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Design of the seismic monitoring network for the stimulation experiments in the Bedretto Deep Underground Rock Laboratory

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Motivation

To investigate processes related to geo-energies on the hectometer scale, a new deep Underground Laboratory for Geoenergy research (BULG, Bedretto, Switzerland) is currently being set up. A key component for all planned experiments towards engineering of a geothermal reservoir is a seismic monitoring network that enables us to: i) detect all induced seismicity in a wide range of magnitudes to provide a robust FMD ii) allows reliable localization of all events in order to monitor the temporal and spatial development of the stimulated and circulated volume and iii) characterize the source properties of the induced events to gain an improved understanding of the stimulation processes.

Figure 1: Impression from the new Bedretto Deep Underground Laboratory for Geoenergy Research. The lab provides unparalleled access to a large undisturbed rock volume in the widely homogeneous Rotondo Granite.

Sensors

The frequency range at which a seismic event radiates its energy is dependent on its magnitude and the induced stress drop. What portion of this radiated seismic energy is recorded at a distant sensor depends on path and site effects between source and sensor (e.g., attenuation, coupling), and on the capabilities of the sensor to record ground displacement, velocity or acceleration (i.e., sensitive frequency range, noise floor). For the expected range of induced seismicity of events as small as Mw = -4, the Bedretto seismic network aims at recording events in the frequency range of a few tens of Hz up to some tens of kHz. At the same time high-frequency sensors show inherently a smaller signal sensitivity and vice versa. The design of the seismic network is thus a trade-off between the spatial density of sensors along the boreholes, the signal sensitivity and the frequency range.

