Journal of Structural Geology 32 (2010) 1185–1186

Contents lists available at ScienceDirect

Journal of Structural Geology

journal homepage: www.elsevier.com/locate/jsg

Faulting and fracturing of carbonate rocks: New insights into deformation mechanisms, petrophysics and fluid flow properties

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Foreword

The idea for this special issue of the Journal of Structural Geology came after the great interest shown by the attendees of the thematic session entitled "*Faulting in carbonate rocks: new insights on deformation mechanisms, petrophysics, and fluid flow properties*", convened on April 16th 2007 by the two guest editors at the EGU General Assembly in Vienna, Austria. There, scientists of both academic and petroleum communities presented their latest results, which are now included in this volume. The need for a deeper understanding of carbonate deformation arose in the last decade because of the discovery of important oil and gas reservoirs within these rocks. About 60% of the worlds' oil and ~40% of its gas reserves are contained in carbonate rocks (Schlumberger Market Analysis, 2007, www.slb.com). For this reason, both public and private investors have lately supported research projects aimed to a better characterization of faults and fractures in carbonate rocks, as well as of their petrophysical and hydraulic properties.

The contributing authors carried out their studies using different approaches: (i) field analysis of deformed outcrops, (ii) statistical fracture analysis, (iii) microstructural examination of carbonate fault rocks, (iv) numerical simulation of fault and fracture 4D distribution, (v) petrophysical characterization of specific carbonate facieses, (vi) experimental studies of mechanical analogues, and (vii) geochemical investigation of calcite veins. Most authors combine two or more of these approaches. The first 8 papers in the special issue deal with fracture types and distribution; they are followed by 8 papers concerning fault zone structures and processes.

The paper written by Resor and Flodin deals with the forward modeling of synsedimentary deformation associated with the carbonate margin of the Permian Capital depositional system (Guadalupe Mountains, USA). The authors compute the differential compaction associated with prograding and aggrading steep-sloped margins, which determines modifications of strata geometries. The results of their work, supported by field evidences, are consistent with tensile stress concentrations and brittle deformation at the carbonate margins.

Gale, Lander, Reed and Laubach present a numerical modeling of fracture porosity evolution in dolostones. The authors develop a geometric crystal growth model for synkinematic dolomite vein infilling in fractured dolostones, buried to depths of ~1–5 km, by taking into account different fracture opening rates and assuming constant temperature and supersaturation with respect to dolomite. By supposing that the rapid dolomite accumulation within cement bridges takes place during the crack-sealing processes, the authors obtain results that resemble the cement morphologies observed in natural dolomite fracture fill.

Larsen, Grunnaleite and Gudmundsson document the fracture distribution within a large fault zone crosscutting shallow-water carbonate rocks. After measuring the attitude and characteristics of fractures intersected by scanline surveys, the authors compute the spacing properties, the coefficients of variation and the apertures of each fracture set. The results of the fieldwork are used to populate a boundary-element model, from which both secondary porosity and secondary permeability of a fractured carbonate multilayer are inferred.

Frost and Kerans focus on the syndepositional fracture patterns visible in a reef complex. Based on field data, the authors address the relationships among the syndepositional fractures and lithofacies, depositional position and stratigraphic architecture in order to assess the mechanical stratigraphy of the reef complex. Their results are consistent with pronounced variations of fracture aperture and intensity among the different carbonate facieses, as well as with the strong control exerted on fracture orientations by their position along the depositional profile.

Benedicto and Schultz analyze the amount of contractional strain, assessed from the layer geometry, which is accommodated by a set of stylolites present in the damage zone of the Gubbio normal fault (Italy). The authors study the amplitudes of fault-related bed-parallel stylolitic teeth and spikes, and compute the scaling relationships between the along-strike trace length and both maximum and average amplitudes of stylolitic topography. The results show that stylolites behave mechanically as anticracks and compaction bands, propagating to greater lengths proportionally to the contractional strain accommodated.

Caputo proposes a model to estimate the joint/fault ratio in layered carbonates. By setting the three major generic stress

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0191-8141/$ – see front matter
doi:10.1016/j.jsg.2010.04.008

components (overburden, pore-fluid pressure and tectonics) and assuming time-dependant variations of the remote tectonic stress, the author simulates layered carbonate rocks involved in brittle deformation. The results suggest that extensional fracturing is inversely proportional to depth and directly proportional to pore-fluid pressure. Case studies from different tectonic settings are presented to test the numerical results.

