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Invited review

Deep crustal expressions of exhumed strike-slip fault systems: Shear zone initiation on rheological boundaries

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ABSTRACT

The formation of major exhumed strike-slip faults represents one of the most important dynamic processes affecting the evolution of the Earth's lithosphere. Detailed models of the potential initiation, their properties and architecture of orogen-scale exhumed strike-slip faults, which are often subparallel to mountain ranges, are rare. The initiation of strike-slip faults is at depth, where temperature-controlled rheological weakening mechanisms play the essential role localizing future strike-slip faults. In this review study, we highlight that in pluton- and metamorphic core complex (MCC)-controlled tectonic settings, as end-members, the initiation of strike-slip faults occurs by rheological weakening along hot-to-cold contacts deep within the crust and mantle lithosphere, respectively. These endmember processes are potential mechanisms for the initiation of orogen-scale exhumed strike-slip faults at depth result in a specific thermal and structural architecture. Similar processes guide the overall displacement and ultimately the exhumation at such deep levels. These types of exhumed strike-slip dominated fault zones expose a wide variety of mylonitic, cataclastic and non-cohesive fault rocks on the surface, which were formed at different structural levels of the crust during various stages of faulting and exhumation. Exhumation of mylonitic rocks is, therefore, a common feature of such reverse oblique-slip strike-slip faults, implying major transtensive and/or transpressive processes accompany pure strike-slip motion during exhumation. A major aspect of many exhumed strike-slip faults is their lateral thermal gradient induced by the lateral juxtaposition of hot and cold levels of the crust controlling relevant properties of such fault zones, and thus the overall fault architecture (e.g., fault core, damage zone, shear lenses, fault rocks) and its thermal structure. These properties of the overall fault architecture include strength of fault rocks, permeability and porosity, the hydrological regime, as well as the nature and origin of circulating hydrothermal fluids.

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1. Introduction

Formation of major exhumed strike-slip faults represents one of the most important dynamic processes significantly affecting the lithosphere-asthenosphere system. The exhumed strike-slip fault zones commonly preserved as long-standing zones of weakness in the Earth's crust (Handy, 1989), and the manners in which they form are known to be of significant importance for earthquake mechanics (e.g., Wesnousky, 1988; Stirling et al., 1996; Lyakhovsky et al., 2001; Carpenter et al., 2011) associated with surface displacements along their strike representing important global geological hazards (e.g., Rutter et al., 2001; Mooney and White, 2010). Near-surface rocks along faults are broken by cataclastic processes and have, therefore, no or a low strength. For a wide variety of practical purposes, for example, tunneling and underground excavation, exploration of hydrothermal ore deposits, geothermal energy and hydrocarbon exploitation (e.g., Aydin and Eyal, 2002; Sorkhabi and Tsuji, 2005; Weinberg et al., 2005; Bense et al., 2013; Wilson et al., 2013), the study and prediction of the anatomy of exhumed strike-slip fault zones is of particular interest. Due to high porosity, steep fault zones represent pathways for ascending and descending fluids and related alteration processes by fluid-rock interaction (e.g., Mittempergher et al., 2009; Faulkner et al., 2010; Pei et al., 2015). This is also especially true of exhumed strike-slip faults in which mixed ductile and brittle fault rocks control the strength, porosity and permeability (Faulkner et al., 2010).

