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Fault zone development and strain partitioning in an extensional strike-slip duplex: A case study from the Mesozoic Atacama fault system, Northern Chile

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Abstract

Upper crustal strike-slip duplexes provide an excellent opportunity to address the fundamental question of fault zone development and strain partitioning in an evolving system. Detailed field mapping of the Mesozoic Atacama fault system in the Coastal Cordillera of Northern Chile documents the progressive development of second- and third-order faults forming a duplex at a dilational jog between two overstepping master faults: the sinistral strike-slip, NNW-striking, Jorgillo and Bolfin faults. These are constituted by a meter-wide core of foliated S-C ultracataclasite and cataclasite, flanked by a damage zone of protocataclasite, splay faults and veins. Lateral separation of markers along master faults is on the order of a few kilometers. Second-order, NW-striking, oblique-slip subsidiary fault zones do not show foliated ultracataclasite; lateral sinistral separations are in the range of ~10 to 200 m with a relatively minor normal dip-slip component. In turn, third-order, east–west striking normal faults exhibit centimetric displacement. Oblique-slip (sinistral–normal) fault zones located at the southern termination of the Bolfin fault form a well-developed imbricate fan structure. They exhibit a relatively simple architecture of extensional and extensional-shear fractures bound by low displacement shear fractures. Kinematic analysis of fault slip data from mesoscopic faults within the duplex area, document that the NW-striking and the EW-striking faults accommodate transtension and extension, respectively. Examination of master and subsidiary faults of the duplex indicates a strong correlation between total displacement and internal fault structure. Faults started from arrays of en echelon extensional/extensional-shear fractures that then coalesced into throughgoing strike-slip faults. Further displacement leads to the formation of discrete bands of cataclasite and ultracataclasite that take up a significant part of the total displacement. We interpret that the duplex formed by progressive linkage of horsetail-like structures at the southern tip of the Bolfin fault that joined splay faults coming from the Jorgillo and Coloso faults. The geometry and kinematics of faults is compared with that observed in analog models to gain an insight into the kinematic processes leading to complex strike-slip fault zones in the upper crust.

Keywords: Strike-slip duplexes; Strain partitioning; Faults; Atacama; Andes

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1. Introduction

Examining the architecture and kinematics of fault-fracture networks in strike-slip duplexes at various scales can provide important insights into the nature of fault development and the relation between bulk regional deformation and local strain patterns. This is in turn relevant for understanding the process of nucleation, propagation and arrest of earthquakes, specifically at dilational jogs of major crustal strike-slip fault zones (e.g. Hill, 1977; Sibson, 1987; Poliakov et al., 2002).

The excellent three-dimensional exposure of the Mesozoic strike-slip Atacama fault System (AFS) (Arabasz, 1971; Scheuber and Andriessen, 1990), in the hyperarid desert of northern Chile, provides a good opportunity to document the progressive development of faults and fault rocks and compare these observations with available field, experimental and numerical models.

In this paper, we examine the nature, geometry and kinematics of individual centimeter-to-kilometer-long fault zones of the AFS, developed within quartz-feldspathic rocks. Well-exposed horizontal and vertical separation of markers in combination with good kinematic indicators on mesoscopic fault surfaces are used to obtain the regional and local distribution of incremental strain axes representative of individual faults and fault networks at various scales. The combination of geometric and kinematic data is then used to propose a general model for fault zone development in upper crustal strike-slip duplexes. Our aim is to better understand the processes driving master and subsidiary fault development, the nature of the linkage between overstepping fault strands, and the strain partitioning patterns arising from fault interaction in strike-slip settings.

1.1. Strike-slip duplexes

Strike-slip tectonics is a broad subject that has been addressed from different perspectives including field and experimental work. Geometrical, kinematic and dynamic analyses of crustal-scale transcurrent fault systems, such as the San Andreas Fault in California (e.g. Crowell, 1974; Sylvester, 1988) set the foundations of field structural geology of strike-slip faults including propositions of basic terminology and interpretations for the tectonic significance of these faults. For instance, a closer examination of apparently simple strike-slip faults revealed the existence of splays, faults bends and steps, early recognized as key elements in the structural evolution of these structures (e.g. Crowell, 1974). Decades before these field-based studies, pioneer experimental analog models by Riedel (1929) and then Tchalenko (1970) provided a useful framework through which the progressive structural evolution of strike-slip fault systems can be examined. Analog models of strike-slip deformation, such as those by Tchalenko (1970), Hempton and Neher (1986) and Naylor et al. (1986), have been compared with real examples and striking similarities were found and explained in terms of Mohr–Coulomb theory of shear failure. Among the typical features of transcurrent fault systems observed in both analog experiments and nature, are an arrangement of splay faults joining overlapping strike-slip faults, a structure called strike-slip duplex by Woodcock and Fisher (1986).

The concept of duplexes was first applied to structural geology to designate imbricate fault arrays associated with thrust tectonics (Boyer and Elliott, 1982). A duplex involves a set of imbricate faults that transfer the displacement from a floor thrust to a roof thrust. The development of extensional or contractional strike-slip duplexes associated with transcurrent tectonics, as analogy with their dip-slip counterparts, was suggested by Woodcock and Fisher (1986) (Fig. 1a). These authors argue that the formation of strike-slip duplexes is best understood as a kinematic response to imposed boundary constraints, rather than by the stress-control or bulk strain approaches usually applied to wrench tectonics. However, the precise nature, geometry and kinematics of fault-fracture networks in strike-slip duplexes remain poorly known. For instance, maintaining plane strain conditions in strike-slip duplexes is more complicated than in the dip-slip counterparts. For dip-slip systems, the thickening of a contractional duplex or thinning of an extensional duplex is easily accommodated by distortion of the free ground surface allowing plane strain in vertical section. In contrast, the widening or narrowing of contractional or extensional strike-slip duplexes, must be accommodated by lateral distortion of the rock overburden to maintain plane strain in horizontal section, which is then rarely achieved (e.g.