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Numerical modeling of fluid flow in a fault zone: a case of study from Majella Mountain (Italy)

Valentina Romano[a,*], Jeffrey De'Haven Hyman[b], Satish Karra[b], Albert J.Valocchi[c], Maurizio Battaglia[a], Sabina Bigi[a]

[a]*Earth Science Department, Sapienza University of Rome, Piazzale Aldo Moro 5, Rome 00185, Italy*
[b]*Computational Earth Science Group (EES-16), Earth and Enviromental Sciences Division, Los Alamos National Laboratory, Los Alamos, NM, 87545, USA*
[c]*Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, Urbana, IL 61201, USA*

Abstract

We present the preliminary results of a numerical model of fluid flow in a fault zone, based on field data acquired at the Majella Mountain, (Italy). The fault damage zone is described as a discretely fractured medium, and the fault core as a porous medium. Our model utilizes dfnWorks, a parallelized computational suite, developed at Los Alamos National Laboratory to model the damage zone and characterizes its hydraulic parameters. We present results from the field investigations and the basic computational workflow, along with preliminary results of fluid flow simulations at the scale of the fault.

Peer-review under responsibility of the scientific committee of the European Geosciences Union (EGU) General Assembly 2017 – Division Energy, Resources and the Environment (ERE).

Keywords: fluid flow; fracture network; fault; numerical modeling; CO_2 storage

* Corresponding author. Tel.: +39 06-4991-4165
E-mail address: valentina.romano@uniroma1.it

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1. Introduction

Faults are regions of mechanical and permeability heterogeneities in the upper crust that strongly influence subsurface fluid flow. The distribution of the fault main components (core, damage zone) can lead the fault zone to act as a conduit, a barrier or a combined conduit-barrier system [1]. Typically the core, where most of the fault displacement is accommodated, occurs as a narrow, localized slip zone, containing high strain products; damage zones are mechanically related to the growth of the fault zone and they show a network of subsidiary structures surrounding the fault core that includes smaller faults, fractures, veins, cleavage and folds [2-4]. The damage zones are surrounded by undeformed host rocks. The impact of fault systems on fluid flow has importance for many areas of the geosciences, including the assessment and monitoring of reservoirs for CO_2 sequestration. If leakage occurs, the main migration pathways would be along compromised boreholes or gas permeable faults [5].

This study integrates geological field work and numerical modeling of fluid flow of CO_2 in a fault zone, in a multidisciplinary approach to the problem. The target of this study is the NE normal fault exposed in the Roman Valley Quarry, Majella Mountain, near the town of Lettomanoppello, Abruzzo (Italy) (Fig. 1).

