$^{87}Sr/^{86}Sr$ and $\delta^{11}B$ analyses highlight the transformational origin of geothermal fluids in the South German Molasse Basin

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Hydroisotop

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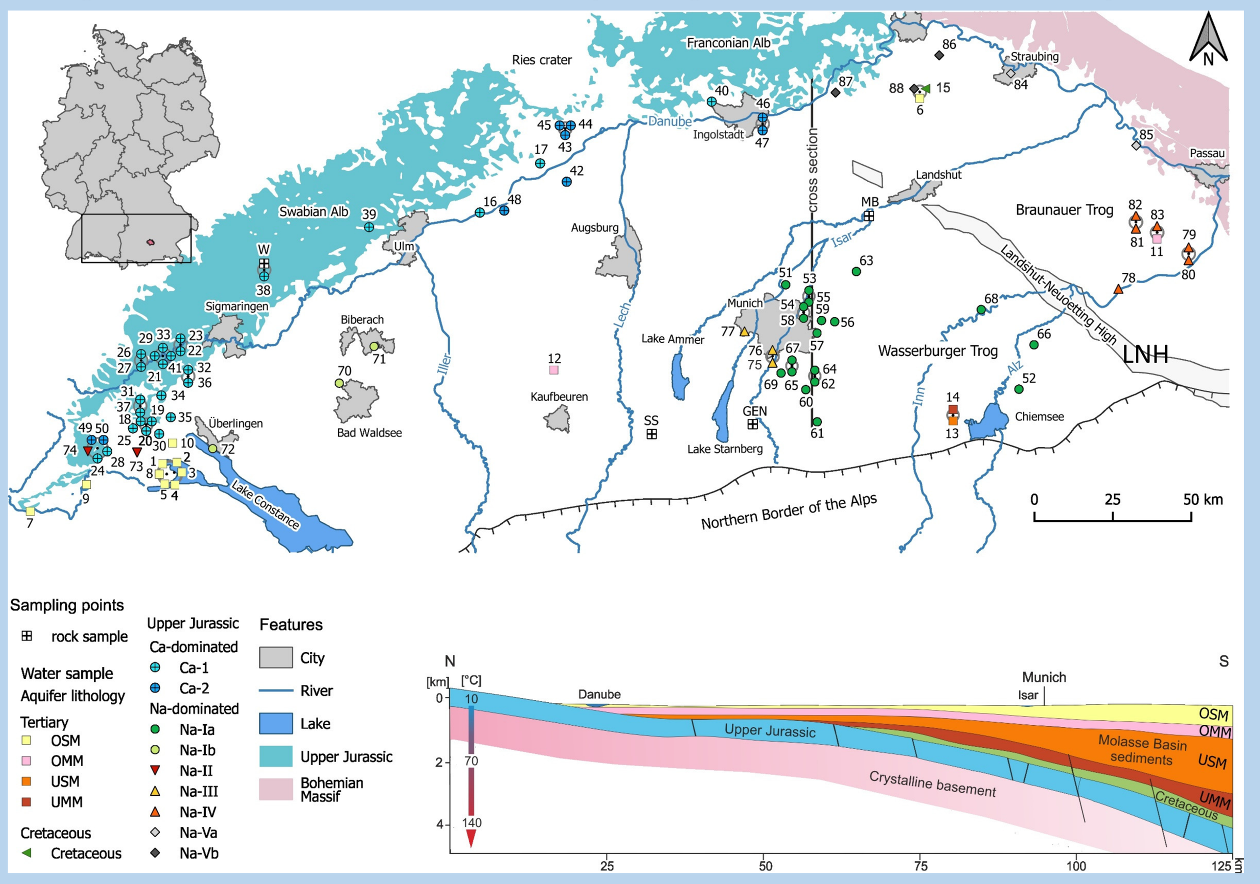
Introduction

The Upper Jurassic aquifer in the South German Molasse Basin (SGMB) represents an intensively used reservoir for many purposes such as drinking water production in shallow parts of the basin as well as balneological and geothermal applications (up to 160 °C) in greater depths.

