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# Quantifying the Effects of Porosity and Saturation on Rock Thermal Properties: TCS Measurements From the RINGEN Research Centre

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PUSH IT
synergys
Systems for energy synergies

## ROCKS AS BATTERIES: THE SCIENCE OF THERMAL STORAGE

The search for cleaner and more sustainable energy sources is one of the greatest challenges of our time. Over the past few decades, the adverse consequences of our unsustainable use of non-renewable energy resources for power generation and heating have grown increasingly clear. One of the most promising choices is to use geothermal heat — the Earth's natural thermal energy — as a renewable energy source , along with long-term subsurface heat storage.

Projects like SYNERGYS and PUSH-IT use research infrastructure such as the RINGEN Research Centre in Litoměřice, Czech Republic, to develop efficient designs of subsurface heat exchangers required in next-generation geothermal systems. The practical operation of this sort of system is essentially dependent upon the thermophysical properties of the host rock, especially thermal conductivity (λ), thermal diffusivity (α) and heat capacity (c), for heat transfer and storage that are achieved in the subsurface geothermal environment.

## METHODOLOGY

The study employed the Thermal Conductivity Scanner (TCS), an optical scanning device designed to measure the thermal conductivity(λ) and thermal diffusivity(α) of rock samples with high spatial resolution.

The rock samples were collected from borehole LT-M2-01 in Litoměřice, Czech Republic.

Measured samples:

- Water-saturated samples- naturally (in situ) saturated
- Dry samples- oven-dried at a constant temperature of 106˚C

To ensure uniform emissivity during measurements, surfaces were coated with high-emissivity black paint or wrapped in black foil (depending on sample state).

The objective of the measurements was to determine the thermal conductivity and thermal diffusivity of sedimentary rocks in order to investigate the influence of saturation and porosity on these thermal parameters. The resulting data allow evaluation of how differences in pore structure and fluid content influence the heat-transport properties of the studied lithologies.

## DATA PROCESSING

During data processing, a statistical analysis was performed in which outlier values exceeding the ± standard deviation range from the initial trend were excluded. The final regression models and confidence bands were then calculated using the cleaned datasets. Processed data were used for the graphical representation of porosity. For the vertical plotting shown in Fig. 4, unprocessed (raw) values were used.

