PREFACE

Why do earthquakes happen? Why do some faults slip aseismically, while others generate catastrophic ruptures, sometimes over thousands of kilometers of faults? This age-old issue has influenced and conditioned many societies for which earthquakes remain one of the most damaging and potentially the deadliest geohazard in densely populated areas. Because of the depth at which most seismic events nucleate, direct observations and measurements are impossible to make. Thus, a deterministic prediction of the timing, location, and magnitude of an earthquake seems unrealistic. However, since the plate tectonic revolution of the 1960s, significant progress has been made in understanding the physics of faulting. This, combined with short-term earthquakes statistics, is the key to develop better probabilistic forecasting models that are underpinned by physical constraints. Such models represent the most effective way to mitigate earthquake damage and human causalities.

Fault zones in the brittle crust are intricate structures with physical properties evolving over timescales ranging from a few seconds to millions of years and involving slip spanning several orders of magnitude, from millimeters to tens of kilometers. In particular, dynamic ruptures lead to change of on-fault and off-fault physiochemical properties and microstructure, which in turn affect nucleation processes, extent and timing of rupture, seismic wave radiation, and aseismic deformation. As a consequence, study of brittle faulting and earthquake processes is fundamentally multidisciplinary, involving field observations, geodetic and seismological measurements, laboratory experiments, numerical studies. Recently, a thorough effort has been made to bring together these different disciplines of earth sciences, in order to develop a better understanding of the dynamic processes occurring during earthquakes and the associated evolution of fault zones. Systematic micro- and macrostructural field studies [e.g., *Faulkner et al.*, 2006; *Dor et al.*, 2006; *Mitchell and Faulkner*, 2009; *Savage and Brodsky*, 2011], as well as seismic surveys [e.g., *Li et al.*, 2006; *Cochran et al.*, 2009; *Froment et al.*, 2014], have recently been performed on fault zones, a key component to understanding the energy balance of earthquakes [e.g., *Rice*, 2002; *Kanamori*, 2006]. Relating fault mechanics to fault zone structure, several authors have underlined the importance of combining field observations with geodetic and seismological measurements to understand what controls the seismic and aseismic slip behavior [e.g., *Biegel and Sammis*, 2004; *Thomas et al.*, 2014; *Audet and Burgmann*, 2014]. Recent studies have successfully bridged the gap between rocks physics, laboratory experiments, and seismic observations of dynamic processes and fault zone evolution [e.g., *Schubnel et al.*, 2006; *Brantut*, 2015]. These multidisciplinary approaches, with a real feedback between field observations, laboratory experiments, and theoretical developments, allow the development of mechanically constrained numerical models of earthquake faulting that take into account the interplay between the dynamically evolving off-fault medium and the rupture propagation [e.g., *Dunham et al.*, 2011; *Bhat et al.*, 2012; *Xu et al.*, 2014]. If physically accurate, these numerical models are powerful tools to investigate dynamic rupture propagation, spontaneous dynamic off-fault deformation, and high-frequency ground motion, which are essential for seismic risk mitigation.

This desire to cross traditional disciplinary bounds and promote multidisciplinary studies provided the initial stimulus to organize the 2014 AGU Fall Meeting session, "Fault Zone Properties and Processes during Dynamic Rupture," from which this monograph derives. Workshops on similar subjects were also sponsored by the International School of Geophysics in May 2013, titled "Properties and Processes of Crustal Fault Zones," and by the Royal Society in May 2016, titled "Faulting, Friction and Weakening: From Slow to Fast Motion," demonstrating that the community is now recognizing the importance of endorsing such an interdisciplinary approach. Papers in the present volume capture the current state of the art of this discipline by providing an overview of the existing knowledge on the physics of dynamic faulting. The contributions to the volume cover observational and experimental fault fabric and mechanics, the evolution of fault zone physical and chemical properties, dynamic rupture processes, and physically and observationally consistent numerical modeling of fault zones during seismic rupture.

Whearty et al. seek the upper limit of off-fault damage associated to dynamic rupture by studying the fault zone architecture of the San Jacinto Fault. Korren et al. conduct a field study in Taiwan and use pseudotachylyte as a marker to determine seismic rupture parameters. Mitchell et al. display evidence of fluids channeled through a network of microfractures associated with a passing earthquake rupture. Aben et al. perform high strain rate experiments and correlate them with field observations by analyzing several pulverized rock samples. Smith et al. study the microstructural evolution of calcite-dolomite gouges deformed experimentally during coseismic shearing and explore the consequences for interpreting the fault rock record. Lockner et al. analyze the condition for dynamic shear melting in laboratory stick-slip experiments. Chen et al. discuss the role of powder rolling as a mechanism of dynamic fault weakening earthquake rupture models. Kilgore et al., using laboratory experiments, develop methods to relate stick-slip to natural earthquakes and to determine earthquake source properties. Brantut and Platt investigate the efficiency of two major weakening mechanisms, flash heating and thermal pressurization, as a function of depth across a range of representative geological settings. Renard and Candela review the scaling properties of faults and earthquake slip roughness, compare with numerical models, and raise some implications for earthquake mechanics. Klinger et al., using paleoseismology and long-term morphology, explore the conditions for fault branching for strike-slip earthquakes. Passelègue et al. track the occurrence of precursory processes with increasing fault strength during laboratory earthquakes. Ampuero and Mao, using numerical simulation and fracture mechanics theory, show the geometrical control of the seismogenic depth on the damage zone thickness of mature faults. And finally, Thomas et al. present a numerical study that explores the nonlinear coupling between earthquake ruptures and the dynamically evolving off-fault medium.

We believe this is the first collection of manuscripts that takes a multidisciplinary approach to study the evolution of fault properties and processes at play during dynamic rupture, with particular emphasis on the effect of on-fault and off-fault thermal-hydrology-mechanics-chemical coupling on seismic ruptures. This monograph will therefore prove to be a valuable contribution for any Earth scientists, researchers, and students interested in earthquake processes and properties of fault zones.

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