7th EUropean Congress on REgional GEOscientific Cartography and Information Systems (EUREGEO)
Bologna, Italy,
From 12th to 15th June, 2012

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA
POLO RAVENNA

Interdepartmental Centre for Environmental Sciences Research (C.I.R.S.A.)

Integrated Geoscience Research Group

Evaluation of a Discrete Fracture Network (DFN) Model and comparison with fractured carbonate outcrops, Monte Conero, Italy

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Fractures typically form patterns that reflect the stress history and geologic history of the area. In this study fractures are studied with a particular emphasis on the qualitative and quantitative analysis of mechanical types of fractures. All mechanical types of faults and other fractures (veins, joints, stylolites, breccias) are important because they are related to each other mechanically and geometrically. The spatial relationship between them and the bedding planes gives an idea of the drainage into – and flow through – the aquifer. The fractures determine to a large extent the hydraulic conductivity of the aquifer because they can be either barriers or pathways for fluids. The most important fractures that tend to increase the circulation of fluids are faults/breccias and joints, but it is also important to consider those that generally block the fluid movement such as veins and stylolites. The aim of this study is to compare the results of DFN modelling using FracSim3D with maps of fractured carbonate outcrops. This evaluation is made in terms of the geometrial, mechanical and hydraulic properties of fractures, such as, length, connectivity, orientation, position and structural typology, in order to define the qualitative accuracy of the model for a fluid flow analysis.

WHY A FRACTURE NETWORK MODEL?

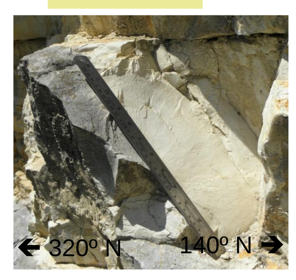
Characterization of fracture geometry and distribution is important for understanding fluid flow in fractured reservoirs and aquifers with applications in hydrology, petroleum- and mining engineering, storage of CO_2 and the use of geothermal energy. Because it is impossible to characterize every single fracture, modelling of fracture networks with Discrete Fracture Network (DFN) models may be used, combining stochastic modelling, Monte Carlo simulations and fracture properties measured for example on outcrops of rocks. FracSim3D, elaborated by Xu & Dowd (2010), is one of the available programs which offers representations in two and three dimensions and statistical tools for the analysis of the results.

METHOD AND RESULTS

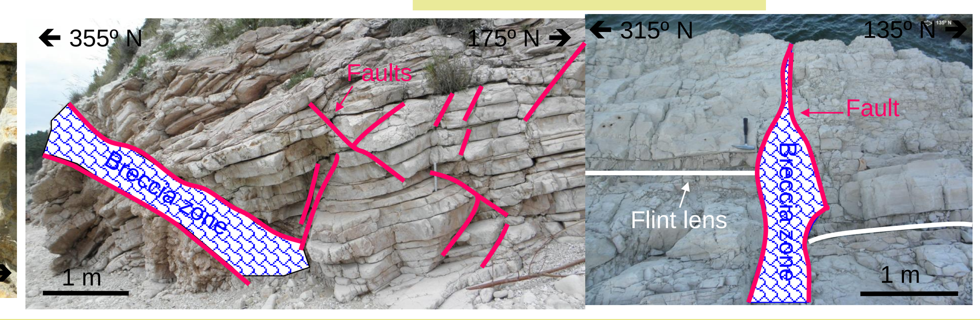
The use of Geographic Information System (GIS), Excel macro-script, field-work data and fracture maps, was combined to create the input for FracSim3D. Three cases were studied, considering fracture properties including orientation, length and fracture type. One case considers measurements made during field work on exposures of Mesozoic fractured carbonate outcrops near *Monte Conero* (*Le Marche* Region, Italy). The other two cases were derived from the fracture maps elaborated in previous studies of Mollema and Antonellini, in the Dolomites area (Northern Italy) and deformation bands in the Navajo Sandstone, Buckskin Gulch in Utah (USA).

