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Seismic imaging of a megathrust splay fault in the North Chilean subduction zone (Central Andes)

Ina Storch [a], Stefan Buske [a], Cedric Schmelzbach [b], Peter Wigger [c]

[a] TU Bergakademie Freiberg, Institute of Geophysics and Geoinformatics, 09599 Freiberg, Germany
[b] ETH Zürich, Institute of Geophysics, 8092 Zürich, Switzerland
[c] Institute of Geological Sciences, Freie Universität Berlin, 12249 Berlin, Germany

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ABSTRACT

Prominent trench-parallel fault systems in the arc and fore-arc of the Chilean subduction zone can be traced for several thousand kilometers in north–south direction. These fault systems possibly crosscut the entire crust above the subduction megathrust and are expected to have a close relationship to transient processes of the subduction earthquake cycles. With the motivation to image and characterize the structural inventory and the processes that occur in the vicinity of these large-scale fault zones, we re-processed the ANCORP'96 controlled-source seismic data set to provide images of the faults at depth and to allow linking geological information at the surface to subsurface structures. The correlation of the imaging results with observed hypocenter locations around these fault systems reveals the origin and the nature of the seismicity bound to these fault systems. Active and passive seismic data together yield a picture of a megathrust splay fault beneath the Longitudinal Valley at mid-crustal level, which can be observed from the top of the subduction plate interface and which seems to be connected to the Precordilleran Fault System (PFS) known at the surface. This result supports a previously proposed tectonic model where a megathrust splay fault defines the Western Altiplano as a crustal-scale fault-bend-fold. Furthermore, we clearly imaged two branches of the Uyuni-Kenayani Fault (UKF) in a depth range between 0 and 20 km. In summary, imaging of these faults is important for a profound understanding of the tectonic evaluation and characterization of the subduction zone environment, for which the results of this study provide a reliable basis.

1. Introduction

In North Chile, two prominent large-scale fault systems exist, the Atacama Fault System (AFS) in the fore-arc and the Precordilleran Fault System (PFS) in the arc and fore-arc (Fig. 1). Both fault systems are oriented mainly parallel to the trench and can be traced at the surface for several thousand kilometers in north–south direction. According to their length at the surface, they are expected to have a large depth extension. It has been speculated that the AFS and PFS reach down to the subduction plate interface; hence, they can be considered as megathrust splay faults. However, the structure of these fault systems in the upper kilometers and the depth extent of these fault systems are not well known, but a number of tectonic models have been presented in recent years mainly based on geological information, with a particular focus on the PFS (e.g., Farias et al., 2005; Reutter et al., 1996; Victor et al., 2004;). However, direct evidence from, for example, geophysical imaging confirming the existence and the structure of these fault systems at depth is still missing.

In 1996, a 370 km long West–East trending reflection seismic profile was acquired in North Chile (ANCORP'96) with the goal to image the entire crust of the Central Andean arc and fore-arc system (Oncken et al., 2003). This data set has already been processed using post-stack and pre-stack imaging techniques (Buske et al., 2002; Oncken et al., 2003; Yoon et al., 2003, 2009). Several challenges had to be faced when processing this data set, such as a low CMP fold of the data (4 to 6), the absence of proper near-surface model for static corrections due to a lack of closely spaced measurements and the existence of steeply dipping structures in a complex, crystalline environment. Nevertheless, several features such as the downgoing plate interface (Nazca reflector) and the Quebrada Blanca Bright Spot (QBBS) at mid-crustal level were clearly imaged. However, these reflection seismic images were not providing conclusive information on the upper crust (<10 km depth), which is probably due to the very sparse acquisition geometry (6.25 km source spacing, 100 m receiver spacing) and the partly insufficient removal of source generated noise including surface waves overwhelming early arriving reflections.

We re-processed the ANCORP'96 data set with the overall goal to obtain improved reflection seismic images of the upper and middle crust. In particular, the aim was to recover the shallow and potentially steeply dipping segments of the large-scale fault systems (AFS and

E-mail addresses: ina.storch@geophysik.tu-freiberg.de (I. Storch), buske@geophysik.tu-freiberg.de (S. Buske), cedric.schmelzbach@erdw.ethz.ch (C. Schmelzbach), wigger@geophysik.fu-berlin.de (P. Wigger).

