Post-metamorphic palaeofluid evolution of the crystalline complex of the Mecsekalja Zone

A Mecsekalja Zóna kristályos komplexum posztmetamorf paleofluidum evolúciója

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Theses of Ph.D. dissertation

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2013, Szeged

Introduction

The dissertation discusses the post-metamorphic palaeofluid evolution of the crystalline metamorphic rocks of the Mecsekalja Zone, near Ófalu village, south Hungary. The rocks of the study area now observable at surface outcrops were metamorphosed ca. 300 Ma ago. During its uplift history a complex stress evolution must have worked upon the rock mass, the most momenta of which can hardly be recognized, and the most phases of which possibly did not leave an inquirable clue. Crystalline rocks can be considered impermeable, and it is the deformation of the rock that enhances the efficiency of fluid flow, both in micro and mezoscale. The stress activated microscale porosity is testified by fluid inclusion planes in granites and also by rock mechanical experiments, while veins of different configurations are the mesoscale products of deformation. The above considerations suggest that the uplift history of the Ófalu crystalline mass is also the period of a complex palaeofluid history, the momenta of which are determined by the obscure stress history of the Mecsekalja Zone.

The investigation of the palaeofluid evolution of a rock mass has several different purposes. From a practical viewpoint it is the investigation of the physicochemical circumstances and the composition of a fluid once flowed, or those of subsequent fluid generations, i.e. temperature and pressure, and dissolved species. Data of this kind can help understanding the actual status of fluid evolution at a potential site of water, petroleum or ore exploitation.

Another important practical application of palaeofluid investigations is when a prognosis is necessary to be given for the future behaviour of a fluid-rock system. This is the case if the investigated rock mass comes into question as a disposal of nuclear waste. In this case it is of crucial importance to see what kind of fluid flow events occurred in the geologic past and to understand the geologic nexus of these, i.e. what factors governed the fluid flows and which of these can possibly exist in the hazardous time period. The solution to this latter, i.e. the nexus of the singular fluid flow events requires a systematic approach and the models developed in the course of the evaluation of the relevant data converge towards a fluid flow model what we call the hydraulic behaviour model. This includes the flow paths activated during the flow events (macroscopic fractures, microfractures or the extant porosity), the operation of the flow paths (i.e. continuous or intermittent), the flow type (i.e. advective, fracture channelized or pervasive), the fluids role in the activation of the flow path, the stress field's role in the activation, etc.

The above section illustrates the complexity and multitude of information that enables the recognition of a model of this kind, and of course foreshadows the difficulties of gathering the necessary body of information. The dissertation is built up of published and submitted papers on the palaeofluid evolution of the Mecsekalja zone. The dissertation serve as a state of the art in the understanding of the palaeofluid evolution of a crystalline rock mass. The first two chapters discuss the sequence of fluid flow events, as can be

recognized petrographically, and try to reveal the physicochemical properties of the fluids based on supplementary microthermometric data. Stable isotope data are applied to unravel the fluid source and the time of the texturally distinguished flow events. The third and the fourth chapters concentrate on singular flow events. In these cases the available data made possible the construction of more detailed models of the fluid flow, i.e. these articles should be considered as attempts for the reconstruction of the hydraulic behaviour of individual flow events.

Samples and analytical methods

For the reconstruction palaeofluid evolution of the Ófalu Metamorphic Complex, macroscopic (75 samples), microscopic (77 thin sections) and cathodoluminescence microscopic observations, microthermometric (6 texturally distinguished mineral types were successfully applied for fluid inclusion microthermometry) and stable isotope (44 stable isotope data, including 4 hydrogen isotope compositions of inclusion fluids) measurements were carried out.

Microscopic observations allowed the definition of the sequence of vein mineral generations (cross-cutting relations), and in several cases led to several conclusions on the operation of the fluid-rock system, e.g. intermittence in case of crack-seal textures, fracture-channelized flow in case of syntaxial textures. The application of cathodoluminescence microscopy (carried out at the Institute for Geological and Geochemical Research, Research Centre for Astronomy and Earth Sciences, Hungarian Academy of Sciences,

with a Reliotron instrument) revealed pervasive fluid flow paths (metasomatic alteration of the pre-existing calcite phase) and latent brecciated subzones of the veins.

The fluid inclusion data (measured at the Department of Mineralogy, Geochemistry and Petrology, University of Szeged, on a Linkam THMSG 600 heating-freezing stage, mounted on an Olympus 41BX microscope) supplied estimates of the minimum precipitation temperatures of the vein minerals and subsequent fluid flow events. Based on the cryogenic data (final melting temperature measurements) it was possible to compare the fluid flow events defined at the Mecsekalja Zone with those defined in the region.

The stable isotope measurements were carried out on a ThermoFinnigan delta plus XP continuous-flow mass spectrometer using a GASBENCH II preparation device as an inlet port, at the Institute for Geological and Geochemical Research, Research Centre for Astronomy and Earth Sciences, Hungarian Academy of Sciences. The distribution of the data verified the texturally distinguished groups and with the application of the relevant fractionation equations (in case of phases where relevant microthermometric data was possible to be acquired) made possible to constrict the source of the parent fluid. In several cases the trend or the distribution of the data of a phase revealed the relevance of fluid mixing or local fluid-rock interactions.

