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Geothermal alteration of Kamchatka rock physical properties: experimental and pore-scale modeling study

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Alternative renewable energy sources research is getting more and more attention due to its importance for future exploitation and low ecological impacts. Geothermal energy is quite abundant and represents a cheap and easily extractable power source for electricity generation or central heating. For these purposes naturally heated geothermal fluids are extracted via drilled wells; after cooling water is usually pumped back to the reservoir to create a circle, or dumped into local streams. In addition to fundamental interest in understanding natural geothermal processes inside the reservoir, in both cases fluids can significantly alter rock properties around the well or stream bed, which is of great practical and ecological importance for the geothermal industry. Detailed knowledge of these transformations is necessary for power plant construction and well design, geophysical modeling and the prediction of geological properties. Under natural conditions such processes occur within geological time frames and are hard to capture.

To accelerate geothermal alteration and model deep reservoir high temperature and pressure conditions we use autoclave laboratory experiments. To represent different geothermal conditions, rock samples are autoclaved using a wide range of parameters: temperature (100-450°C), pressure (16-1000 Bars), solution chemistry (from acidic to alkali artificial solutions and natural geothermal fluids sampled in Kamchatka), duration (from weeks to 1 year). Rock samples represent unaltered andesite-dacite tuffs, basalts and andesite collected at the Kamchatka peninsula. Numerous rock properties, e.g., density (bulk and specific), porosity (total and effective), hygroscopicity, P/S wave velocities, geomechanical characteristics (compressive and tensile strength, elastic modulus), etc., were thoroughly analyzed before and after alteration in laboratory autoclave or natural conditions (in situ). To reveal structural changes, some samples were scanned using X-ray microtomography prior to any alteration and after the experiments. 3D images were used to quantify structural changes and to determine permeability values using a pore-scale modeling approach, as laboratory measurements with through flow are known to have a potential to modify the pore structure. Chemical composition and local mineral formations were investigated using a «Spectroscan Max GV» spectrometer and scanning electron microscope imaging.

Our study revealed significant relationships between structure modifications, physical properties and alteration conditions. Main results and conclusions include: 1) initial porosity and its connectivity have substantial effect on alteration dynamics, rocks with higher porosity values and connected pore space exhibit more pronounced alterations; 2) under similar experimental conditions (pressure, temperature, duration) pH plays an important role, acidic conditions result in significant new mineral formation; 3) almost all physical properties, including porosity, permeability, and elastic properties, were seriously modified in the modeled geothermal processes within short (from geological point of view) time frames; 4) X-ray microtomography was found useful for mineral phases distribution and the pore-scale modeling approach was found to be a promising technique to numerically obtain rock properties based on 3D scans; 5) we conclude that alteration and change of reservoir rocks should be taken into account for re-injecting well and geothermal power-plant design.