MECHANICAL FRACTURE TYPES: Structural discontinuites present in the areas

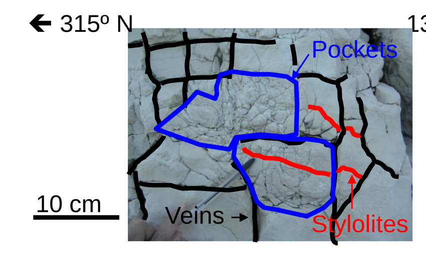
Joints



Faults/Breccias

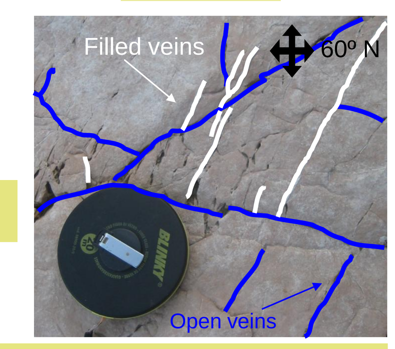


Pockets of breccias



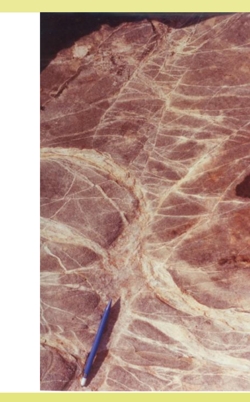
Open or porous fractures ➔ permeability

Veins



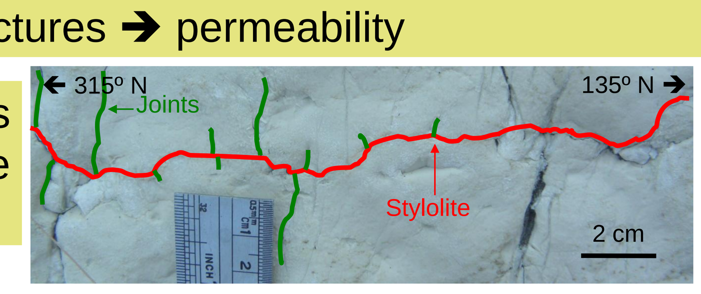
Considered as open fractures ➔ permeability

Deformation bands (cataclastic faults)