New scientific results

1. **The main period of the vein formation in the Ófalu metamorphic rocks was between the Triassic and the Cretaceous.** This statement is constrained by the affiliation of the earliest carbonate phase ($Cal_{EB}1$) to marine carbonates based on its isotope composition, and the Anisian commence of marine carbonate deposition in the region. A body of evidence, including hydrogen isotope data and analogies in the Mórágy area suggest that the youngest veins found in the study area (Cal_{ANT}, relative age is defined by cross-cutting relations) are related to the Cretaceous dyke emplacement.
2. **The remnant voids that lasted after the filling and occlusion due to precipitation from and advectively flowing fluid subsisted for considerable time on the geologic scale.** This is implied by the infill of these voids with multiple mineral generations of very different temperatures and possibly origin. The remnant voids of the $Cal_{EB}1$ veins are filled with zoned dolomite, the minimum entrapment temperature of the fluid is 95 °C, blocky quartz that precipitated from low temperature fluid (<50 °C) and with a subsequent massive space filling calcite. Taking into consideration that these fluids formed in different geologic environments, it is plausible to assume that these remnant voids subsisted for a long geologic period of a sequential sealing history.

3. **Fluid percolation was an effective flow mechanism in the Ófalu metamorphic rocks, and possibly generally effective in crystalline rocks.** This is a further consequence of cementation in the remnant voids. Since these remnant porosities were subsisted due to the clogging of the original fractures, the parent fluids of the subsequent mineral phases could hardly be transported along the pre-existing vein system. The validity of this statement is becoming more relevant as the younger phases of the remnant voids are being considered. Percolation in case of the subsequent fluids is constrained by the cathodoluminescent images, i.e. metasomatism of the $Cal_{EB}1$ crystals along the percolation paths, and activation of cathodoluminescence due to substitution of activator elements.
4. **The pervasive microcrack systems of the metamorphic rocks were formed as a result of seismic damage around the Ófalu tectonic line during its active phase contemporaneous with a dyke emplacement period.** This statement is supported by the trend of the microcrack calcite isotopic composition, what can be interpreted either as a trend formed due to mixing of magmatic fluid and seawater or as CO_2 degassing after isotope exchange between the parent fluid and the pre-existing vein calcite. Both phenomena are inherent in seismic activity and documented in the literature. Vigorous seismic activity

during the volcanic activity in the Eastern Mecsek is constrained by sedimentary features.

5. **The microcrack system represents the basement of the hydraulic system that produced hydrothermal interpillow chimneys at the Pusztakisfalu section.** This is implied by the relation to the volcanic activity in both cases, and by the similar salinities of the parent fluids. The involvement of the Mecsekalja tectonic line in producing the observed microcrack systems and in the flow event is also constrained by its proximity, i.e. the above mentioned phenomena can be studied along its trail.
6. **The antitaxial veins most prevalent in the gneissic rocks of the Ófalu metamorphic belt are the product of a single flow event, and their formation was governed by seismic activity.** The antitaxial veins collected at different sites of the study area contain primary fluids of a very uniform salinity range; hydrogen isotope compositions of the entrapped fluids indicate their volcanic origin. The textural patterns indicate crack-seal behaviour and the fluctuation of the fluid pressure. The latter is constrained by the very wide range of densities of the entrapped parent fluid. The recurrent fluid pressure enhancement events and local failures can be satisfactorily explained by repeated seismic cycles, and related stress recovery and stress release cycles.

7. **The pervasive flow of the antitaxial calcite parent fluid occurred along the stress induced elastic microcrack system, the efficiency of the flushing the host rock was enhanced by the microcracks.** The efficient flushing is constrained by the widespread occurrence of the antitaxial veins in the study area, and by the uniform salinities of their primary inclusions. The opening of elastic microcracks due to the enhancement of stress intensity is well studied discipline of rock mechanics. Furthermore many pre-earthquake phenomena are derived from the opening of microcracks in regions around active faults, as discussed in the literature.
8. **The efficiency of fluid pervasion enhanced by stress in a crystalline rock is determined by the mechanical properties of the medium.** The fluid generations identified in distinguishable carbonate and fluid inclusion generations (Cal_{MC}, Cal_{ANT} parent fluids, secondary fluids entrapped in the Cal_{SF} calcite) are mixed up in the fluid inclusion planes of the Mórágy Granite. Thus fluid pervasion was less efficient in the precursor microcrack system of the fluid inclusion planes in the granite compared to the stress induced microcracks of the metamorphic rocks, according to the seismically driven fluid flow model.
9. **Syntaxial veins represent a basically different degree of fluid-rock interaction and less rock buffered fluid compositions compared to antitaxial veins.** This is

indicated by the different range of stable isotope compositions in case of the syntaxial veins cross cut the studied amphibolite body compared to those of the antitaxial veins of the gneissic rocks. The difference possibly reflects different degrees of fluid-rock interactions during fracture channelized flow and flow along the stress induced microcrack systems.

10. **The antitaxial veins represent local fluid-rock systems and separated fracture porosity subsystems**. This statement is implied by the stable isotope composition data of the antitaxial veins, and by the distribution of the data, i.e. clustering with respect to sampling site.

Relevant publications

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Dabi, G., Bajnóczi, B., Schubert, F., M. Tóth, T., 2012. Szivárgó oldatáramlási események a Mecsekalja-zóna kőzeteiben. (Percolative fluid flow events in the crystalline rocks of the Mecsekalja Zone – In Hungarian). III. Kőzettani és Geokémiai Vándorgyűlés, Telkibánya, pp. 10. In Hungarian.