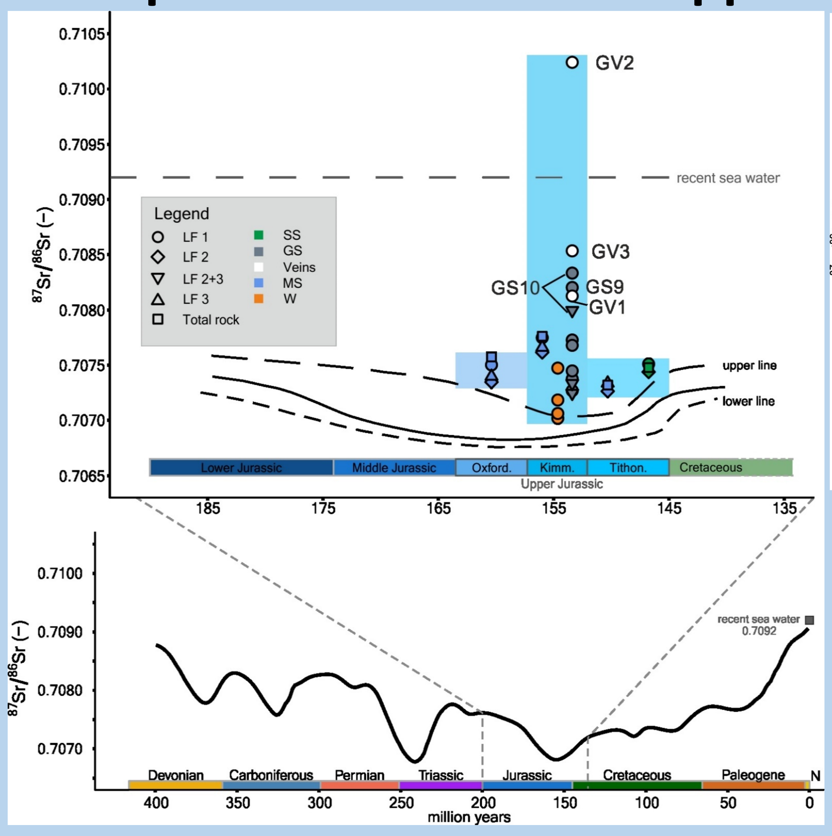
The hydrochemical composition of the Upper Jurassic groundwaters in the South German Molasse Basin (SGMB) indicate a heterogeneous hydrogeochemical evolution, which contradicts previous flow model concepts. For this study, the data of 88 groundwater samples from different campaigns across the Tertiary, Cretaceous and Upper Jurassic lithology were investigated for hydrochemical solvents, $^{2}H/^{18}O$-H_2O isotopes, $^{87}Sr/^{86}Sr$ ratios as well as $\delta^{11}B$ values. In addition, the geochemical composition, $^{87}Sr/^{86}Sr$ and $\delta^{11}B$ values were analysed from depth-oriented Upper Jurassic rock samples (drill cores) to delineate water-rock interaction in the aquifer system.

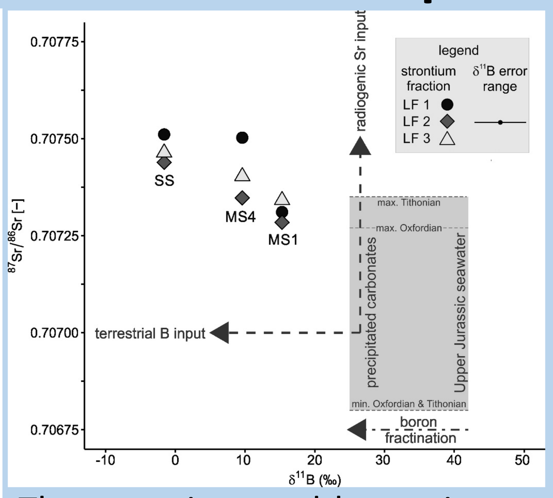
Regional situation, sampling locations and hydrochemical classification



The SGMB basin filling consists of Tertiary, Cretaceous and Jurassic sediments. The fill contains shallow marine and continental-fluviatile sediment sequences derived from erosional processes of the uprising Alps and crystalline rocks of the Bohemian Massif in the vicinity of the SGMB. Contrary to recent hydraulic potentials (W to E and Danube oriented), the water chemistry and isotope data show distinct provinces in the western, central, eastern, and northern part of the SGMB.

