

Doctoral School of Earth Sciences

**Complex characterisation of Mecsekalja Zone using single quartz grains of  
drill cuttings from Sztl-1 well**

Ph.D. Thesis

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## **I. Introduction, objectives**

In the Earth's crust the shear zones are deformation localisation structures, in which strain is notably higher than in the surrounding rock body (Ramsay, 1980; Ramsay and Huber, 1987; van der Pluijm and Marshak, 2004; Passchier and Trouw, 2005; Fossen, 2010). In several places, because of their intensive deformation, shear zones behave as excellent fractured fluid reservoirs. Therefore, the petrographic and structural characterisation of these formations is extremely important. The metamorphic rocks in the crystalline basement of the Pannonian Basin contain numerous faults and shear zones. In the Pre-Neogene basement of the Tisza Mega-unit these formations are mostly known from a few surface outcrops and drill core specimens, which provide only rather diffuse information and their bring up is costly. However the drill cuttings are mainly continuously available from the wells that penetrated the basement and their collection is inexpensive.

The drill cutting samples usually include  $\mu\text{m}$ - $\text{mm}$  size rock and mineral fragments, dominantly quartz grains. Quartz ( $\text{SiO}_2$ ) is the second most frequent rock-forming mineral in the Earth's crust. It is stable and resistant within a wide range of temperature and pressure conditions. Quartz is a common product of metamorphic reactions and its metamorphic evolution determines the chemical composition of quartz grains. In the crystal lattice of quartz various trace elements (Al, Ti, Ge, Na, K, Li, B) (Götze et al. 2004) may also appear connected to the  $\text{SiO}_4$  tetrahedrons. Although quartz is a “nominally anhydrous mineral” (NAM), in its crystal lattice hydrogen (‘water’) may occur both in the form of hydroxyl defects ( $\text{OH}^-$ ) and molecular water ( $\text{H}_2\text{O}$ ) (Stenina, 2004). The amount of ‘water’ in the crystal lattice of quartz significantly influences its ductile and brittle behaviour and decreases its mechanical strength and rigidity (Jones, 1975). Under different pressure and temperature conditions quartz deforms in different ways following diverse deformation mechanisms. Thus, each quartz grain of the available drill cutting samples in its microstructure may provide valuable information regarding its deformation history (Hirth and Tullis, 1992; Stipp et al., 2002; Vernon, 2004; Passchier and Trouw, 2005; Halfpenny et al., 2012).

The aim of the project is to work out a reproducible method for metamorphic and deformation history reconstruction using single quartz grains of drill cuttings. Based on the developed method and using the drill cuttings of the Szentlőrinc-1 (Sztl-1) well from almost 2 km depth, the project aims the metamorphic and structural reconstruction of the Mecsekalja Zone in SW Hungary. Moreover the project aims spatial correlation of the borehole data with previous models concerning the evolution of the Mecsekalja Zone.

## **II. Methods applied**

During this research because of the tiny grainsize of the drill cutting samples development and application of special methods was required. Primarily the microstructural analysis of the quartz grains was made optically by polarization microscopy. The microstructurally different quartz grains was identified using Raman spectroscopy based on certain spectral attributes of Raman spectra measured on quartz grains. The linear combination of the spectral attributes, which in the best way describe the difference between the microstructurally different quartz grains, was computed using discriminant function analysis.

Ductile shear zones along the studied well were localized by counting the proportion of the microstructurally different quartz grains with depth. During the analysis, 100 pieces of randomly selected (JMicroVision: point counting method) quartz grains were microstructurally examined in every 25 m, and analysis was performed every 5 m in the possible fractured zones defined by well-log interpretation.

The brittle shear zones got localized along the studied well by statistical evaluation (discriminant function analysis) of the available direct-indirect well-logs (density, gamma ray, resistivity, spontaneous potential and calliper log), which are able to follow fractured state of the rock body.

Temperature data that are preserved in microstructurally different quartz grains was determined on the basis of the Ti content of quartz grains. The Ti content was measured by LA-ICP-MS. From the resulted Ti concentrations (ppm) temperatures were calculated with using the Ti-in-quartz (TitaniQ) thermometer of Thomas et al. (2010). The 'water' content (OH, H<sub>2</sub>O) of quartz grains was measured by micro-FTIR.

## **III. New scientific results**

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

- 1) The quartz grains of the drill cuttings from the Sztl-1 well can be classified into three groups microstructurally (grains with undulose extinction (U), grains with subgrains (S), and grains with recrystallized grains (R)). These different quartz grain types presumably formed due to diverse dynamic recrystallization mechanisms; bulging (BLG) and subgrain rotation (SGR).

