 2). Overpressured fluids carried with slope debris into the subduction channel are likely to hydrofracture the base of the overriding plate. Thus, the continental margin is being thinned by subduction erosion along the base of the plate and by extension across the upper ~9 km.

The transition from creep to the updip limit of the seismogenic zone along the plate boundary roughly coincides with a change of physical properties of the subduction channel and the overriding plate. The creep to stick-slip transition is concurrent with a velocity increase to >6 km/s and a porosity decrease to <5% of the lower part of the continental basement (Figure 1). The decline in fluid content at the plate boundary leads to increased friction and the increase in strength of the overriding plate allows storing of elastic energy.

In summary, the fluids subducted with the slope debris seem to play a fundamental role influencing the long-term tectonic processes of the continental plate as well as the location of the seismogenic zone. Fluids in the subduction channel may be governing basal tectonic erosion and their migration through the upper plate may control the localization of the detachment and the locus of extension of the upper plate. When fluids are expelled from the subduction channel mechanical coupling of the plates increase and large earthquakes may occur.

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