SCCER SoE
SWISS COMPETENCE CENTER for ENERGY RESEARCH
SUPPLY of ELECTRICITY

70 NRP Energy Turnaround
National Research Programme

SCCER-SoE Annual Conference 2017

In cooperation with the CTI
Energy
Swiss Competence Centers for Energy Research
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Commission for Technology and Innovation CTI

Anhydrite-dissolution porosity in the Upper Muschelkalk aquifer, NE-Swiss Molasse Basin: implications for geo-energy and gas storage

L. Aschwanden, A. Adams, L.W. Diamond, M. Mazurek

Rock-Water Interaction Group, Institute of Geological Sciences, University of Bern, Baltzerstrasse 1+3, CH-3012 Bern, Switzerland

Introduction

In the Swiss Molasse Basin (SMB; Fig. 1), deep saline aquifers are one of the options under investigation for geothermal energy production and for geological storage of gas. Particularly the Middle Triassic dolomites within the Upper Muschelkalk (Trigonodus Dolomit) show encouraging aquifer properties along the northern margin of the SMB.

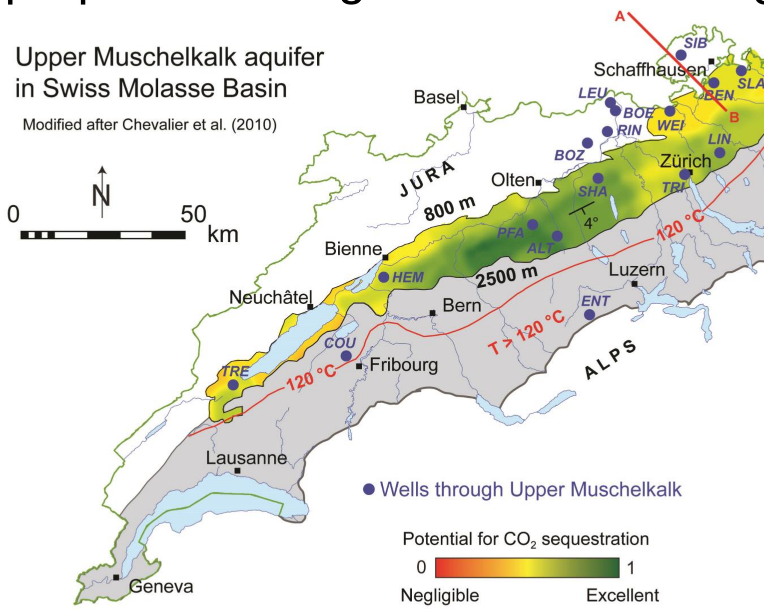


Fig. 1: *CO_2 storage potential of the Upper Muschelkalk aquifer in the Swiss Molasse Basin within the technically favoured depth range for CO_2 storage (800-2500 m). The 120 °C isotherm (red line) marks the minimal temperature required to produce geothermal electricity.*

Matrix porosity and permeability are locally high (<25% and <100 mD, respectively), in part due to beds rich in cm-dm scale cavities left by the dissolution of eogenetic anhydrite nodules (Fig. 2). However, the spatial distribution of anhydrite-dissolution pores is not well known as the basin is underexplored. The present study reconstructs the genesis and evolution of these pores, thus providing conceptual understanding to support ongoing exploration.

Fig. 2: *Drill-core section of the Trigonodus Dolomit at the BEN borehole. The cm-dm scale cavities originate from the dissolution of eogenetic anhydrite nodules.*

Methods

The reconstruction of the genesis and evolution of the anhydrite-dissolution cavities is based on drill-core samples from various boreholes across the Swiss Molasse Basin and it includes:

- Standard petrographic investigations
- Analyses of stable and radiogenic isotopes (i.e. δ^2H, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$) of rock-forming (dolomite) and pore-filling (quartz, calcite and kaolinite) minerals
- Fluid inclusion studies of pore-filling quartz and calcite

Petrography

Some of the anhydrite-dissolution cavities have been affected by two events of mineral precipitation: (1) precipitation of quartz during anhydrite dissolution; (2) a second, younger event in which calcite and kaolinite co-precipitated.