Isotope characteristics of Upper Jurassic rock samples

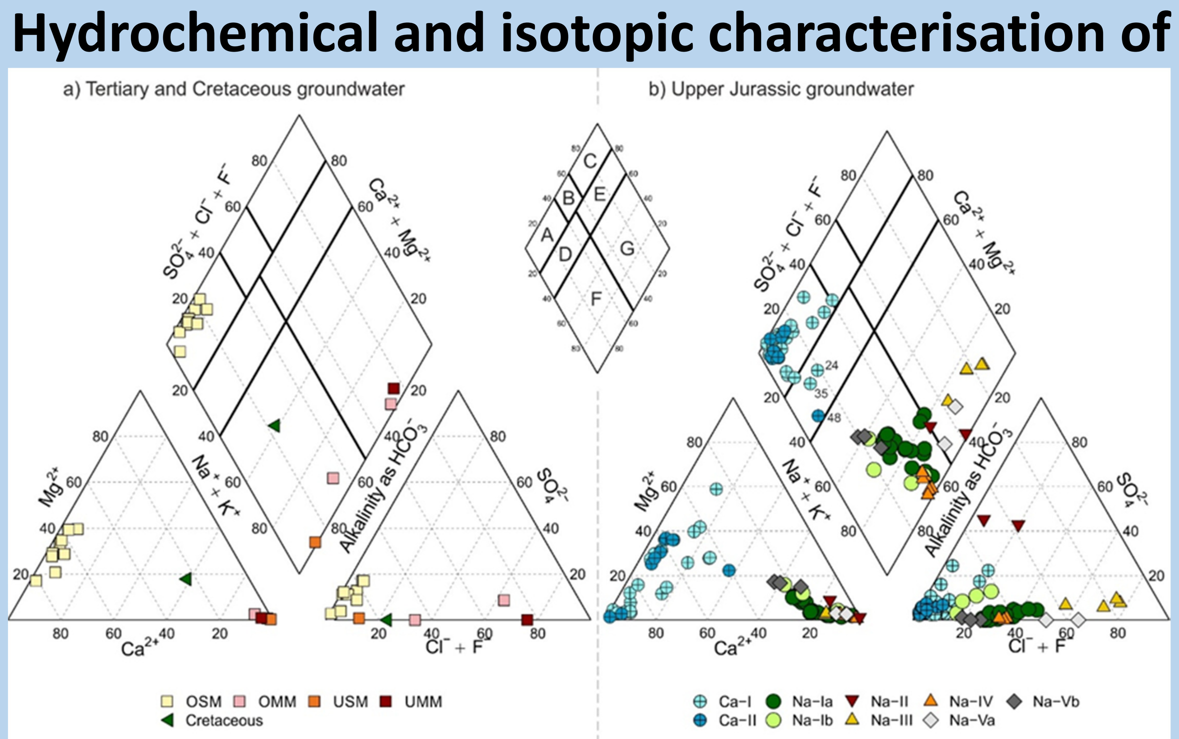


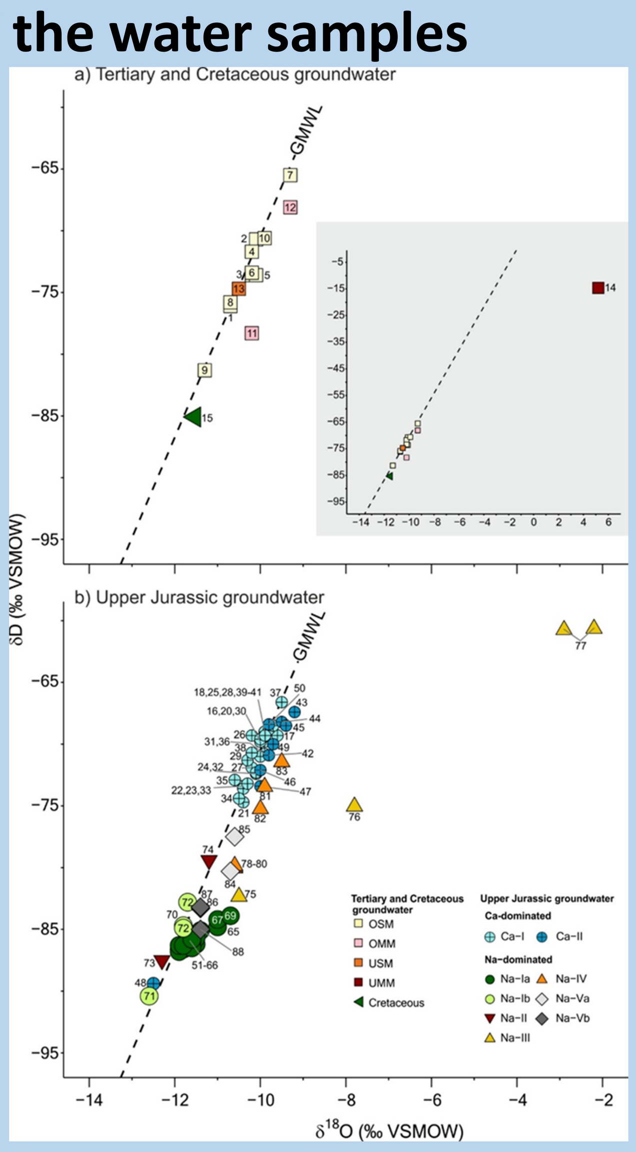


Rock samples from the central SGMB were measured as bulk and in stepwise leaching fractions (0.1 M; 0.5 M; 2.0 M HCl) to indicate water-rock interaction with calcite, dolomite or silicate residuals.

The strontium and boron isotope signatures of the drill core samples show a similar deviation from the marine Upper Jurassic carbonate characteristics due to a slight homogenous radiogenic or terrestrial input. This indicates a significant pre- or syn-depositional influence on the Upper Jurassic carbonates in the SGMB from the crystalline rocks (e.g. Bohemian Massif and LNH to the east of the Upper Jurassic offshore zone).

