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Architecture of an exceptionally exposed seismogenic source: The Bolfin Fault Zone (Atacama Desert, Chile)

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The geometry of fault zones (e.g. fault surface roughness, fault rock distribution, network of secondary faults and fractures) is one of the main factors controlling earthquake nucleation, rupture speed and length of main shocks, foreshock and aftershock evolution, ground motion and seismic radiation pattern. Despite the pivotal role that fault geometry bears on earthquake mechanics, little is known about the precise architecture of fault zones at seismogenic depths. In fact, most exhumed faults, especially those capable of producing moderate to large earthquakes (faults > 20 km in length) are discontinuously and poorly exposed at the surface because of vegetation cover and/or weathering.

Here we present a detailed, though preliminary, structural geology survey of a large exceptionally exposed, exhumed seismogenic fault in the Atacama Desert (Chile), the Bolfin Fault Zone (BFZ). The BFZ is a sub-vertical NNW-striking, left-lateral strike-slip fault belonging to the ∼1000 km long Atacama Fault System. The BFZ is hosted in amphibolites, granodiorites and quartzdiorites of the Coastal Cordillera and records Mesozoic (sinistral) and Cenozoic (normal) displacements.

We integrated Unmanned Aerial Vehicle surveys with detailed mapping of the network of ductile shear zones and brittle faults of the BFZ to produce high-resolution maps of the fault zone structure over four representative transects along fault strike. We conducted mineralogical, microstructural and geochemical investigations of the fault zone rocks.

From this field and microstructural study, four main deformation events were recognized, based on their crosscutting relationships observed in the field. An early deformation event (D0) consists of NW- to N- striking ductile (amphibolitic to granulitic facies) shear zones. The first brittle deformation event (D1, BFZ sensu-strictu) consists of NW- to NE-striking sinistral strike-slip faults associated with greenschists to sub-greenschists (albite + chlorite + epidote + actinolite) foliated cataclasites and pseudotachylytes. The mineral assemblage and Al content in chlorite constrain deformation conditions at 6-8 km depth and 280-350°C ambient temperature. The presence of pseudotachylytes, formed in a fluid-rich environment, as attested by the abundance of amygdules in the matrix (only associated with the D1 event) documents the ancient seismicity of the fault zone. A N-, NW- and NE-striking fault set consisting of dextral transtensional faults represents the intermediate brittle deformation event (D2) and is marked by hydrothermal epidote (+ quartz + calcite) precipitation. Lastly, two conjugate fault sets, a NNE-SSW to NE-SW strike dextral-normal and a ESE-WNW strike sinistral-normal transtensional faults filled with calcite (+ palygorskite ± gypsum ± halite), are interpreted as the youngest (Miocene to post-Moicene) deformation event (D3). The occurrence of palygorskite constrains D3 deformation conditions of < 150°C to ambient temperature.

Given the exceptional exposure and the relatively easy accessibility compared to other fault zones cropping out in desert areas, the Bolfin Fault Zone provides a unique opportunity to (1) examine the structure and the evolution of seismogenic fault zones in the Earth's continental crust and, (2) produce 3-D fault models for earthquake rupture numerical simulations.