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PETROLOGY, METAMORPHIC EVOLUTION AND SPATIAL CORRELATION  
OF THE JÁNOSHALMA ORTHOGNEISS BLOCK

Theses of PhD dissertation

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## RATIONALE OF THE RESEARCH

Since the end of the 1950s and beginning of the 1960s the focus of hydrocarbon research had been geared from the porous sediments settled on the metamorphic basement towards the fractured crystalline metamorphic rocks as a consequence of the fact that had been highlighted that these rocks also may store considerable amounts of hydrocarbon in their fracture systems. The fractured metamorphic rocks may store besides hydrocarbons some hot water, even steam, therefore may play an important role in terms of energy research.

The complex research aimed at the identification of the area that is suitable for the final disposal of low and medium radio activity waste of the Paks Nuclear Power Station has started in 2000 in Hungary. The research covered all geological formations in Hungary in terms of suitability for this end. The Jánoshalma area, which forms part of the Körös Complex in the crystalline metamorphic basement of the Great Hungarian Plain, was considered during this research activity. At the time of that research we only had acceptable level of information of the quality and types of the metamorphic rocks that build up the Jánoshalma dome, and of the size of the metamorphic high. The metamorphic evolution of the main rock types, the structure of the dome and possible relationship with other parts within or outside of Tisza Unit had not been examined beforehand.

During the first stage of the screening, which is the phase of the detailed pre-examination exclusion (negative screening); the Jánoshalma dome did not get excluded. During the next stage of the screening that covers identification of the potentially suitable formations (positive screening); it only failed due to the lack of sufficient information about the exact quality, structure and homogeneity of the rock body.

In the research of the fractured fluid reservoirs it is of decisive importance that we know as much detail about the qualities of the fracture network as possible. In the metamorphic basement of the Great Hungarian Plain the most considerable event that had led to the fracturing of the basement rocks is related to the Neogene subsidence of the Pannonian Basin. The different mineral assemblage and texture rocks react to the same stress field with different deformation activities, therefore they fracture in different ways. Due to the complex structure of the basement, in order to be able to research the fracture system, therefore thorough knowledge of the rock column is required in the first place.

As a consequence of the above described application possibilities, therefore detailed research of the Jánoshalma metamorphic high is particularly reasonable.

## OBJECTIVE

The objective of the dissertation is to exactly reconstruct the geological evolution and to create the rock column model of the Jánoshalma elevated high, based on all the available bore core samples that form the basis for the applied geological research.

I completed this objective by following the below research process:

1. In order to identify the main lithologies of the Jánoshalma metamorphic high I made examinations into the mineral structure and texture of the 47 available bore core samples. According to microscopic examinations I defined the main rock types and identified the mineral assemblage generations.
2. Based on main and trace element composition I defined the protolith of the main rock types and their major geochemical characteristics.
3. On the basis of the bulk rock chemical composition of the rocks I carried out thermobarometric modelling.
4. Based on mineral chemistry analysis I specified the main rock types and carried out thermobarometric calculations. I compared the results to those of the thermobarometric modelling. With these results I determined the metamorphic evolution of each main rock type.
5. I made examinations on mezo and micro scale of the relationship of the main rock types, created the rock column model and based on the results I had so far, I determined its geological evolution.
6. I applied various rock texture, structure and geological evolution correlation points in order to correlate the Jánoshalma metamorphic high with other parts of the Tisza Unit.

## APPLIED METHODS

During the petrographical examinations I prepared macroscopic descriptions of the bore core samples and used 85 thin sections to create the microtextural descriptions.

The chemical composition of the samples has been defined by using the following methods:

Major and trace element compositions of 17 samples have been examined by XRFS method in the Department of Geology and Environmental Sciences of the Veszprém University. The definition of the trace element concentrations of 4 samples have been completed by nuclear electron activation method in the nuclear reactor of the Budapest University of Technology.

The mineral chemistry analyses have been completed at the Leoben University (Montanuniversität Leoben) and at the Geological Survey in Bratislava (GÚDŠ).

The BSE (back scattered electron) images were taken at the Geological Survey in Bratislava (GÚDŠ).