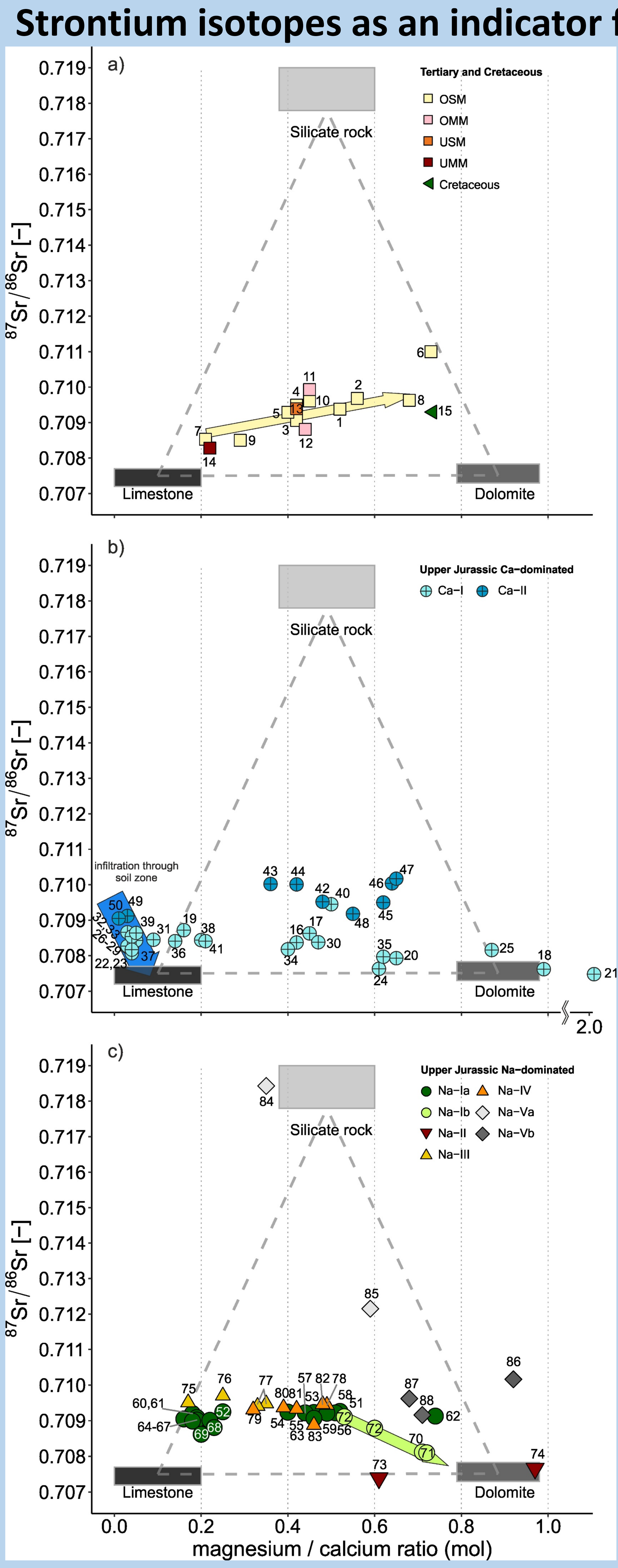
Hydrochemical and isotopic characterisation of the water samples

