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HYDRODYNAMIC AND HEAT TRANSPORT MODELLING OF BASEMENT FLUID RESERVOIRS APPLYING COMPLEX FRACTURE NETWORK ANALYSIS METHOD

Theses of Ph.D. dissertation

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I. Introduction, objectives

Regional gravitational flow system is located below the Hungarian Great Plain which is separated by thinner or somewhere thick sedimentary zone from the fluid system stored in the deep, often overpressured, fractured crystalline and carbonatic basement regime. The basement complex is not impermeable in spite of its great depth and fluids of various age and content are stored in there due to the secondary porosity and tectonism. The overpressure has generally been remained and the flow system has been separated from the overlaying hydrostatic regime where thick pseudo-impermeable covering sediments were deposited. However the hydraulic connection could be developed between the two zones in such not uncommon geologic-hydrogeologic situations where the insulating sedimentary layers are extenuating or missing due to the basement morphology. The presence of the brine with high total dissolved solid content in the deeper overpressured system has been detected in the Pannonian and Pleistocene sediments by geophysical and geochemical methods at several locations. The exploration of these areas has significant importance regarding to hydrocarbon mining and geothermal energy exploration.

The first part of the dissertation is based on mathematic analysis of fracture networks in rock masses. The independent properties for describing a fracture system in a realistic way are fracture length distribution, fracture density and the relative dip of fracture groups. In the knowledge of these the size of the interconnected percolation clusters can be determined. The representative elementary volume can also be derived in the function of these three basic parameters.

The second part deals with the complex analysis of the hydrodynamic and heat transport processes of the two basically different flow systems. This was performed by numerical modelling where the results of methodological analyses (percolation and representative elementary volume) made on discrete fracture networks were used as the basis. The main objective was to find the answers and explanations for the following questions:

- How can the mapping of the percolation properties of fracture networks can be performed based on the most important geometrical parameters; how percolation depends on the input parameters?
- Could these derived parameters be determined unequivocally, could spatial appearance and features of the fracture system be forecasted precisely based on the measurable fracture parameters?
- What minimum homogenous elementary volume can be set in case of fractured rocks and what is the effect of changing fracture spatial density, length and orientation on this volume?
- What kind of method can be applied in such cases when fluid flow properties of both porous and fractured formations should be analysed together in one system?
- Which direction the basement fluids get supply from, which flow paths can be realistic?
- What kind of hydraulic connection exists between the fractured basement reservoir and the overlying sedimentary formations?
- How the basement lithology and geometry effect the flow field and whether the flow is being changed as a consequence of change in the location of rock blocks with similar composition?
- How the flow system changes by the effect of structural and tectonic variety?

- How the basement fluids can join into the gravitational flow system of the younger, Upper Pannonian - Quarter sediments?
- How sensitive is the model for the change of hydrodynamic parameters, particularly for hydraulic conductivity?
- What is the rate of anomaly caused by basement metamorphic domes in the temperature field?
- What is the role of conductive and convective heat flow in the development of the temperature field?

II. Applied methods

The analysis of hydrodynamic and heat transport processes of such hydrogeological systems disclosed in the introduction is considerably difficult with common methods, as software packages written for numerical flow modelling in porous media are not able to properly handle the structural elements typical for fractured reservoirs. Giving the solution, a complex fracture network analysis method and modelling procedure were used that provide tool for those problems which try to find solution for fluid flow properties of reservoirs built up by mainly crystalline rocks.

The essential of the method is that the information obtained from the fractured rock is being systematically built into the structure of the numerical transport model. First the most important parameters (fracture density, fracture length and aperture distribution, orientation) of the individual fractures and the whole network of the rock mass are being set in an appropriate discrete fracture network simulator. The next step is to make further hydrodynamic parameter calculations on the stochastically generated fracture networks and make percolation and representative elementary volume calculations. This information will be presented in an equivalent continuum model as the input parameters of the hydrodynamic and heat transport calculations. Actually, considering the whole procedure, a hybrid type modelling is performed with the connection of the discrete fractures and the homogenized flow field.

The importation of integrated fracture parameters (REV – cell size, connected fracture groups – effective porosity, permeability tensor – hydraulic conductivity) and porous rock parameters into the finite element and finite difference numerical modelling systems is performed by common methods.