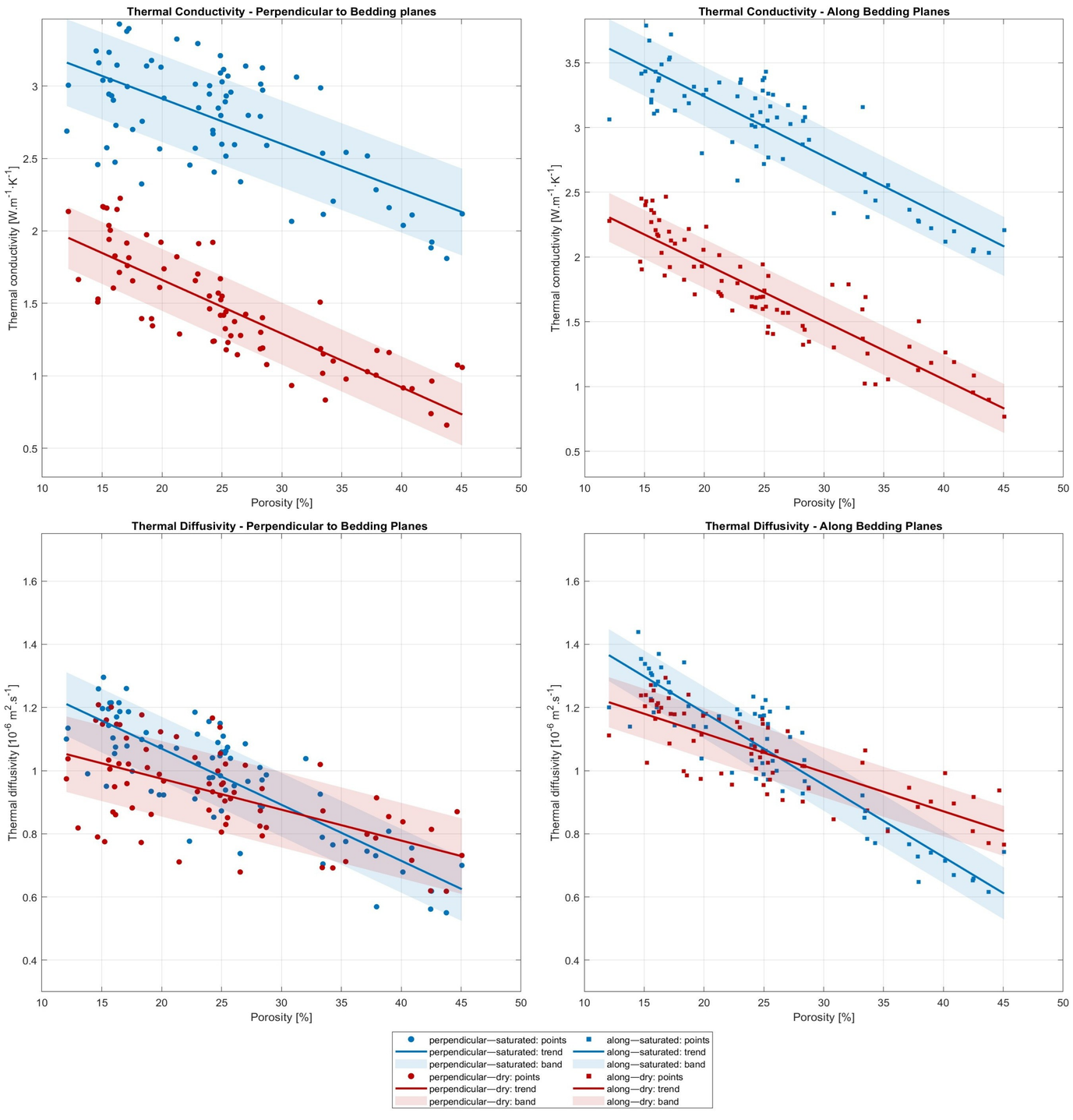



Fig. 3:Relationship between porosity and thermal properties of sedimentary rocks in perpendicular and along bedding planes. Thermal diffusivity in saturated rocks follows faster decrease because fluid saturation increases the volumetric heat capacity (ϱc) much more than the thermal conductivity λ (taken from equation: (α=λ/ϱc).

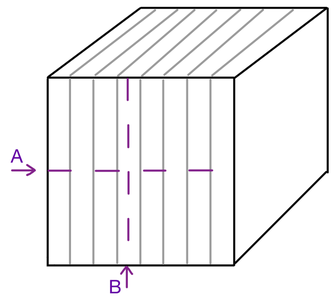



Fig.1: Schematic of measurement directions.

Measurements were preformed in two directions (A,B)(Fig.1) relative to the bedding planes (defined by the movement of the heat source and sensors(*)).

Direction A provides both thermal conductivity and thermal diffusivity along the bedding planes, representing the material's properties parallel to bedding planes. In contrast, direction B provides an auxiliary thermal conductivity used to calculate the final thermal conductivity perpendicular to the bedding planes, while the thermal diffusivity measured in this direction already represents the final thermal diffusivity perpendicular to the bedding planes.

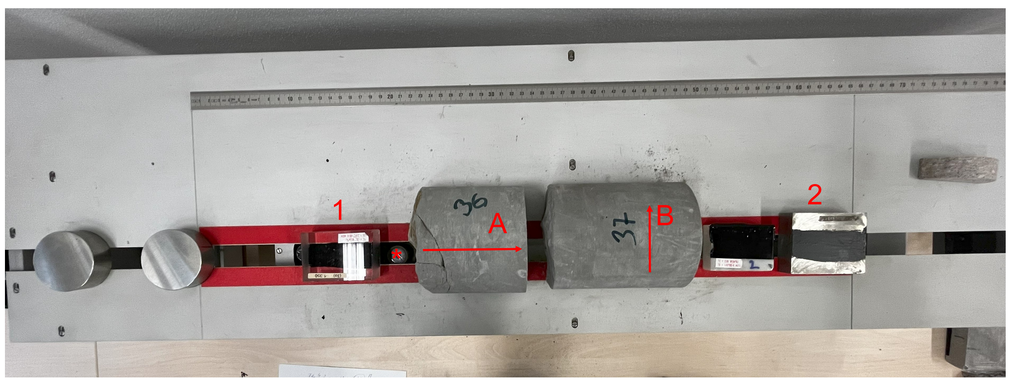



Fig. 2: Photograph of the TCS device used for thermal property measurements of core samples. Calibration was performed using reference standards with known thermal properties, specifically quartz glass(1) and titanium(2).

