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Elaboration of Multi-Scale Fluid Flow Modeling System in Fractured Rocks for Exploitation of Geothermal Energy

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ABSTRACT

The Pannonian Basin of Hungary represents one of the areas of highest geothermal energy potential in Europe. The basin is a deep Neogene depression, surrounded by the Carpathian mountains, filled by more than 6000 m of Miocene – Pliocene sediments. These are underlain by pre-Neogene metamorphic crystalline basement rocks of granitoid composition.

In order to efficiently and sustainably exploit this geothermal resource, both water and heat balances need to be fully understood. One component of this understanding is a knowledge of the geothermal fluid (i.e. hot groundwater) flow regime in the fracture systems of the underlying basement. This, in turn, requires information on the tectonic framework that has shaped these fracture systems and controls their permeability distribution. Unfortunately, direct study of the crystalline basement (beneath 6000 m of sediments) is impractical and glimpses of the basement can only be caught in deep exploration boreholes.

However, in other parts of the world, similarly fractured bedrock aquifers, shaped by analogous extensional tectonic regimes, can be observed in the shallow subsurface. In particular, study of the rocks of the Oslo palaeograben (Norway) offer insight into the fracture systems likely to be found in the sub-Pannonian basement. Fortunately, the granitoid basement rocks of south-east Norway are found at the surface, exposed by glacial activity and post-Tertiary erosion, and may be examined in detail and used an analogue for understanding of deep rocks.

1. INTRODUCTION

There are several fractured HC-reservoirs in the metamorphic basement of the Pannonian Basin. Their research is rather problematic, because the crystalline bodies are inhomogenous both lithologically and structurally. The main aim of the present evaluation is combine diverse approaches for better understanding a typical metamorphic reservoir, Mezősas-W.The methods involved are

- classical petrology and structural geology for rock classification;
- Computer Tomography to understand internal structure of core samples as well as measure fracture network geometric parameters;
- rock mechanics to measure deformation parameters of diverse rock types;
- CBIL measurement to follow fracture intensity along selected wells;
- fracture network simulation to upscale geometric information;
- seismic attribute evaluation to combine small and large scale data.

2. GEOLOGICAL SETTING

The study area (Fig. 1) is the western flank of a large metamorphic dome uplifted during the Neogene. The dome itself consists of different high grade metamorphic rocks, essentially of diverse gneiss and amphibolite varieties. At the deepest structural position an orthogneiss block can be found, which at places contains large enclaves of mafic composition. Because of rheological reasons, the enclaves are more intensely fractured than the host gneiss. Above the orthogneiss zone a paragneiss zone follows along a wide shear zone. Previous studies suggest that this gneiss type is hardly fractured. Along a next shear zone a medium grade amphibole gneiss follows, which is the most intensely fractured among all typical lithologies.

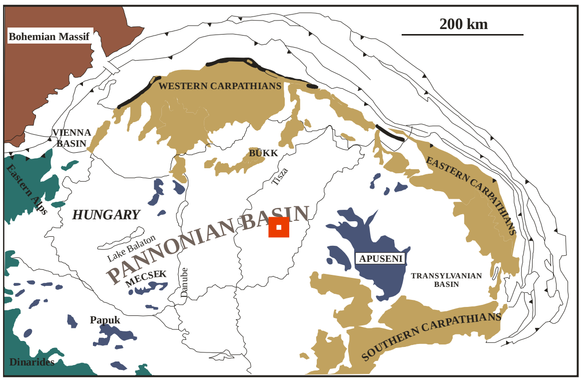

Figure 1: The study areas

3. METHODS

For establish a method for evaluation and ranking of potential site for enhanced geothermal system we elaborated two Hungarian depleted hydrocarbon fields and one Norwegian outcrop of fractured metamorphic rocks. The multi-scale aspect was approached from high-scale core measurements (rocks mechanics, using the most up-to-date computer tomography technique and the rupture tests) to lower, well-scale pressure development and production test to low, field-scale seismic interpretation and interference test. To simulate the fluid flow in fractured rocks first a sophisticated fracture modeling was used, then this fracture system was mounted in the flow model. The Norwegian site experiences were applied as a reference to test our subsurface fracture structure.

Using this fracture flow models the aptitude of the site for EGS could be tested and evaluated.

3.1 Rock Mechanics

Twenty undeformed samples were picked up for rock mechanical measurements. These cores represent all diverse rock types of the reservoir. The cylindrical samples were tested under various uniaxial loading conditions. In order to increase the damage, accumulation and avoid violent rupture an irregular cyclic loading was applied were the peak compressive pressure was about 70-80% of the uniaxial compressive strength. We measured the axial (and lateral) deformations. The characteristic rock parameters are the following (Table 1).

