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Non-invasive detection of fractures, fracture zones, and rock damage in a hard rock excavation — Experience from the Äspö Hard Rock Laboratory in Sweden

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ABSTRACT

A key requirement for licensing of the construction of underground repositories for nuclear waste is the demonstrated capability to verify design assumptions involving the presence and extent of the excavation damage zone around tunnels, shafts, emplacement holes and caverns. As part of ongoing work to select and refine key technologies and techniques towards this end, geophysical surveys were performed at two locations within the Äspö Hard Rock Laboratory in Sweden. Earth resistivity (RES), induced polarization (IP), and Ground Penetrating Radar (GPR) data were collected using a variety of survey parameters; Light Detection and Ranging (LiDAR) data were collected as a reference for surface structures, surface topography, and site geology. Based on an analysis of the data, models for the Highly Damaged Zone (HDZ) and Excavation Damage Zone (EDZ) at both sites were developed. The HDZ was found to be approximately 5 to 10 cm in thickness, and the EDZ was found to extend between 15 and 35 cm below the excavation surface. Two-dimensional (2D) RES profiling generated the most reliable assessment of the HDZ, whereas chargeability data and GPR data were more useful in the estimation of the EDZ dimensions.

1. Introduction

The long term safety case for an underground nuclear waste repository is based in large part on the management of the zones of damaged rock around excavations and shafts. These can form pathways for advective or diffusive radionuclide release and transport beyond the repository rooms and can create short circuit pathways along backfilled shafts. The Excavation Damage Zone (EDZ) and Highly Damaged Zone (HDZ) are areas where micro-scale and macroscopic fractures develop, respectively, around underground openings due to construction-induced damage and stress re-distribution. The definitions of EDZ and HDZ used in this paper are (Diederichs et al., 2013):

- Excavation Damaged Zone (EDZ) — region of inelastic but discontinuous induced fractures or non-interacting displacements on existing structure. Intensity of damage increases towards the excavation surface.
- Highly Damaged Zone (HDZ) — region of discrete and continuous macro-fractures and/or opening or slip along existing structures due to unloading and associated strains during void creation. May exist without any construction induced damage.

The understanding, prediction, identification, management, and monitoring of these zones are of importance to those developing excavations with strict design requirements, as relatively small amounts of damage can lead to issues. In particular, the development of EDZ and HDZ contributes to the decreased excavation stability in both the short and long terms, as well as increased rockmass permeability (Bossart et al., 2002). In the case of nuclear waste storage in deep geological repositories, these issues are of significant concern due to the potential flow pathway along the HDZ/EDZ (Diederichs et al., 2013; Tsang et al., 2005) and the degree of damage needs to be identified to verify design parameters.

In a perfectly homogenous, isotropic medium, where all damage is induced by stress redistribution (i.e. the construction process itself induces negligible damage), gradational zones of damage can be expected to develop, with the degree of damage decreasing away from the excavation as the stress concentration decreases (see Fig. 1). Where natural fractures exist and/or damage is generated by the construction process, it is difficult to predict how new fractured zones might develop. In particular, micro-scale EDZ damage may irregularly clump around macro-scale HDZ fractures or natural fractures, and this damage may be due to highly local stress concentrations, or due to dynamic loads associated with construction.

Drilling, either to obtain core samples from near the boundary of an excavation or for the installation of down-hole equipment to determine

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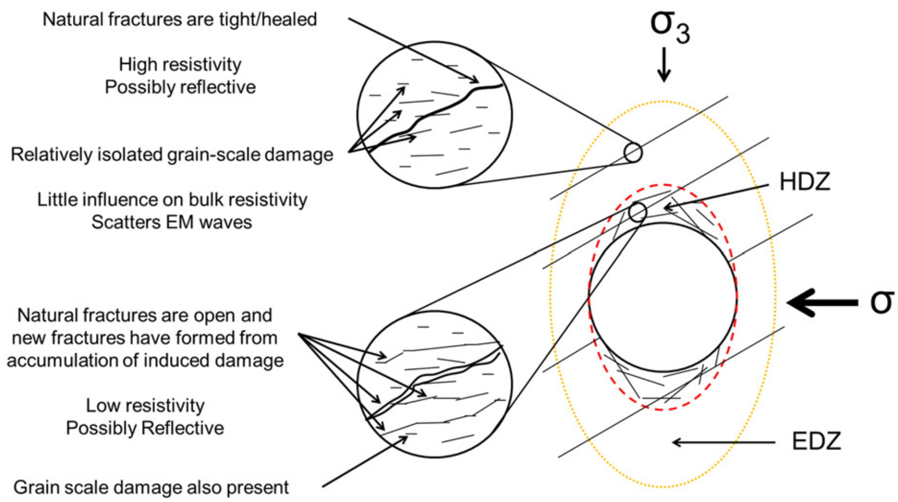

Fig. 1. Schematic diagram illustrating a simple conceptual model for HDZ/EDZ with potential influences on some physical properties of interest described; note that σ_1 and σ_3 represent the major and minor principal stresses, respectively.

