

Controlling Seismicity During a 6.1-km-Deep Geothermal Stimulation in Finland

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We show that near-real-time seismic monitoring allowed control of induced earthquakes during the hydraulic stimulation of a 6.1 km-deep geothermal well near Helsinki, Finland. This ST1 Deep Heat Oy and Fortum Oyj energy-company effort is located on the campus of Aalto University in Espoo, Finland. The aim is to boost the initial temperature of the campus' district heating water, with development costs being offset by saving in imported fuel and carbon emissions. The uncased 1000 m and 42° inclined bottom of the stimulation well, drilled into Precambrian crystalline rocks, was divided into five injection stages. A total of 18,160 m³ of water was pumped into these rocks over 49 days in June and July 2018. The stimulation was monitored using a network of 24 borehole seismometers. These sensors were located at 0.30-2.65 km depths in boreholes at distances of 0.01 to 8.0 km around the project site. Using induced-earthquake data pumping was either stopped or varied between wellhead-pressures and rates of 60-90 MPa and 400-800 l/min. This procedure avoided a project-stopping M2.1 induced earthquake, a limit set by local government.

A key element of the monitoring network was a 12-level array of 3-component seismometers placed at 2.20-2.65 km depth in the OTN2 well. This array was complemented by an additional 12-station satellite network surrounding the site. We reprocessed locations for 6150 events (Fig 1). The seismicity data show a monotonic increase of maximum earthquake magnitude with cumulative injected volume. This followed the trend predicted by a recent fracture mechanics model by Galis et al. (2017), but remained much lower than predicted by McGarr (2014). Our observations suggest that using the Galis et al. model allows forecasting of the maximum controllable induced event size based on the elastic energy stored in the stimulated volume.

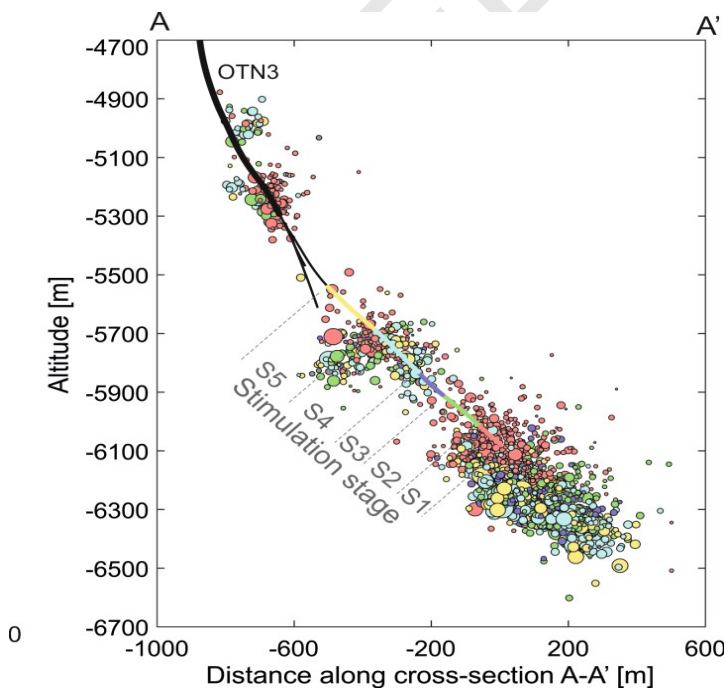


Figure 1. SW-NE depth section showing seismicity color-coded with Phases P1-P5.

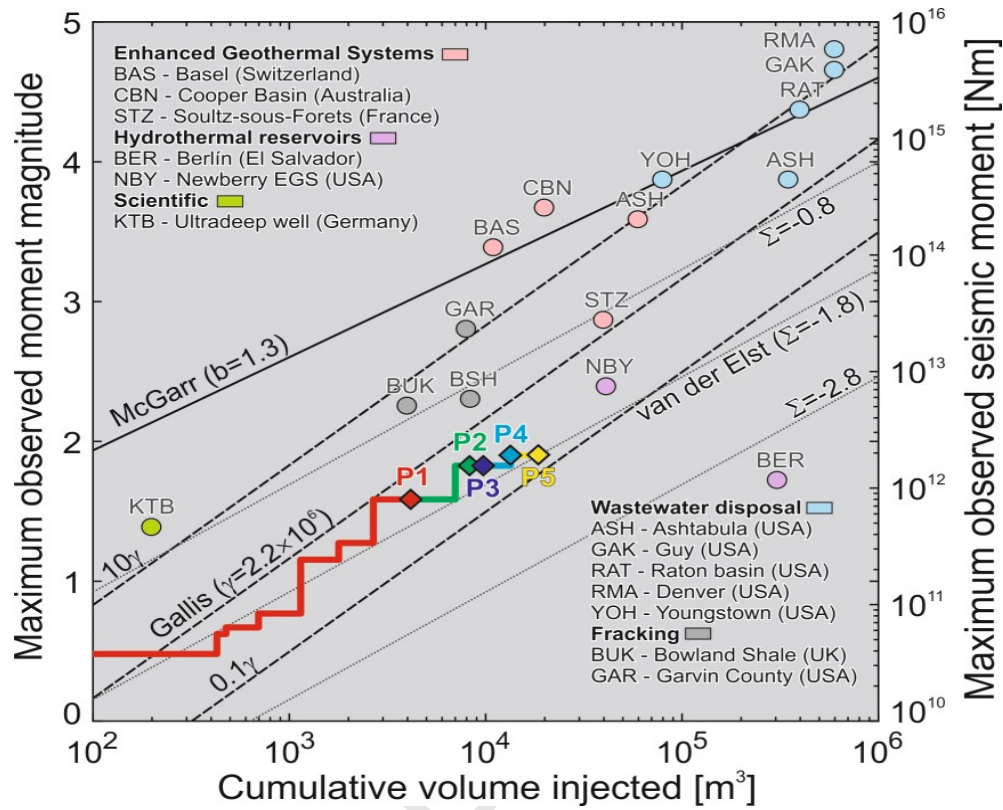


Figure 2. Evolution of seismic moment versus cumulative volume of fluid. Circles are from varying projects. Maximum magnitude from different models assuming result from this study are shown with solid, dashed and dotted lines.