Table 1. The Characteristic Rock Parameters.

Uniaxial compressive strength [MPa]	Young's modulus E [GPa]	Poisson coefficient [-]
19,18	18,17	0,16

The pressure-axial deformation diagram of a selected sample (Fig 2) exhibits large hysteresis loops with small softening effects. The accumulated permanent strain at zero pressure indicates considerable accumulated damage. The sample was relatively intact after the test as we can see on Fig 3.

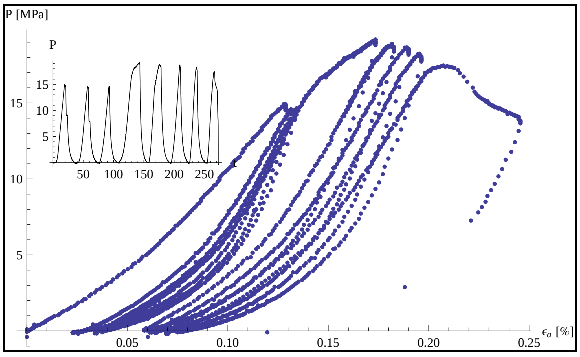

Figure 2: Compressive pressure as a function of axial deformation of the cylindrical sample. The inset shows the time dependence of the applied pressure. The sampling rate is 10Hz

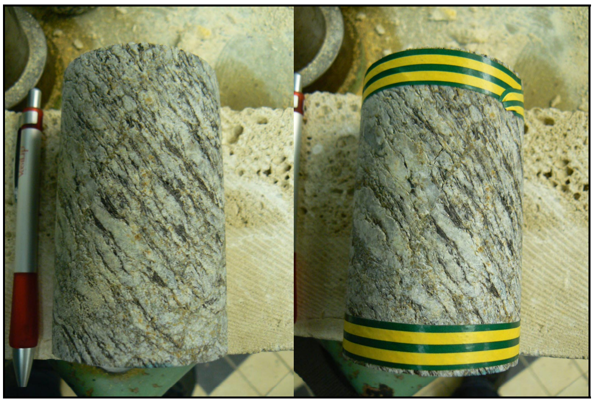

Figure 3: The investigated sample before and after the cyclic loading test

3.2 Computer Tomography

The goal of Computer Tomography measurements and interpretations was the characterization of core samples concerning petrophysical assessments, determination of microtectonic and structural parameters of fracture networks in 3D. According to saturation profiles, two main types of fracture rock samples can be distinguished. Some samples behave as a breccia, while most of them are fractured (micro-fractured, open fractured, combined type; Fig. 4).

Results of the uniaxial mechanical crush tests were combined with CT evaluations. Based on these results it was possible to determine the ability of fracturing in case of the different lithologies. On the CT images the running and ending of fracture network in each zones could be observed and mapped. The results were compared with the mechanical measurement evaluations and the petrophysical parameter change was compared to those detected prior to crushing (Fig. 5).

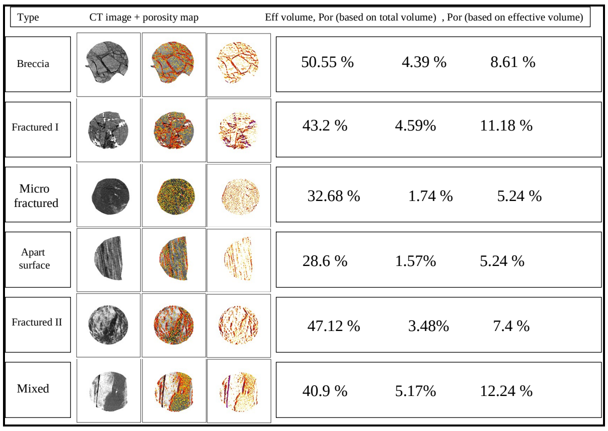

Figure 4: Damaged rock classification based on CT image evaluation

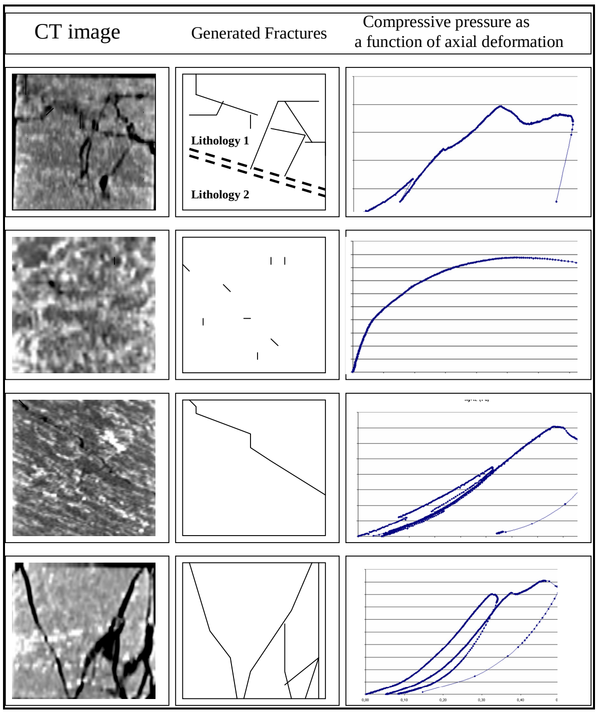

Figure 5: Comparison of CT images and stress-strain diagrams for different rock types