#### NEW SCIENTIFIC RESULTS

1. I defined the magmatic origin of the myrmekitic feldspars in the Jánoshalma gneiss.

I identified 3 types of occurrences of the feldspars in the gneiss. I discovered that myrmekite appears in the big sized resorbed sericitic feldspar porphyroblast from the feldspar types. I observed in these occurrences the myrmekitic sericitic feldspars are replaced by fresh feldspars. Quartz blebs and vermicules are often visible in the fresh feldspars, which once were contained in the original myrmekitic feldspar grains. I determined on the basis of microtextural characteristics that the myrmekitic feldspars formed before the metamorphosis of the gneiss; therefore they are prekinematic, of magmatic origin. Based on their textural characteristics and the myrmekite forming theories in the literature, the origin of myrmekite is of magmatic crystallization.

2. Based on textural examinations on the mezo and micro scale, I defined the protolith of the Jánoshalma gneiss to be of magmatic origin.

I discovered polygonal texture in the matrix of the gneiss that suggests equilibrium circumstances. The polygonal texture is not pervasively, but only separately present in the gneiss. Straight grain boundaries exhibiting „soap foam” are observable in the scale of some grains. It can also be observed that the sericitic grains are replaced by fresh feldspars. Its presence in the metamorphic rocks refers to high temperature static recrystallization or dynamic recrystallization due to stress. Although the D1 was a high temperature metamorphic event, the resulted texture does not suggest equilibrium circumstances. Separate occurrence of polygonal feldspar grains, and the replacing fresh D1 feldspar on the grain boundaries imply

pre-metamorphic origin of the polygonal feldspar texture. Low temperature mylonitic deformation that can be observed in some gneiss samples caused grain size reduction and it took place following the D2 metamorphic event. In consideration of the above described observations, the static and/or dynamic recrystallization origin can be excluded.

As a consequence I concluded that the polygonal feldspars are prekinematic, they are of magmatic origin and formed part of the granodiorite protolith. Based on this, the Jánoshalma gneiss is of magmatic origin, consequently orthogneiss.

3. With the help of textural observations and major element composition of the gneiss I carried out thermobarometric modelling and defined the two-stage metamorphic evolution of the gneiss.

The gneiss can be characterised by two schistosity planes, S1 and S2, which suggest two deformation events of the gneiss. The biotite + K-feldspar + plagioclase + ilmenite + quartz ± garnet ± sillimanite mineral assemblage of D1 suggest high temperature, while the biotite + muscovite + plagioclase + quartz + ilmenite + magnetite of D2 suggest lower temperature circumstances.

The biotite, muscovite and quartz inclusions in garnet imply the first reconstructable event of the orthogneiss, which can be linked to one stage preceding the thermal climax of D1 event. The D1 metamorphic event is characterised by the mineral assemblage of biotite + K-feldspar + plagioclase + quartz + ilmenite ± garnet ± sillimanite. Sillimanite was observed in the core of S2 muscovite. Its presence suggests high temperature metamorphism, the circumstances of which I determined 700-850 °C and  $P < 0.65$  GPa using thermobarometric modelling (de Capitani, 1994). The minimum temperature limit of the D1 metamorphic event is indicated by the equilibrium reaction of muscovite+quartz=sillimanite+K-feldspar+H<sub>2</sub>O. The maximum temperature and the maximum pressure are limited by the transformation of ilmenite into rutile.

The S1 schistosity plane defined by the high-temperature mineral assemblage is overprinted by the lower temperature biotite + muscovite + plagioclase + quartz + ilmenite + magnetite S2 assemblage related to D2. The S1 and S2 schistosity planes are nearly perpendicular to each other. I established the metamorphic circumstances of D2 as 530-580 °C for maximum temperature and 1.1 GPa for maximum pressure. The difference between the maximum temperature data refers to the chemical inhomogeneity of the gneiss. The maximum temperature can be related to the presence of garnet which in the gneisses is strongly dependant on the chemical composition.

Chloritization of biotite following the D2 metamorphic event refers to retrogression.

4. I concluded that Jánoshalma metamorphic crystalline high is a uniform orthogneiss block and I determined its 7-stage geological evolution.

I stated that the majority of the Jánoshalma high consists of the most frequent rock type, i.e. the orthogneiss. Amphibolite and eclogite were only revealed on rare occasions in a few bore holes and their positions do not suggest any orientation. Based on these I came to the conclusion that these rock types are not present in the basement in continuous extensions, but sporadically.

