The in-situ stress state of the Rhine-Ruhr region and its implications for the geothermal energy utilization

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The Rhine-Ruhr region is one of the largest metropolitan areas in Europe, with more than 10 million inhabitants, located in western Germany. The region is defined by the rich coal-bearing layers from the upper Carboniferous period, extracted as early as the 13\textsuperscript{th} century and belonging to the sub-Variscan Trough. In 2018, after more than 700 years of exploration, the last black coal mine was closed in the area. One of the most promising re-uses of the abandoned coal mines is the exploitation of geothermal energy sources. Additionally, to the geothermal energy extracted from existing mines, potential deep geothermal reservoirs within the Rhine-Ruhr, may exist at depths between 4.5 and 6 km, where Devonian limestones were found. Based on the available temperature profiles from deep exploration wells in the area, geothermal gradient amounts to 36.8°C/km and results in reservoir temperatures between 170°C and 220°C, which will enable not only heat but even electricity production. This study provides a comprehensive investigation of the full in-situ stress state tensor with its anisotropy and presents crucial physical formation and natural fracture properties. The data for this investigation was acquired from the extensive borehole logging and geomechanical campaigns carried out in deep coal exploration wells throughout the 1980s as well as from the recent shallow geothermal research wells. Acquired data allowed assessing critically-stressed, i.e. hydraulically active, fractures undergoing shear displacement, being primarily responsible for the future geothermal reservoir permeability. Extensive sets of microseismic, subsidence and drilling data were used to confirm the results of the analysis. Additionally, wellbore stability analysis and potential drill paths for the future medium-to-deep geothermal wells in the region were assessed. This study is a part of the 3D-RuhrMarie project, which aims to assess the intrinsic seismic risk within the Rhine-Ruhr region to promote safer and economically more efficient exploration and exploitation of the future geothermal resources.