Continental-scale strike-slip fault zones are common tectonic features, particularly at convergent plate boundaries produced by oblique convergence and continental indentation (Storti et al., 2003). They are deep crustal expressions of the interaction between kinematic boundary conditions, rock rheology, and associated stress fields. During the last decades, many studies involved field observations, laboratory experiments, seismology, hydrogeology, and analytical and numerical modelling, have concentrated on describing and understanding the architecture, rock failure processes and mechanisms of the continental exhumed strike-slip zones (e.g., Allen, 1965; Katili, 1970; Fitch, 1972; Sibson, 1977; Scholz, 1980, 1989, 1990; Wise et al., 1984; Hanmer, 1988; Sylvester, 1988; Woodcock and Schubert, 1994; Wintsch et al., 1995; Tikoff and de Saint Blanquat, 1997a; Läufer et al., 1997; Brown and Solar, 1998; Brown and Phillips, 1999; Teyssier and Tikoff, 1998; Paterson and Schmidt, 1999; Evans et al., 2000; Handy et al., 2001, 2005, 2007; Holdsworth et al., 2001; Storti et al., 2003; Rosenberg, 2004; Corti et al., 2005; Kim and Sanderson, 2006; Cunningham and Mann, 2007; Morrow et al., 2007; Finzi et al., 2009; Griffith et al., 2009; Wibberley et al., 2008; Bistacchi et al., 2010; Molnar and Dayem, 2010; Frost et al., 2011; Keppler et al., 2013; Evans et al., 2014). However, the structural evolution and formation mechanisms of exhumed strike-slip faults and of their implications for lithosphere dynamics are still poorly understood. Detailed models of the potential initiation, and properties and architecture of orogen-scale exhumed strike-slip faults and how these relate to exhumation are rare.

In the following section, we review the state of exhumed continental-scale strike-slip fault systems, which represent a deep-crustal region across fault zones now exposed at the surface. We will discuss exhumed strike-slip faults, in which initially ductile structures are superimposed by brittle structures and their sequential formation relates to the exhumation of ductile fault rocks. The following controversial key issues are addressed: (1) Which relevant properties of such orogen-scale exhumed strike-slip fault zones with mixed ductile and brittle rocks can be deduced from fault sections? (2) What mechanisms exhume such faults? (3) How do orogen-scale strike-slip faults nucleate and initiate along rheologically weak zones? (4) How do thermal structure and fluids at the crustal level of fault change during various faulting and exhumation stages? The main emphasis of this review study is on the initiation of strike-slip faults at these end-member controlled tectonic settings. Many orogen-scale strike-slip faults initiate and further develop along rheologically weak linear zones at depth. These zones include (a) faults with abundant granite intrusions, (b) along lateral borders of hot metamorphic core complexes (MCCs), or (c) zones of rheological weakness due to ascending fluids or the presence of rheologically weak minerals such as talc or graphite.

2. Review of deep structure of continental strike-slip faults

Many continental strike-slip faults (Fig. 1) are observed to be weak compared with the surrounding rocks through evidence of geological, geophysical and laboratory measurements of frictional strength. The

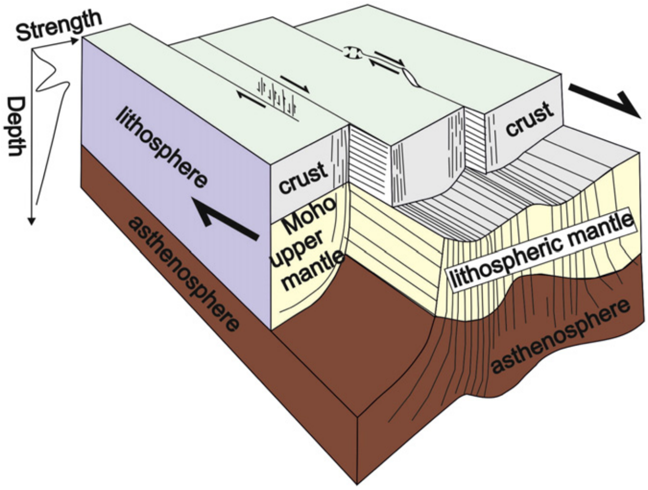

Fig. 1. Cartoon showing major continental intraplate strike-slip fault zone in the upper crust passing downwards into shear zones in the lower crust and lithospheric mantle. Schematic strength vs. depth profile or continental lithosphere shown to the left. Figure modified from Teyssier and Tikoff, 1998, Vauchez et al., 1998 and Storti et al., 2003.