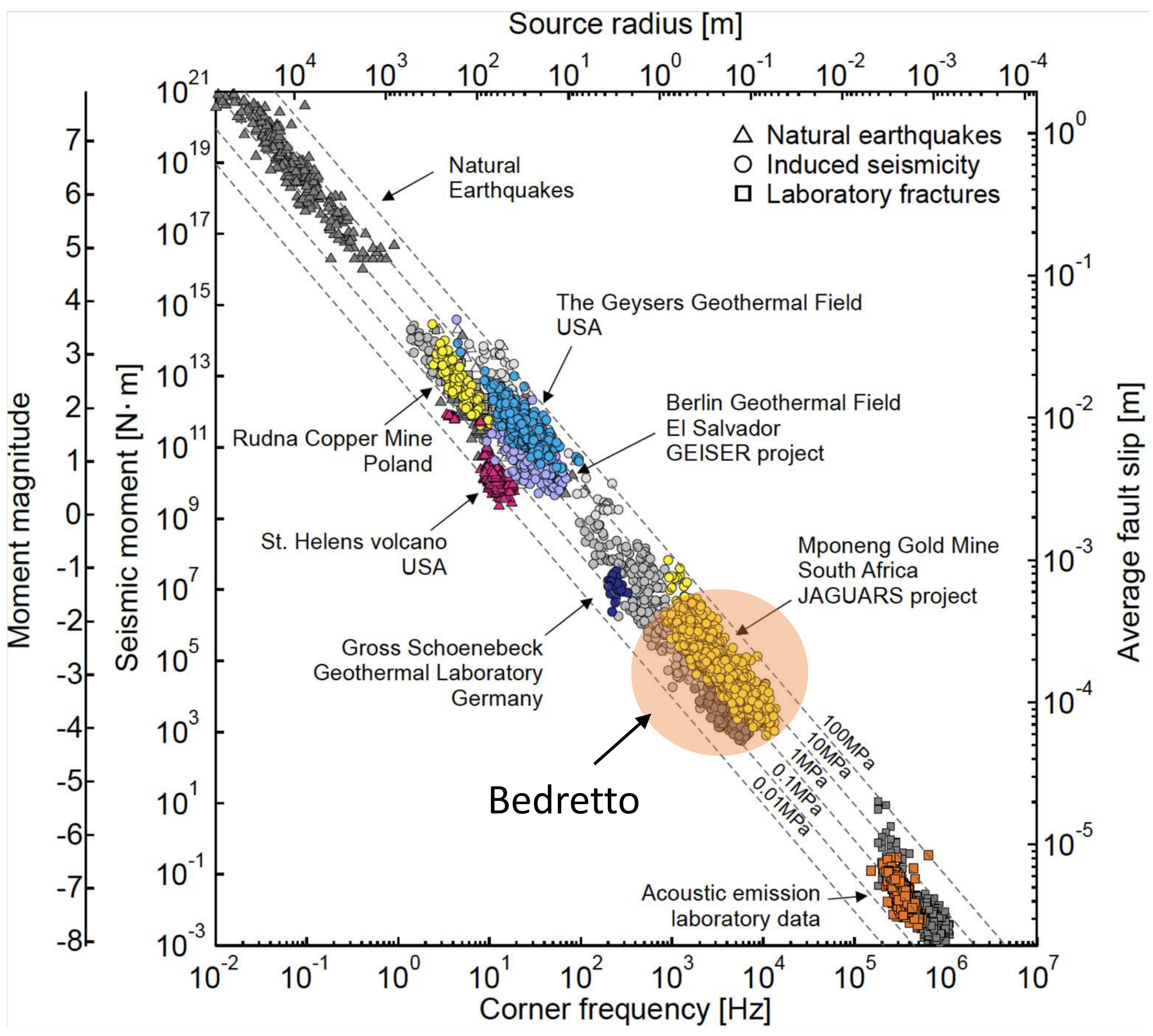

Figure 2: Dependence between seismic moment, moment magnitude, source radius, average faultslip, and corner frequency for natural earthquakes (gray triangles) in comparison with data from several studies in the low-magnitude range, both from surface exploration and underground experiments (from Manthei & Plenkers, 2018). The expected range of induced seismic events for Bedretto is shown as orange circle.

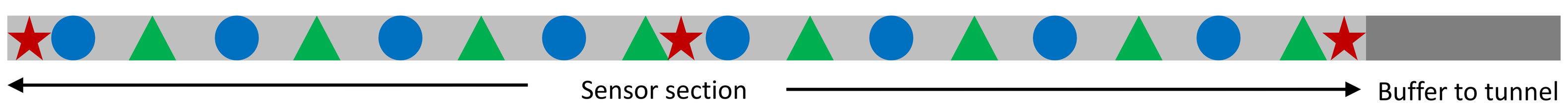

Figure 3: Conceptional instrumentation of a seismic monitoring borehole:
- 8 x high-sensitive acoustic emission sensors
- 8 x 3-component, calibrated accelerometers
- 3 x downhole sources per borehole for active tomography (piezo)

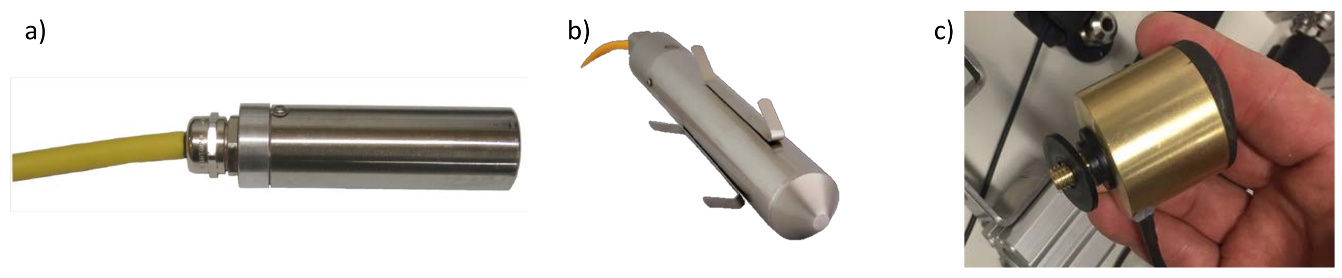

Figure 4: Candidate sensors to be used for the seismic monitoring network:
a) IMS 25 kHz accelerometer, frequency range: 2Hz – 25kHz, sensitivity: 0.1V/g
b) IMS 14Hz geophone, natural frequency: 14Hz, sensitivity: 56.1V/m/s
c) GMuG piezo acoustic emission sensor, frequency range: 50Hz – 35kHz

Network geometry

Our experimental setup includes a central stimulation borehole of 300m length, surrounded by a set of three monitoring boreholes at partly oblique angles to the stimulation borehole (Figure 5). The monitoring boreholes are directed such that the distance to the stimulation well increases with distance. The monitoring boreholes may be kept shorter than the stimulation borehole. This geometry allows the volume to be monitored at different resolutions: i) a high-resolution zone, fully surrounded by sensors at relatively short distances, ii) a transition zone, which is still partly surrounded by sensors at somewhat larger distances and iii) a remote zone, outside of the sensor coverage and at substantially larger distances.

