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Mini-Seismic Methods for a comprehensive in-situ characterization of salt structures

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BGR developed a broad series of seismic, lower-band ultrasonic and ultrasonic in-situ methods (Mini-Seismic Methods, MSM) which were applied over the last 20 years in different national and international underground facilities, which cover all potential host rocks for final repositories for high-level heat producing radioactive waste. In Germany MSM-investigations were performed mainly in rock salt formations in three underground facilities at depths between 230 m and 930 m below ground, in the divisions Zechstein 2 (z2) and Zechstein 3 (z3). In both divisions several groups and formations were encountered and seismically characterized, e.g. anhydrite-bearing rock salt like Lamellenanhydrit 1 (z3HA1) till Bänderanhydrit (z3HA11) and Kaliflöz Staßfurt (z2SF).
Piezoelectric transducers and impact sources applied as seismic sources, whereas different 1- and 3-component piezoelectric transducers used as seismic receivers. 3-component piezoelectric transducers used to overcome the challenging full space conditions in underground situations (polarization analyses, hodograms). Transient recorders with up to 160 channels are used as recording systems. According to the used center frequencies of the seismic emitters (0.1 kHz – 100 kHz) spatial resolutions in typical rock salt formations allows a spatial resolution for P-waves between $\lambda p \approx 45$ m (rather conventional seismic) and $\lambda p \approx 4.6$ cm (borehole based interval velocity measurements). For S-waves the seismic wave lengths are between $\lambda s \approx 26$ m and $\lambda s \approx 2.6$ cm. Depending on the applied MSM and on the local site situation distances between 5 cm and 250 m are scanned. For example, typical values for the derived dynamic Young's moduli, measured at different scales, are between 37 GPa (z2HS1/zsHS2) and 76 GPa (anhydrite-bearing z3HA4 and z3HA7).
In our presentation we focus exemplarily on the following issues:
• Detection and characterization of Excavation Damaged Zone (EDZ) and Excavation disturbed Zone (EdZ) features with borehole based MSM but also with non-invasive MSM (refraction tomography). It seems that a differentiation between EDZ and EdZ features (extent and degree) can be derived. These are additional information for geomechanical modellers.
• Borehole disturbed Zones (BdZ). Interval velocity measurements with an appropriate evalution give an unique opportunity to characterize these feature, which are of relevance for any other borehole based method, e.g. geotechnical investigations like permeability measurements.
• Differentiation between rock salt groups.
• Seismic anisotropy. In-situ MSM results at different scales show clear indications for the existence of seismic anisotropy.
• Sensitivity studies for the detection of brain or gas inclusions, e.g. with XHM.
• P- and S-wave velocities, combined with additional site information (e.g. density) used to assess the porosity of rock salt.
• Further aspects: derivation of dynamic elastic moduli, influences of seismic velocity dispersion and comparison of Young's moduli, derived in-situ (dynamic elastic) and derived from core material in laboratories (static elastic). These investigations aim to contribute to actual approaches to reconcile static and dynamic elastic moduli.
• Wide angle reflections are used for structural characterization.
MSM, especially the non-invasive ones, are quick employable, robust and cheap tools, which allow a reliable access to relevant basic geomechanical rock properties.