Doctoral School of Earth Sciences

Relationship between micro-fracture network and karstification in recent (Mecsek) and paleokarst (Gomba) reservoirs

PhD Thesis

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1. Introduction and Aims

Karstic and paleokarstic fluid reservoirs are of extremely heterogeneous structure and have a major share both in the area of hydrocarbon production and of geothermal energy utilization. The fracture system forms the main storage spaces and the migration pathways in the usually layered or bedded carbonate formations, which are further subdivided by possible cavities or collapses but smaller dissolved caverns can also significantly increase pore space.

Carbonate bodies that can be suitable for hydrocarbon storage or have undergone karstification are easy to find in several places in the Precenozoic basement of Hungary (Dolton 2006). The Gomba hydrocarbon reservoir, which can be found in the Paleogene Basin, can also be related to fractured limestones. The area started to be studied in the late 1990s, while production began in the early 2000s. No geological and geophysical information accumulated since then got published so we know them only from the internal reports of MOL PLC. There are many karstic areas in Hungary what are used in the drinking water supply (e.g. Tata, Tatabánya, Miskolc and Orfű) too.

One of the dissertation goals is to recognize the relationship between the fracture network and the macro-karstic forms (caves, dolinas) in a nearsurface karstic area of Mecsek Mts. near Orfű. Another main dissertation aim was the petrological description of the carbonate body of the Gomba hydrocarbon reservoir, with special regard to the fracture system that determines possible karstification stages. The last main aim was to explore the depth intervals underwent karstification with the help of fracture system simulations as well as to point out zones where no major cavity system was able to develop.

The work includes two parts. The first section treats the relationship between the geometric parameters of a fracture network and the karstic forms, while the second one is related to the Gomba field fracture network and petrology. The main questions to answer are the followings.

1) Can the fracture network contribute to compartmentalization a reservoir?
2) How do spatiality of fracture network geometric parameters and the locality of the karstic objects relate to each other?
3) What fracture geometrical parameter has the most important effect on the spatial distribution of the karstic objects?
4) Can fracture system serve as a HC migration pathway in the Gomba field?
5) Has fracture dissolution and karstic processes any effect on behaviour of the Gomba field?
6) How one can localize traces of karstification in the carbonate rocks of the Gomba reservoir?

The forthcoming sections represent a selection of published and submitted papers about the research of the fracture network and karstic phenomena of the Western Mecsek study area as well as about the petrography and fracture network modelling of the Gomba field.

2. Applied methods

Resulting from the peculiarities of the study areas slightly different methodology seemed to serve the purpose in the two areas examined. Nevertheless, the working process was the same in both cases: petrological description, fracture parametrization, DFN simulation and eventually making conclusions.

As for the Mecsek area petrological description was based on literature thanked to the ample references, in the case of Gomba field the petrological reinterpretation of the cores seemed necessary. So I have examined the available rock samples of both Gomba-1 and Gomba-3 both on macroscopical and thin section scales. Besides optical microscopic analyses also Scanning Electron Microscopic, X-ray Powder Diffraction, X-ray Fluorescent, Raman Spectrometry, UV-spectroscopic, cathode-luminescent, fluid inclusion as well as stable isotopic measurements were carried out. Raman microspectroscopy was also applied to calculate the Tmax of the carbonaceous material (Beyssac et al. 2002, Rahl et al. 2005).

In case of exposed breccia sections texture analysis was done with image analysis methods on thin section scale using Olympus Stream Essential and ImageJ softwares. We have measured the size, the average axial direction of the clasts, the proportion of the clasts and matrices and also sphericity.

What differed most in the methods applied in the two areas was fracture parametrization. If on surface, samples were provided by rock exposures of various sizes (0.1–2.0 m^2, in case of the Gomba field samples were taken from CBIL/FMI logs measured during drillings and from the cores themselves. In both cases we have examined the length distribution of the fractures (E), aperture of the fractures (a), and fracture density which have been described by fractal dimension (D). In case of the Mecsek sample area we have derived any parameter from digitalized rock exposures (11 samples altogether, 1727 fractures). While in the case of the Mecsek area we have calculated the D parameter by box-counting, in drillings (Gomba samples) we have derived D from the Hurst-exponent determined from the interpreted CBIL/FMI data.

