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The joys and woes of missing seismicity: the case of the Longyearbyen CO_2 Lab

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Due to its remoteness and closed energy system comprising a coal-fueled power plant powered by locally mined coal, the Longyearbyen CO_2 Lab project presents a unique opportunity to demonstrate the entire CO_2 value chain from source to geological CO_2 sequestration. The formation considered as potential reservoir consists of sandstone-siltstone layers at 672-970 m depth, overlain by ca. 450 m of cap-rock shale, presenting itself as under-pressured, unconventional reservoir where fluid injectivity is strongly influenced by tectonic fractures.

We show results from the analysis of data recorded on three different networks: the permanent Longyearbyen CO_2 Lab microseismic network comprising both shallow and deep borehole geophones, the temporary SEISVAL broadband seismometer network and the permanent SPITS array run by NORSAR. Due to the extremely high latitude location at 78°N, we encountered challenges not typical for other monitoring sites, e.g., harsh climate, digitizers exposed to a high degree to electromagnetic fields due to their installation in a cabin together with other equipment; difficult grounding of machinery due to permafrost; strong variations in seismic velocities due to the seasonally thawed active layer in the uppermost part of the permafrost; permafrost or transition layer to underlying rocks acting as highly attenuating layer, decreasing signal amplitudes recorded on shallow borehole sensors; constraints on the installation of instruments from environmental concerns; limitations on the placement of sensors during summer. Both the installation of instruments as well as methods of data analysis had to be adapted to these challenges.

Shortly after the first water injection test in 2010, a microseismic event ($M \sim 1$) was recorded and located close to the injection well, followed by a series of aftershocks. Later injection tests did not generate any detectable microseismic events; nevertheless, pressure and flow rate showed a pattern characteristic for fracture opening potentially indicating "aseismic" fracture propagation, in agreement with geomechanical testing and modelling.

However, microseismic monitoring has the disadvantage of only being applicable during periods of seismic activity. Therefore, we conducted a feasibility study to determine the applicability of noise-based imaging methods. The f-k analysis of continuous SPITS records shows distinct directional patterns with very abrupt seasonal changes: body wave phases dominate throughout the year (from southwest direction), but during the summer, a strong signal from surfaces waves invading from SSE becomes visible.

Zoback and Gorelick (2012) claim that the main threat to the integrity of CO_2 storage is that even small- to moderate-sized earthquakes triggered by injection of large volumes may break its seal. Thus, it is encouraging that most injection tests at the CO_2 Lab site did not produce microseismic events. Since only minor volumes (up to 100 000 tons of CO_2 per year) are envisioned to be injected into this severely underpressured aquifer capped by a thick and geomechanically robust cap rock, the lack of clear seismic signatures associated with water injection activity thus far confirms the feasibility of the storage site as a safe and viable CO_2 storage site.