HDZ/EDZ dimensions can lead to further damage (Souley et al., 2001). Therefore, there is a desire to develop efficient and non-invasive methods for characterizing and monitoring the EDZ and HDZ. Geophysical methods have already been demonstrated as useful tools for non-invasive EDZ/HDZ detection. A large amount of research has been conducted on the use of active and passive seismic methods for this purpose (see Carlson and Young, 1993; Cabrera et al., 1999; Backblom and Martin, 1999; Cosma et al., 2001; Alheid et al., 2002; Malmgren et al., 2007, for example). Ground Penetrating Radar (GPR) and resistivity methods have shown potential in a few isolated studies, although their use requires further testing and development (Scott et al., 1968; Kruschwitz and Yaramanci, 2004; Suzuki et al., 2004; Gibert et al., 2006; Silvast and Wiljanen, 2008; Kantia et al., 2013; Lesparre et al., 2013). This study aims to further test these methods through the comparison of multiple different data sources to test for consistency of the results obtained. Also, by providing a systematic evaluation of the influence of some resistivity survey parameters, the authors aim to provide guidelines for future geophysical surveys used for similar applications.

2. Test sites

In October, 2012, geophysical surveys were performed in two niches at the Äspö Hard Rock Laboratory (HRL), 20 km North of Oskarshamn, Sweden. The niches (NASA 2376A and NASA 2715A) are located at depths of 315 m and 358 m below surface level, respectively (Fig. 2). Both sites were constructed in Äspö diorite, a fine to medium grained igneous rock with ~1 cm potassium-feldspar megacrysts, and some fine-grained granite present in dykes and veins. The diorite has 0.4% porosity and the granitic dykes have 0.2% porosity (Johansson et al., 1998). Although it is difficult to estimate the porosity increase expected in the

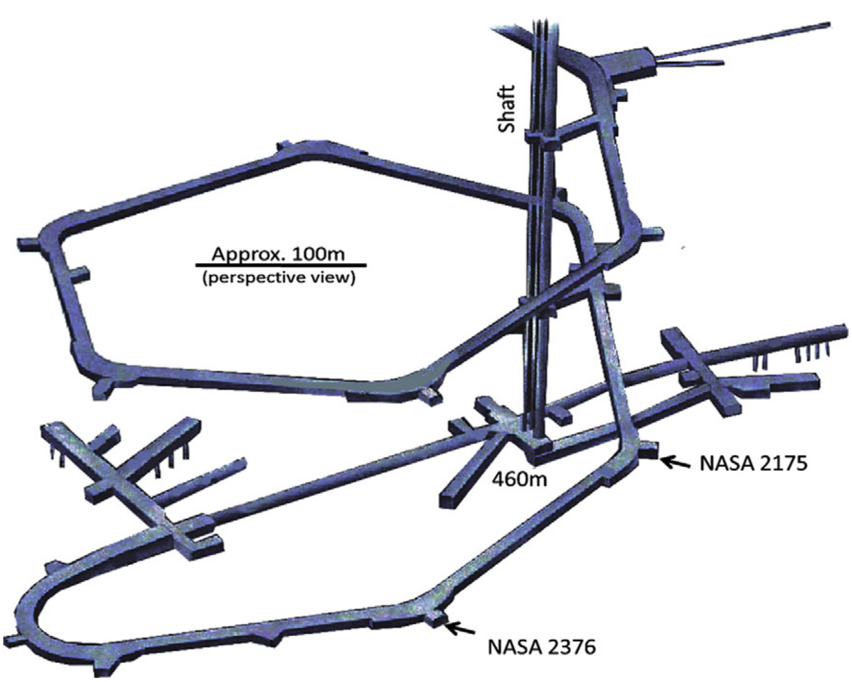

Fig. 2. Perspective view of Äspö laboratory layout with the two niches (NASA 2715 and 2376) marked for this study.