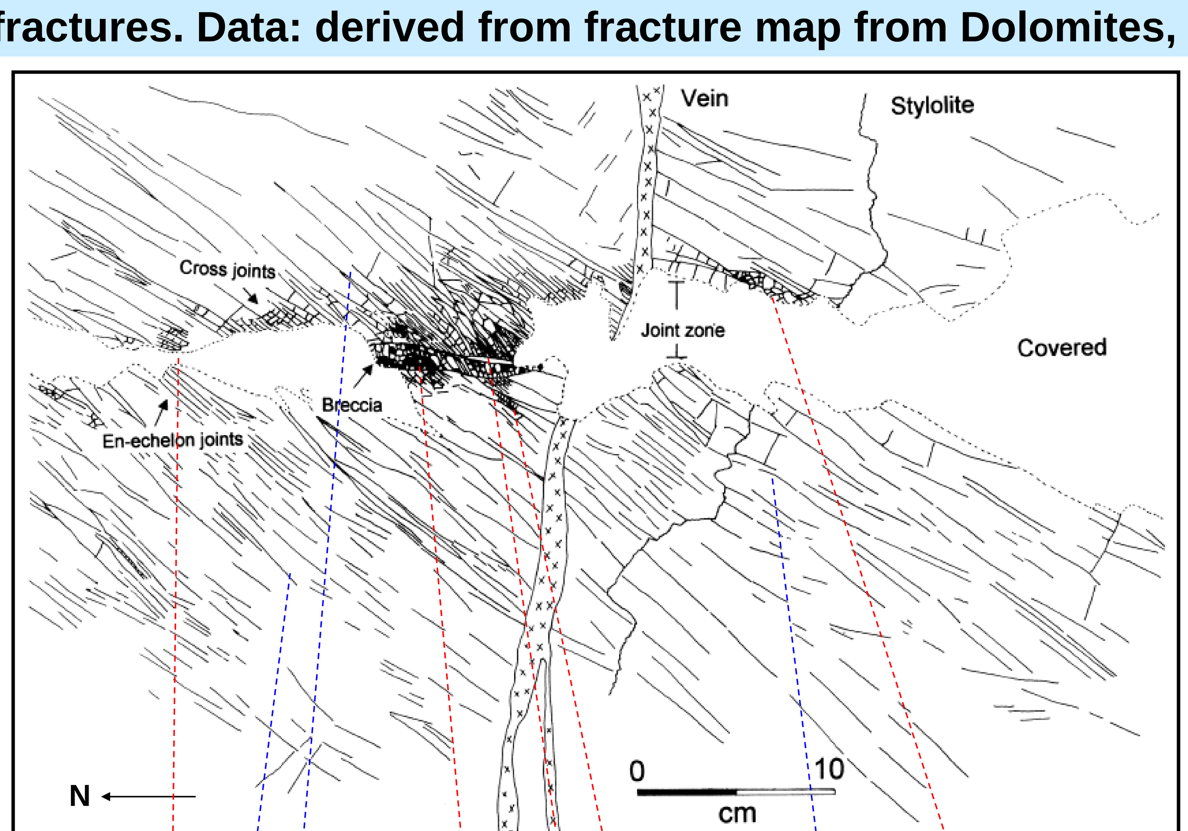


Bands porosity lower than matrix porosity (sandstone) ➔ not contribute to permeability (barries)

Stylolites: Close fractures ➔ not contribute to fracture permeability

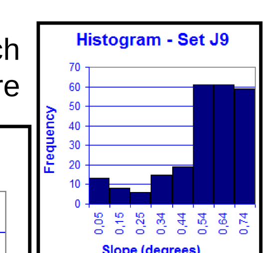


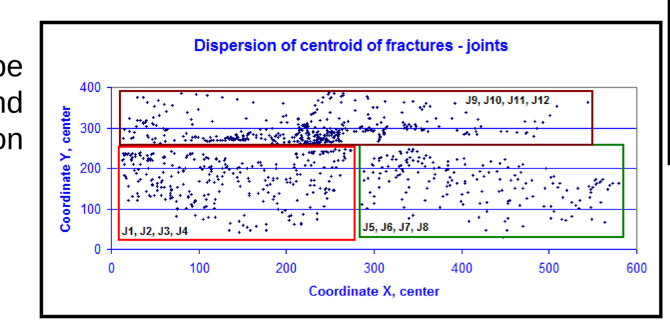
Case 1: Separated domains for different densities and types of mechanical fractures. Data: derived from fracture map from Dolomites, Northern Italy.



Generating sets according to type of fracture, spatial distribution and orientation

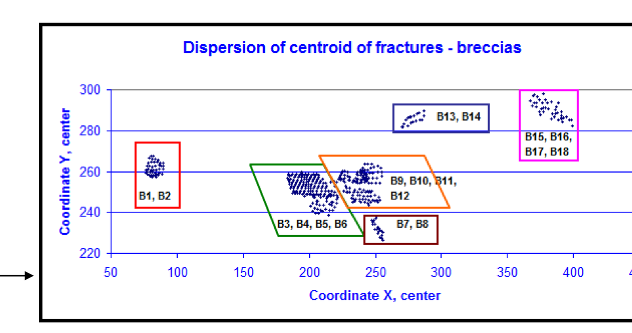
Generating a histogram for each set of mechanical fracture

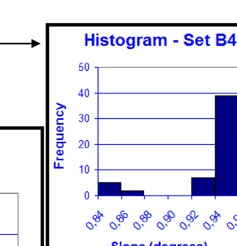




Field measurements (dip-direction, dip-angle and lenght of the fractures)

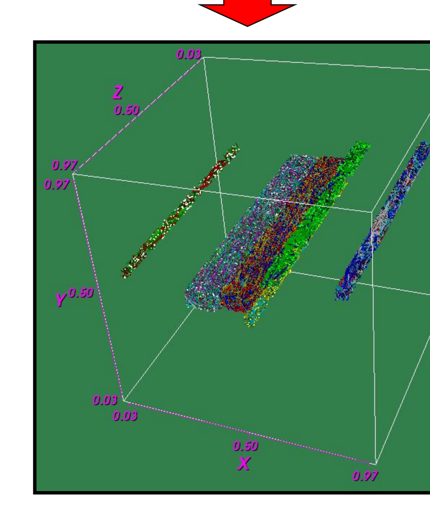
Map data (spatial distribution of the fractures)