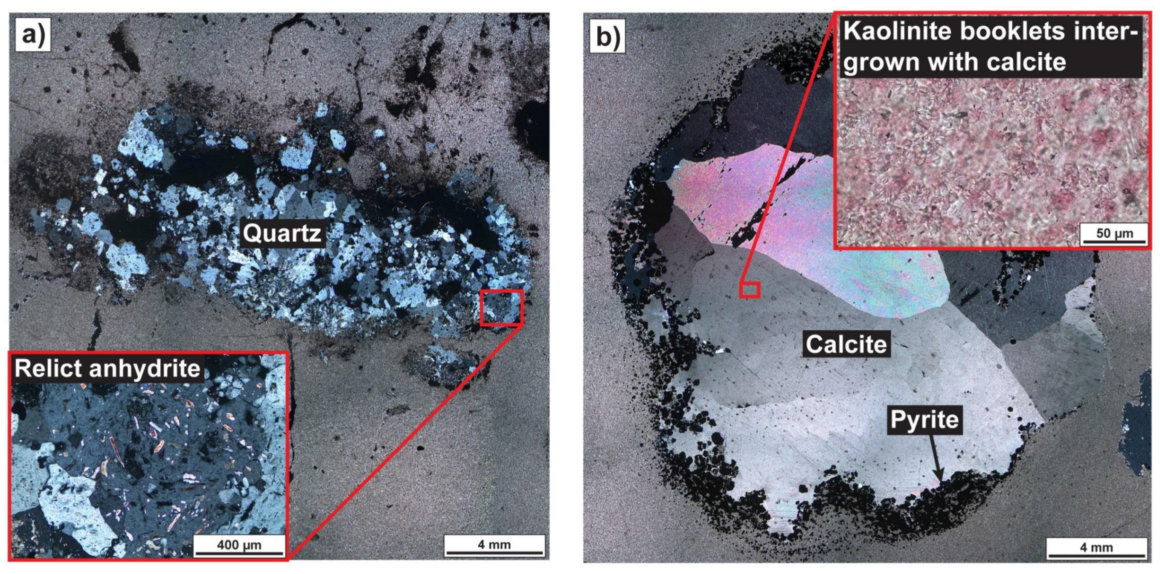


Fig. 3: *Thin-section microphotographs of a) pore-filling quartz with solid inclusions of relict anhydrite and b) of paragenetically younger pore-filling calcite intergrown with kaolinite.*

Fluid inclusion studies

Primary saline water and methane inclusions were trapped simultaneously in both quartz and younger calcite. Homogenisation temperatures are therefore equivalent to trapping temperatures (Fig. 4a).