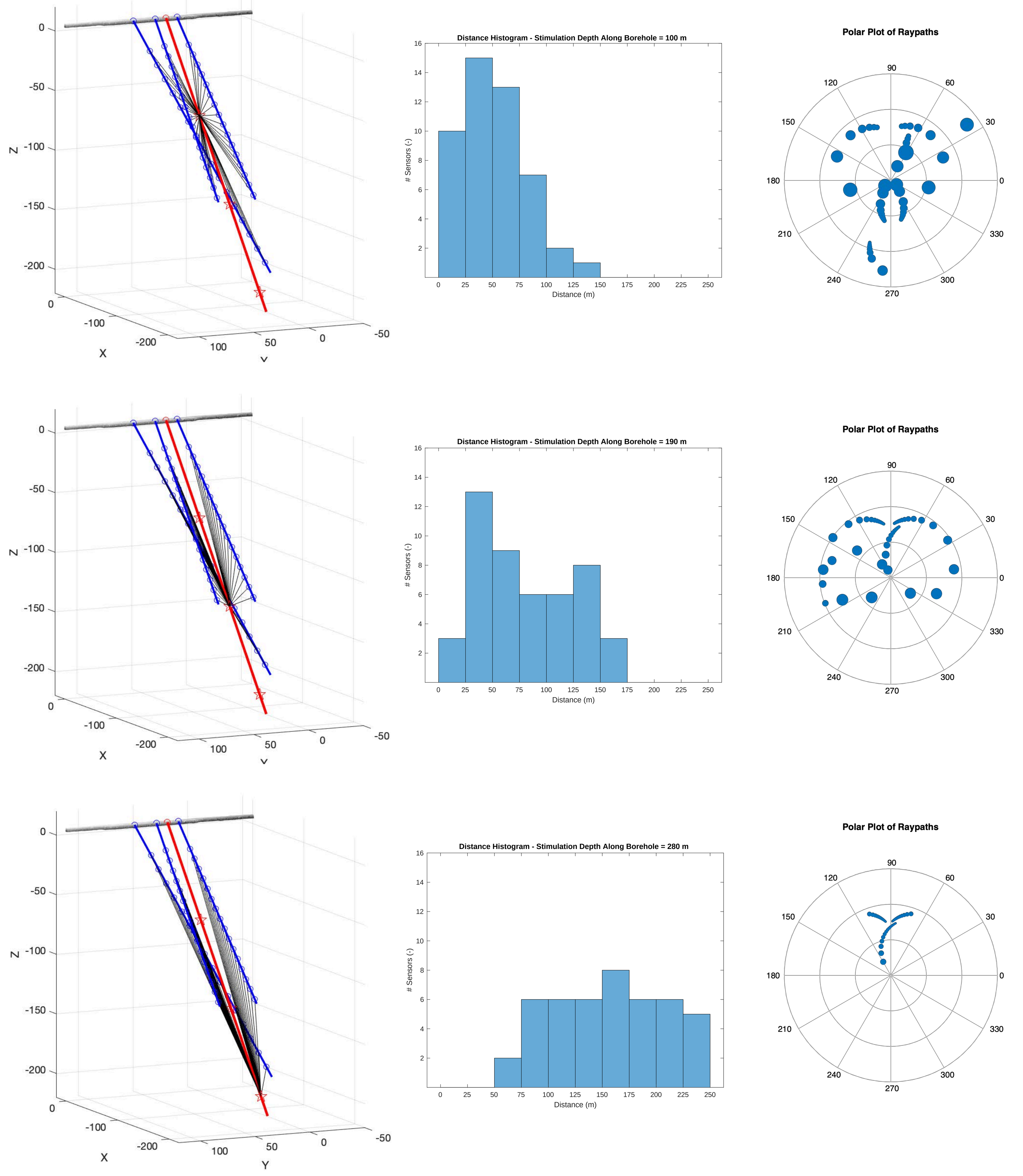

Figure 5: Ray-tracing for events at different locations along the stimulation well and the network of seismic sensors in three surrounding monitoring boreholes (left) together with the histograms of sensor distances (center) and the polar-plot of the individual seismic rays (right). Size of the circles corresponds to the source-receiver distance.