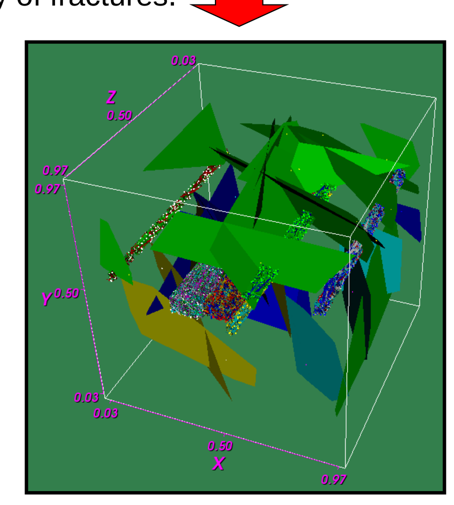


Each set (bounded spatially) is added to FracSim3D through stochastic simulation using Poisson distribution with parameter lambda equal to the density of fractures.

Each histogram is added to FracSim3D as a non-parametric model.

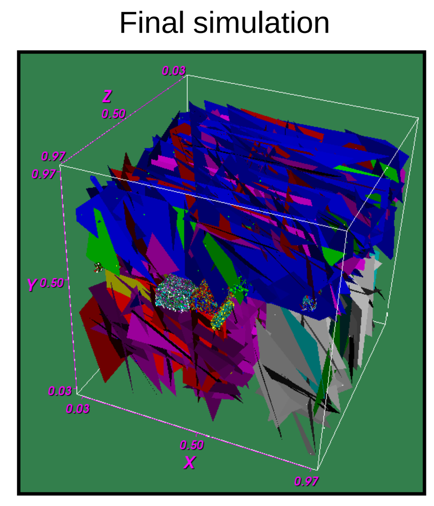


Simulation of breccia sets



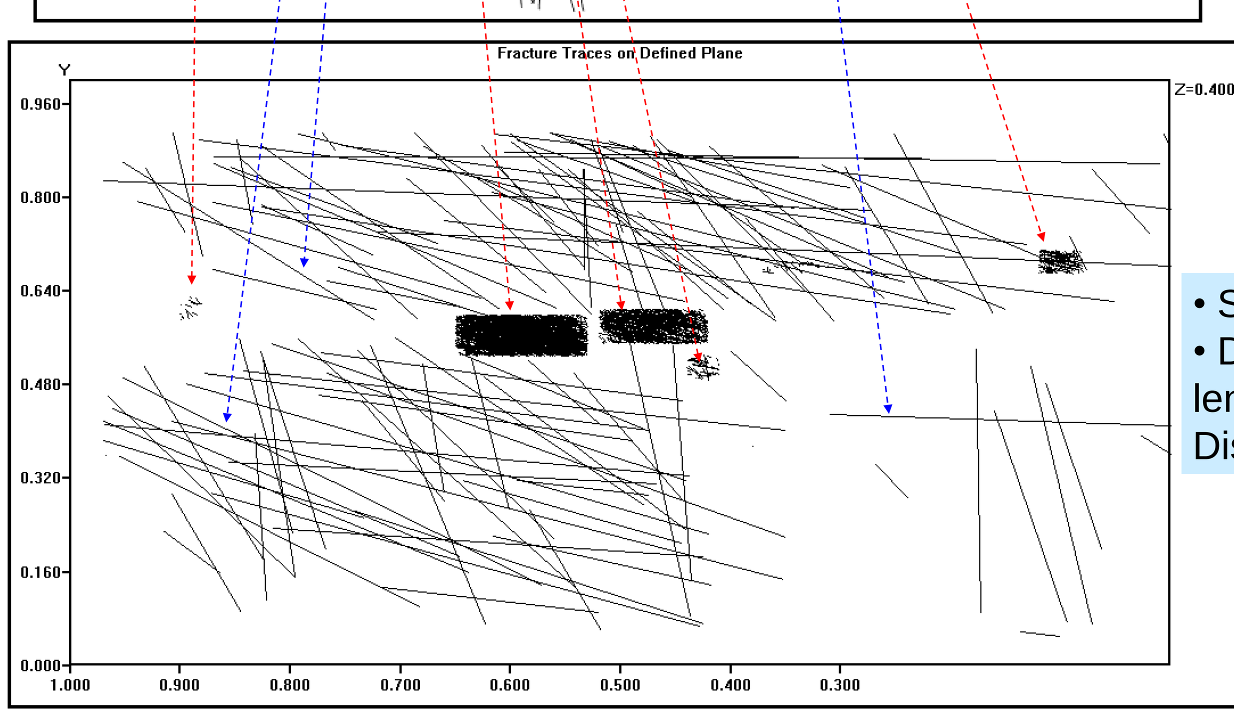
Simulation of breccia sets and the main joint sets

