Advances in Interpretation of Geological Processes: Refinement of Multi-scale Data and Integration in Numerical Modelling

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Advances in Interpretation of Geological Processes: Refinement of Multi-scale Data and Integration in Numerical Modelling

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Preface

This Special Publication deals with some of the themes treated during the XVI Deformation Rheology and Tectonics Conference, held in Milano on 27–29 September 2007, and analysed in depth during the workshop, held in Oropa-Biella on 29 September–2 October 2007. A pre-conference excursion was held on the Monviso metaophiolites and Dora–Maira UHP continental crust (23–26 September 2007).

The conference and workshop were mostly devoted to compare results from different field, laboratory or modelling strategies, and to envisage mismatches between outcomes from different analytical or methodological approaches. They help to identify non-consistent results introduced by: (i) new approaches in gathering and processing field or laboratory data (e.g. deformation mechanisms in various thermal environments, P–T estimates during metamorphic and deformation cycles, age data in metamorphic terrains and tectonic units size); (ii) different modelling approaches, combining aspects from surface to the deep interior of the Earth; and (iii) numerical techniques (finite elements or finite differences) applied at different scales. The integration of modelling and natural and experimental data enlighten whether the huge amount of empirical data available on the P–T–t evolution of crust and mantle rocks is at present adequately used to check and interactively optimize numerical models of geodynamic processes.

This volume contains 12 contributions dealing with natural and experimental data, model predictions, and integration of natural data and modelling results.

Villa examines whether microtextural and microchemical disequilibrium in minerals is compatible with thermal diffusion as the main factor controlling isotope transport in geochronometers. He reviews recent results of laboratory experiments and of integrated petrology–microchemistry–geochronology studies, and argues that dissolution–reprecipitation is both more widespread in natural systems and a more rapid transport process than diffusive reequilibration. In his perspective, the true significance of isotope chronometry is mostly a record of geohygrometry.

Forster & Lister propose an example of the refinement of multi-scale data and its integration into numerical modelling of Argon diffusion in K-feldspar. The standard assumption is that the range of diffusion domain sizes is limited. They use fractal geometries instead, in one example based on the assumption that the 'holes' in a Menger Sponge define intact diffusion domains surrounded by a fast-diffusion matrix. Numerical modelling based on this assumption shows that 'feathered' Arrhenius plots, as observed in data from the South Cyclades Shear Zone (SCSZ), Ios, Aegean Sea, Greece, can thereby be explained. Based on the UCLA database, diffusion parameters for K-feldspar have been assumed to be relatively unretentive, with closure temperatures for typical cooling rates in the range 250–350 °C. This paper shows that the analysis of Arrhenius data must be carried out so that the results are consistent with a Fundamental Asymmetry Principle: otherwise the values obtained for the diffusion parameters may considerably underestimate the actual retentivity. The new analyses of data from the SCSZ imply that closure temperatures as high as 450–500 °C may have applied for the larger, most retentive, diffusion domains.

Mamtani & Greiling test the application of fractal analysis of quartz grains in a syntectonic granite (Godhra Granite, India) to evaluate temperature and strain rate. They present fractal (ruler) dimension (D_r) data from quartz grain-boundary sutures in 12 thin sections, and demonstrate application of D_r as a geothermometer and its usefulness in investigating superimposition of low-T over high-T fabrics in different parts of the granite. Mamtani and Greiling also calculate the area–perimeter fractal dimension (D_a) of quartz grains, which has earlier been proposed as a strain-rate gauge based on experimental studies. Their data yield geologically reasonable strain rate of the order of $10^{-11.4}\ s^{-1}$ for low T (300 °C), but extremely high strain rates (*c.* 10^{-7}–$10^{-8}\ s^{-1}$) for the high-T calculations (>600 °C). Based on these results they propose that D_a can be used as a strain-rate gauge only for low-T calculations and further research is needed to apply the method to higher T.

Cirrincione *et al.* investigate progressively deformed rocks, belonging to a crustal-scale mylonitic shear zone, and quantify, by means of an integrated microstructural and petrophysical study, the relationships between textural and elastic properties. Their results highlight how several parameters, operating as counterbalancing factors, control the seismic anisotropy.

Watanabe based on the electrical resistivity change in deforming wet halite rocks (Watanabe & Peach 2002), demonstrates that brine must exist on grain boundaries as a thin fluid film. Although such grain-boundary brine is contradictory to dihedral angle studies (e.g. Holness & Lewis 1997), it is also required to explain the observed rapid grain-boundary migration.

