1 Foreword to Special Issue: “Fault Zone Structure, Mechanics and Evolution in Nature
2 and Experiment”

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13 **Foreword**

14 Tectonic faults in the Earth’s upper crust are geometrically complex zones of localized
15 deformation and rock damage that evolve over wide length- and time-scales. Fault zones influence a
16 range of crustal processes including fluid flow, mechanical strength, basin evolution, and
17 earthquake nucleation, propagation and arrest. Because of this, fault zones motivate considerable
18 academic and commercial research, and have been the focus of a large body of work involving field
19 observations, theory, numerical simulations, experiments and seismology.

20 Despite recent progress, significant aspects of fault zone structure and evolution remain
21 poorly understood. Uncertainties remain as to the main deformation mechanisms that are active
22 during the seismic cycle. It is also largely unclear how deformation is partitioned between principal

faults and adjacent regions of off-fault damage, and to what extent associated fluid flow is influenced by varying fracture modes in different lithologies. A further problem concerns the evolution of fault roughness and fault rock granularity during slip and how this impacts on fault mechanical behavior. Some of these issues are discussed in this Special Issue of the *Journal of Structural Geology* which arises from a session held at the European Geosciences Union (EGU) General Assembly in Vienna, April 2011. The contributions in this volume highlight some of the complexity of natural fault systems. Common themes that link many of the contributions are the relationships between fault zone structure and fault dynamics, and the importance of fault zone structure for sub-surface fluid flow, particularly in fractured carbonates. The 11 papers here are divided in to two parts, although the subdivision is somewhat arbitrary given the multidisciplinary nature of many of the contributions. Papers in Part I, *Fault zone structure and evolution*, deal mainly with field characterization of fault zones at outcrop to regional scales, and associated observations of fault rock microstructures. Papers in Part II, *Fault roughness and brittle rock damage*, present field and experimental constraints on the geometry and mechanical properties of fault slip surfaces, pulverized and sheared fault rocks, and cataclastic deformation bands.

Part I. Fault zone structure and evolution

Agosta et al. describe the structure and deformation mechanisms of shallowly exhumed normal fault zones in clay-bearing conglomerates and carbonate grainstones from the Granada Basin in Spain. Clay smearing and cataclasis were particularly important deformation mechanisms in the conglomerates, whereas jointing, pressure solution and local brecciation surrounding slip surfaces dominated in the carbonate grainstones. Overall, they suggest that the fault zones acted as combined conduit-barrier systems to fluid flow. *Petracchini et al.* present observations of small faults and fractures that cut well-bedded marly and pelagic carbonates of the Cingoli anticline in Italy, a potential analog for carbonate reservoirs in the nearby Po Plain and Adriatic Sea. They identify several distinct sets of largely strata-bound pressure solution seams that formed during

48 compaction and bedding-parallel flexural slip, leading them to propose a model in which faults
 49 developed relatively late during the folding process by linkage of bedding surfaces and pressure
 50 solution seams. The authors also discuss the role that such structures, below the typical seismic
 51 resolution, may have on subsurface fluid flow in folded upper-crustal carbonate sequences of this
 52 kind. *Reyer et al.* describe faults with centimeter- to meter-scale offsets cutting both carbonate and
 53 clastic sediments in the Northwest German Basin. Their field and laboratory measurements indicate
 54 that only fault zones in carbonates have well-defined damage zones with higher fracture densities
 55 compared to background fractures in the wall rocks. This leads the authors to suggest that fault
 56 zones in carbonates will promote sub-surface fluid flow to a greater extent than fault zones in clastic
 57 sedimentary rocks. *Fondriest et al.* present field and microstructural observations of a fault zone
 58 exhumed from <2 km depth crosscutting dolostones in the Southern Alps of Italy. They focus on
 59 cataclasites in the millimeter- to centimeter-thick slipping zones of the principal, as well as
 60 subsidiary faults, and find widespread evidence for fault rock fluidization, injection and clast size
 61 sorting. They conclude, in part by comparison to a seismically-active fault in dolostones, that the
 62 microstructures formed during seismic slip. The final paper by *Rutter et al.* synthesizes previous
 63 observations from the large-displacement Carboneras fault zone in south-eastern Spain, and
 64 presents new age determinations and a new geological map to better constrain its geological
 65 character and movement history. The structure of the ~1 km wide Carboneras fault zone consists of
 66 two main fault strands, each containing multiple fault gouge zones enclosing elongate tracts of wall
 67 rock lithologies. The authors suggest that the fault zone formed as part of a transform system
 68 associated with slab retreat during closure of the Alboran Sea in the western Mediterranean region.