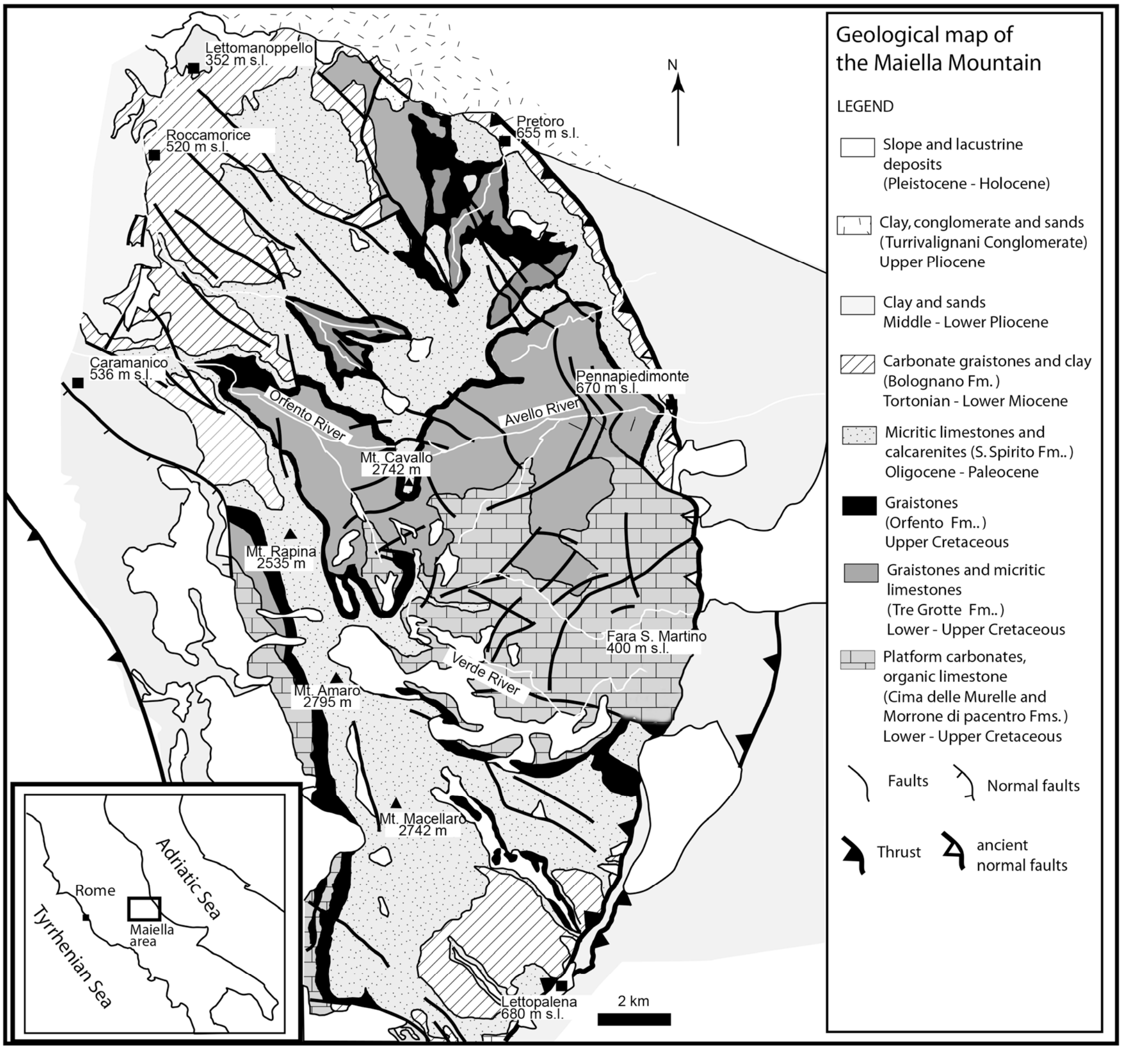

Fig. 1 Geological map of Majella Mountain (modified after [7]).

This fault zone is considered a good analogue to study hydrocarbon reservoirs because of the massive leakage of tar in the system of fractures. The objective is to transfer the methodology developed for this study to other geological settings, through the appropriate calibration of the geometric and petro-physics parameters of the fault system. The Majella is a thrust related, asymmetric, box shaped anticline. The mountain carbonate outcrops are part of a lower Cretaceous-Miocene succession, covered by a siliciclastic sequence of lower Pliocene age [6]. The fault exposed in the Roman Valley Quarry cuts the lower member of the Bolognano Formation (Oligo-Miocene). This member is made up of medium to coarse grained carbonate grainstones with calcirudite and marl rich intercalations.

2. Methodology

The conceptual model used in this study consists a fault core, modelled as a continuum porous medium and the hanging wall and foot wall damage zones modelled discrete fractured media (Fig. 2, b). The fracture systems have been represented employing a Discrete Fracture Network (DFN) approach [8]. We integrated existing information with our own structural surveys of the area to better identify the major fault features (e.g., type of fractures, statistical properties, geometrical and petro-physical characteristics). The fracture systems of both the foot wall and hanging wall damage zones have been characterized by collecting data along 21 scanlines across the fault profile (Fig. 2, a). The scan lines allowed us to measure the fractures length, aperture, orientation and spacing. Four systems of fractures were recognized for both damage zones. These parameters, along with their statistical properties have been used as input for generating DFN models.

