Electrical and hydraulic rock properties in geothermal high-enthalpy settings

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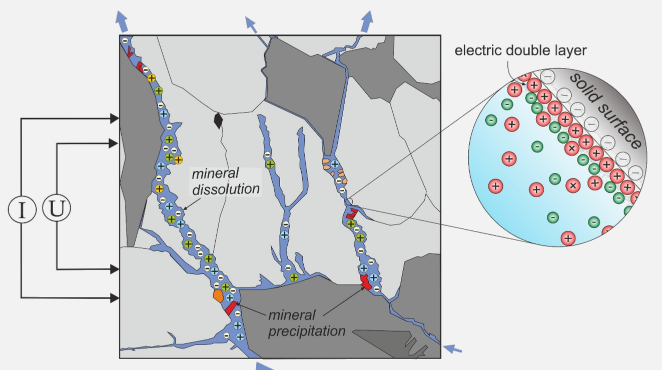
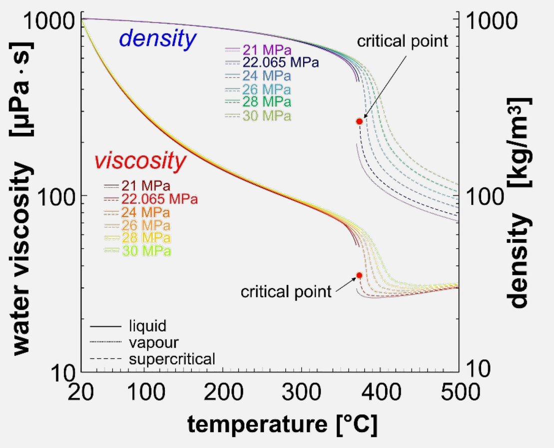
1 Introduction

Resistivity surveys are often used in geothermal reservoir exploration to delineate sub-surface conditions, as electrical properties are sensitive to temperature, porosity, alteration of the rock, fluid content and the nature of formation fluids. Several conduction mechanisms contribute in parallel to the electrical properties of a rock:

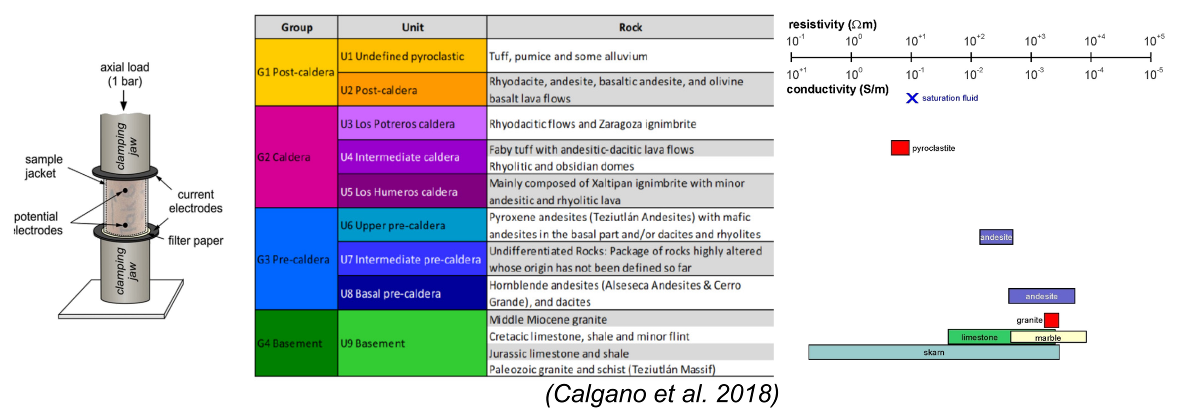
- electrolytic charge transport
- electrokinetic processes at the mineral-fluid interface
- intramineral electrical conductivity



Moreover, the extreme changes in the fluid density and viscosity with temperature affect ion mobility, ion concentration, the dielectric constant and the chemical reactivity, what makes the interpretation of resistivity survey data very complex. However, for temperatures > 250°C only very few petrophysical data are available to correlate measurements at the earth surface with material properties in the depth. In the framework of GEMex we have studied both the electrical resistivities of relevant pore fluids and the electrical and hydraulic properties of rock samples during fluid percolation up to 530 °C at maximum.