When studying the Gomba samples I have also examined the individual fractures by image analysis. As we had a large database of fracture geometrical results we had the opportunity to carry out multivariate statistical processing on the data through which I targeted the grouping of dissolved and non-dissolved fractures. Finally I have prepared fracture- network models using RepSim software (M. Tóth 2003, 2010). Then I have compared the structure of the models with the known lithological structure and with the technical problems that occurred during the drillings. I also managed to point out the zones where major cavity-formation is rendered possible around the wells and vertical sections where we cannot expect major cave systems.

3. New scientific results

The research presented in the dissertation has provided the following new scientific results:

1. In the Mecsek study area I have pointed out two fracture zones communicating through fractures with a non-fractured zone between them. The sinks in one fractured zone (e.g. Trió-cave, Gilisztás-cave, Szuadó-cave) are hydraulically connected with the spring in the other fractured zones (Vízfő-cave). The hydraulic connection between the two areas can mainly be explained by the flow along the bedding surfaces.

2. Through studying the Mecsek area I have shown that the microfracture network is able to divide an area interpreted hydraulically unified into parts where the hydraulic connection definitely does not go through the fracture system. This also means that regions can be separated within an aquifer where solution is able to create connected subsurface cave systems and also parts where the formation of major cave systems is hindered. All parameters (as climate, soil thickness, surface morphology, lithology etc.) may be the same, the formation of karstic cavities in a particular aquifer is not of the same probability.

3. I have separated three rock types in the Triassic sequence of the Gomba reservoir. The most frequent rock type is a limestone with oncoidal grainstone, wackestone texture, which also served as precursor of a dolomitic limestone resulting from the fabric-selective recrystallization. The limestone is overlain by a breccia body of varying thickness and chaotic texture. Both composition of the breccia matrix (high content of dickite and quartz) and of the breccia framework grains (carbonates, metamorphic rocks and

claystones) and also the textural parameters render tectonic origin out of question. Mineralogical, geochemical and image analysis results show that the breccia formation is linked to karstification and is genetically hydraulic and/or regolith.

4. Based on the characteristics of fracture fillings and the mineral composition I have concluded that the Gomba reservoir must have experienced higher temperatures in the past than nowadays (125 °C). The Raman thermometry results of the organic material in the fractures as well as the presence of dickite and framboidal pyrites show that the maximum temperature of the burial can be estimated as ~220 °C.

5. Regarding the fracture system of the Gomba field, I have separated 4 fracture generations. I have found oil inclusions in the calcite fillings of the youngest fracture system – younger than the breccia formation – characterized by identical UV-spectra with the oil produced nowadays. That way I was able to prove that the fracture system is an active part of the recent hydrocarbon migration. Additionally, I have also found bitumen fillings in the older fracture generations what indicate a previous hydrocarbon migration phase.

6. The image analysis of the individual fractures indicates that the shape of several fractures has been greatly modified due to dissolution. The application of the discrimination function to separate the dissolved and non-dissolved fractures numerically made it possible to calculate the extent of dissolution. I have pointed out that non-dissolved fractures formed even in the most fractured parts of the rock which could not have taken part in the coeval flow system.

7. In case of the Gomba field I have proved the existence of a karstification event. This event is suggested by the presence of cavity crossed during the drilling, by the fresh-water limestone clast found among the breccia clasts the texture of which is mostly similar to that of a dripstone, by the high number of dissolved fractures, by the dissolution traces on the cores, and also by the significant amount of dickite in the breccia matrix which is the polytype modification of kaolinite produced by the tropical weathering conditions during sedimentation.

8. In case of the reservoir in the surrounding of the Gomba-1 and Gomba-3 wells the fracture network does not constitute a consistent fracture system. In the case of both wells two major fracture sub-systems are separated by a non-fractured zone. Therefore, as in the Mecsek, areas can be assigned which structurally determine the zones where major cave systems could be formed and where they could not. Each depth interval suitable for cave formation contains some trace of paleo-caves (e.g. cave sediment, open cavity, extreme/total mud loss). Based on geological setting and published analogues from literature the contemporary cave-system must have been an epigenetics, branchwork-type cave, with NE–SW main passages.

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