Based on the metamorphic evolution, frequency and spatial relationships of the above described revealed rock types (mostly orthogneiss, three samples of amphibolite, one sample each of eclogite and granite) I drew the conclusion that Jánoshalma metamorphic crystalline high is a uniform orthogneiss block and its evolution history consists of the following phases:

1) The phase of mafic intrusion: it is related to the replacement of the gabbroic protolith of the eclogite.

2) Phase D0: medium-temperature and medium-pressure metamorphism of the amphibolite xenolith and high-pressure and medium-temperature metamorphism ( $710\pm 10$  °C, 2.6-2.7 GPa) of the eclogite xenolith.

3) Phase of the granodiorite intrusion: the chemical composition of the orthogneiss suggests granodiorite protolith. Based on the geochemical data the intrusion is of peraluminous composition and syn-collision origin.

4) Phase D1: development of S1 schistosity plane in the orthogneiss characterised by metamorphic circumstances of 700-850 °C and  $P < 0.65$  GPa and presence of sillimanite.

5) Phase D2: development of S2 schistosity plane in the orthogneiss; with the application of thermobarometric modelling I established metamorphic circumstances of 580 °C for maximum temperature and 1.1 GPa for maximum pressure.

6) Phase D3 (formation of mylonite): the evidences of the last plastic deformation event are only visible in a few samples. I observed dynamic recrystallization of quartz and kink-band structure on micas. In certain instances mica also recrystallized and fine grained low-temperature mylonite developed. The occasionally present, low-mica granite refers to post-kinematic granite intrusion. There are no traces of metamorphism; however the quartz ribbons indicating dynamic recrystallization and the presence of deformed feldspars show post-intrusion stress.

7) Phase of brittle deformation and metasomatism: it affected both the xenoliths and the hosting orthogneiss. In the case of Jánoshalma orthogneiss eclogite, the hydrated and carbonated parts differ not only in the various secondary mineral assemblages, but also in the preservation of high-pressure phases in the carbonated type.

5. I determined that Jánoshalma orthogneiss contains xenoliths and xenocrysts.

Resorbed amphibole and atoll-shaped garnet occur sporadically in the orthogneiss, their arrangement do not show any orientation. The amphibole grains are always resorbed displaying wiggly grain boundaries caused by rounded embayment of quartz and feldspar.

There is no another type of amphibole in the gneiss. Atoll-shaped garnets differ significantly from the garnets that are present in the matrix or as inclusions in feldspars in the gneiss, since they are bigger in size and inclusion free. Based on these observations I defined amphibole and atoll-shaped garnet to be xenocrysts. Orthogneiss is the most frequent rock type in the Jánoshalma metamorphic high. Amphibolite was revealed from 3, while eclogite was revealed from 1 borehole, so I inferred that these rock types do not form a continuous zone in the Jánoshalma metamorphic high, but they are present as smaller separated blocks in the gneiss. The relationship between orthogneiss and eclogite was revealed in bore hole JhÚ-16. Along the contact a narrow transition zone of around 3 centimetres exists with decreasing amounts of garnets and amphibole towards the gneiss. No trace of deformation or any indication of dislocation is present. Gneiss contains medium-grade amphibolite xenoliths too with the aforesaid transition zone along the contact zones. According to the above-mentioned observations and the fact that orthogneiss contains rock types with different metamorphic evolution, I defined amphibolite and eclogite as xenoliths in the gneiss.

6. On the basis of micro textural observations and mineral chemical compositions I detected the presence of high-pressure metamorphism in a metabasite from the basement at the Jánoshalma area. I defined the eclogite facies assemblage of omphacite + garnet + phengite + kyanite + zoizite + rutile + K-feldspar + quartz. By dint of thermobarometric calculations and thermobarometric modelling I proved the medium-temperature high-pressure metamorphism of the Jánoshalma eclogite, so it can be classified as a B-type eclogite (Coleman, 1965). Based on thermobarometric modelling I defined 680 °C minimum temperature and 2.7 GPa maximum pressure for the stability field of the mineral assemblage. These data are in good agreement with the temperature and pressure values that were calculated with calibrated thermobarometers (710±10 °C and 2.6-2.7 GPa).