2 Laboratory Experiments



(Calgano et al. 2018)

Fig. 1. The electrical properties of 26 outcrop samples predominantely representing basement units were determined at ambient conditions. For most samples the porosity was < 2 % and accordingly their electrical resistivity was high (> 500 Ωm). Lower resistivities (36 – 300 Ωm) were observed for porous pyroclastites and a limestone with pronounced cleavage. Exceptional low resistivities of 4 – 72 Ωm were determined for skarn samples (35 – 40 % pyrite) even at oven dry conditions.

HP/HT-Set-ups

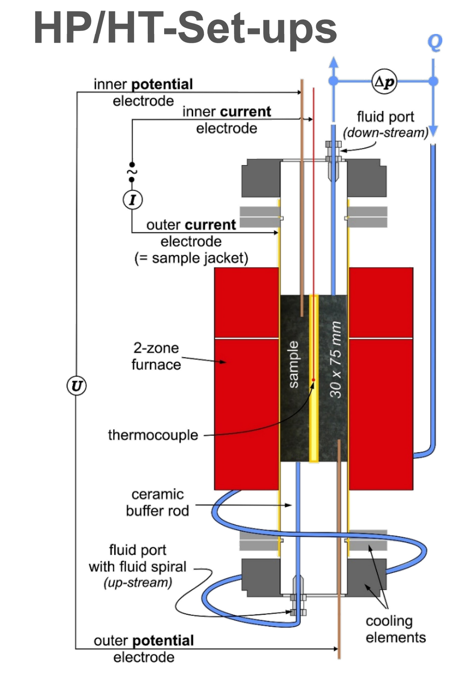


Fig. 2. Set-up for combined measurements of electrical and hydraulic properties of rocks at simulated in-situ conditions, which are applied in an internally heated gas-pressure vessel.

For **conductivity measurements** in both set-ups we use a coaxial 4-electrode layout with two pairs of current and potential electrodes. The conductivity, σ, is calculated from sample resistance, R, and geometry factor, c, which considers the electrode layout:

$$\sigma_{sample} = \frac{I}{U} \cdot c$$

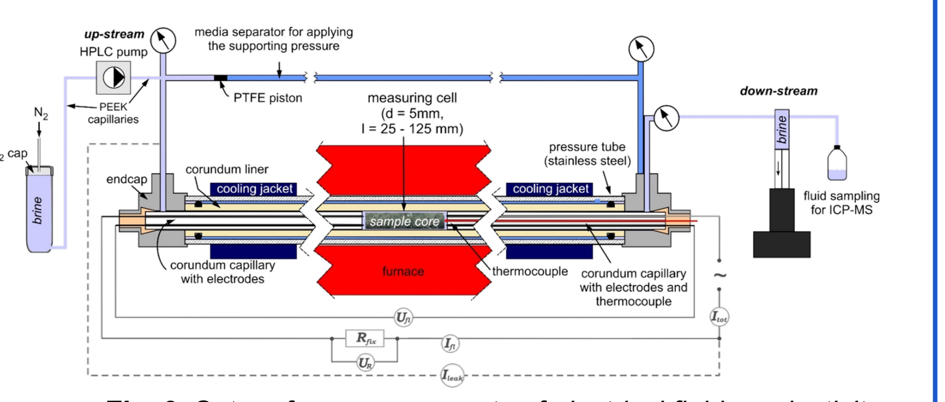


Fig. 3. Set-up for measurements of electrical fluid conductivity and reactive flow experiments.

3 Reactive flow experiments

To date, the possibility to describe the temperature dependence of conductivity of mixed brines by models adequately is still limited. Thus, as a prerequisite for the interpretation of measurements on rock samples we have studied complex solutions containing up to 5 different solvates and representing the chemisty of Los Humeros fluids.

