Doctoral School of Earth Sciences

Complex evaluation of the Kiskunhalas-NE fractured metamorphic hydrocarbon reservoir

Theses of Ph.D. dissertation

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I. BACKGROUND

The crystalline basement of the Great Plain of Hungary has provided an interesting research topic for decades; its basic and also applied research aspects are multiple. Although industrial interest largely determines its exploration, samples and geophysical data obtained in this way could give a good insight into the geology of the area.

The Kiskunhalas-NE hydrocarbon field has been produced since the mid-1970s. In this area more than one reservoir block exists; there is a northern reservoir with a Palaeozoic metamorphic basement and a southern one with a Mesozoic carbonate basement. The reserving formations from different ages and material (Palaeozoic metamorphic rocks, Mesozoic carbonates and Miocene sediments) in certain cases behave as one hydraulic regime. The focus of the present study is the reservoir with the metamorphic basement. Several different publications (T. Kovács 1973, Árkai 1978, Cserepes 1980, T. Kovács and Kurucz 1984, Cserepes-Meszéna 1986, Árkai 1993) and unpublished industrial reports have noted several rock types in the crystalline basement (gneiss, micaschist, amphibolite, different mylonitic types, migmatite, and a low-grade phyllite); however, in interpreting the reservoir the whole area has been handled as a homogeneous block. Actually, the KIHA-NE reservoir has a highly compartmentalized nature, since there are at least ten independent hydraulic regimes in the field.

On the one hand, this present study is situated within basic geological research. A review on any hydrocarbon field is necessary from time to time because new methods and novel scientific theories can enrich existing knowledge about the narrowly studied fields and their wider geological environment. In this way it will be possible to enrich the highly sporadic information about the crystalline basement of the Pannonian Basin in the wider neighbourhood of the study area.

On the other hand, this research also has an *applied* geological point of view. Newly acquired knowledge about the field provides more adequate framework about the characteristics of the reservoir. It can help to create a better reservoir model which can contribute to more effective production, and which can provide guidance about field development processes, even regarding the drilling of new wells. The new methods, data management or the routine of test series learned or developed in the course of this project could be utilized in the future. The official review of the Kiskunhalas fields in the MOL Plc., begun in 2008, provides actuality for this research. In the wider environment (around Jánoshalma and Kiskunhalas) the RAG (Rohöl-Aufsuchungs Aktiengesellschaft) currently conducts research.

II. METHODS APPLIED

For the purpose of the identification and classification of the lithology units of the field, and to give a detailed petrographic and textural description, macroscopic and microscopic examination and prudent microtexture analyses were carried out. In the course of the pertographic study, the available core samples of 15 wells and more than 100 thin sections were investigated.

Thermometric examinations were also carried out on the samples to clarify the genetic relations between the rock units. The sutured quartz grain boundaries of the mylonitised lithologies were used for the deformation-related thermometer of Kruhl and Nega (1996). On the calibrated textural thermometer a linear function is suggested between the fractal dimension of the sutured quartz grain boundaries and the formation temperature. Two lithologies of the field contained representative amounts of carbonaceous material that allowed the possibility of using the carbonaceous material thermometer using Raman microspectroscopy (Beyssac et al. 2002, Rahl et al. 2005, Aoya et al. 2010). The method is based on the irreversible and temperature dependent character of the graphitisation process. The resulting temperature estimate is the maximum temperature the rock reached along a given *PT* path.

On the representative samples, destructive and non-destructive rock mechanical treatment and a 3-dimensional scan with X-ray Computed Tomography (CT) were fulfilled, parallel and perpendicular to the foliation. In this way the fracture tendency and the brittle behaviour of the petrologically different rock types were estimated. The amount (cumulated fracture length) and the geometry (fractal dimension) of the provoked fracture system determine the reservoir features of the lithologies.

For spatial extension of the point such as geological information along the wells, datasets of over a decade old digitalised open-hole well-logs (gamma, resistivity, neutron, density, and acoustic logs) were used. For lithology identification and lithology boundary estimation conventional cross plots, lithology sensitive MN plot (Schlumberger, 1989) and discriminant analysis were carried out. The estimated lithology boundaries were represented along geological sections to explore the geometry and the structural build-up of the field.

