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BeFo 382 - Detailed Comparison Study of 3D-characterized Rock Mass and Geophysical Models

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Introduction

Geophysical measurements and geophysical models are commonly used tools for cost-effective mapping of geological macro- and microstructures, such as spatial variations in soil and bedrock. However, the validation of geophysical models are often based on relatively few drillings or soundings. Due to the scarcity of validation information, there often remain invalidated regions in the geophysical models, which is especially problematic for heterogeneous geologies. Furthermore, in some cases it can be difficult to compare the low-volume, linear, information from boreholes with the geophysical models since they represent the subsurface at different scales and with different dimensionality. Thus, there is commonly a lack of knowledge on how geological macro- and microstructures in heterogeneous rock can be imaged with geophysics. To improve this understanding, it is necessary to have dense geological verification information of the volume corresponding to the volume investigated with geophysics, and of the same spatial (and temporal) resolution, or higher.

This paper presents a study where resistivity and integral chargeability three-dimensional (3D) models, representing a volume in the vicinity of a rock quarry (Figure 1), is compared to a quasi-3D characterization of rock mass volume. By repeating the geological mapping of the rock wall as the quarry operation reaches further into the rock volume mapped with geophysics, we retrieve a semi-continuous geological characterization of the same rock mass volume characterized by the geophysical investigations. This enables a detailed comparison between geophysical results and rock volume, where factors such as fracture and weathering zones or rock type is being considered.

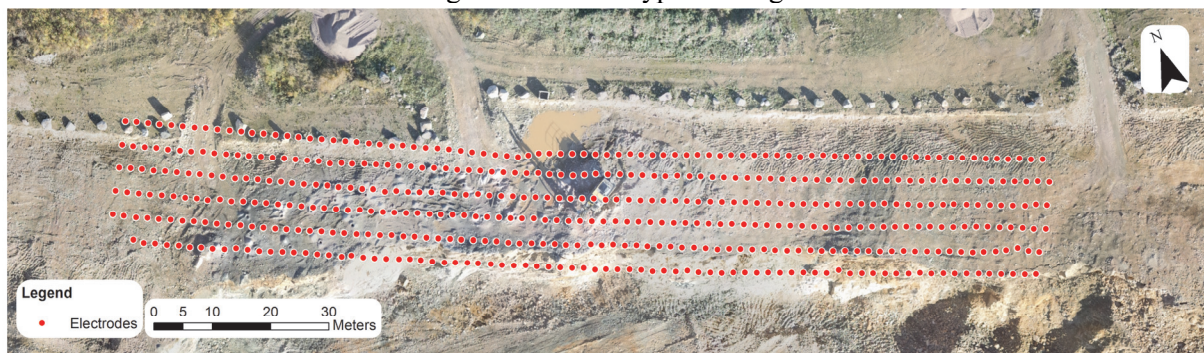


Figure 1. Aerial orthophoto of part of the rock quarry acquired approximately half a year after the geophysical investigations were performed. Positions of the electrodes used for the geoelectrical measurements are shown as red dots.

Geological setting

The investigated quarry is situated on the horst Romeleåsen in Southern Sweden. The horst consist mainly of Precambrian granitic gneisses and amphibolites that are cut by NW-SE trending Permian mafic dykes. With exception for the young dykes all rocks have been intensely deformed. Larger amphibolite bodies are generally lens shaped. Locally the rocks show extensive hydrothermal alteration and zones of brecciated rocks are relatively common. To gain petrological and petrophysical information, rocks have been sampled along the geophysical profiles and representative samples from drill cores from other parts of the quarry are also being used. The groundwater levels in the area are artificially controlled and are expected to be well below the maximum investigation depth of this study.

Rock documentation: Gigapixel panorama, drone-based 3D model and geological interpretation

The rock in the quarry is being exploited for construction aggregate by blasting in benches, leaving vertical walls about 18-20 meters high after each rock break, the propagation being around 5 meters. After removal of the resulting muck pile, the rock wall is exposed and can be documented.