7. I identified that Jánoshalma orthogneiss block was developed in an ancient subduction-accretionary complex.

I appointed that D0 is only related to the metamorphism of the xenoliths and orthogneiss underwent only D1 and D2 metamorphism. Thus granodiorite intrusion assimilated the xenoliths after the subduction and eclogitization of the mafic rocks (D0). In this case the theory of subduction-accretionary complexes or Alaskan-type orogenic belts (Ochsner 1993) can be applied. In such model continuous continental sediment supply during subduction of the oceanic crust causes development of accretionary prism. After uploading of the subduction trench due to the continuous external sediment supply, the accretionary prism tends to grow oceanwards. Consequently, the subduction zone retreats oceanwards, too. From a critical moment on, mantle derived magmas intrude directly to the lower part of the accretionary prism. That causes granulite facies metamorphism and melting of the sedimentary beds of the accretionary prism. In this way hybrid magmas (H-type granitoids) form due to mixing of mantle derived M-type and sedimentary derived S-type granitoids (Castro et al. 1991). These granitoids rise along the steep dipping inner structures of the accretionary prism to the upper part of the crust (Zurbriggen 1996). During upwelling, these intrusions may drag slabs of different rock types from different depths with them that are present as xenoliths in the magmatic body. In this way hybrid magmas (H-type granitoids) form due to mixing of mantle derived M-type and sedimentary derived S-type granitoids (Castro et al. 1991). These granitoids rise along the steep dipping inner structures of the accretionary prism to the upper part of the crust (Zurbriggen 1996). During upwelling, these intrusions may drag slabs of different rock types from different depths with them that are present as xenoliths in the magmatic body. Although, there is no direct evidence for presence of steep dipping slices of the accretionary prism in the mentioned area, occurrences of xenoliths of diverse metamorphic pressure in the orthogneiss implies that a process similar to the subduction-accretionary complexes may have taken place.

8. On the basis of various rock texture, structure and geological evolution correlation points I proved the relationship between Jánoshalma high and the metamorphic basement of the north-eastern part of the Tisza Unit.

I detected that based on the rock types their characteristics and the above described structure the Jánoshalma metamorphic high shows strong similarities with the Szeghalom high on the northern verge of Békés-Basin in the north-eastern part of Tisza Unit and with

Mezősas-Furta dome in its eastern extension. All three areas are characterised by the presence of orthogneiss containing xenocrysts and xenoliths of different metamorphic evolution. In the Furta area contact of the orthogneiss and amphibolite, in the Jánoshalma area the contact of the orthogneiss and eclogite were revealed. The typical textural features in all three areas are myrmekitic and poikilitic feldspar porphyroblasts and occasional polygonal feldspar texture. Amphibole and garnet xenocrysts occur in all three areas as well. Evidences of post-metamorphic mylonitic stress such as elongated, dynamically recrystallized quartz ribbons and mica fish can unmistakably be identified. The post-metamorphic granite also appears in the orthogneiss in these three areas. The amount and the appearance of myrmekite varies in the three areas, however its presence can always be related to the feldspar porphyroblasts. Detailed petrographical research of the myrmekites of the Szeghalom dome was carried out. Based on the evidence of this, myrmekite is a relic phase in the Szeghalom gneiss, its most likely origin is by magmatic crystallization.

I determined that orthogneiss of the same type and metamorphic evolution can be traced in the basement towards NE (e.g. Szank, Füzesgyarmat, Dévaványa regions), where orthogneiss bodies also contain myrmekitic feldspar grains as well as diverse mafic and ultramafic xenoliths (Zachar and M. Tóth, 2001; Zachar and M. Tóth 2003; M. Tóth and Zachar, 2003). In most of these localities late LT mylonitic deformation is typical too (Schubert and M. Tóth, 2002) providing an important point in further correlation studies. Lelkes et al. (2000) found an exposure of ultramylonite in borehole Mőcsény-1 west from the Jánoshalma high. Based on garnet relics the protolith of the ultramylonite has been specified as orthogneiss.

The previously known migmatite and meta-sandstone were later identified by M. Tóth et al. (2005) as mylonitic orthogneiss in the Ófalu region. Based on zircon morphology data they found similarities between the Ófalu orthogneiss and orthogneiss in the northern verge of Békés-Basin in the north-eastern part of Tisza Unit. Szepesházy (1962) assumed the existence of a continuous orthogneiss zone of SW-NE orientation in the basement of the Tisza Unit.

Evidences of eclogite facies metamorphism in the Variscan orogen testify the important role of subduction in the evolution of the orogen (O'Brien et al., 1990) and can serve as correlation points. Based on the arrangement of the appearance of eclogites in the Tisza Unit (Ravasz-Baranyai, 1969; M. Tóth, 1995, 1996, 1997; Horváth et al. 2003) M. Tóth and Zachar (2003) suggest the existence of an ancient suture zone between the Körös Unit and Görcsöny areas.