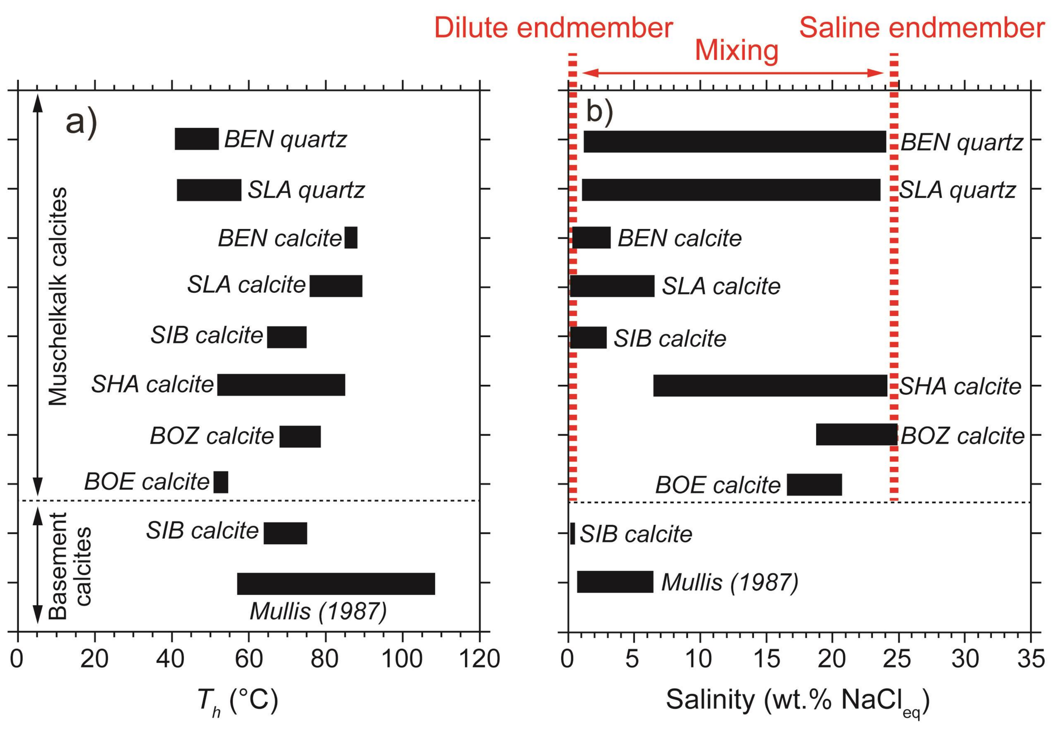


Fig. 4: *Microthermometric results of primary fluid inclusions in pore-filling minerals. Salinity is based on ice-melting temperatures.*

Isotope analyses

Pore- and fracture-filling calcite in the Upper Muschelkalk yield