Motivation for Research

Understanding processes occurring within rocks is critical for modern science and industry. Rocks form the foundation of landscapes and play a crucial role in storing resources such as water, gas, and oil. Many gas, oil, and geothermal water deposits are found in rocks with complex structures, such as shales, sandstones, and limestones. In some rocks, fluids flow freely through channels, large pores, and fractures, while in others, they encounter obstacles like tiny pores or impermeable microstructures. Both permeable and barrier-like structures are often anisotropic, meaning they have different properties in different directions. Unfortunately, most current research methods treat the rock medium as isotropic, leading to inaccurate predictions of their filtration capacity. Understanding the impact of anisotropy is essential for the extractive industry and environmental protection. Our project aims to develop modern tools that will enable the investigation of these phenomena with precision unattainable by existing research techniques.

Project Objective

This project aims to develop an innovative research method based on nuclear magnetic resonance imaging (MRI) – specifically, Diffusion Tensor Imaging (DTI). This technique, widely used in medical diagnostics to track neural connections, will be adapted for studying rocks. Its application will allow visualization of water flow in pores by identifying the most probable diffusion directions (Principal Diffusion Tracts, PDT) within the rock (Figure 2). By adapting this technique, it will be possible to precisely determine key pore space parameters, such as permeability, porosity, and tortuosity.

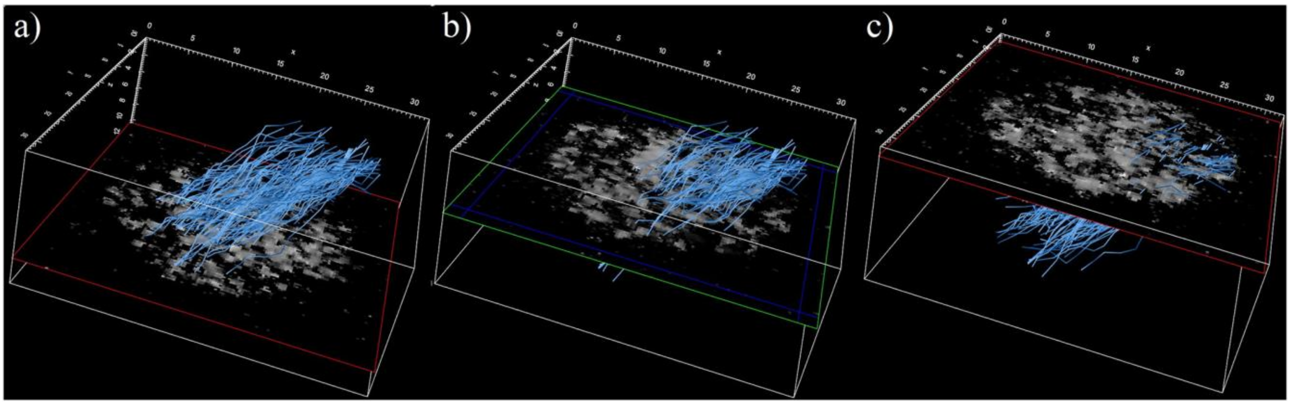

***Figure 2**: Principal Diffusion Tracts (PDT) identified using the DTI technique for a sample of limestone, showing the most permeable water flow paths visualized on the lower (a), middle (b), and upper (c) MRI cross-sections of the rock core [1].*

Research Description

In the initial phase, we will create phantoms–model samples with a controlled pore structure, both isotropic and anisotropic. These phantoms will be used to test the accuracy and calibration of the DTI method and identify potential measurement errors. Next, we will conduct measurements using MRI scanners with varying magnetic field strengths (from low to high). We will use advanced algorithms to analyse the obtained images, identifying water flow paths in the rock and areas with significant permeability differences. In the subsequent phase, the MRI measurements will be supplemented with standard methods for studying pore space, such as mercury porosimetry, gas adsorption, gas permeability, magnetic susceptibility, electrical conductivity and X-ray diffraction analysis.

Expected Outcomes

Ultimately, based on the collected data, we will develop mathematical models that more accurately represent fluid flows in rocks. These models will account for the anisotropy of the studied rock media, enabling better predictions of their behaviour under various geological conditions. The developed methodology can also be adapted to other fields such as geotechnics, hydrology, or archaeology. Our research has the potential to contribute to more efficient exploitation of hydrocarbon and geothermal water deposits, better water resource management, and a reduction in the negative environmental impacts of resource extraction.

References

[1] A. T. Krzyżak, W. Mazur, A. Fheed, and W. P. Węglarz, "Prospects and Challenges for the Spatial Quantification of the Diffusion of Fluids Containing 1H in the Pore System of Rock Cores," *J Geophys Res Solid Earth*, vol. 127, no. 3, p. 23299, Mar. 2022, doi: 10.1029/2021JB023299.