Guerriero, Iannace, Parente, Vitale, Mazzoli and Giorgioni address the power law distribution of fracture apertures, showing that uncertainties in the estimation of cumulative fracture apertures increase for large aperture values. By using a multi-scale analysis from thin-section to outcrop scales on layered Cretaceous limestone and dolomites exposed in the Sorrento peninsula (Italy), they quantify the uncertainties for each aperture value.

Holland and Urai focus on the evolution of anastomosing crack-seal vein networks by studying a special type of zebra carbonates exhumed in limestones from about 5 km. The authors interpret the presence of dense bundles of fine veins and sub-parallel arrays of host rock fragments as the result of numerous crack and reseal events. The results of their observations and analyses are consistent with the vein network morphologies depending on the contrasting mechanical properties of infilling material and surrounding carbonate host rocks.

Aydin, Antonellini, Tondi and Agosta document the structural features present along the eastern forelimb of a carbonate anticline, Majella Mt. Italy. The authors investigate a complex system of fractures, faults and kink bands crosscutting platform carbonates of Cretaceous age. By analyzing in detail the failure modes and faulting processes, as well as the crosscutting and abutting relationships among the different structures, the authors propose a conceptual model of tri-shear-like deformation.

Kim and Sanderson investigate the fluid flow properties of carbonate fault damage zones. The authors examine the local variation of fluid flow, recorded by stalactites, in relation to the fractures and small faults crosscutting an outcropping fault. The results of their work show pronounced fluid flow, and therefore stalactite formation, in correspondence of the extensional fault jogs. Conversely, only small amounts of fluid flow were documented within contractional fault jogs.

Agosta, Alessandroni, Tondi and Aydin study the deformation mechanisms and permeability of oblique normal faults in Oligo-Miocene slope-related carbonates. The authors describe in detail the structural features present within two major fault damage zones invaded by hydrocarbons. By using tar distribution as a proxy to assess the fault permeability, different hydraulic properties are documented for faults characterized by various lengths, throws, as well as internal structure.

Molli, Cortecci, Vaselli, Ottrici, Cortopassi, Dinelli, Barbieri and Mussi investigate the chemical and isotopic compositions of the vein infilling within a marble host rock. By deciphering after assessing the fault architecture, which show a pronounced asymmetry across the main slip surfaces, the geochemical data are plugged into a mathematical model of fluid-rock interactions during fault development. The results of their computation show a pronounced fluid flow localized within specific compartments of the normal fault.

Kurz, Hausegger, Rabitsch, Kiechl and Brosch analyze the mechanical processes associated to fault breccia formation, cataclasis, and focused fluid flow within the fault core of a large strike-slip fault. The authors integrate stable isotope analysis of fault rock cements with the mechanical modelling of the fault. The results show a continuous equilibration between protolith-derived fragments and a meteoric-derived fault fluid in the fault damage zone.

Zahm and Bellian investigate the amount of fractures deformation due to fractures in relation to the stratigraphic variability of basinal carbonates. The authors combine both sequence stratigraphy and petrophysical analyses of the host rock with field assessment of fracture intensity in order to formulate a predictive model of fracture distribution within layered carbonates.

Van Gent, Holland, Urai and Loosveld model the evolution of fault zones in layered carbonates. Several processes, including fragmentation, brecciation and formation of dilatants jogs, are taken into account. Deformation is assessed by time-lapse photography and particle imaging velocimetry to calculate displacement field evolution, and the near-vertical opening of fractures.

Billi reviews the mechanical processes associated with the development of carbonate fault rocks in order to provide a reference for future studies of carbonate micromechanics. Three main processes, bulk-crushing, chipping and shear-fracturing, are shown to take place in cataclastic carbonate rocks.

As guest editors of this special issue we acknowledge the precious contribution provided by 35 reviewers, who generously lent us some of their time and expertise to improve the overall quality of the volume. We also thank the Elsevier and Journal staff, the sponsors of the Faults and Fractures in Carbonates Project of the Camerino University, and, most important, the authors themselves, who invested their time and energy for this special issue. We believe that the papers collected here may provide an invitation, and a portal, into the physical, mechanical, and hydraulic processes associated with carbonate deformation.