Is the basement-sediment transition zone in the Rhine graben a good geothermal reservoir? An analogue approach in the CANTARE-Alsace project

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ABSTRACT

The development of geothermal exploitation in the Upper Rhine Graben for heat and power generation requires detailed knowledge of the subsurface in order to mitigate associated geological risk and streamline exploitation techniques. In addition to temperature, two other conditions are required for geothermal energy exploitation from depth: the presence of a geothermal fluid that acts as a heat vector and a reservoir permeability sufficiently high to produce and re-inject this fluid..

The objective of the CANTARE-Alsace project, funded by the ANR (grant agreement ANR-15-CE06-0014) and steered by three academic partners (BRGM, LyGHeS and EOST) and one local industrial partner (ES-G), is a better characterization of the basement-sediment transition zone in the Rhine Graben. This zone is located at a depth range where the temperature reaches values between 120 and 200 °C, which are economically exploitable for industrial heat or electricity. Furthermore, several recent projects have targeted this zone as a permeable reservoir. However, this zone is more complex and its geothermal potential is strongly affected by different types of heterogeneities, such as lithology, fracture networks and/or the geometry of this zone. The characterization of this transition zone and its heterogeneities is a great challenge to the development of geothermal resources exploitation in deep basins throughout Europe.

This project is based on analogues of the rocks that form the basement-sediment transition (Figure). Some of the examined samples are sourced from boreholes that intersected the transition zone inside the Rhine Graben at great depth (Soultz-sous-Forêts, ca. 5km; Rittershoffen, ca. 3 km). Other samples are sourced from outside the graben in the Vosges Massif at shallow depth (Ringelbach, ca. 150m). Other shallow boreholes (ca. 100m) are present in the Strengbach catchment, in the Vosges Massif, and in the upper part of the basement, close to the sediment layers that outcrop less than 2 km to the east. Two quarries also offer access to outcrops of the transition zone (Saint Pierre Bois in France and Waldhambach in Germany).

Multidisciplinary and multiscale approaches are used on these sites to characterize the transition zone: structural analysis of the fracture network that constitutes the deep fluid pathway, fluid-rock interaction studies to determine to origin of fluids and their age, characterization of petrophysical properties, and geophysical investigations to image the geometry of this zone.

The project is on-going and the results are numerous. We present here only an overview of our results; details can be found in other presentations in the framework of this workshop.

Although much of the connected fracture network in the Rhine Graben was created as a result of the main tectonic phase of the graben opening, fracture networks at the different sites appear to be related to local tectonics. This is particularly true in the case of the Saint Pierre Bois quarry, which is located within the Permian Villé basin (active since the end of the Hercynian orogenesis). The pre-rift tectonics are largely represented in the basement, where fractures and faults were reactivated during the rift phases. The above sedimentary layers show a lower fracture density related to rift tectonics.

The major fractures and faults formed during the Hercynian provide dark surfaces in the field, and consist of cohesive fracture/fault rocks (breccia and cataclasite) due to pronounced silicification and minor illite formation (Lerouge & Dezayes, 2017). At the transition, alteration of Ca-bearing primary minerals such as plagioclase, amphibole or titanite in biotite-amphibole granites or gneiss are a Ca source for further carbonate precipitation in fractures (Ringelbach, Strengbach, Waldhambach), whereas alteration of K-feldspar seems to be a possible source for Ba, and the precipitation of barite in fractures (Ringelbach, Saint Pierre Bois, Strengbach, Waldhambach). Research dedicated to using accessory authigenic minerals to date hydrothermal fluid circulations provides evidence

of As-Ba-Sr-REE-bearing alumina-phosphates associated with Mg-rich clay minerals, xenotime or titanium oxides. The presence of such accessory minerals on both sides of the cover/basement transition confirms that circulating fluids mobilized trace elements from the Hercynian basement on a large scale through the cover/basement transition prior to the opening of the graben (Dezayes & Lerouge, submitted).

The exploration of the petrophysical variation present across the transition zone shows that the sedimentary rocks are more permeable, have lower P-wave velocity, and lower compressive strength than the basement rocks (Griffith et al., 2016; Heap et al., 2017). The porosity of the rocks is generally low and results from a high quartz cementation and to dissolution of plagioclase and K-feldspar (Kushnir et al., 2018a). Thermal properties are not particularly related to lithology and do not appear to correlate with porosity (Kushnir et al., 2018b). Obviously, fractures control the permeability in all types of rocks (Kushnir et al., 2018c).

The Ringelbach catchment is particularly adapted to subsurface geophysical investigations due to the absence of the filtering effect of the sedimentary cover. Electro-magnetic and seismic soundings have been carried out to map the resistivity and P-wave velocity distribution within the transition zone. The interpretation of such data reveals the geometry and complexity of the basement-sediment transition zone, with the presence of large-scale altered electrically conductive faults cutting through several hundreds of meter thick altered top of the basement.

Finally, a 3D geological model including seismic velocities has been performed at the North Alsace scale in order to refine the velocity model and therefore better localise the microseismic events induced by stimulation and exploitation operations.

The next steps will be to gather these results into a conceptual model of the hydraulic behaviour of the transition zone for the sites and then use these newly developed models to inform geothermal energy exploitation in this context.

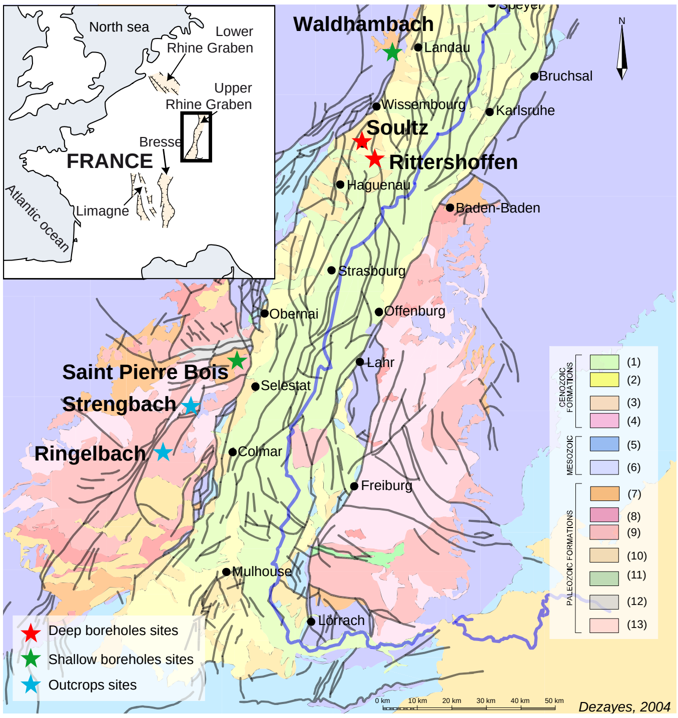

Figure – Location of sites used as analogues for studying basement-sediment transition zone of the Upper Rhine Graben. (1) Quaternary fluvial deposits; (2) Quaternary loess, eolian deposits; (3) Tertiary marine and lacustrine limestones, marls, evaporites; (4) Tertiary basalt; (5) Jurassic limestones; (6) Triassic sandstones, marly limestones, anhydrite (German Trias); (7) Permian red sandstones; (8) Carboniferous volcanism; (9) Carboniferous granites; (10) Dinantian conglomerate; (11) Ordovician-Silurian Limestones and continental altered rocks; (12) Ordo-Silurian-Cambrian clay and argillaceous sandstones; (13) Siluro-devonian paragneiss and orthogneiss.

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