Structural evolution of a crustal-scale seismogenic fault in a magmatic arc: The Bolfin Fault Zone (Atacama Fault System)

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Motivations and aims of the study

The geometry and evolution in space and time of seismogenic fault zones control main-shock earthquake ruptures and associated seismic sequence. However, the nucleation and evolution of seismogenic crustal-scale (i.e., 10s of km-long) faults is poorly known because exhumed crustal-scale faults are hardly exposed along their whole length at the Earth’s surface. In this study, we aimed at:

- investigating the *structural evolution* of a *crustal-scale* (i.e., 10s of km-long) *seismogenic fault* hosted in the continental crust;
- examining the influence of *precursory structures* on the *fault geometry* over the scale of a *crustal-scale fault*.

Methods

- Detailed geological field surveys along the >40-km-long seismogenic Bolfin Fault Zone (BFZ) of the Atacama Fault System (Atacama Desert, Northern Chile);
- Image analysis of satellite and drone images;
- Microstructural, mineralogical and geochemical investigations of host rocks and fault zone rocks.
The exhumed seismogenic Bolfin Fault Zone (BFZ)

- >40-km-long seismogenic, splay fault of the 1000-km-long sinistral, strike-slip Atacama Fault System (AFS)

- Mesozoic oblique subduction of the Phoenix oceanic plate

- Deformation along the AFS spatially and temporally associated with magmatism

- Exceptional outcrop exposures due to hyper-arid climate and slow erosion rates

Modified from Jaillard et al. (1990); Scheuber and Gonzalez (1999); Cembrano et al. (2005); Gomila et al. (2016)
Evidence of ancient seismic faulting ($T \leq 310 \, ^\circ C$ and 5-7 km depth)

- Pseudotachylyte injection vein
- Pseudotachylyte fault vein

Green protobreccia to cataclasite
(chlorite + epidote + albite + quartz + (Fe-)actinolite)

$20 \, \mu m$

Kfs+Pl microlites

Pl clast
The BFZ: northern & central segments

Seismic faulting exploited magmatic foliation of plutons

magmatic foliation
andesitic/tonalitic dykes
Chl-rich cataclasites
pseudotachylytes

Playa escondida
Sand Quarry
Quebrada Corta
Ni Miedo
Seismic faulting exploited magmatic foliation of plutons

Miocene continental deposits

BFZ fault core

Jurassic meta-diorites

150 m
The BFZ: fault linkage & southern segment

NW-striking splay and horsetail linkage faults
- Magmatic foliation
- Andesitic/tonalitic dykes
- Chl-rich cataclasites
- Pseudotachylytes

Seismic faulting exploited andesitic dykes
- Magmatic foliation
- Andesitic/tonalitic dykes
- Chl-rich cataclasites
- Pseudotachylytes

Fault Bend
Quebrada Larga
Seismic faulting exploited andesitic dykes
Structural evolution of the seismogenic Bolfin Fault Zone

**Syn-to-late magmatic deformation**

- $T > 700 \, ^\circ C$
- Depth $< 10 \, km$
- Diachronous plutons emplacement: development of magmatic foliations

**Multiple dyke intrusion**

- $310 \, ^\circ C < T < 700 \, ^\circ C$
- Depth $\approx$
- Emplacement of NW-SE and NE-SW dyke sets

**Seismic faulting**

- $T \leq 310 \, ^\circ C$
- Depth 5-7 km
- Formation of the Bolfin Fault Zone: chlorite-rich cataclasites and pseudotachylytes
Conceptual model of formation of the Bolfin Fault Zone

1: pre-faulting framework
2: fault nucleation
3: fault growth

1: emplacement of plutons and multiple dyke sets;
2: fault nucleation along precursory anisotropies favorably oriented with respect to the far-stress field;
3: fault growth through NW-SE splay and horsetail faults (hard linkage)
Conclusions

- The Bolfin Fault Zone was seismogenic, as attested by widespread occurrence of pseudotachylytes, and active at ambient temperatures of $\leq 310 ^\circ C$ and depths of 5-7 km in a fluid-rich environment.

- Seismic faulting exploited magmatic foliations and dykes well-oriented with respect to the subduction-related stress field.

- The sinuous geometry of the Bolfin Fault Zone results from hard linkage of anisotropy-pinned fault segments during fault growth.
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Satellite images from https://earthexplorer.usgs.gov/