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## Magnetic resonance in weathered & fractured granite aquifer: case studies in Alsace

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### SUMMARY

Hard-rock aquifers are known to be highly heterogeneous. Despite a low water content, they are useful but fragile water resources, especially in medium mountains in Alsace, north-east of France.

Exhumed crystalline basement rocks often exhibit altered facies, and with fractures and faults either due to geological stresses or weathering process. They are particularly vulnerable to erosion and act as conduits, barrier or storage to fluids.

Thus, studying these structures, close to the surface or at in depth, provides insights on exploitable aquifers for drinking water but also a toward a better understanding of deep aquifers or geothermal resources.

Two studied sites were chosen for somehow a common lithology and providing boreholes data and outcrop respectively, allowing a description of the spatial distribution of physical properties. Magnetic resonance sounding and geoelectrical measurements were acquired on such sites to inform on their underground structure and water content distribution.

**Key words:** MRS, geoelectrical methods, granite, fractures, Vosges mountains.

### INTRODUCTION

Exhumed crystalline basement rocks often exhibit altered facies, with fractures and faults either due to geological stresses or weathering process. They are particularly vulnerable to erosion and act as conduits, barrier or storage to fluids (Roques et al., 2014; Place et al., 2016). Therefore, hydrogeological behaviour is complex in the damage zone of the rocks with alteration products that can precipitate locally and increase or decrease permeability and porosity (Nishimoto et al., 2010; Roques et al., 2014; Place et al., 2016).

In this paper, geoelectrical measurements and Nuclear Magnetic Resonance Sounding measurements (MRS) have been performed on several sites in Alsace. Two of them are presented here, to evaluate the hydrological parameters and storage capacity of a granitic basement rock.

Geophysical surveys have already been used to characterize such heterogeneous medium (e.g. Baltassat et al., 2005; Dewandel et al., 2006). The aim of this study is to target the zones of expected higher porosity and permeability, i.e. the damage zone in fractured parts and the generally most altered zone at the top of the basement: the transition zone between the sediments and the crystalline rocks.

The selected sites have been investigated in the recent years for various objectives and their descriptions can be found in the literature (Pierret et al., ; Dezayes et al., 2021). Both sites are situated in the North East of France in the Vosges Mountain.

### St Pierre Bois Quarry

The St Pierre Bois (SPB) site is included in an exploited carrier with a manmade outcrop allowing to visualise the geological contact between the granitic basement and the arkose overlying sediments (sandstone enriched in quartz, with a moderate porosity). It is particularly interesting to have access to the limit between basement rocks and sediment layers as this zone is often referred as a permeable target at depth down to several kilometres and cannot be easily studied. As it is, this particular outcrop can be considered as an analogue of the same transition zone at depth and its study aims at a better understanding of the hydrogeological properties and change in physical properties between the two compartments.



Figure 1. Picture of a man-made outcrop with – in red – bedding of the sedimentary deposit (sandstone) and – dotted white line – the geological limit between sandstone and the crystalline basement rock.

Three geophysical methods have been applied to acquire various and complementary physical properties. The electrical resistivity tomography (ERT) and the MRS were used to

evaluate the resistivity of the medium and an estimate of its water content (i.e. saturated porosity). For the very shallowest part, some ground penetrating radar profiles allowed to describe, at a high resolution, the layers in the sedimentary part, until a maximum depth of 2.5m with 100 MHz antenna.

The outcrop of the quarry has been carefully described (ref?). Petrophysics properties have been evaluated for a selection of samples, mainly providing matrix properties (Kushnir). Fracturation density and orientations (but also deposits in fractures) have been mapped and related to the regional context (Dezayes et al., 2021).

## THE STRENGBACH CATCHMENT

The Strenbach catchment is a small basement watershed (80 ha) located at an altitude between 880 to 1150 m. Mainly covered by spruce forest, it benefits from a long-term hydrological and geochemical monitoring (since 1986): rainfall / snowfall, runoff, vegetation surveying, etc... (Pierret et al., 2018).

This site has been (and still today) thoroughly investigated with surface geophysics, including MRS (Boucher, 2015), ERT (Gance et al., 2015) and more recently with active surface and borehole seismic (Lesparre et al., 2020b; cite Zillmer) and passive seismic imaging and monitoring (cite jerome?).

## RESULTS & CONCLUSIONS

More than 25 MRS soundings performed at Strenbach site allowed estimating the varying thickness of the top weathered zone between 8 to 24 m which has the larger MRS porosity (3-5%), see figure 2 for instance. The underlying rock is characterized by a porosity < 2%, which is a higher value than fresh granite matrix porosity.

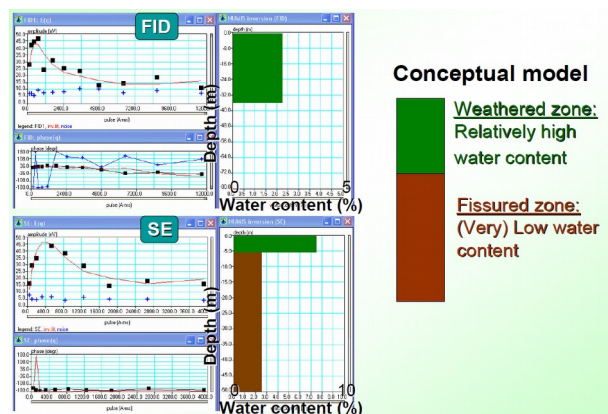


Figure 2. Sample of MRS data at a favorable site, both FID and spin echo (SE) sequences were used (which site?).

Spatial variations of MRS combined with soil, geology and geochemical information led to a hydrological model with 5 zones. These zones were then used to define an initial hydrodynamic model, later refined after optimisation to fit the observed MRS data and hydrological records (Lesparre et al., 2020a).

In St Pierre Bois quarry, the upper sedimentary layer revealed a mean resistivity of 80  $\Omega$ .m and the presence of a perched aquifer within a 2 to 4% MRS porosity. Deeper, an increase of MRS water content, up to 3% far below the resistive contact with the basement was observed, revealing a significant storage at the top of basement.

On both studied sites, the signal to noise ratio is a key issue for MRS as in general on hard-rock aquifers. Surface MRS results were confirmed with borehole nuclear magnetic logging (NML), i.e. spatially variable water content within a weathered layer with  $\sim$  3-5 % porosity a thick hard rock aquifer with an average porosity < 2% close to water filled fractured zones, water content > 6% (after NML).

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