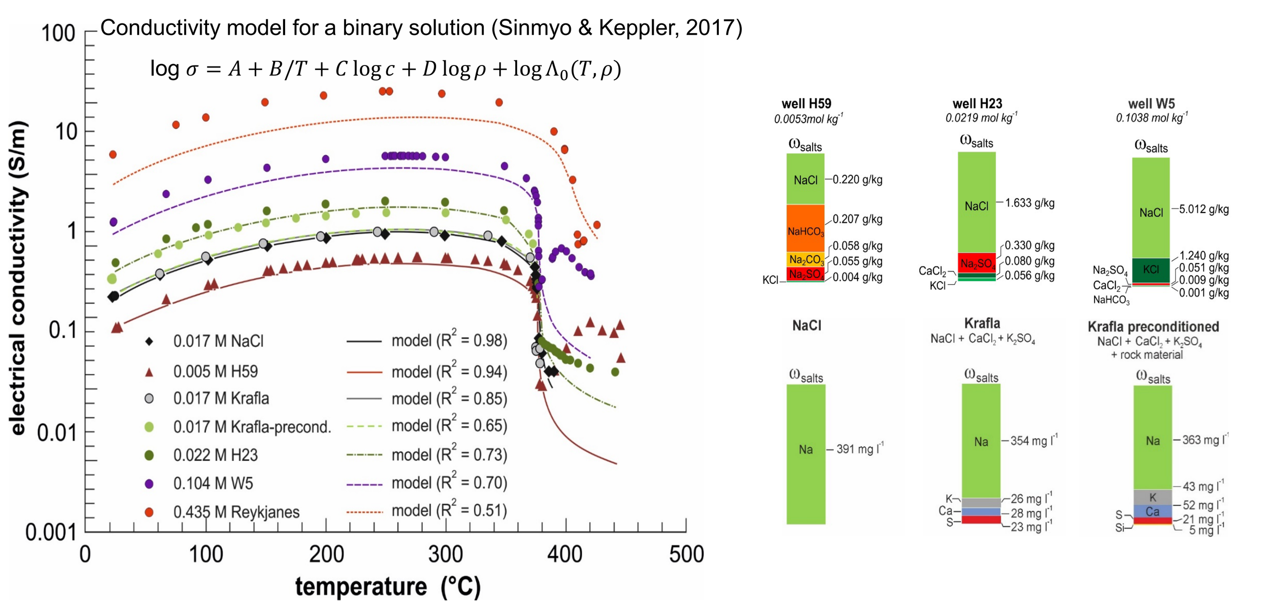


Fig. 4. Electrical conductivity of various rock samples representing the basement and reservoir units of the target area.

The Los Humeros system under study is characterized by a fracture dominated carbonate basement covered by an andesitic reservoir, where the permeability is both fracture and matrix-dominated (Lasinska and Rochelle, 2018). Accordingly, the studied rocks samples reflect the geological situation of hydrothermal systems in the Transmexican Volcanic Belt.

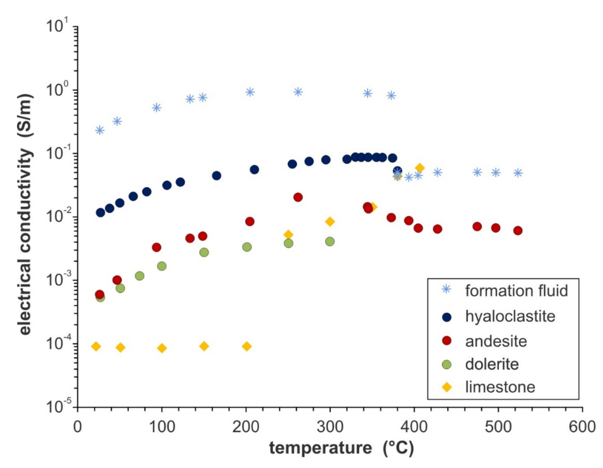


Fig. 5. Electrical conductivity of various rock samples representing the basement and reservoir units of the target area.