## PUBLICATIONS

1. **Zachar, J.**, M. Tóth, T., Janák, M. (2007): Eclogite xenolith from the orthogneiss terrane of the Tisza Megaunit, Jánoshalma area, crystalline basement of southern Hungary. *Lithos*, 99, 3-4, 249-265.
2. M. Tóth, T., **Zachar, J.** (2006): Petrology and deformation history of the metamorphic basement in the Mezősas-Furta crystalline high (SE Hungary). *Acta Geol. Hung.*, 49, 165-188.
3. **Zachar, J.**, M. Tóth, T. (2004): Petrology of the metamorphic basement of the Tisza Block at the Jánoshalma High, S Hungary. *Acta Geol. Hung.*, 47/4, 349-371.
4. M. Tóth, T., **Zachar, J.** (2003): Evolution of the Déva orthogneiss (Tisza block, Hungary) and its geodynamic consequences. *Journal of the Czech Geological Society*, 48, Abstract Volume, 127-129.
5. **Zachar, J.**, M. Tóth, T. (2003): Xenoliths of various metamorphic evolutions in the Déva orthogneiss (Tisza block, Hungary). *Journal of the Czech Geological Society*, 48, Abstract Volume, 137-139.
6. M. Tóth, T., **Zachar, J.** (2002): Eclogite remnants across the Tisia Block: Indication for a Variscan suture zone?. *Geologica Carpathica*, 53, 149-151.
7. **Zachar, J.**, M. Tóth, T. (2001): Myrmekite-bearing gneiss from the Szeghalom Dome (Pannonian Basin, SE Hungary). Part I.: Myrmekite formation theories. *Acta Mineralogica Petrographica*, 42, 33-37.
8. **Zachar J.**, M. Tóth, T. (2001): Myrmekite-bearing gneiss from the Szeghalom Dome (Pannonian Basin, SE Hungary). Part II.: Origin and spatial relationships. *Acta Mineralogica Petrographica*, 42, 39-43.

## CONFERENCES

1. Geology without frontiers: Magmatic and Metamorphic evolution of the Central European Variscides, Blansko Ceskovice, 2003
2. Conference of young geologists, Salgótarján, 2003
3. 64<sup>th</sup> EAGE Annual Conference Exhibition, Florence 2002
4. Conference of young geologists, Salgótarján 2002
5. XVII.<sup>th</sup> Congress of Carpathian-Balkan Geological Association, Bratislava 2002
6. Fractured metamorphic hydrocarbon reservoirs, Szeged 2002
7. Hungarian PhD. Conference, Budapest 2000
8. Exhumation of metamorphic Terranes, Rennes, France 1999

## OTHER PUBLICATIONS

1. M. Tóth, T., Schubert, F., **Zachar, J.** (2000): Neogene exhumation of the Variscan Szeghalom dome, Pannonian Basin, E. Hungary. Geological Journal, 35, 265-284.
2. M. Tóth, T., Schubert, F., **Zachar, J.** (2002): A Mezősas és Mezősas- Nyugat repedezett kristályos tároló repedéshálózatának vizsgálata, és matematikai szimulációja. I. Kőzetváz modell. (Analysis and mathematical simulation of the fracture system of the Mezősas and western Mezősas-Furta fractured reservoir. I. Rock column. Manuscript) Kézirat, MOL Adattár, Szolnok, 1-34.
3. M. Tóth, T., Schubert, F., **Zachar, J.** (2002): A Mezősas és Mezősas- Nyugat és Furta repedezett kristályos tárolók repedéshálózatának vizsgálata, és matematikai szimulációja. II. Kőzetváz modell (Furta). (Analysis and mathematical simulation of the fracture system of the Mezősas and western Mezősas-Furta fractured reservoir. II. Rock column, Furta. Manuscript) Kézirat, MOL Adattár, Szolnok, 1-17.
4. M. Tóth, T., Schubert, F., **Zachar, J.** (2001): A Dorozsma repedezett kristályos tároló repedéshálózatának vizsgálata, és matematikai szimulációja. I. Kőzetváz modell. (Analysis and mathematical simulation of the fracture system of the Dorozsma fractured reservoir. I. Rock column. Manuscript) Kézirat, MOL Adattár, Szolnok, 1-40.