Documentation of a rock wall of this type is potentially dangerous due to the danger of falling rock from unstable parts of the bench face. Since the 1990s the fast development of digital photography has resulted in widespread adoption of safer ground based photogrammetric methods, often assisted by the likewise quickly developing lidar technology, and these methods should today be considered to be standard methods (Lato and Vöge, 2012). Being ground based, these methods provide high resolution but since they typically need accurate positioning of the equipment and sometimes control points on the rock wall, the measurements can be time consuming. During the first decade of the century, the use of airborne close-range photogrammetric methods has become feasible. These make it possible to create a three-dimensional, scaled, terrain model without the need to specify a priori control points with known loci. Instead, extracted features from multiple overlapping images are used to create a point cloud describing the geometry of the mapped surface, associated with photographic information. In combination with an unmanned aerial vehicle (AUV), this provides a cost effective alternative to ground based mapping. An early UAV adaptation to describe landslide morphology was done by Niethammer et al. (2012), and one by Westoby et al. (2012) where consumer grade ground based cameras were used for rock wall and terrain mapping but the method is now widely accepted and the number of reported implementations is rising quickly. A recent overview of the subject is given in Carrivick et al. (2016).

In this study, two approaches relating to photogrammetric mapping of the rock mass are used. In each quarrying work cycle, after removal of the muck (see above) the rock wall is photographed with a 36.3 MP digital camera (Nikon D800E) using a robotic panorama head (GigaPan Epic Pro) that facilitates the aiming of the camera, and makes the process of image acquisition repeatable. The choice of lens is still a work in progress but a 500 mm Hasselblad long focal as well as a Nikon 70-210/f4 zoom lens are under evaluation. In the mosaic showed in this paper, 16 by 38 images have been used to produce an image with ~184'000 by 51'000 pixels (~9 GP and 0.5 millimeter per pixel, Figure 2, top), using the commercially available software PTgui pro (v. 10.0.16).