high $^{87}Sr/^{86}Sr$ ratios relative to the dolomite matrix. These high values overlap with the $^{87}Sr/^{86}Sr$ signatures of basement water and calcite fracture-fillings.

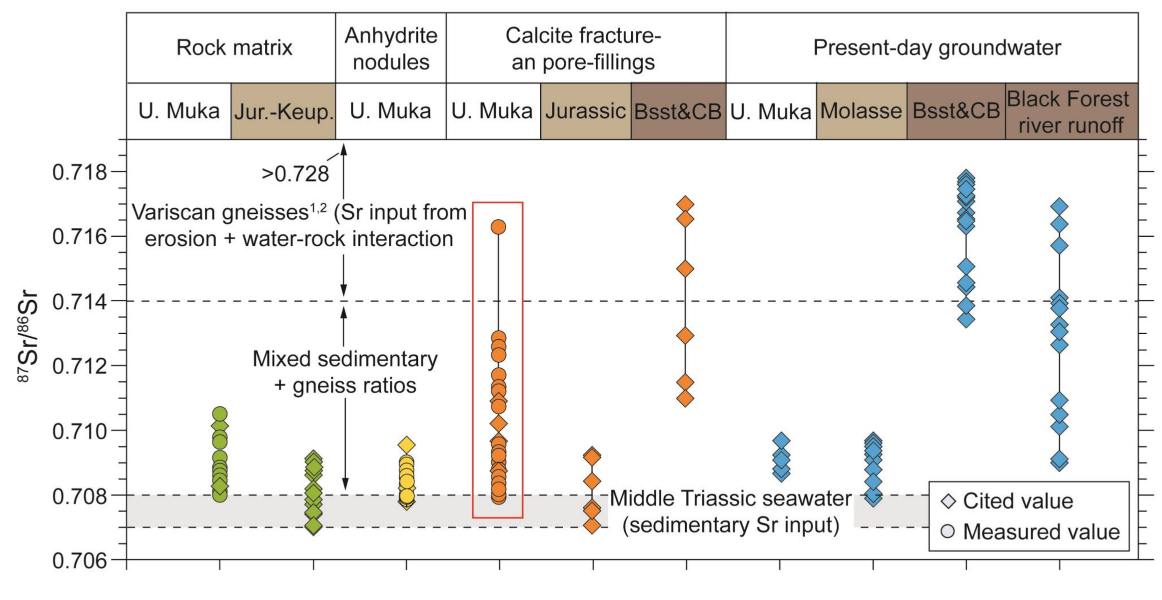
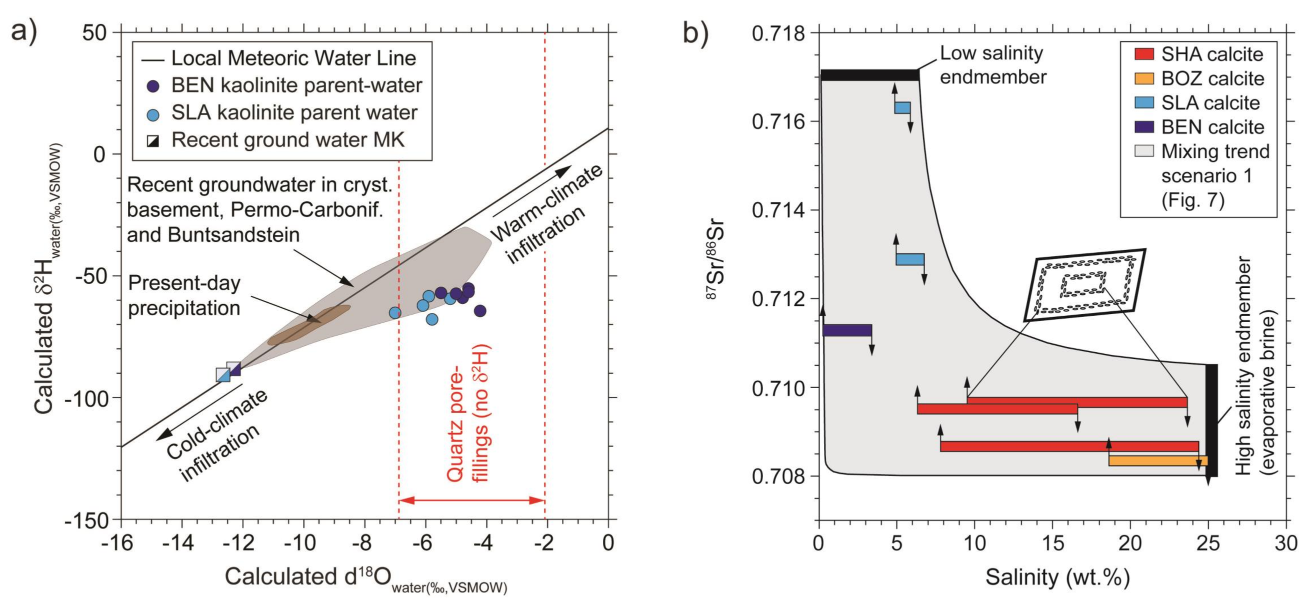