Final simulation



Fracture map resulted in the plane X = 0, Y = 0 and Z = 0.4 simulation unitary cube

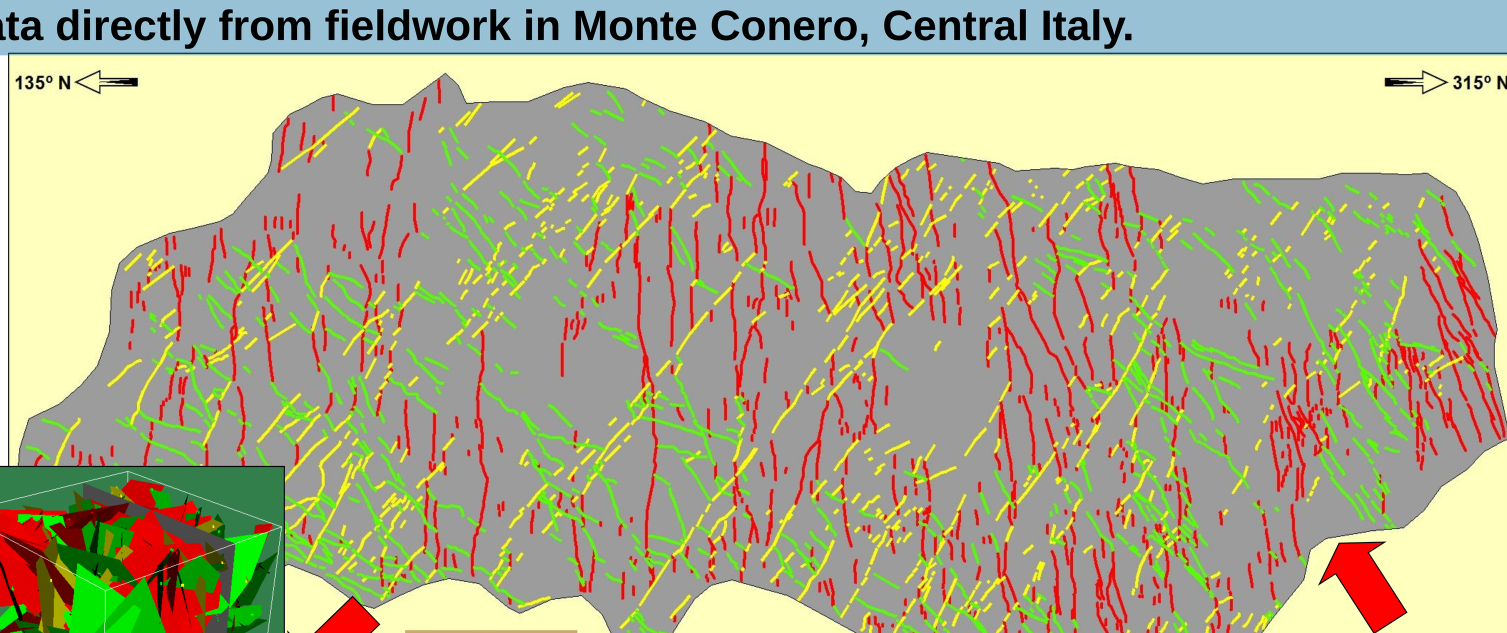
FracSim3D worked with a simulation unit cube. Therefore, the coordinates of the original system were tightened, creating a visual distortion

