Geophysical and Hydraulic Properties in Rock

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SUMMARY

An extensive database with data from southern Sweden invites for a thorough investigation of the geophysical and hydraulic properties. In the first attempt to find a relation between geophysical and hydraulic properties the information from core drillings and CVES are used. The records from the drillings include lithology, weathering and hydraulic conductivity. From the inverted CVES profiles separate soundings are extracted at positions close to the core drillings.

The results from the investigation are not easy to interpret. Some drillings and resistivity soundings shows good correlation and some do not. The problem might be that the resistivity measurements have a too low resolution compared to the very detailed observations from the core sample. Another problem could be that the core drilling and resistivity sounding most likely are made at positions close to each other but not the exact same place.

As expected this type of investigation is too simple for a complex relationship as the one that might exist between geophysical and hydraulic properties. It shows the importance of further investigations of existing and new data.

Introduction

Large efforts are put into finding a relationship between geophysical and hydraulic properties (de Lima and Niwas, 2000; Guérin, 2005; Heigold et al., 1979; Kosinski and Kelly, 1981; Kowalsky et al., 2004; Linde, 2005; Purvance and Andricevic, 2000; Slater and Lesmes, 2002). No general petrophysical relationship between electrical conductivity and hydraulic conductivity exists, which is not either too simplified to be useful or does not assume unrealistic details in the available information about the rocks (Linde, 2005). An extensive database with data from southern Sweden invites for a thorough investigation of the geophysical and hydraulic properties.
The extensive database exists because of problems with rock properties at construction of a railway tunnel in southern Sweden. In 1992 the construction of an 8.6 km long twin-track tunnel was initiated. Only one third of it is completed so far because of severe problems with clay weathered zones and high water pressure in fractured water bearing rock. During the years the difficult conditions have resulted in extensive use of geophysical methods and hydrological measurements. In all there exists a substantial amount of data from the area. These data should give a good basis for finding a link between geophysical and hydraulic properties of the rocks.

Method

During the last 15 years there has been measured more than 20 km of CVES, 25 km VLF, 6 km Slingram, 15 km magnetic surveys, several TEM soundings and 15 km seismic refraction. Additionally the ground water level has been measured twice a month in 80 shallow wells. There are more than 100 deep wells and 50 core drillings. Since year 2000 there is manually measured stream discharge twice a month at 15 observation points scattered at 7 small streams. Of these 15 observation points 6 have also been measured automatically once an hour. Pumping tests and different well loggings have been conducted and the precipitation is measured daily.
In the first attempt to find a relation between geophysical and hydraulic properties the information from core drillings and CVES are used. A motivation for finding a link between the geophysical properties and the properties of the rock is that is would enhance the possibility to save money by doing the more cost efficient geophysical measurements instead of the expensive core drillings. More important is that CVES gives a continuous cross section whereas the core drillings are point observations.
The records from the drillings include lithology, weathering and hydraulic conductivity. Lithology and weathering are based on visual interpretation made by the site geologist. The weathering is given with values from 1 to 5, where 1 is fresh rock and 5 is highly weathered rock. The hydraulic conductivity is measured in intervals of 5 to 10 meters. The position and length of the intervals are based on the geology and the possibilities for placing the packer used for the measurements. The CVES profiles were measured with an electrode spacing of 5 or 10 meter and a layout of 400 or 800 meter. The penetration depth is around 60 meter for.

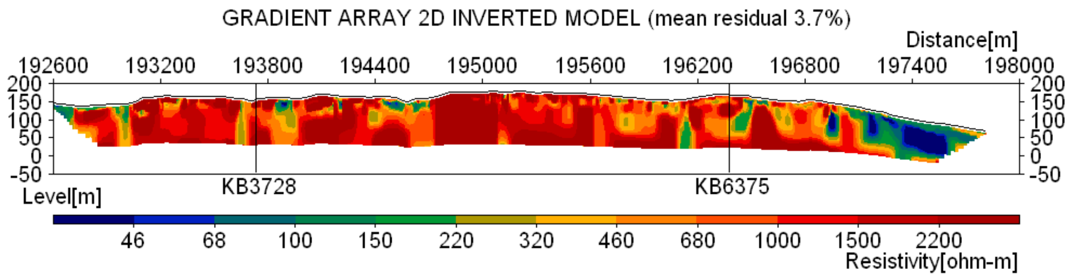

Figure 1. The CVES profile used for the extraction of resistivity soundings. KB3728 and KB6375 are core drillings.

the former and 120 meter for the latter. The data is inverted using the program RES2DINV From the inverted CVES profiles separate sub-models are extracted at positions close to the core drillings. Figure 1 shows an example of a CVES profile used for the extraction of models. The profile is part of a longer profile and was measured with layouts of 800 meter. The extraction resulted in a multiple layer model where the layer thickness is controlled by the inversion program. All information is plotted as a function of depth.