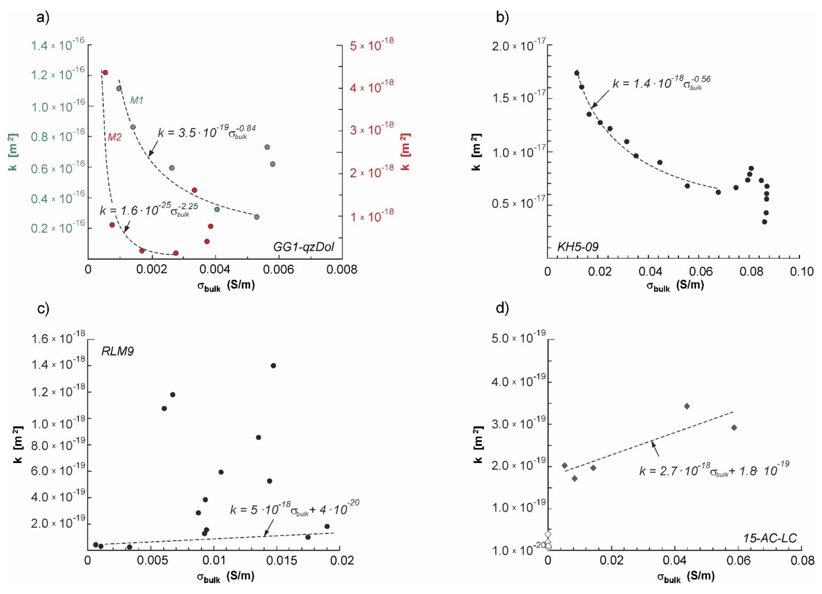


Fig. 6. Relationship of permeability, k, and bulk conductivity, σ_{bulk}, (a) for the studied dolerite (GG1-qzDol), (b) the volcanic breccia (KH5-09), the andesite (RLM9), and (d) for the limestone (15-AC-LC).

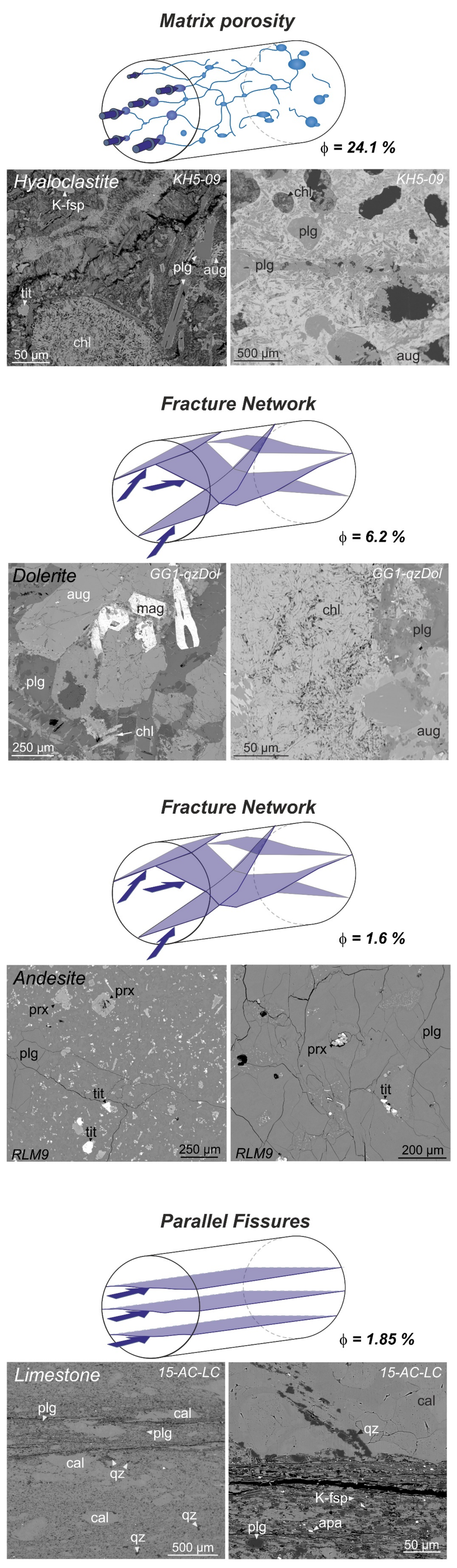


Fig. 7. SEM images of the studied sample materials before experiments.