Zucali ***et al.*** compare the evolution of microstructures of a polycrystalline aggregate of gypsum observed by optical microscope with those obtained from combined analysis of diffraction data (i.e. X-ray and neutron texture). The comparison shows that during experimental deformation the gypsum accommodated strain by both brittle and plastic deformation mechanisms, developing Riedel-like micro-fault systems together with plastic foliations and no brittle to plastic transition occurs; however, both plastic and brittle structures contemporaneously accommodate and localize strain during the deformation.

Using a 2D fully dynamic coupled petrological–thermomechanical model, **Baumann** ***et al.*** have investigated numerically viscous slab breakoff during continental collision. Five phases of model development are distinguished: (a) oceanic slab subduction and bending; (b) continental collision initiation followed by the spontaneous slab blocking, thermal relaxation and unbending; (c) slab stretching and necking; (d) slab breakoff and accelerated sinking; and (e) post-breakoff relaxation. The results also demonstrate: (i) a non-linear dependence of the duration of the breakoff event on slab age; and (ii) localization of viscous slab breakoff at depths of 410–510 km owing to the buoyancy effects of the olivine/wadsleyite transition.

By means of 2D viscoelastic numerical models, **Gardi** ***et al.*** investigate the geodynamic processes proposed in the literature for the Western Alps, comparing the results with available geodetic, geological and seismotectonic data. The main achievements of this study are that an important vertical isostatic readjustment is most probably active in this portion of the Alpine chain and that a slight horizontal compression is also necessary, most likely due to the Africa–Eurasia convergence.

Splendore ***et al.*** perform a 3D thermo-rheological analysis to analyse the rheological structure of the lithosphere in the Mediterranean. Their results indicate that a strong lithosphere paves the Tyrrhenian, in particular below the Provençal Basin and the Calabrian Arc, while a soft lithosphere characterizes the Pannonian Area. In addition, at shorter wavelengths, the northern block of the Adria microplate is rheologically differentiated (half an order of magnitude stiffer) than the southern one. Once the predicted lithosphere stiffness is accounted for within a tectonic model, Splendore *et al.* succeed in predicting the extensive deformation style in the surrounding of Sicily, southern Calabria and part of the southern Tyrrhenian, and the compressive deformation style in the Algerian region, as evidenced by the Word Stress Map 2008 compilation. A χ^2 statistic test confirms that a significant part of the Africa–Eurasia convergence is absorbed through the Calabrian Subduction.

Meda ***et al.*** simulate the oceanic subduction beneath a continent, using a 2D thermomechanical model, to investigate the role played by the mantle hydration in the recycling of continental crust in the wedge region, and compare the results with the natural data from the Sesia–Lanzo Zone (SLZ), Western Alps. The predicted mixing of crust and mantle slices, characterizing the central part of the wedge, can justify the alternance of tectonic units coming from shallow crustal levels with units from deeper crustal levels, similar to the mixing occurring in some portions of the SLZ. The simulated geodynamic scenario generates P–T conditions coherent with those recorded in the subducted continental crust of the SLZ, indicating that the prograde and retrograde P–T evolution of this Alpine nappe can be totally accomplished under an active subduction regime.

Salvi ***et al***. evaluate structural and metamorphic memory of polydeformed and polymetamorphic rocks of Central Alps by means of 3D modelling of geological bodies. Structural analysis integrated with petrology allows construction of a map of dominant fabric domains, constituting the base to estimate the per cent volume of textural reworking during polycyclic (pre-Alpine and Alpine) deformations, and shows that fabric evolution and metamorphic transformation degree increase proportionally above the threshold of 60% volume affected by fabric rejuvenation. Structural and metamorphic overprint during the last deformation stage involved less than 50% of rock volume. These estimates of volumes preserving textural and mineral relicts after phase transitions can help to evaluate the potential influence that relict domains exert on the choice of physical parameters for thermomechanical modelling, such as density or viscosity.

Hobbs ***et al.*** derive feedback relations between deformation and metamorphic mineral reactions using the principles of non-equilibrium thermodynamics. Such relations lead to strain-rate softening, which produces shear zones, folds and boudins by non-Biot mechanisms. These processes are intimately related to the observation that mineral reactions progress to completion only in high-strain areas, driven by energy dissipated from inelastic deformation.

Readers interested in additional information on other topics treated during the 16th DRT Conference are referred to the abstract volume (*Rendiconti della Società Geologica Italiana*, 2007, Volume 5-I), to the field guides of pre-Conference Excursion and post-Conference Workshop (*Quaderni di Geodinamica Alpina e Quaternaria*, 2007, Volume 9) and to the keynote lecture reports (*Thematic Section of Italian Journal of Geosciences*, 2008, Volume 127-2).

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