Fig. 5: *Strontium isotope ratios for rock matrix, anhydrite nodules, secondary pore- and fracture fillings and the recent groundwater in the Muschelkalk and in its overlying (beige) and underlying (brown) units (Bsst: Buntsandstein; CB: Variscan gneiss basement; Pearson et al., 1991; Nagra, 2001; McArthur et al., 2001; Durand et al., 2005).*

Isotope analyses

Stable and radiogenic isotopes show that the original hypersaline porewater of the Muschelkalk was diluted by infiltration of meteoric water containing radiogenic Sr. This water overlaps with the $\delta^{18}O$-δ^2H of basement waters.



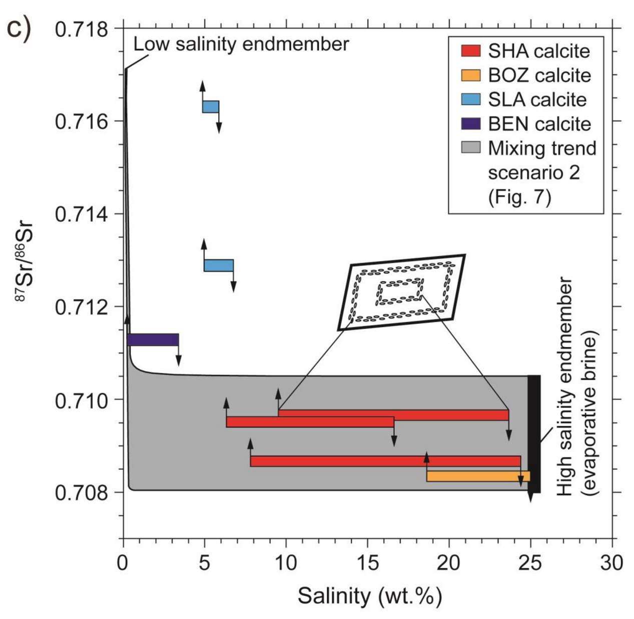


Fig. 6: *a) Isotope signatures of the parent-water of quartz and kaolinite pore-fillings calculated on the basis of fluid inclusion trapping temperatures. The clear petrographic evidence that calcite and kaolinite partly co-precipitated is taken as evidence that the temperatures of mineral formation derived from the primary fluid inclusions in calcite are also valid for kaolinite. b,c) Fluid inclusion salinities in calcite pore- and fracture-fillings as a function of the mineral's $^{87}Sr/^{86}Sr$ ratio. The grey areas represent calculated mixing trends for the two infiltration scenarios outlined in the next section.*

Discussion

- Fluid inclusion and isotope evidence shows that anhydrite was dissolved by influx of meteoric water with high $^{87}Sr/^{86}Sr$ ratios.
- The only feasible sources of radiogenic Sr in the local stratigraphy are the underlying Buntsandstein and Variscan gneiss basement (Fig. 7).

→ Two scenarios are conceivable for the path of infiltration (Fig. 7)

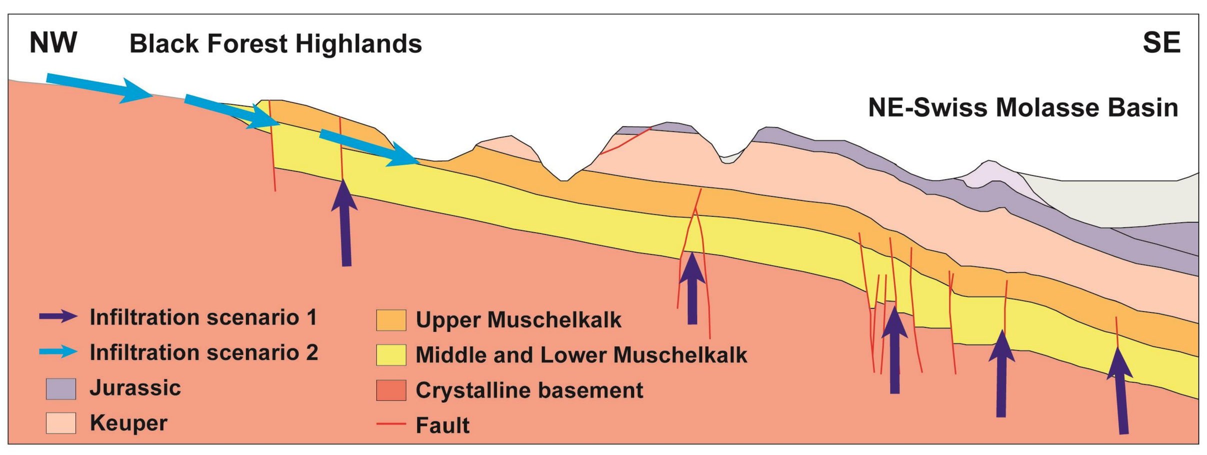


Fig. 7: *Water modified by the interaction with crystalline basement rocks could have infiltrated the Upper Muschelkalk according to two different scenarios: (1) fluid ascent along cross-formational faults or (2) lateral recharge of meteoric runoff from the Black Forest Highlands, where the basement rocks are exhumed (see Fig. 1 to locate the profile; modified after Müller et al., 2002).*

→ Calculated mixing trends for calcite parent-waters show that mixing of a hypersaline, strontium-rich brine with low-salinity, strontium-poor meteoric runoff from the Black Forest Highlands cannot explain the intermediate salinity of primary fluid inclusions in the radiogenic secondary calcites at the BEN and SLA wells. In contrast, mixing with strontium-enriched basement water explains the observations.

Conclusions

Anhydrite-dissolution porosity in the Muschelkalk was caused by the incursion of groundwater from the underlying crystalline basement and/or the Buntsandstein, which ascended along cross-formational faults. Accordingly, anhydrite-dissolution porosity is spatially restricted to the vicinity of deep-seated tectonic structures, which hydraulically connect the crystalline basement and the Muschelkalk. This finding should aid in focussing geothermal and gas-storage exploration in the Swiss Molasse Basin.