3.3 Well-Test

3.4 Interference-Test

3.5 Seismic Interpretation

Seismic attributes give an excellent possibility to build reservoir models. Calculation of an attribute applied in our case uses Semblance coefficient (around a given channel) and Manhattan distance (between target channels). Values of the coherency depend on the number of the neighbor channels and the range of the time window. This choice of coherency shows significant anomalies around the productive perforations. According to our experiences, brecciated/fractured zones indicate coherency anomalies in the metamorphic basement (Fig. 6). Productive intervals are generally found near (or inside) these zones.

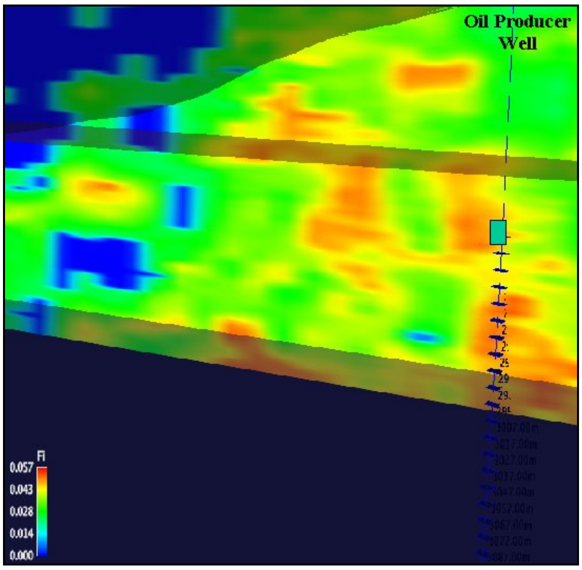

Figure 6: Model porosity in the metamorphic reservoir based on seismic attributes

3.6 Fracture Network Simulation

Fracture intensity using CBIL data were evaluated in two different ways. On the inter fracture distance curves the most deformed intervals become visible. These zones usually show the position of shear zones between neighboring metamorphic blocks. Fractal dimension of fracture intersection series was also calculated and used to build DFN (discrete fracture network) models around the wells. Results of simulation confirm that communicating fracture network exists along the shear zones as well as the amphibolite rich segments of the basement. Both the orthogneiss and the paragneiss is essentially impermeable (Fig. 7).

3.7 Fluid Flow Simulation

For fluid flow simulation, the well-known and widely accepted FEFLOW v5.4, - a monophasic, finite element flow and heat transport code - was used.

CONCLUSION

We showed that in the fractured Mezősas-W field, reservoir parameters are under lithological and structural control. The most permeable zones belong to shear zones, rich separate blocks of diverse metamorphic evolution. Among the lithologies amphibolite is more porous than the gneiss types.

This type of rock framework is suitable for EGS system pilot project.

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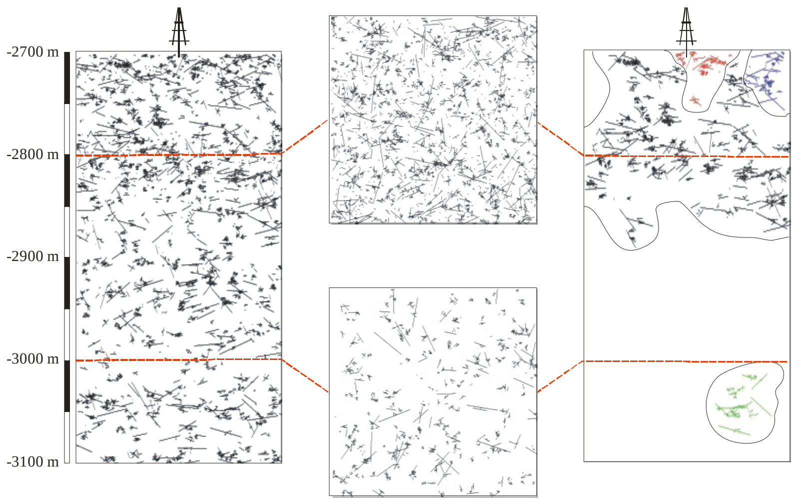

Figure 7: Fracture simulation