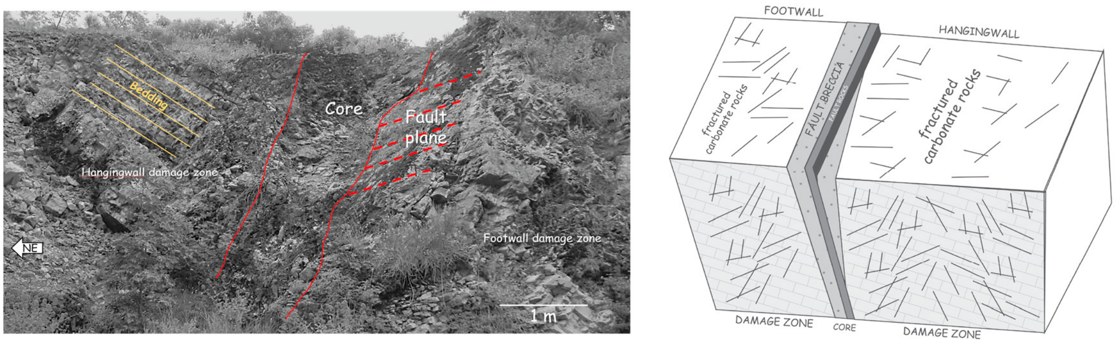

Fig 2. (a) Outcrop view of the fault zone; (b) conceptual model of the fault zone.

We used dfnWorks [9], a parallelized computational suite, developed at Los Alamos National Laboratory (LANL), to generate three dimensional Discrete Fracture Networks (DFN) and simulate fluid flow and transport. The dfnWorks suite has been optimized to be combined with existing codes, e.g. PFLOTRAN [10], to compute subsurface flow and reactive transport. Fracture size, location, and orientation are stochastically generated based on statistical distribution obtained in the field. Each fracture is represented as by a planar two-dimensional polygon embedded in the three-dimensional space and the network is the intersecting sets of all polygons. The fracture sets are generated and meshed using the feature rejection algorithm for meshing (FRAM) [11], which creates a conforming Delaunay Triangulation of the DFN. The dual mesh of the triangulation coincides with the Voronoi control volume, which are a sense optimal for two-point flux finite volume solvers.

3. Results

In order to have a good representation of the fracture systems, we performed one hundred realizations of both the hanging wall and foot wall damage zone (Fig.3, left). For each realization, using the flow solver (Fig.3, right), we calculated the total flow rate and pressure drop for the fracture system and evaluate effective permeability tensor, using a custom Python code. This gave a good estimate of the hydraulic properties of the discrete domain: the order of magnitude of the permeability obtained from the preliminary calculation is 10^{-12} m^2.

The coupling between two dissimilar media presents a major challenge, especially for the case of discrete-continuum coupling. To overcome this problem, we have taken advantage of the high fracture density of the damage zones to build up an equivalent continuum domain. We made the assumption that the volume used for the generation of the DFN, can provide a good representation of the damage zone. The hydraulic parameters, obtained from all the DFN realizations, can be transposed to an equivalent continuum medium. Figure 4 shows a simplified example of the equivalent continuum domain. The domain is "divided" by material IDs, according to the distance from the fault plane that identifies the damage zones (blu), the outer core (white), the inner core (red). For each material ID the code assigns the hydraulic properties and prepares a file used by PFLOTRAN for the flow simulation. In the damage zones, the properties for each control volume are selected randomly from the distribution of permeability (xx, yy and zz components) obtained from the multiple realizations of the DFN. Multiphase flow simulations for water-CO_2 system will be performed with PFLOTRAN on the equivalent continuum domain at the scale of the fault zone, while applying different boundary condition scenarios at the top and the bottom.