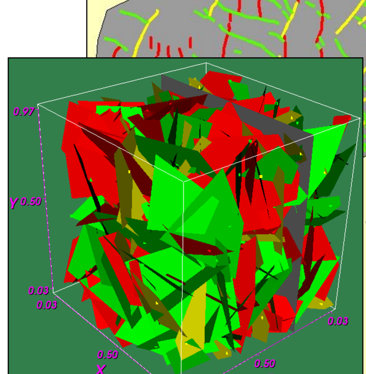


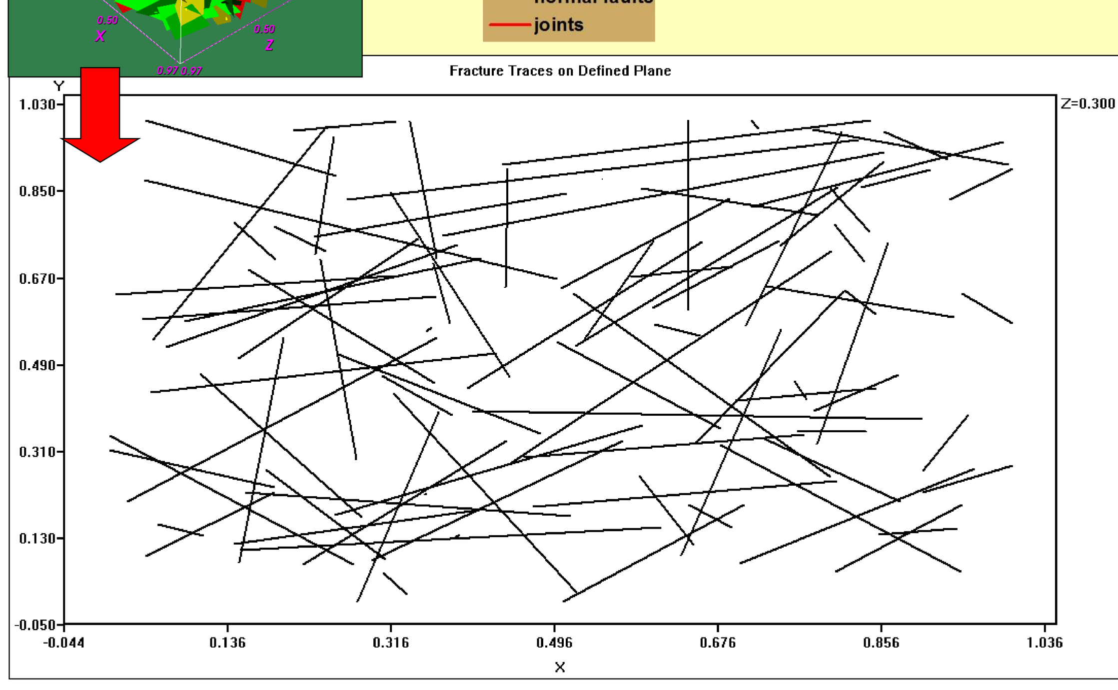
- Similarities: 1. Breccia locations (conditioned by the methodology). 2. Joint sets
- Differences: 1. Internal structure of the breccias. 2. Covered areas. 3. Fracture lengths increased. 4. Connectivity increased. 5. Fracture density increased. 6. Discontinuity between different density domains.