III. NEW SCIENTIFIC RESULTS

The following new scientific results have emerged in the course of these investigations:

1. In the Kiskunhalas-NE field, four main rock units were identified. On the basis of neighbourhood relations, these types define the following ideal rock column from the bottom upwards: orthogneiss, orthogneiss mylonite, graphitic gneiss mylonite and graphitic carbonate phyllite.
2. The deepest known formation is an orthogneiss body with amphibolite xenoliths and mica-poor granitic dykes. According to its mineral assemblage and relict igneous textures (mirmekite, idiomorphic zircons) one can assume that it is identical to the neighbouring Jánoshalma orthogneiss characterised by $T < 580$ °C metamorphic temperature. Because of the similar mineral assemblages and the presence of the relict igneous textures, this orthogneiss might be the protolith of the orthogneiss mylonite following the orthogneiss upwards.
3. The other lithology type of the mylonitised zone, the graphitic gneiss mylonite, is clearly different from the orthogneiss based on its index minerals (graphite, pyrite). It is also different from the uppermost graphitic carbonate phyllite because of the high quartz+feldspar+sericite content of the graphitic gneiss mylonite; its undeformed protolith is unknown in the field. The Raman microspectroscopy based carbonaceous material thermometer result for this lithology is $T = 410\pm45$ °C.
4. The uppermost structural position, characterised by graphitic carbonate phyllite, has a subordinate role in the field. It consists of chaotically folded light (carbonate+sericite+some quartz) and dark (graphite, pyrite, clay

minerals) bands. The Raman microspectroscopy based carbonaceous material thermometer result for this lithology is $T = 375 \pm 15$ °C.

5. The mylonitised zone, constituting a significant part of the rock mass, is built-up by two petrologically different lithologies, uniformly bearing textural elements (bookshelf structure, microboudinage, mica fish) developed in an extensional stress field on a micro scale. The sutured quartz thermometer results of both mylonitised lithologies give around $T_{def} \sim 455$ °C.
6. Along the incompatible rock column, nearly 200 °C metamorphic peak temperature difference exists. The $T_{def} \sim 455$ °C value for the mylonitised zone could mean a shear zone was active at approximately 15 km depth, depending on the geothermic gradient. The recent order of the rock units might have developed in the course of this post-metamorphic tectonic event. Although the presence of extensional textural markers in the mylonite zone do not preclude a compressional stress field in respect of the whole rock body, the possibility of a shear zone in the extensional stress field is more likely.
7. On the basis of the rock mechanical investigations, the reservoir features of three predominant rock types in the area (orthogneiss, orthogneiss mylonite, graphitic gneiss mylonite) are significantly different. The graphitic gneiss mylonite has the best reservoir features, as it tends to have a large and connecting fracture network, achieved by lower invested work relative to the other lithologies. A characteristic feature of each measured parameter is the high anisotropy. The samples crushed parallel to the mylonitic foliation have much more favourable properties from the reservoir point of view, than the samples crushed perpendicular to the mylonitic foliation.

8. With the available open-hole well-log datasets, the orthogneiss and mylonite lithologies could be separated along the given wells; the resistivity and the density logs have a major role in the separation. The mylonite and the graphitic carbonate phyllite zones could also be separated. Nevertheless, the two petrologically different mylonite lithologies (orthogneiss mylonite, graphitic gneiss mylonite) could not be separated on the available open-hole well-logs. In this way, three rock units were identified (orthogneiss, mylonite, graphitic carbonate phyllite), and the lithology boundaries were estimated between them along the wells.
9. The estimated lithology boundaries were represented along geological sections. The gneiss/mylonite boundaries appear as a low angle (<5°) plane with northern dip (13-18°); interpreted as a onetime detachment fault linked to a formation of a core complex if it worked in the extensional stress field.
10. Also taking into consideration the hydraulic regimes of the field, several normal faults of a later brittle deformation event could be identified. These normal faults behave as impermeable faults between the productive mylonitised bodies. Nevertheless, the presence of some regime boundaries should be the result of the petrological diversity of the mylonite zone, which also means rock bodies with different fracture tendency. The high anisotropy of the mylonite lithologies further modifies the reservoir body geometry.

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