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Introduction

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The process of brittle faulting is complex, involving slip over spatial scales of millimeters to hundreds of kilometers and time scales ranging from fractions of a second to millions of years. As a result, faulting and earthquakes cut across traditional disciplinary bounds, forcing the geologist to consider results from solid mechanics and elastodynamics and those in seismology and mechanics to come to grips with geologic and geodetic data that bear on earthquake rupture processes and fault mechanics. For these reasons, the study of faults and earthquakes is fundamentally multidisciplinary, drawing from laboratory friction and fracture experiments, field studies of natural faults, seismological studies of earthquake rupture, and theoretical modeling of fault behavior and crack dynamics. Recent work on our subject has focused on issues such as the evolution with displacement of fault stability, the dynamics of earthquake rupture, the relation between fault zone structure and stability, and the mechanical and chemical effects of pore fluids on fault zones.

This special issue grew out of a desire to pull together these varied approaches to fault and earthquake mechanics and to highlight the multidisciplinary nature of this research. A symposium at the May 1993 meeting of the American Geophysical Union provided the initial stimulus for the papers contained here, although many papers were contributed later. A testimony to the level of activity in this broad field of inquiry comes from the large number of papers received. As a consequence, the special issue will be published in two parts. Part I contains 17 papers and Part II will contain a similar number.

Recent advances in faulting, rock friction, and earthquake mechanics derive from theoretical, field, and laboratory viewpoints. Thus, we have organized the papers into broad themes based on these three disciplinary viewpoints, while recognizing that many of the studies fall into two or even all three of these themes. These themes will carry over into Part II of this special issue.

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Part I begins with seven papers on the theme of *Earthquake Source Mechanics and Fracture Mechanics: Theory and Observation.* It begins with a paper by Cochard and Madariaga who develop a dynamic rupture model based on rate- and state-dependent friction laws. They study the effect on rupture of stress distribution on the fault plane, showing the existence of narrow slip pulses and providing the first detailed view of the physics which may give rise to this phenomenon. Their study raises several interesting issues, including the possibility that ruptures "know" how large they will be from the onset and thus accumulate slip, within the narrow time window available, appropriate for their final length. Pisarenko and Mora also study an elastodynamic model involving velocity-dependent friction. They describe a discrete model for friction between rough elastic surfaces and deduce a friction law based on asperity contact behavior. They find friction velocity dependence which mimics that observed experimentally for rocks at lower rates, and attribute velocity weakening to inertial and elastodynamic effects associated with slip at high velocities. McGarr, in a study of mining-induced and laboratory earthquakes, presents a detailed comparison of source parameters and shows that seismic efficiencies are quite low in both cases and may have an upper bound. His work is important for understanding laboratory studies of the earthquake source and for the interpretation of the absolute state of stress on faults from earthquake data.

Three studies explore models based on statistical physics and fault self-organization. Sornette, Miltenberger, and Vanneste describe the development of fault systems by repeated earthquakes. Their work provides a critical link in understanding to what extent earthquake complexity and the complexity of fault patterns arises from the chaotic nature of dynamic rupture or from material heterogeneities and long-range elastic interactions. In a similar vein the works by Main, Henderson, Meredith, and Sammonds and by Henderson, Main, Maclean, and Norman show the interplay between microscopic material properties and physical and chemical effects operating on many scales. They discuss the importance of these effects for earthquake scaling. In the final paper of this section, De Bramaecker and Wei describe a model for crack propagation which may have important implications for fault growth and development. They challenge the dichotomy set-up, on the one hand, by the existence of long shear faults in nature, yet, on the other hand, the observation that shear cracks tend not to grow in their own plane.

The five papers included under the theme *Faulting and Crustal Deformation: Field Observations and Modeling* give a flavor of what has become a thriving enterprise within the field of fault and earthquake mechanics. Increasingly, the role of earthquake rupture in fault growth is being recognized and the link is being made between fault zone structure, fault stability, and the state of stress around faults. The first two papers in this section demonstrate the link between fault slip, stability, and structure. Kanaori, Kawakami, and Yairi study fault slip and historical seismicity along the Median Tectonic Line, Japan and conclude that significant slip occurs aseismically or in events with anamalously slow rupture. On the basis of their seismotectonic analysis, they conclude that the Median Tectonic Line characteristically does not produce great earthquakes. The link between fault structure and the time scale over which features are produced is also present in the work by Bruhn, Parry, Yonkee, and Thompson. They quantify the complex pattern of fractures in and around the Wasatch normal fault, Utah, and relate the processes of fracturing and hydrothermal alteration to changes in elastic moduli, fluid transport properties, and possibly the stability of fault slip. They show how slip is localized within the fault zone and establish the episodic nature of fracturing, fracture healing, and fluid flow.

The work of Sibson and that of Evans and Langrock attests to the complexity of faulting and fault structures, yet the apparent mechanical simplicity implied by their relation to the stress field. Sibson uses published observations of geometric relationships for faulting in a variety of tectonic settings to constrain natural coefficients of friction, while Evans and Langrock present a detailed stress inversion analysis of small faults associated with the Wasatch fault. Both report evidence in support of brittle faulting by Coulomb failure and fault slip with friction coefficients of 0.6 or so, consistent with laboratory measurements. Important exceptions to this include the San Andreas fault of California, the apparent weakness of which is most likely due to elevated fluid pressure, according to Sibson. Both also find evidence for significant rotation and misalignment of faults within the stress field through time. The final paper of this section, by Ma and Kusznir, is a study of the effect of layering on coseismic and postseismic fault slip. Their models include the effect of gravity and allow computation of the manner in which slip varies with depth for various assumptions about the elastic properties of the crust and upper mantle.

The final section includes five papers on the theme of *Frictional Slip, Failure, and Deformation Mechanics: Laboratory Studies.* This section begins with two papers on stick-slip motion and dynamic rupturing. Kato, Yamamoto, and Hirasawa present a careful experimental study of dynamic shear rupture along a simulated fault in rock and evaluate parameters of the slip weakening model using laboratory measurements of near-fault strong motions. Their observation that the strong motion duration is much shorter than the slip duration is potentially very important for interpreting earthquake recordings and understanding the dynamics of earthquake rupture.

The study of Anooshehpoor and Brune continues this theme, focusing on heat generation and elastic radiation during stick-slip sliding in foam rubber. They observe slip pulses, grossly similar to those modeled by Cochard and Madariaga, and find that displacement normal to the slip surface is sufficient to significantly reduce normal load and thus frictional heat production. If their results can be extrapolated to faults, they offer an explanation for the lack of a heat-flow anomaly over the San Andreas fault, California.

Scott, Lockner, Byerlee, and Sammis present data on the strength and deformation characteristics of a natural fault gouge from the Lopez fault in Southern California. Studying both undistributed and remoulded gouge they find that the state of consolidation and the experimental configuration affect failure strength through the Coulomb-Mohr parameters as well as the processes of shear localization. The paper by Sammis and Steacy also considers deformation within fault gouge. They discuss a grain bridge model for the micromechanics of friction in granular gouge and emphasize the importance of dilation for understanding the systematics of friction data. The tie between laboratory work on gouge and field studies of faulting is highlighted by the last paper, which considers wear rate and the accumulation of gouge during frictional sliding. Nagahama and Nakamura use the Pi theorem to model variations in wear rate and propose a general relation for the dependence of wear rate on normal stress and material properties.

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