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Anhydrite-dissolution porosity in the Upper Muschelkalk carbonate aquifer, NE-Switzerland: implications for geothermal energy and geological storage of gas

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Abstract

The Upper Muschelkalk carbonate aquifer within the Swiss Molasse Basin is currently being investigated for its potential for geothermal energy exploitation and geological storage of gas. Porosities of up to 25% are locally observed where early diagenetic (Triassic) anhydrite has been dissolved by groundwater. However, the dimensions and the spatial distribution of this type of cavernous porosity are not well known, as the Basin is underexplored. The present study reconstructs the genesis and evolution of these pores from drill-core studies, thus providing conceptual understanding to support ongoing exploration in the deeper, hotter southern regions of the Basin. The reconstruction is based on petrographic investigations, analyses of stable and radiogenic isotopes and fluid inclusion studies. The results show that the anhydrite dissolved during the Neogene upon influx of chemically modified meteoric runoff from uplifted crystalline domes in the Black Forest area of southern Germany. As this hydrogeological system is spatially restricted to the shallow, northern margin of the aquifer, we conclude that zones of anhydrite-dissolution porosity are unlikely to extend deeper into the Basin. Exploration in the deeper realms of the Basin should therefore target other types of porosity and permeability, e.g. sucrosic dolomite facies and fracture networks.

Keywords: Upper Muschelkalk; anhydrite dissolution; Black Forest

1. Introduction

In the Swiss Molasse Basin (SMB), deep saline aquifers are one of the options under investigation for geothermal energy production and for storage of gas (seasonal methane and CO2 sequestration). Particularly the Middle Triassic dolomites within the Upper Muschelkalk (Trigonodus Dolomit) show encouraging properties along the northern...
margin of the SMB. Matrix porosity in the northern margin is locally high (<25%), in part due to the presence of vuggy beds that contain cm–dm scale cavities formed by dissolution of eogenetic anhydrite nodules. These pores are in some cases well connected, as reflected by permeabilities up to $10^{-13}$ m$^2$. A key question is whether dissolution-porosity can also be expected in the deeper, largely unexplored southern realm of the SMB, which is of more interest for geothermal and gas-storage applications. The present study reconstructs the genesis and evolution of the dissolution pores, thus providing conceptual understanding to support ongoing exploration. One hypothesis is that the dissolution is due to recent influx of meteoric water from the Black Forest Highlands situated north of the SMB (Fig. 1a). This hydrogeologic system developed in response to Neogene doming of the Black Forest area, which resulted in erosion of the Mesozoic sedimentary cover down to the crystalline basement and induced lateral infiltration of meteoric water towards the southeast (Fig. 1b). Exfiltration occurs both towards the west (Rhein River system) and towards the northeast (Neckar River system). According to this hypothesis, dissolution porosity would be expected only along the northeastern margin of the SMB. A contrasting hypothesis is that the porosity is due to eogenic processes related to the Mid-Triassic depositional environment or its subsequent burial during the Mesozoic. In such a case, the high porosities could perhaps be expected throughout the SMB.

The reconstruction of the genesis and evolution of the anhydrite dissolution cavities is based on drill-core samples from two boreholes situated at Benken (top Muschelkalk at 811 m depth) and at Schlattingen (top Muschelkalk at 1112 m depth), and it includes standard petrographic investigations, analyses of stable and radiogenic isotopes (i.e. $\delta$D, $\delta^{18}$O, and $^{87}$Sr/$^{86}$Sr) of rock-forming (dolomite) and pore-filling (quartz, calcite and kaolinite) minerals and fluid inclusion studies of pore-filling quartz and calcite.

![Fig. 1. (a) The recent hydrogeological system at Benken and Schlattingen (modified after Nagra), which developed in response to (b) Oligocene–Neogene doming of the Black Forest area. Inset in (a) shows location of Swiss Molasse Basin (SMB). The Upper Muschelkalk sits within the Mesozoic sediments marked blue in (b).](image)

2. Results

2.1. Petrography

In some intervals of the Muschelkalk aquifer at Benken and Schlattingen the anhydrite dissolution cavities remain empty, but in others the pores have been affected by two events of mineral precipitation: (1) the first involved precipitation of quartz and minor pyrite and sphalerite, leading to only minimal clogging. The quartz crystals contain tiny inclusions of relict anhydrite, indicating that the quartz precipitated during anhydrite
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