- 2) Raman spectroscopy enables discrimination of quartz grain types using certain spectral attributes of the Raman spectra. In the resulting *F1-F2* spectral space the U, S, R extreme grain types define closed clouds, while the microstructurally transitional grains are situated between them.
- 3) Along the studied interval of Szentlőrinc-1 well two gneiss types can be defined with different mineral compositions. Rocks of the upper 100–150 m (1600–1750 m) of the analysed well section beside quartz contain large amount of mica, mainly muscovite. In the lower part (1750–1820 m) the amount of mica decreases, while the amount of feldspars increase. Thus the studied well section can be divided into the upper micaceous and the lower feldspathic gneiss.
- 4) Along the analysed section of Sztl-1well two ductile (1610–1635 and 1750–1765 m) and two brittle (1580–1635 and 1750–1765 m) shear zones can be localised. Based on the proportion of the microstructurally different quartz grains (U, S, R) two ductile shear zones can be localised along the studied well section. The complex statistical analysis of the available direct-indirect well-logs, which follow fracturing (DEL, GR, R, SP, CAL) allow the localization of brittle shear zones.
- 5) Based on the Ti content of the analysed quartz grains the same two metamorphic events can be identified in both gneiss types. The temperature of the early regional metamorphic event was between 500–575 °C, while the following recrystallization went on between 400–475 °C. Thus the two different gneiss types presumably went through the same metamorphic and deformation history.
- 6) Quartz grains with different microstructures and deformation conditions formed at different temperatures. Previous studies (Hirth and Tullis, 1992; Passchier and Trouw, 2005, among others) suggest that bulging (BLG) dynamic recrystallization mechanism acts at ~400 °C, while the subgrain rotation (SGR II) is active at ~500 °C in quartz. This statement is confirmed by Ti in quartz thermometry proving that quartz grains with different deformation conditions display different temperatures (BLG ~400–475 °C, SGR II ~500–575 °C).

- 7) In the Sztl-1 well, along the ductile shear zones the ‘water’ content of the quartz grains decreases towards the central zone.
- 8) Along the Sztl-1 well the coincidence of the ductile and brittle shear zones can be explained through formation of softened zones. Due to the intensive ductile deformation in the central part of the shear zone the quartz grains got dehydrated relative to the nearby rocks. Therefore, the rocks inside the shear zone became more rigid than the surrounding rock bodies with higher water content and were ready to deform in a brittle way.
- 9) During the deformational history of the Mecsekalja Zone two single, successive deformation events can be divided: the ductile shear zones, because of the partial dehydration of quartz grains, reactivated in a brittle way.
- 10) The evolution scheme, based on the detailed analysis of quartz chips from the 2 km depth section of the Sztl-1 well, is conform with the previous surface models concerning to the metamorphic and deformation history of the Mecsekalja Zone. (Szederkényi 1977, 1983; Árkai and Nagy, 1994; Lelkes-Felvári et al. 2000; Király and Török, 2003; M. Tóth et al. 2005). Thus the previous evolution models of the Mecsekalja Zone can be extended toward SW at least until the Sztl-1 well.

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## V. List of publications

### V.1 Articles

- Skultéti, Á., M. Tóth, T., Kovács, I.J., Király, E., Sándorné, J.K. (2017) Metamorphic and deformation history of the Mecsekalja Zone around the Szentlőrinc-1 well using individual quartz fragments from drilling chips. *Central European Geology*, In press.
- Skultéti, Á., M. Tóth, T. (2016): Localisation of ductile and brittle shear zones along the Szentlőrinc-1 well in the Mecsekalja Zone using quartz microstructural and well-log data. *Acta Geodaetica et Geophysica*, 51/2, 295–314.
- Skultéti, Á., M. Tóth, T., Fintor, K., Schubert, F. (2014): Deformation history reconstruction using single quartz grain Raman microspectroscopy data. *Journal of Raman Spectroscopy*, 45/4, 314–321.

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- Skultéti, Á., M. Tóth, T., Kovács, I.J. (2016): A kőzet mechanikai tulajdonságainak és reológiai viselkedésének meghatározása furadéanyag kvarcsezemcséi alapján. In: Török Á., Görög P., Vásárhelyi B (eds.) *Mérnökgeológia-Kőzetmechanika Kiskönyvtár*; 20., 277–288. (ISBN: 978-615-5086-11-3)
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- Skultéti, Á. (2014): Deformation history reconstruction using Raman microspectroscopy data of single quartz grains of Szentlőrinc-1 deep well. In: XLV. Ifjú Szakemberek Ankétja, 14-15.
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