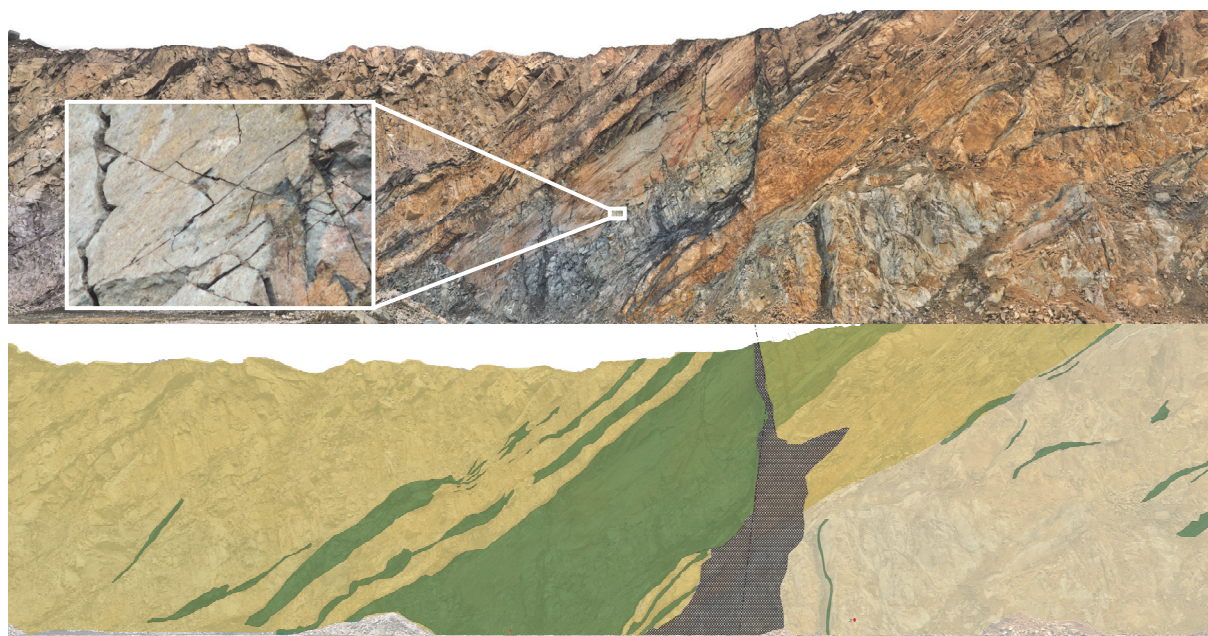


Figure 2. Example of a stitched panorama and a magnification exemplifying the amount of detail available (top). Example of an interpretation of the geology of a rock wall in the Dalby quarry (bottom). Granitic gneisses are shown in yellow-brown and amphibolites in green. The Olive-green amphibolite is altered and rich in biotite. The rocks in the dark brown area are brecciated along a fault (red and black dotted lines). The width of the panorama is approximately 80 meters.

The rock wall is also mapped by an UAV with a 20 MP camera, where typically around 400 still photographs are used to produce a point cloud with three-dimensional information about the rock wall and its surroundings. The point cloud is used to construct a mesh, upon which the texture from the photographs is projected (Figure 3). The software used is Pix4D, but also Photoscan by Agisoft is being

considered for this purpose. So far, the conclusion is that image mosaicking with long telephoto lenses makes the acquisition sensitive to vibrations from e.g. machinery in the quarry and wind, and that the focal depth in these lenses is limited which calls for frequent adjustments of the focus. The UAV images have a lower resolution, and smaller macrostructures cannot be seen. After a first comparison to the geoelectrical measurements, it is likely that it is possible to see larger geological structures on par with what is visualized in the geophysical measurements, and to correlate them to anomalies. However it is still unclear whether microstructures that potentially can affect the petrophysical characteristics of the rock can be mapped or not.

Geophysics: Resistivity and induced polarization 3D tomography

The resistivity and IP tomography measurements were carried out as in-line measurements in six parallel profiles (~160 meter long) with approximately two meters between inline electrodes and four meters between the profiles (Figure 1). At the time of the geophysical measurements, the bedrock was covered by a layer of till (~0 to 2 meters) and the closest distance to the bench wall was approximately 37 meters. A Terrameter LS with modified input filters was used for measuring potentials and for transmitting a 100% duty-cycle current with a pulse duration of four seconds. Resistivity and integral chargeability (0.014 to 3.7 s) data were extracted from the full waveform recordings using recent developments in full waveform signal processing (Olsson et al., 2016). The pre-processed field data were inverted with robust L1-norm and vertical, horizontal, diagonal and cross-diagonal regularization in Res3Dinv (v. 3.11.62) for a subsurface discretized in 160 by 20 1x1-meter horizontal cells and 13 layers with log-increasing cell depth. Figure 3 shows resistivity and integral chargeability inversion models together with the texturized UAV based terrain model.