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70 Part II. Fault roughness and brittle rock damage

71 *Candela et al.* use terrestrial laser-scanning to measure the roughness of the Dixie Valley
 72 normal fault in Nevada, USA. They find that the roughness of the main slip surface is self-affine in

73 character, meaning that it appears smoother at larger scales of observation. Their field
74 measurements of the dimensions of elongate fault rock lenses leads the authors to develop a model
75 in which the self-affine property of the fault roughness is controlled by linkage of a myriad of
76 overlapping slip surfaces during fault zone growth. *Renard et al.* monitor surface roughness
77 evolution and infra-red emissions during analogue friction experiments involving blocks of halite
78 sliding over a sandpaper base. They show that gouge production during the experiments is highly
79 heterogeneous, involving fracturing and formation of elongate striations in the slip direction, as well
80 as migration of gouge particles in various directions with respect to the slip vector. Accumulation of
81 gouge during the experiments resulted in a gradual decrease in the friction coefficient. Finally, the
82 authors compare the geometry and distribution of wear materials in the experiments with the
83 striations commonly observed on natural fault surfaces. *Doan et al.* perform dynamic loading
84 experiments using a split Hopkinson pressure bar containing granite samples with varying amounts
85 of pre-existing fracture damage. They find that pulverization of the granite is easier to achieve in
86 the case of extensive pre-existing damage. Comparison of the experimental data with fracture
87 propagation theory suggests that the strain rate required to pulverize the granite samples is a power
88 law of initial fracture density. Their results imply that pulverized rocks in the field may result from
89 a positive feedback process during successive earthquake loading events. *Dyer et al.* analyze the
90 particle size distributions of gouge materials, and surface roughness of fractures, produced in a
91 granite sample during a triaxial loading experiment. They find that the power law exponent of the
92 particle size distribution increases systematically towards zones of intense comminution associated
93 with fractures and small faults. In contrast, they find no relationship between the surface roughness
94 of fractures and degree of comminution, although opening-mode fractures are slightly rougher than
95 those with small shear offsets. They conclude for the analyzed granite sample that there is no
96 correlation between the particle size distribution of gouge materials and the roughness of fractures
97 that bound such zones of gouge. *Cilona et al.* present field and laboratory observations of
98 deformation bands formed in porous carbonate grainstones of the Majella anticline in Italy, with the

99 aim of understanding the deformation mechanisms active during their development under natural
100 and experimental conditions. By evaluating the various roles of pressure solution, grain crushing
101 and fracturing, they conclude that there are important differences in the deformation mechanisms
102 active during formation of natural and experimental deformation bands in carbonates. Deformation
103 bands are also the subject of the final paper by *Imber et al*, who present observations of conjugate
104 deformation bands cutting unconsolidated sands and gravels in McKinleyville, California. The
105 deformation bands formed at <50 m depth ahead of the propagating tip of the Mckinleyville thrust
106 fault. The authors use a trishear model of fault propagation folding combined with published
107 mechanical data for high-porosity sandstones to test whether the deformation bands may have
108 formed parallel to lines of no finite elongation or parallel to zero extension directions. They
109 conclude that neither of these possibilities adequately explains the orientation of deformation bands
110 in Mckinleyville, and instead suggest that the deformation bands most likely formed in an
111 orientation consistent with the Mohr-Coulomb failure criterion, or in an orientation bound by the
112 Mohr-Coulomb failure criterion and zero extension directions.

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