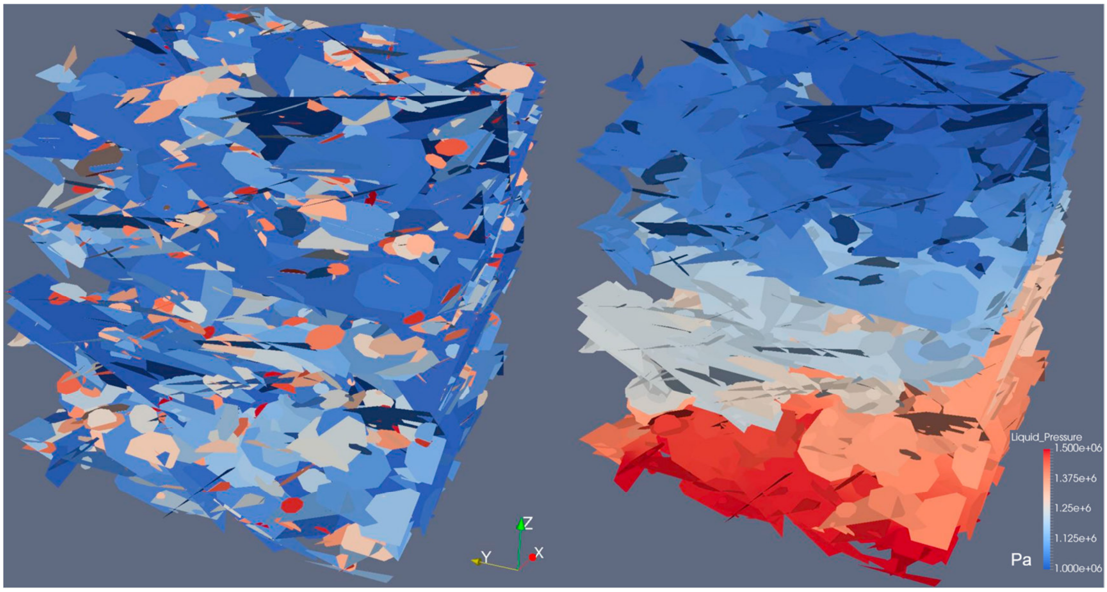

Fig. 3. Example of DFN realization for a 9 m^3 block and 3000 fractures (left) and flow solution for the DFN realization (right); pressure boundary conditions are applied at the bottom and the top of the domain.

4. Conclusions

To conclude, since faults represent the main leakage pathways for CO_2, the study of the hydraulic behavior of a fault system is fundamental to select the best location for geological storage sites and the most appropriate monitoring strategies. To study the CO_2 migration through a fault zone, we have developed a model that couples a continuum porous medium with a discrete fractured medium (Fig. 2, b). The fracture systems have been represented employing a Discrete Fracture Network (DFN) approach that integrates field data on the fracture statistics as well as field data from a fault exposed in the Roman Valley Quarry in Majella Mountain Lettomanoppello, Italy). Finally, we presented preliminary results for this upscaling approach which couples the advantages of discrete modeling at the scale of the fractures with continuum modeling to simulate the fluid flow in the entire fault domain (Fig. 4).

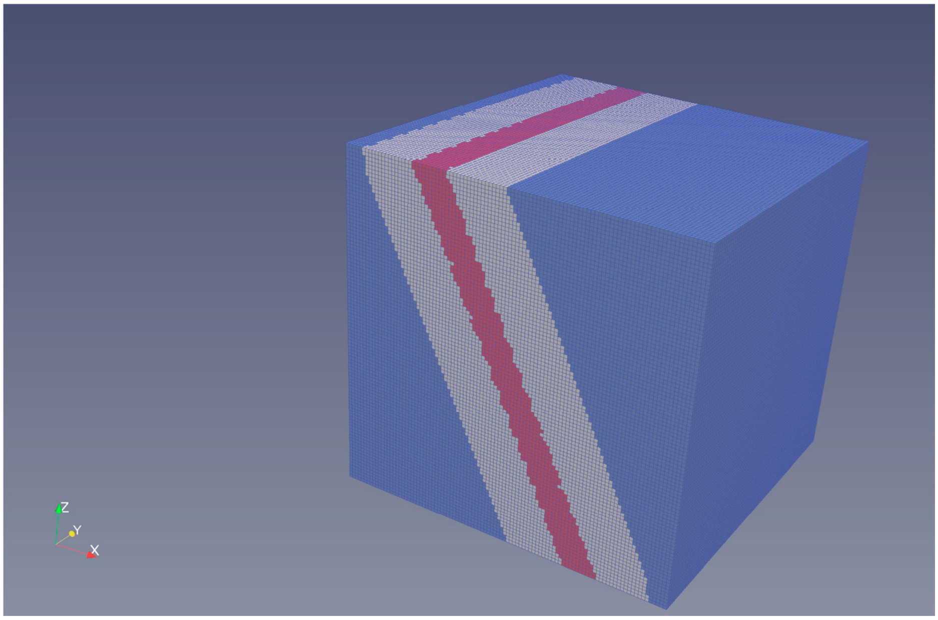

Fig. 4. Simplified version of the continuum domain for a 5x5x5 m block, showing the fault zone components in different colors (red=inner core; white =outer core; blu=damage zone).

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