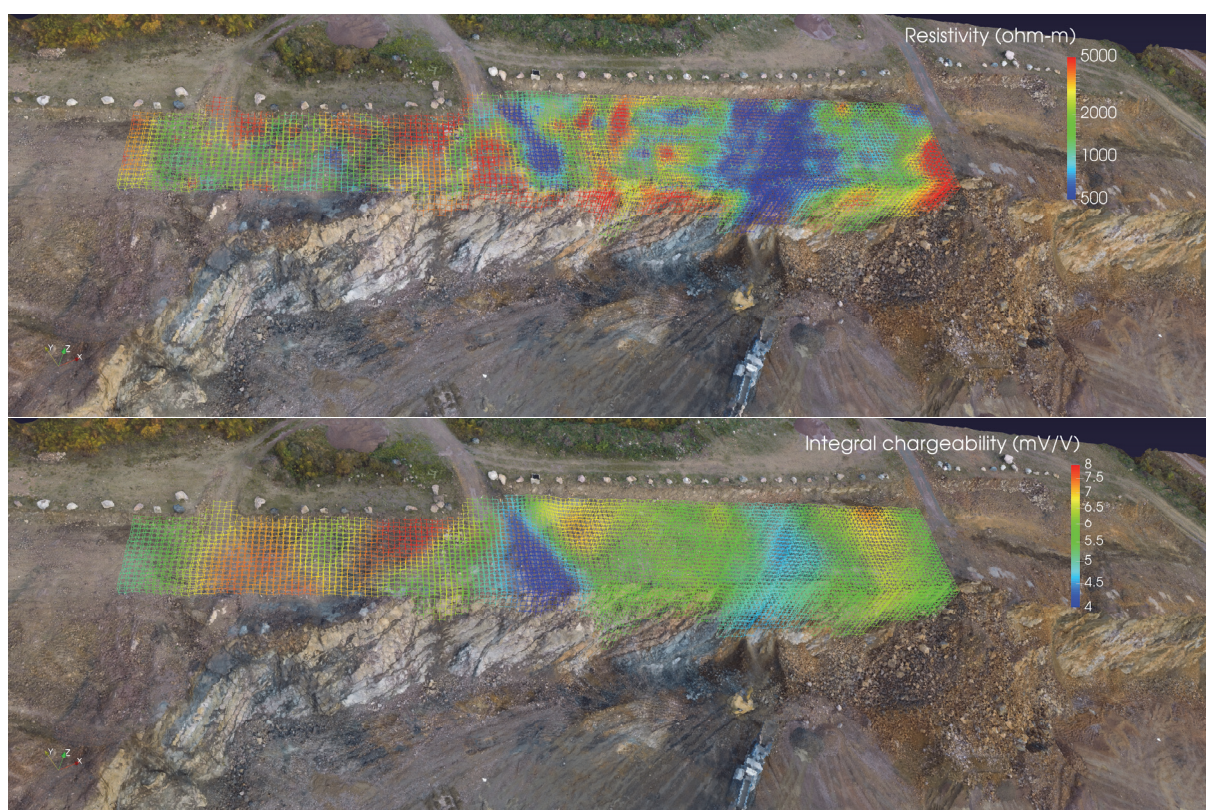


Figure 3. 3D visualization of resistivity (top) and integral chargeability (0.014 to 3.7 s, bottom) inversion models together with texturized mesh model from the UAV mapping.

At the time of print of this paper, the quarrying has reached only a few meters into the geoelectrically imaged rock volume. As can be seen in Figure 3, it is mainly the southeastern most part of the geophysical volume that has been exposed so far. A preliminary interpretation of the resistivity and

integral chargeability models in this region has been made based on the likewise preliminary geological interpretation (Figure 2, bottom) of the high-resolution panorama (Figure 2, top). It is likely that the prominent low resistive zone striking diagonally across the eastern part of the resistivity model (right blue in Figure 3, top) corresponds to the brecciated zone (Figure 2, bottom). This zone also gives rise to lower integral chargeability values compared to the surrounding rock (Figure 3, bottom). The underlying reasons for these geophysical signals are still not fully resolved. Low-resistive zones corresponding to fractured zones are often explained by high groundwater content (see e.g. Danielsen and Dahlin, 2009) but at this site, the groundwater level is expected to be well below the investigated rock volume. However, it is possible that the brecciated rock holds residual water also in the unsaturated zone, which would give rise to a lower resistivity than the less alternated surrounding bedrock. The petrological and petrophysical samples that were collected along the rock wall could give also indications of possible mineralization that may explain the geophysical response.

Outlook

The documentation of the rock volume following each propagation in the quarry will continue to update the rock model with mapped geological structures and material data. This model can then be compared with the geoelectrical parameter models by geometrical and statistical or possibly by applying image analysis methods and machine learning. One issue that needs to be addressed is related to the different resolutions of the geological data (millimeters) and geophysical models (meters) but this could possibly be overcome by conducting geophysical lab measurements on rock samples from the quarry. Another possible issue is related to the anisotropy of the geophysical parameters. Since there are several inclined and deformed geological structures and units in the investigated volume, it is likely that the assumption of isotropic geophysical parameters is not valid for all model cells.

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