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0040-1951/

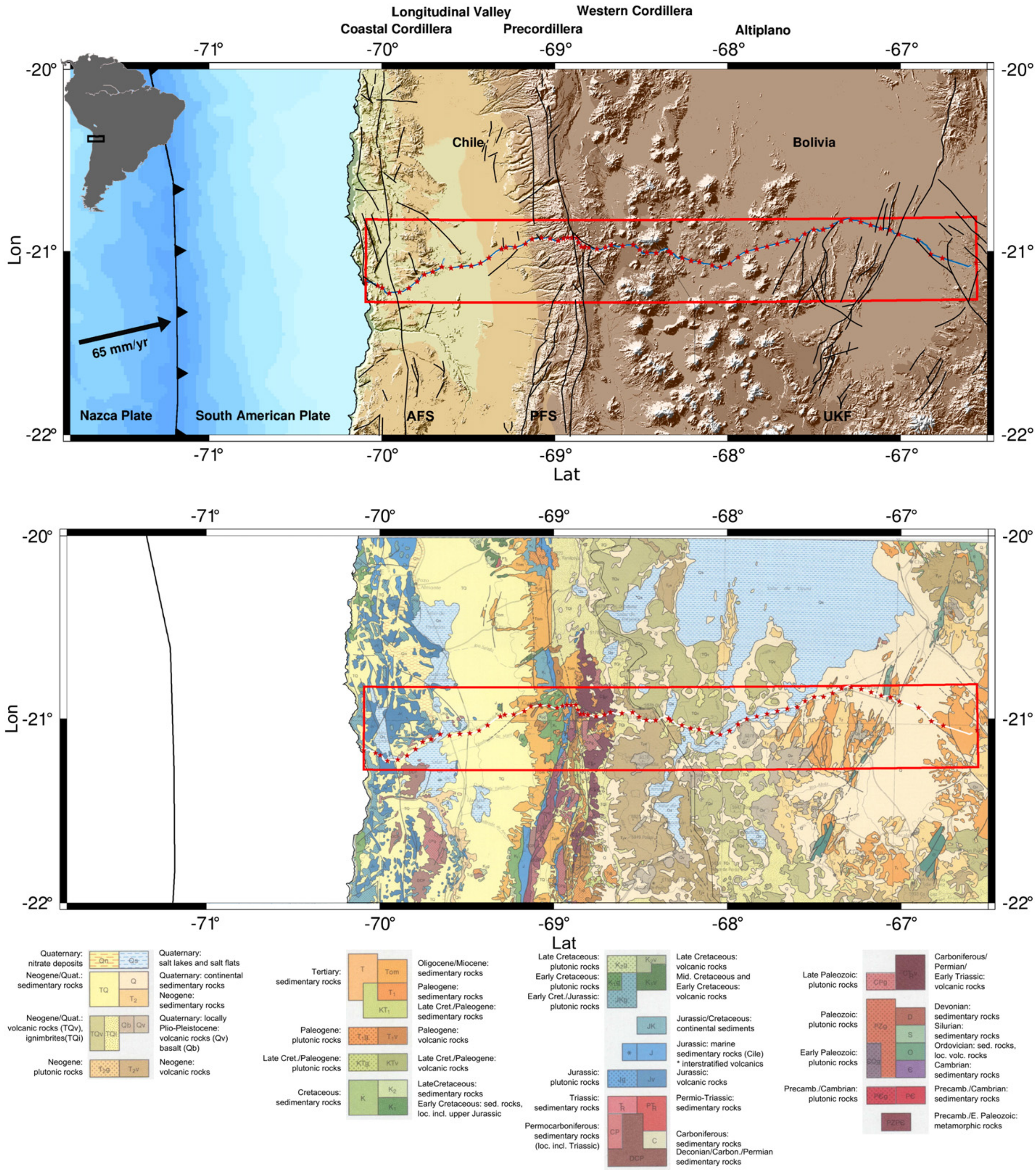

Fig. 1. Top: topography of the study area. The receiver line of the reflection seismic profile ANCORP'96 is marked by the light blue line and shot positions are marked by red stars. The red box denotes the area covered by the migration output. Convergence of the Nazca Plate is illustrated by a black arrow and the major trench-parallel geological units are labelled accordingly. The three large fault zones Atacama Fault System (AFS), Precordilleran Fault System (PFS), and Uyuni-Kenayani Fault (UKF) are marked with black lines and labels are at the bottom of the figure. Bottom: Geological map of the same area modified after Reutter and Munier (2006).

PFS), which had not been resolved by the original processing. The adaptation of recently developed effective linear noise cancellation schemes for noisy seismic data (Schmelzbach et al., 2007) and a new focusing approaches to Kirchhoff pre-stack depth migration (PSDM) termed coherency migration (Hlousek et al., 2015) to the ANCORP'96 data set were expected to deliver enhanced images of the upper crust. These new images were expected to lead to an improved understanding of the structure of the fault systems, with a focus on the depth range