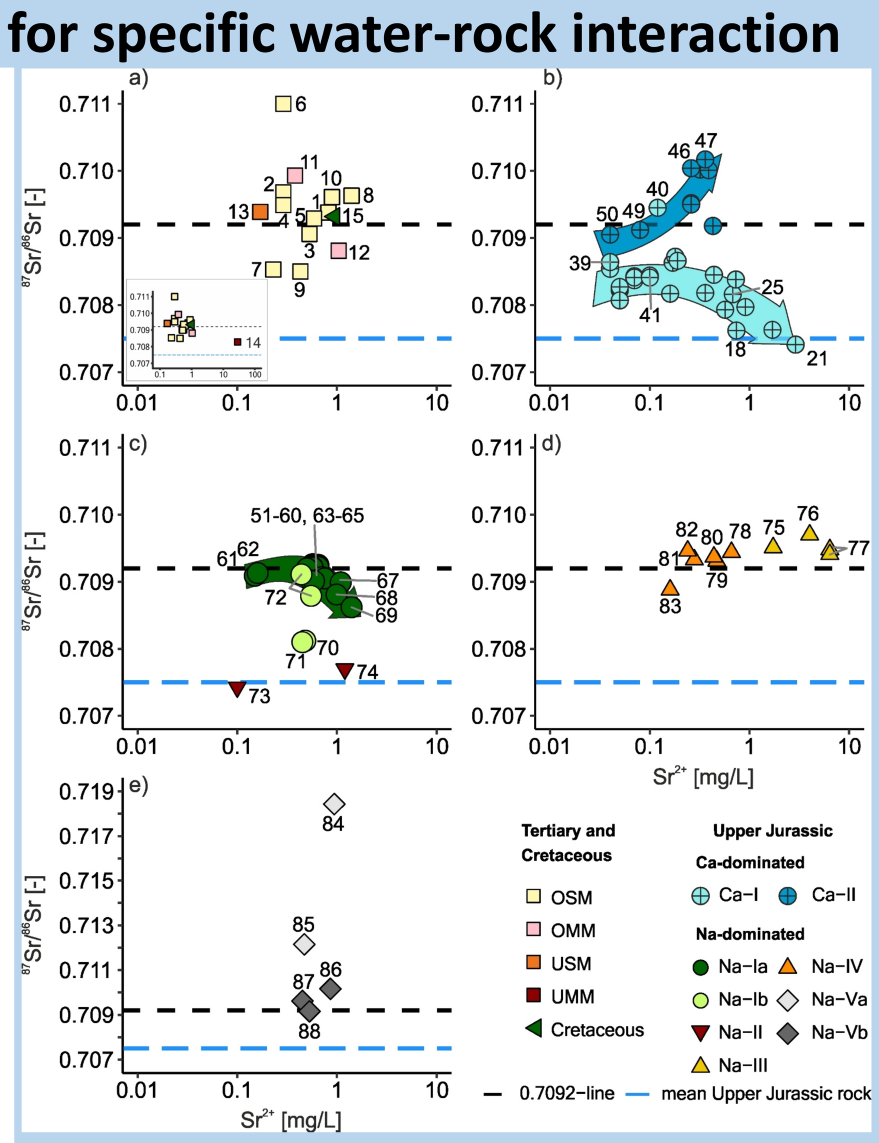




The hydrochemical and isotopic composition of the groundwater samples are very heterogeneous due to the geographic distribution of the samples and the varying depths of the reservoir. The occurring groundwater types (Ca-(Mg)-HCO_3 to Na-Cl) can be grouped by the dominant cation into calcium (Ca), including magnesium, and sodium (Na) dominated waters. The sub-classification (Ca-I to Ca-II) and (Na-Ia to Na-Vb) is based on the geographic location of the samples and their strontium isotope signature.

Strontium isotopes as an indicator for specific water-rock interaction





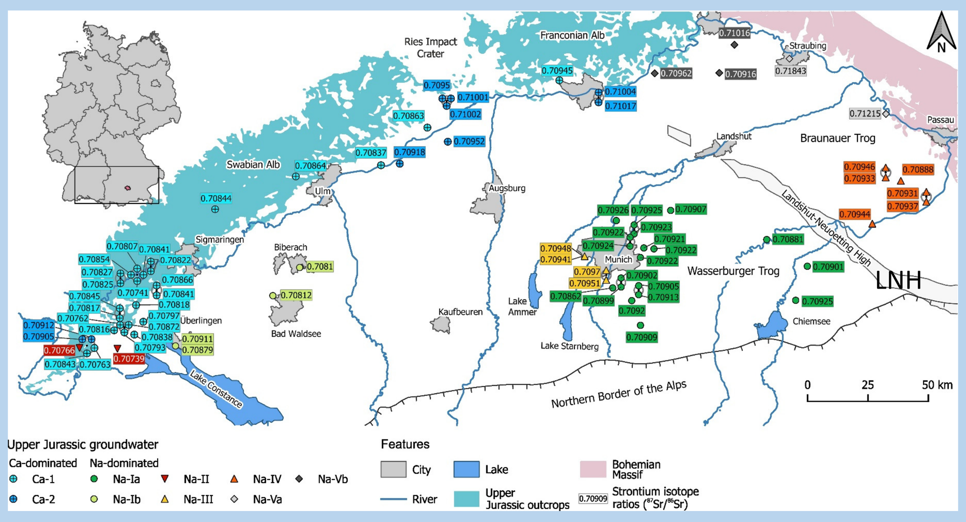
Plots of strontium isotope ratios vs. strontium content and vs. molar magnesium/calcium ratio. a) shows the signatures of groundwater from non-Upper Jurassic aquifers and b) to e) show the signatures of different groundwater types from the Upper Jurassic reservoir.