Tomography

Beyond passive observation of induced seismicity by hydraulic stimulation, changes to the rock volume by pressure changes can be monitored by tomography approaches with active sources (Doetsch et al., 2018). For this purpose a series of active sources are planned along each borehole (red crosses in Figure 6a). Exemplarily, the resulting ray-coverage for a three equally spaced sources and 16 equally spaced sensors are shown in Figure 6b.

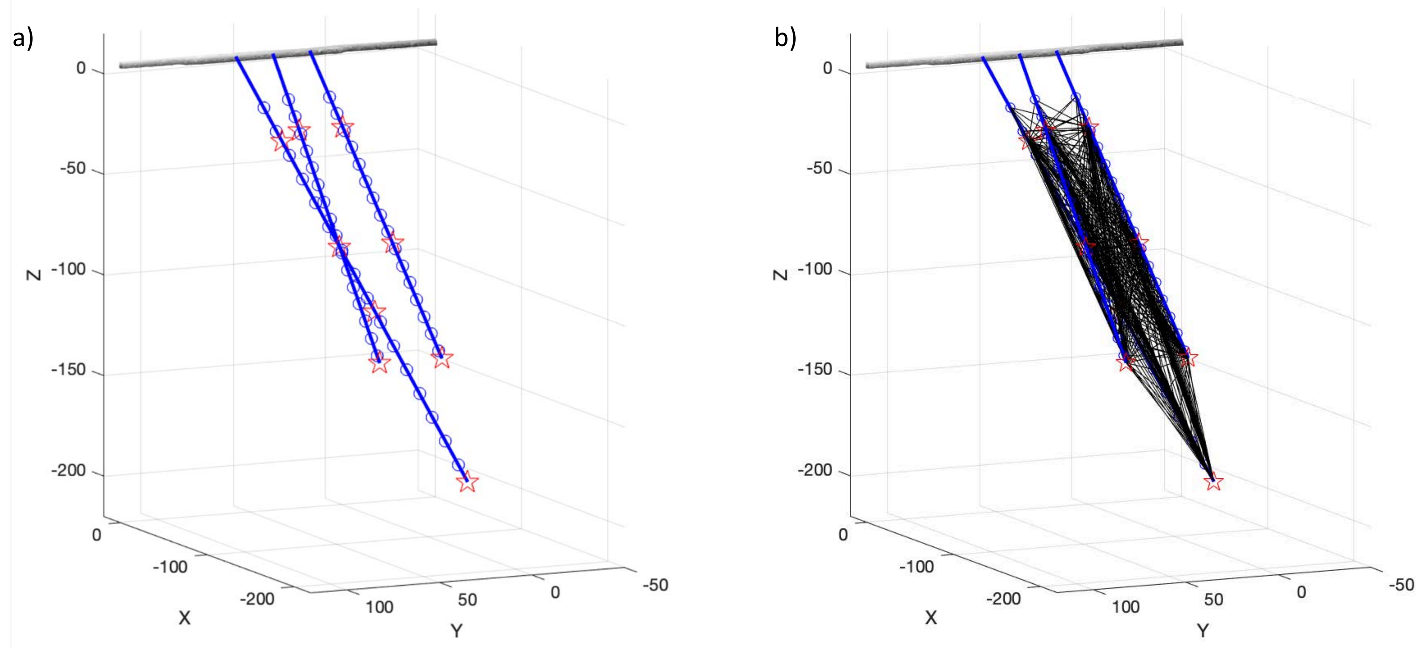

Figure 6: a) Geometry of source and receiver positions in the three wells and b) the resulting raytraces for all source-receiver combinations.

References

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