III. Summary of the results – theses

1., The percolation properties of fracture networks – which is critical in the view of permeability – can be determined on the basis of the most important parameters, such as fracture length distribution, orientation and density. The mathematic relation between the above mentioned geometric parameters and the connectivity of the fracture network cannot be described by explicit functions. A series of nomograms have been made for determining the relation with the use of a DFN modelling method. This helps in specifying the percolation properties of any fracture networks with known parameters.

2., The fracture networks typical for certain rock types has been ranked into 3 percolation classes according to their E–D–α (E: exponent of the fracture length distribution, D: fractal dimension, α: relative dip) parameters. The size of the connected groups is small at low parameter values in case of the first type, a maximum of 10 percent of the entire fractures forms communicating network. In the second case at high parameter values more than 80 percent of the fractures forms connected network. The characteristic fracture network of the middle zone has reverse properties where the size of the interconnected system is not predictable. This system reacts most sensitively for the uncertainties of measurement of the basic parameters.

The second largest group containing communicating fractures reaches the maximum point depending on the input parameters (*E*, *D* and α) when the fracture group is somewhere near to the percolation threshold – below and above this, the size of the sets including the remaining fractures becomes smaller and smaller with the increase of the parameters, comparing to the size of the largest percolation cluster.

3., Modelling procedure has been developed for the quantification of the representative elementary volume of a given fracture network with known E-D-α parameter triplet. The point of the method is that – changing the parameter values inside certain interval – equally probable porosity values are generated in case of all parameter triplets at grid networks with increasing resolution. Recording then the mean and standard deviation values of the porosity, the representative elementary volume is being specified by the calculation of the variation coefficient.

4., A modelling method has been developed for the analysis of the fluid flow and heat transport processes coming off between the basement highs and Neogene sediments of the Pannonian Basin. Accordingly the results of the percolation and REV calculations made by the discrete fracture network simulator are being built into a numerical hydrodynamic and heat transport model where the quantification proceeds as follows:

- conversion of the permeability tensor – calculated by DFN simulator – into horizontal and vertical hydraulic conductivity values;

- REV analysis performed by DFN simulator on the basis of porosity, assigning REV as homogenous cell size;
- performing percolation analysis by using DFN simulator, then estimating effective porosity from connected and not connected fracture groups.

5., There are significant amount of fluids existing in several uplifted basement blocks of the Great Plain which has uncertain origin. The numerical modelling detailed in my dissertation introduces the upfilling mechanism of the pre-Neogene fractured reservoirs. The fluid supply of the basements highs from the direction of younger sediments deposited on the slope exists all along despite of the locally observed extreme overpressure, based on my calculations. This fluid pathway gives explanation for how the basement formations become hydrocarbon reservoirs hence proves the existence of special areas valuable in the view of geothermal energy exploration.

6., The hydrodynamic model provides evidence for that the fluid in-flowing into the overpressured basement highs from their sides flows upwards into the Pannonian sediments. Furthermore it supplies the regional discharge zones of shallow gravitational fluid flow systems along characteristic diverging pathways above the basement complexes or flowing towards surface diverted by recharge zones.

7., Numerical hydrodynamic and heat transport model has been made for introducing the geothermal respect of the procedures mentioned in section 5 and 6. The result of the simulation provides evidence for that the geothermal and hydrogeological processes induce positive heat anomaly in the vicinity of the crystalline basement highs. It means approximately 20°C at the lower section of the overlaying sedimentary formations and this effect decreases gradually and practically ceases at 2-300 m above the tops.

8., At the top of the basement highs where impermeable sedimentary layers are missing, both conductive and convective heat flow are involved in the development of positive temperature anomaly in the sediments of the central zone. The deduction for the combined effect of the two factors was applied by analytical and numerical calculations and was also confirmed by specifying the Peclét-number. Accordingly the conductive and convective heat flow takes approximately equal effect in the investigated geological-hydrogeological system mainly due to the extreme basement overpressure.

IV. Publications list

M. Tóth, T., Vass, I., Schubert, F. (2006). Repedéshálózat szimuláció és paleofluidum rekonstrukció szerepe kommunikáló törésrendszerek vizsgálatában. In: Török Ákos, Vásárhelyi Balázs (ed.) Mérnökgeológia-Kőzetmechanika 2006. Budapest, Hungary, Műegyetemi Kiadó, p. 163-184.

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M. Tóth, T., Vass, I. (2011). Relationship between the geometric parameters of rock fractures, the size of percolation clusters and REV. J. Mathematical Geosciences, 43, p. 75-97.

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