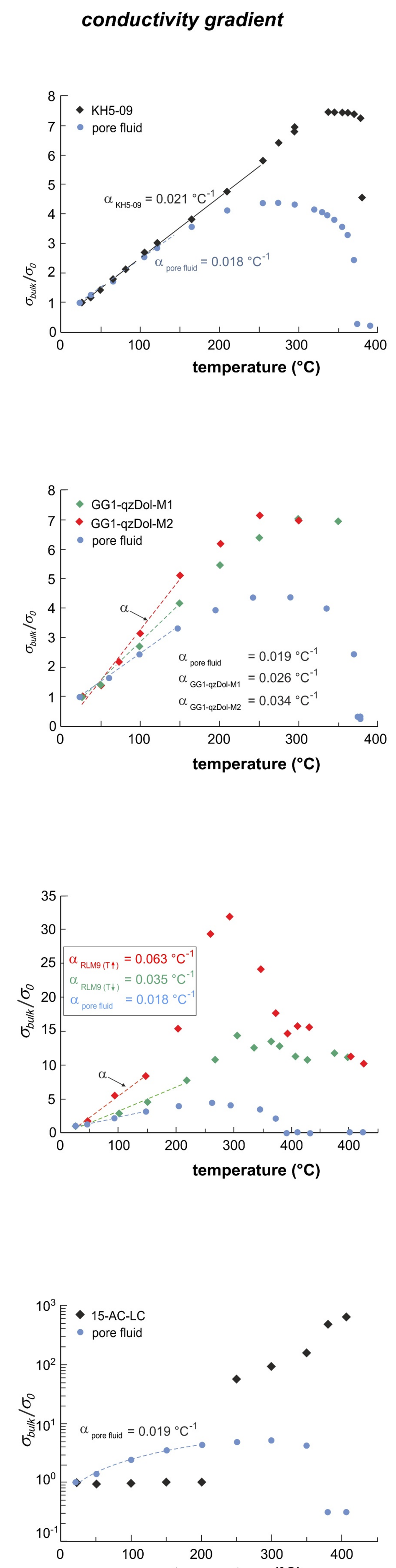


Fig. 8. Electrical bulk and fluid conductivities normalized on the corresponding conductivity at 24 °C.

