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The Nucleation of Large Earthquakes Within Overpressured Fault Zones in Evaporitic Sequences

N. De Paola (1), C. Collettini (2) and D.R. Faulkner (3)

(1) RRG, Earth Sciences Department, University of Durham,UK, (2) GSG, Dipartimento di Scienze della Terra, Universita' di Perugia, Italy, (3) Rock Deformation Lab, Earth and Ocean Sciences Department, University of Liverpool, UK, (nicola.de-paola@durham.ac.uk / Phone: +44-0191-3342333)

The integration of seismic reflection profiles with well-located earthquakes show that the mainshocks of the 1997-1998 Umbria-Marche seismic sequence (Central Italy) nucleated at a depth of ˜6 km within the Triassic Evaporites (TE, anhydrites and dolostones), where CO_2 at near lithostatic pressure has been encountered in two deep boreholes (about 4 km). In order to investigate the deformation processes operating at depth in the source region of the Colfiorito earthquakes we have characterized: 1) fault zone structure by studying exhumed outcrops of the TE; 2) rheology and permeability by performing triaxial loading tests on borehole samples of anhydrites at room temperature, 100 MPa confining pressure (Pc), and range of pore fluid pressures (Pf). Permeability and porosity development was continuously measured prior to and throughout the deformation experiments. The architecture of large fault zones within the TE is given by a distinct fault core of very fine-grained fault rocks (cataclasites and fault gouge), where most of the shear strain has been accommodated, surrounded by a geometrically complex and heterogeneous damage zone. Brittle deformation within the fault core is extremely localized along principal slip surfaces associated with dolomite rich cataclasite seams, running parallel to the fault zone. The damage zone is characterized by adjacent zones of heavily fractured rocks (dolostones) and foliated rocks displaying little fracturing (anhydrites). Mechanical results after triaxial loading tests show that the brittle-ductile transition occurs for Pe = 20-40 MPa and is almost independent of fabric orientation and grain size. Brittle failure is

localized along discrete fractures and is always associated with a sudden stress drop. Conversely, ductile failure occurs by distributed deformation along cataclastic bands. In this case no stress drop is observed. The static k of the anhydrites, measured prior to loading for Pe = Pc-Pf = 10-60 MPa, is generally low, k = 10E-21 - 10E-19 m2, and, for a given Pe, is controlled by grain size and fabrics orientation with variations up to 2 orders of magnitude. The dynamic k measured at failure under constant Pe = 10-40 MPa (k = 10E-20-10E-17 m2) is controlled by the grain size, fabrics and Pe, as k increases up to about 1-2 orders of magnitude for decreasing Pe. All samples, independently whether deforming in a brittle or ductile way, show dilatancy after yielding. The onset of dilatancy coincides with the first increase in k, which increases dramatically prior to localized failure (upward concave curve), whilst tends to stabilize prior to distributed deformation (downward concave curve). Our experiments show that, during sample loading, the pattern of the permeability evolution is controlled by the mode of failure. Overall the integration of our field observations and laboratory data suggests that fault zones within the TE can act as barrier to deep seated CO2 rich crustal fluid flow, and favour the build up of fluid overpressures. During the seismic cycle, the maintenance of fluid overpressures within the fault zone, as far as the co-seismic period, is possible as long as localized brittle failure is prevented within the anhydrites. Brittle failure within the anhydrites occurs at the effective pressure Pe < 10 MPa, which signs the rheological transition from distributed (ductile) to localized deformation (ductile), associated with a dramatic increase in permeability. The formation of patches of pressurised fluids within the fault zone, may favour slip instability and trigger seismic rupture nucleation.