# Alteration of primary minerals from geothermal reservoirs in the Upper Rhine graben

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## Introduction

Deep seated fault systems play an important role in the utilization of deep geothermal energy, especially in non-volcanic enhanced geothermal systems with low natural permeability. In such settings the fluid migration and heat convection takes place through the connected fracture network that is often saturated with saline geothermal fluids, interacting with the primary and secondary mineral content of the host rock (dissolution, precipitation, recrystallization). Intense pervasive alteration can for example be observed in granitic core samples from Soultz-sous-Forêts (e.g. Schleicher et al. 2006). Natural analogues from deep geothermal wells and mining sites in the Black Forest are therefore included in the study. The aim of this research is to comprehend the mineralogical alterations that occur, when the primary mineral assemblage is subjected to a synthetic geothermal fluid at temperatures above 200 °C. Important questions are: (1) what are the relevant reaction steps, (2) how fast do the reactions take place, and (3) can the observed reactions properly be described on the basis of an alteration model? Here, preliminary results from the experimental campaign are presented.

## Experimental design

Batch-type experiments with 2 molar Na-Cl solutions (equivalent ionic strength to natural geothermal fluids) and cylindrical hard rock samples (Ø = 3 cm) have been performed. In order to mimic geothermal conditions the experiments were conducted at 200 and 260 °C. This appears to be a plausible estimation for the temperature at the sediment/basement boundary in the deepest part of the Upper Rhine graben (Sanjuan et al. 2010; Aquilina et al. 1997). Thermodynamically speaking, the experiments are carried out a far-from-equilibrium conditions, the fluid being undersaturated with respect to the primary minerals. Samples were taken from four different lithologies representing potential reservoirs for future geothermal exploration. The petrological characteristics are summarized in Tab. 1.

Tab. 1: Characteristics of the rock samples as geothermal reservoir representatives.

| | Malsburg granite | Tennenbach sandstone | Pfinztal sandstone | Keltern limestone |
|---|---|---|---|---|
| Stratigraphy | Crystalline basement | Lower Buntsandstein | Upper Buntsandstein | Upper Muschelkalk |
| Grain size | 1 – 2 mm | 1 – 2 mm | < 0.2 mm | 0.5 mm and < 0.3 mm |
| Texture | equigranular | equigranular, well rounded grains, silica cement | finely cross-bedded, silica cement | coarse and fine grained parts, partly shell-bearing |
| Mineral phases | Qtz, Ab, Or, Bt | Qtz, Or | Qtz, Or, Ms | Cal, Dol |
| Accessories | Ap, Zrn, Py | Hem | Hem | |

Both, the solid samples as well as the fluid samples will be studied in order to draw a more general picture of the reaction process. The rock sample will be analyzed for dissolution processes, ion exchange reactions of primary minerals and precipitation of secondary minerals. For this purpose, SEM/EDX, optical microscopy, electron microprobe, XRF and XRD have been applied. The fluid composition was determined by ICP-MS, ICP-OES and IC.

**Preliminary results**

After extraction of the granite samples from the experiment, the surface mineral grain are disintegrated from the matrix. Surprisingly, the main dissolution features that can be observed in SEM images are wormholes in quartz grains (Fig. 1). The feldspars, however, do not show substantial dissolution, but are often covered with newly formed clay precipitates. As can be seen in Fig. 2, near-surface biotite grains are totally altered to greenish chlorite.

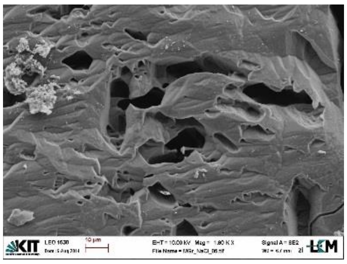

Fig. 1: Wormhole dissolution of quartz grains in the Malsburg granite.

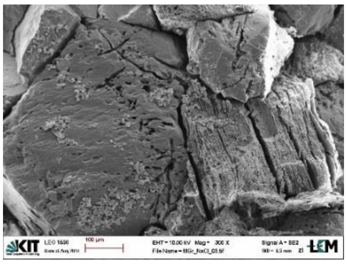

Fig. 2: Alteration of near-surface biotite to chlorite.

The two sandstone samples show a different reaction behavior. Quartz dissolution is less pronounced than in the granite samples. While the feldspar remains (mostly) unaffected, muscovite grains show substantial alteration. The most prominent precipitate that can be found in the SEM images is analcime that occurs in spherical shape in the close vicinity to feldspar grains (Fig. 3). It is usually associated with few-µm small hexagonal kaolinite. The formation of analcime is more pronounced in the Pfinztal sandstone.

Fig. 3: Newly formed spherical analcime with small kaolinite grains on Pfinztal sandstone.

The limestone samples are characterized by dissolution and recrystallization processes of calcite on the surface of the hard rock sample (Fig. 4). Shell fragments largely resist the dissolution process during the experiments, whereas the micritic matrix was dissolved and form depressions in the sample surface.

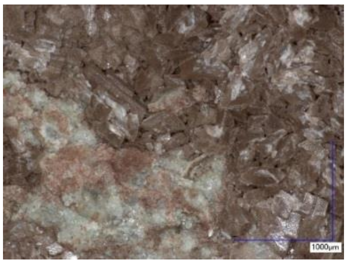

Fig. 4: Recrystallization of calcite on the surface of Keltern limestone.

**Outlook**

The batch-type experiments show different lithology-dependent alteration processes. Several mineral-mineral and mineral-fluid reactions could be described for the different lithologies. Future studies will aim at establishing a more process-based understanding of the alteration reactions. This includes a more detailed focus on the reactivity of single mineral phases and their contribution to the bulk reactivity.

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## Literature

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