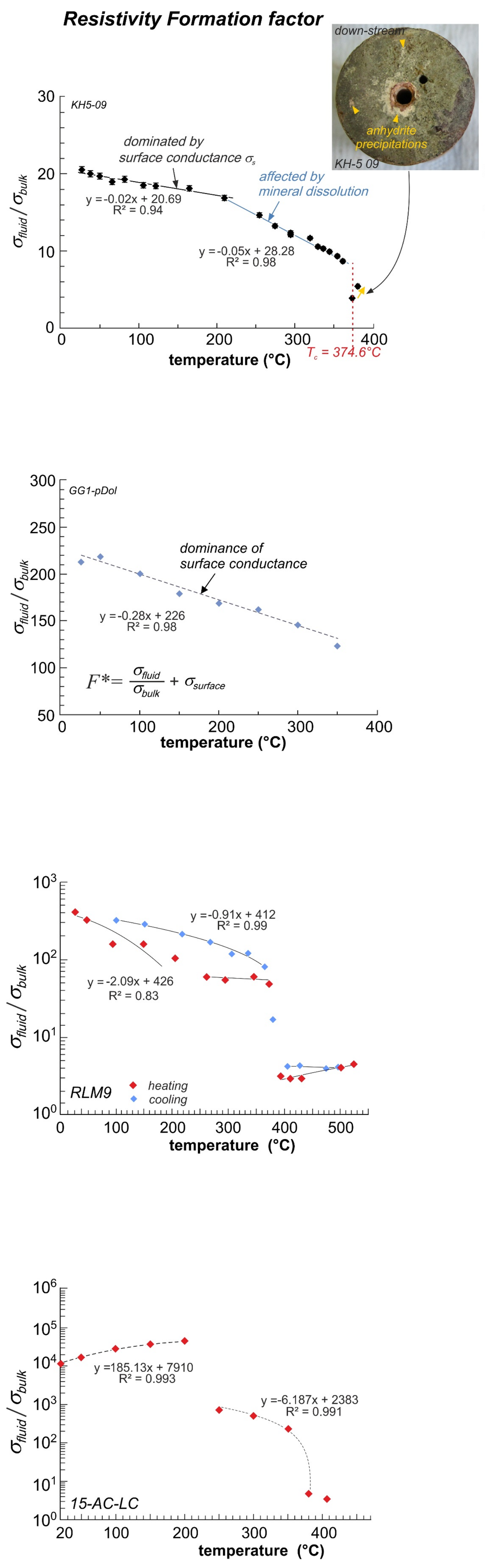


Fig. 9. The apparent formation factors were determined from fluid and bulk conductivities in dependence of temperature.

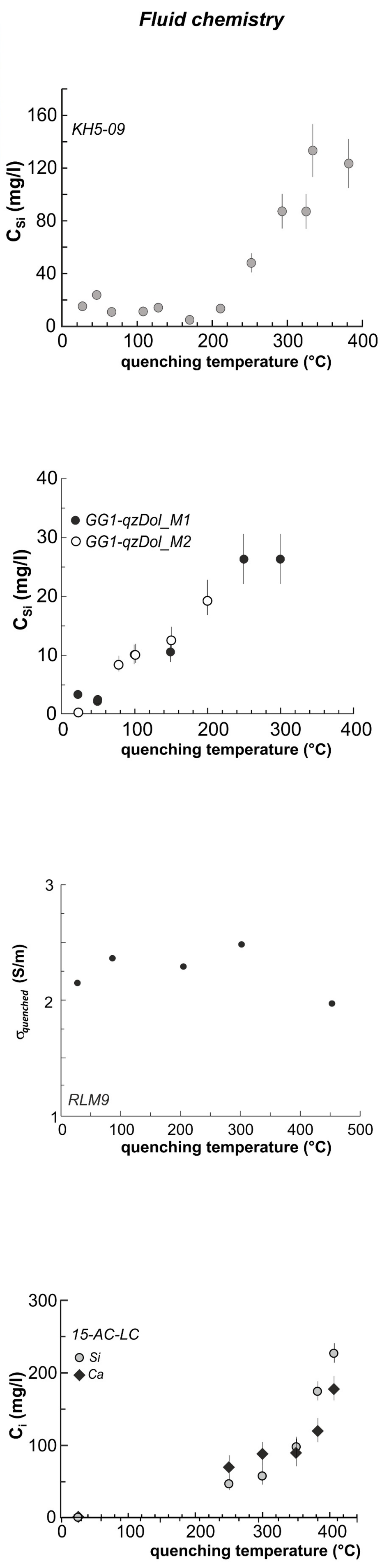


Fig. 10. Si (and Ca) concentrations in the quenched fluids samples. Fluid samples were taken at ambient conditions and analysed via ICP-MS.