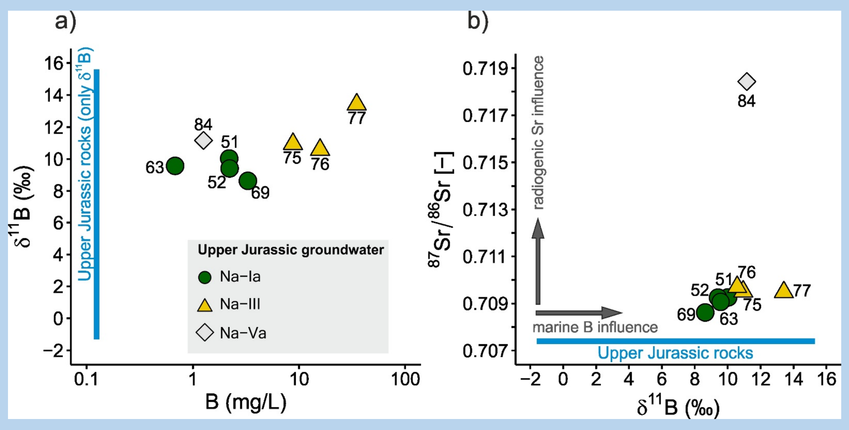
Throughout the SGMB, infiltrating meteoric water, primarily controlled by the acid-carbonate-equilibrium, dissolves strontium in the soil zone and bedrock with a relatively homogeneous initial isotopic signature.

Further dissolution and water-rock interaction along the flow path cause specific changes in the alkaline earth element (Ca^{2+}, Mg^{2+}, Sr^{2+}) composition. These effects can increase the basal strontium content and successively overprint the initial $^{87}Sr/^{86}Sr$ ratios.

As the $^{87}Sr/^{86}Sr$ ratio is not affected by isotope fractionation, the analysed $^{87}Sr/^{86}Sr$ ratio can be used as a characteristic tracer of different strontium-bearing rock sources.

$^{87}Sr/^{86}Sr$ ratios and $\delta^{11}B$ values of Upper Jurassic groundwaters





Results and Conclusions

The results of $^{87}Sr/^{86}Sr$ and $\delta^{11}B$ analyses of the Upper Jurassic carbonates show deviations to the expected values due to some input of eroded terrestrial material from the crystalline Bohemian Massif during sedimentation.

The hydrogeochemical composition, $^{87}Sr/^{86}Sr$ and $\delta^{11}B$ signature of the groundwaters in the Upper Jurassic carbonates shows a broad variety due to different water-rock interaction processes. The resulting in "provinces" in the western, northern, central and eastern SGMB highlighting their specific evolution.

In the central and western SGMB the low mineralised, ion-exchange geothermal fluids (Na-Ia + Na-Ib) were recharged during cold climatic conditions. They differ considerably in hydrochemical and isotope composition from groundwaters in the northern, and eastern parts of the aquifer as well as from $^{87}Sr/^{86}Sr$ and $\delta^{11}B$ signature of the investigated Upper Jurassic carbonates. These groundwaters still represent the hydrogeochemical maturation and the isotopic fingerprint of the overlying Tertiary Molasse formation with a more pronounced radiogenic or terrestrial input from the Bohemian Massif in the vicinity of the SGMB. The comprehensive strontium isotope survey, complemented with boron isotope data therefore provides evidence for a transformational recharge of groundwater into the deeply buried Upper Jurassic aquifer most likely initiated by the widespread latest glaciations in the southern area.

The surrounding groundwaters (Na-II to Na-V) have distinct hydrochemical and isotopic fingerprints due to specific regional hydrogeological conditions. Similar transformational fluxes from the overlying Tertiary molasse formation are also observed here, but the lack of glacial influence in these areas resulted in slower recharge processes into the Upper Jurassic carbonates.

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References:
For detailed information on the investigation program, results and list of references see

Schneider, J.; Heine, F.; Heidinger, M.; Rosner, M. Transformational Geothermal Fluids in the Upper Jurassic Carbonate Reservoir of the South German Molasse Basin. Preprints.org 2022, 2022100090. https://doi.org/10.20944/preprints202210.0090.v1