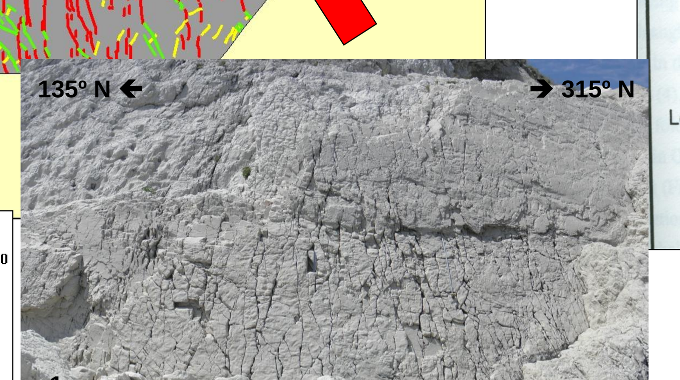
METHODOLOGY CREATED TO GENERATE A DFN WITH MECHANICAL FRACTURE TYPES

Case 2: A single domain for different densities and types of mechanical fractures. Data directly from fieldwork in Monte Conero, Central Italy.



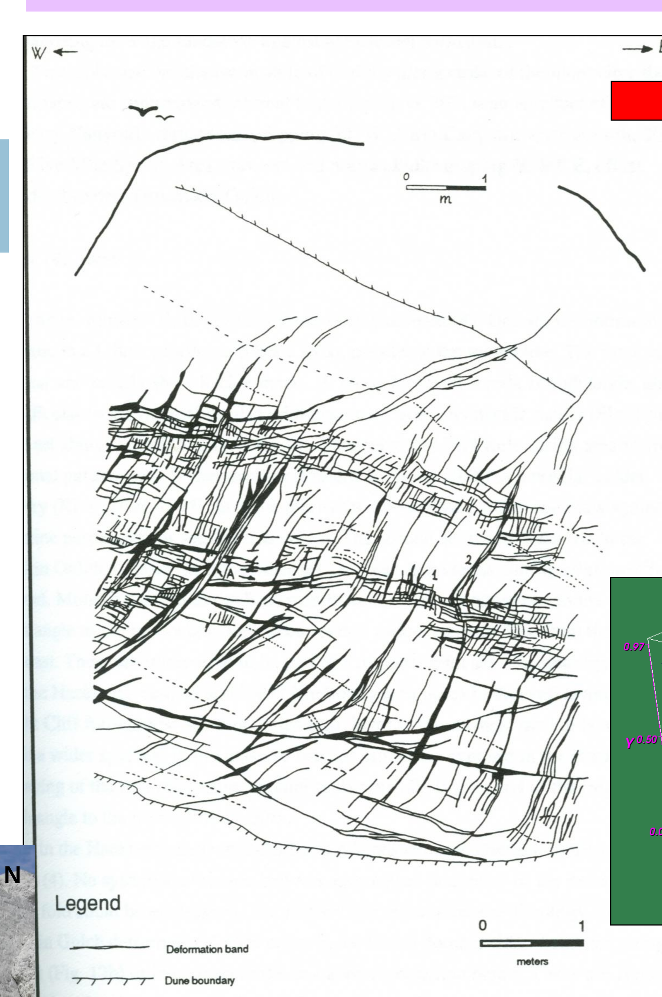


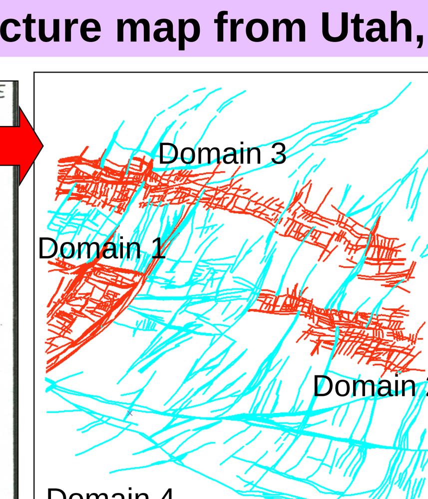




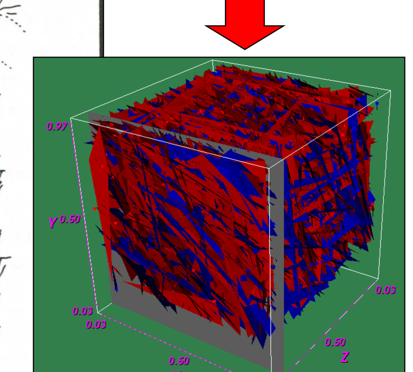
- Fracture properties and hydraulic parameters are altered (increase in lengths and discontinuity of fracture traces not represented).
- Pockets of breccia could not be represented by the model.
- Decrease in the fracture density which reduces the probability of circulation of a fluid.