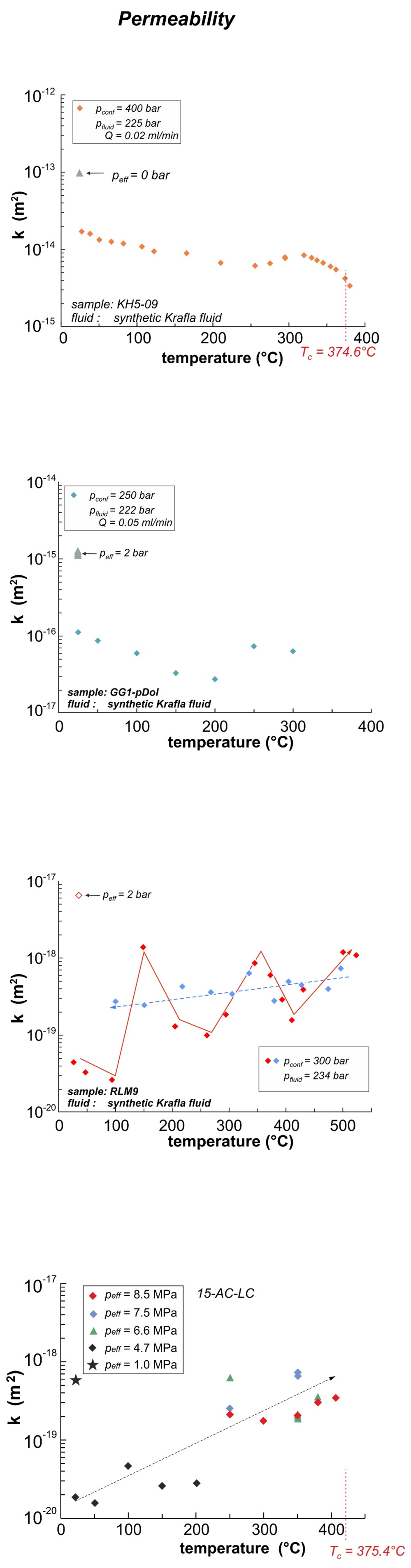


Fig. 11. Permeabilities of fluid saturated rocks samples as function of temperature.

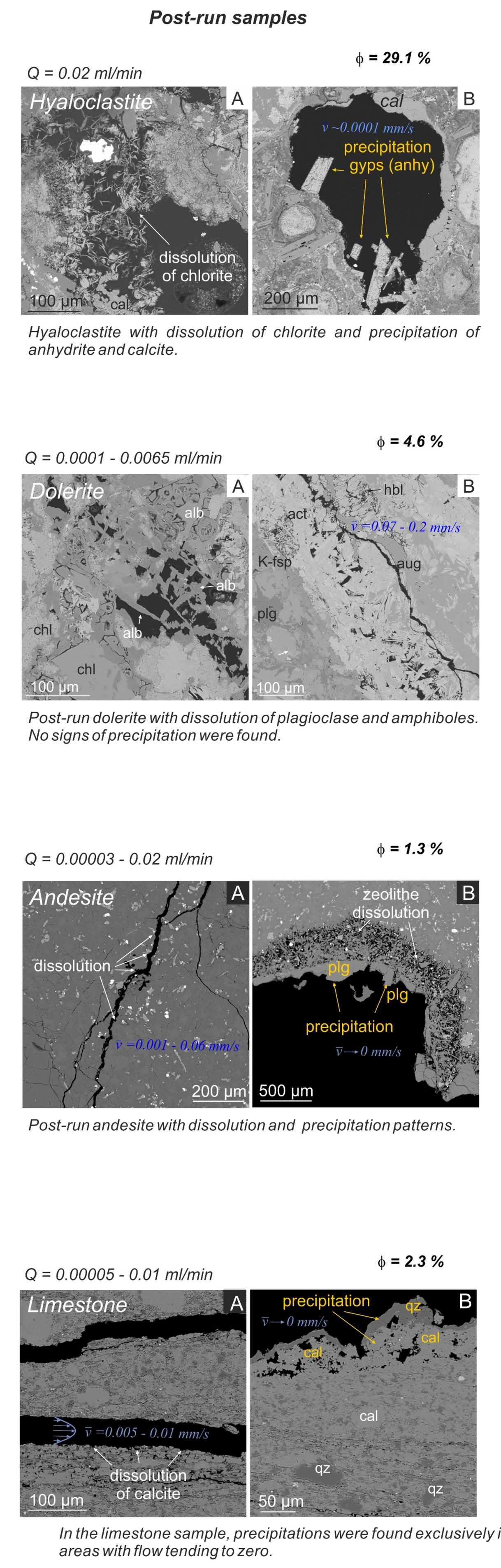


Fig. 12. SEM images of the studied sample materials after reactive flow experiments.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 727550 and the Mexican Energy Sustainability Fund CONACYT-SENER, project 2015-04-68074.
We acknowledge the Comisión Federal de Electricidad (CFE) for kindly providing support and advice and for granting access to their geothermal fields. We are greatful to L. Weydt, K. Bär, C. Rochelle, B. Lepellier, D. Liotta, P. Deb for providing us with sample material. We also acknowledge our Mexican colleagues for their help an collaboration.

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