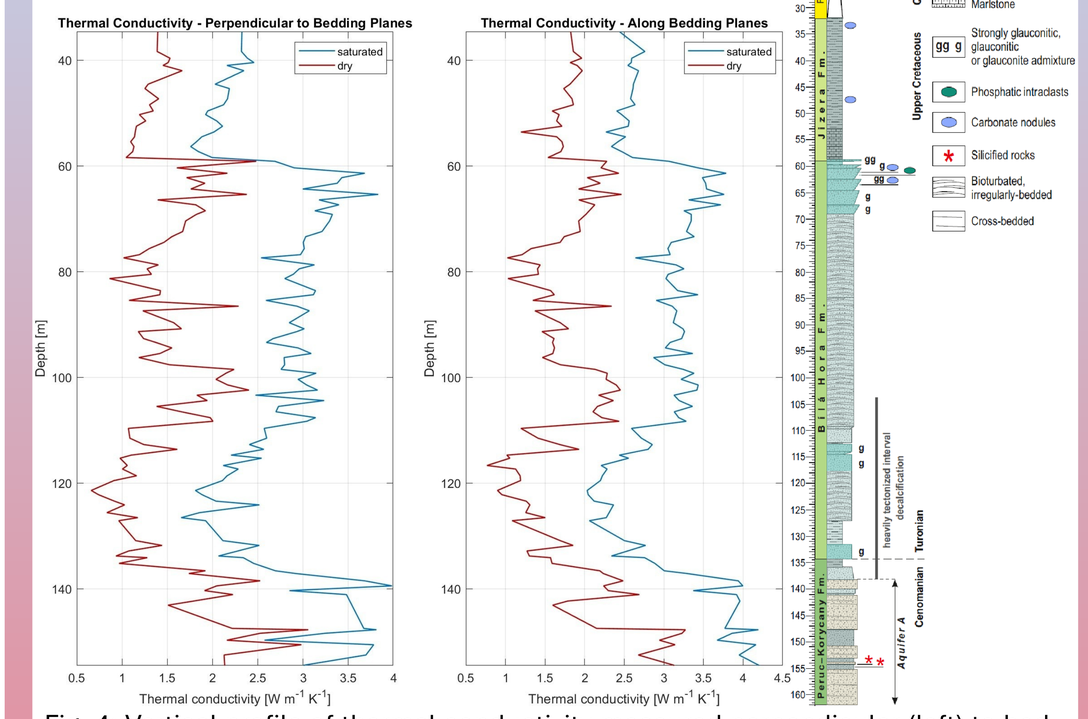



Fig. 4: Vertical profile of thermal conductivity measured perpendicular (left) to bedding planes and along (middle) bedding planes in relation to depth, shown together with the corresponding stratigraphic profile (right).

## DISCUSSION

Experimental findings indicate that porosity and water saturation strongly influence the thermal properties of sedimentary rocks. This effect becomes particularly significant at higher porosity levels, underlining the importance of hydrogeological conditions for subsurface heat storage. These trends are consistent with previous experimental and theoretical studies showing that water saturation increases bulk thermal conductivity relative to dry conditions, especially in porous rocks (Nagaraju & Roy, 2014). The more complex behaviour of thermal diffusivity highlights the role of volumetric heat capacity, which is strongly controlled by moisture content. Water saturation increases heat capacity and can partly offset the reduction in diffusivity otherwise expected with increasing porosity, in agreement with composite heat-transfer models (Banks, 2025)

The results confirm the need for site-specific laboratory measurements in geothermal assessment and BTES optimization. Data obtained from a ~160 m deep borehole were treated as representing a homogeneous unit; therefore, multiple apparent trends likely reflect underlying different porosity intervals.

## CONCLUSION

This study showed that porosity and water content are the major factors determining the thermal behaviour of sedimentary rocks from borehole LT-M2-01. Overall, the porosity of the rock affects the thermal conductivity, where increasing porosity causes a decrease in conductivity, except that water saturation significantly increases conductivity relative to dry environmental conditions, particularly at greater porosity. The thermal diffusivity shows complex trends as a product of the conductivity and volumetric heat capacity effects. The data confirm that there is anisotropy: measurements parallel (along) and perpendicular (across) to the bedding planes show marked differences. For correct measurements of geothermal potential, comprehensive laboratory measurements are critical. Understanding both geological and hydrological effects thoroughly is key to the efficient development and design of borehole thermal energy storage systems and other geothermal technologies.

**REFERENCES**

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