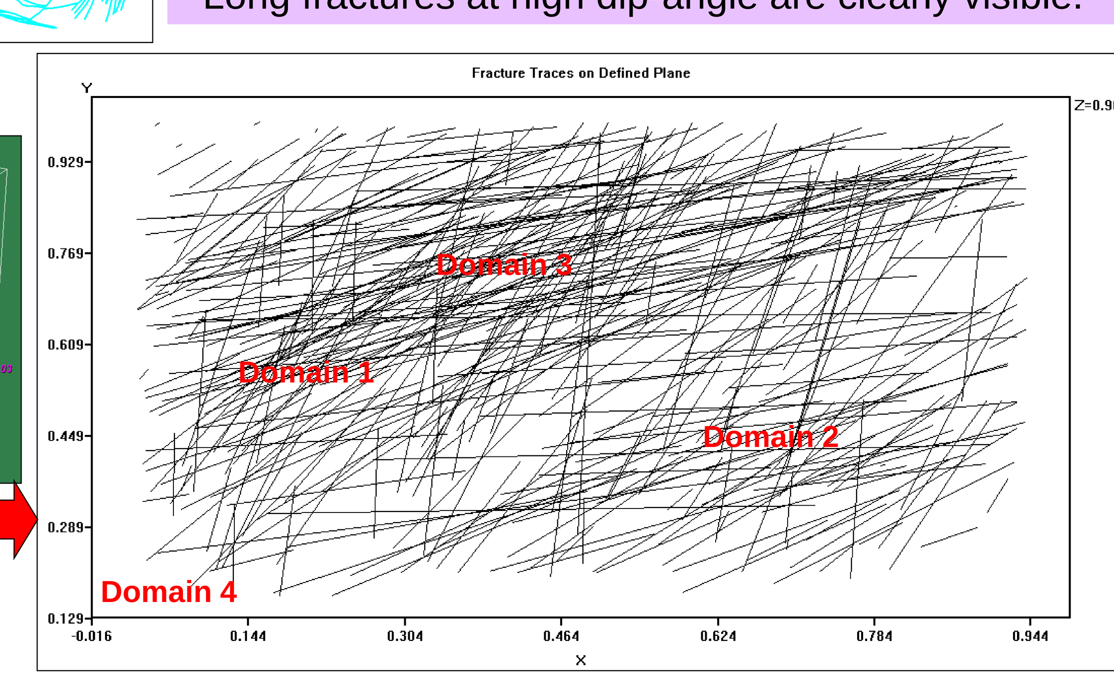
Case 3: Consideration of the methods in case 1 and case 2 for a particular type of mechanical fracture. Data: derived from fracture map from Utah, U.S.A.





- There are similar characteristics to the previous cases: length, connectivity and density of fractures are incremented, whereas fracture orientation is correctly represented.
- Domains are not clearly identifiable due to the high fracture density.
- In this case, due to the type of rock, pathways for fluid flow are reduced.
- Long fractures at high dip-angle are clearly visible.





GENERAL CONCLUSIONS

- In general, the model has some difficulties to represent accurately small or very large areas, it requires necessary to use the unitary cube for the simulations.
- The model changes, positively or negatively, the hydraulic properties of the fractures depending on the method to introduce the data input.
- The actual geometry of the various types of mechanical fractures can not be accurately simulated by DFNs. This is particularly important in breccias which generate porosity in a non-porosity matrix.
- A combination of both particular and global domains of fracture density, as in case 3, is the best method to introduce the data input. Despite the errors mentioned above, the result of the case 3 is the most realistic model.
- Fracture density is a property that must be studied in detail. Due to limitations of the software to represent densities in small areas, this value was manually modified to achieve its representation. Moreover, the use of two-dimensional density values in 3D modeling may be the cause of the errors in the simulations.