Results

Nine core drillings were found to be adequately close to the resistivity profile for a comparison. In figure 2 the data are shown for core drilling KB6375 and for a resistivity

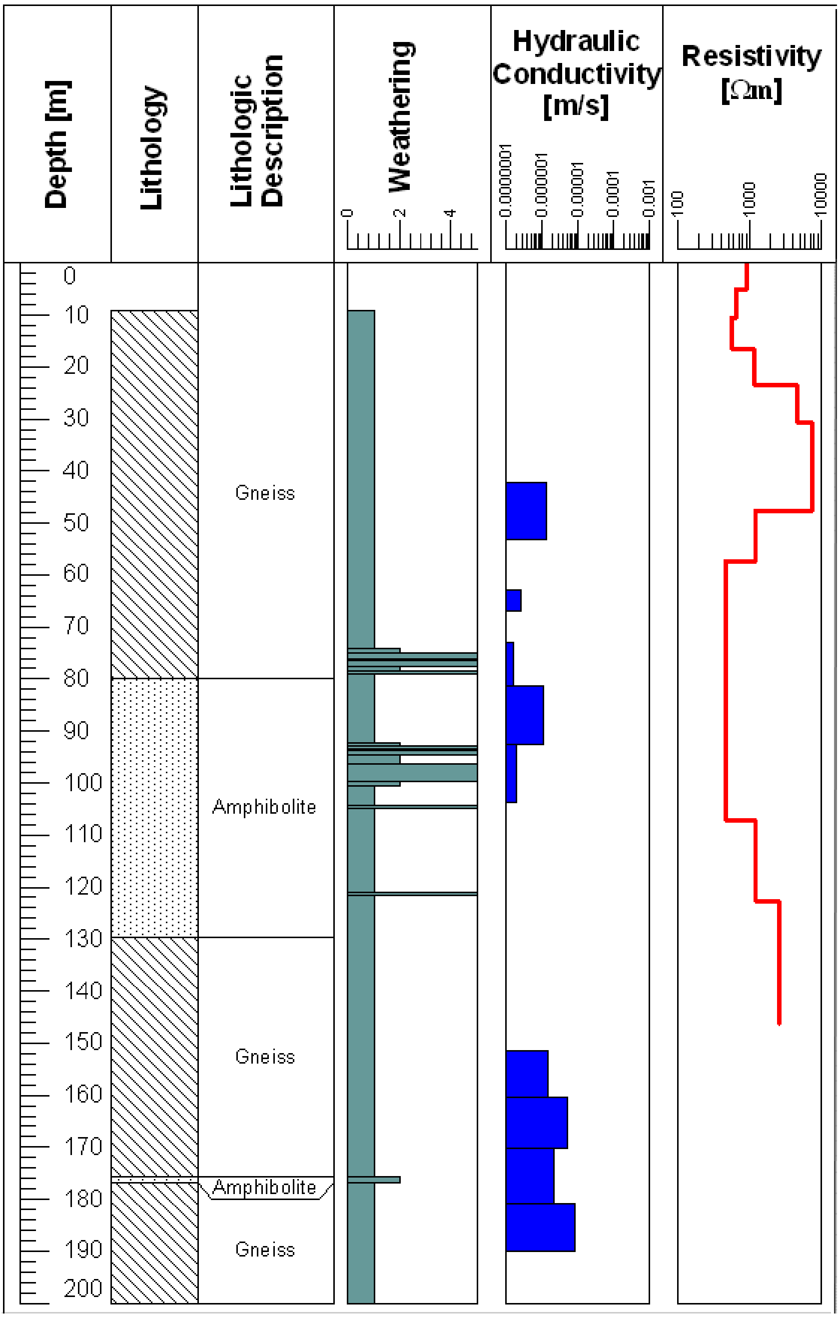

Figure 2. Data from core drilling KB6375 and extracted resistivity model at 196375.

model extracted at the same position, with coordinate 196375 at the resistivity profile in figure 1. The drilling is 200 meter deep and penetrates gneiss and amphibolite. Most of the core is appraised to be fresh rock. In the depth of 75 to 80 meters and 95 to 105 meters there are thin layers which are highly weathered (class 5). The hydraulic conductivity is measured to lie between $1.1 \cdot 10^{-6}$ m/s and $1.5 \cdot 10^{-6}$ m/s in the intervals at 42 to 53 meter, 81 to 92 meter and 155 to 190 meter. The resistivity model in the right side of figure 2 shows resistivities between 500 and 1000 Ωm to a depth of 25 meters. Between 25 and 50 meters the resistivity is more than 1000 Ωm. In the interval between 50 and 110 meters the resistivity is close to 300 Ωm. Figure 3 shows the data from KB3728 and the resistivity model at that position corresponding to coordinate 193728 at the resistivity profile in figure 1. The drilling is 190 meter deep and penetrates gneiss with several thin amphibolite layers. The core consists of thin horizons which are slightly weathered (class 2). In the depth intervals from 100 to 105

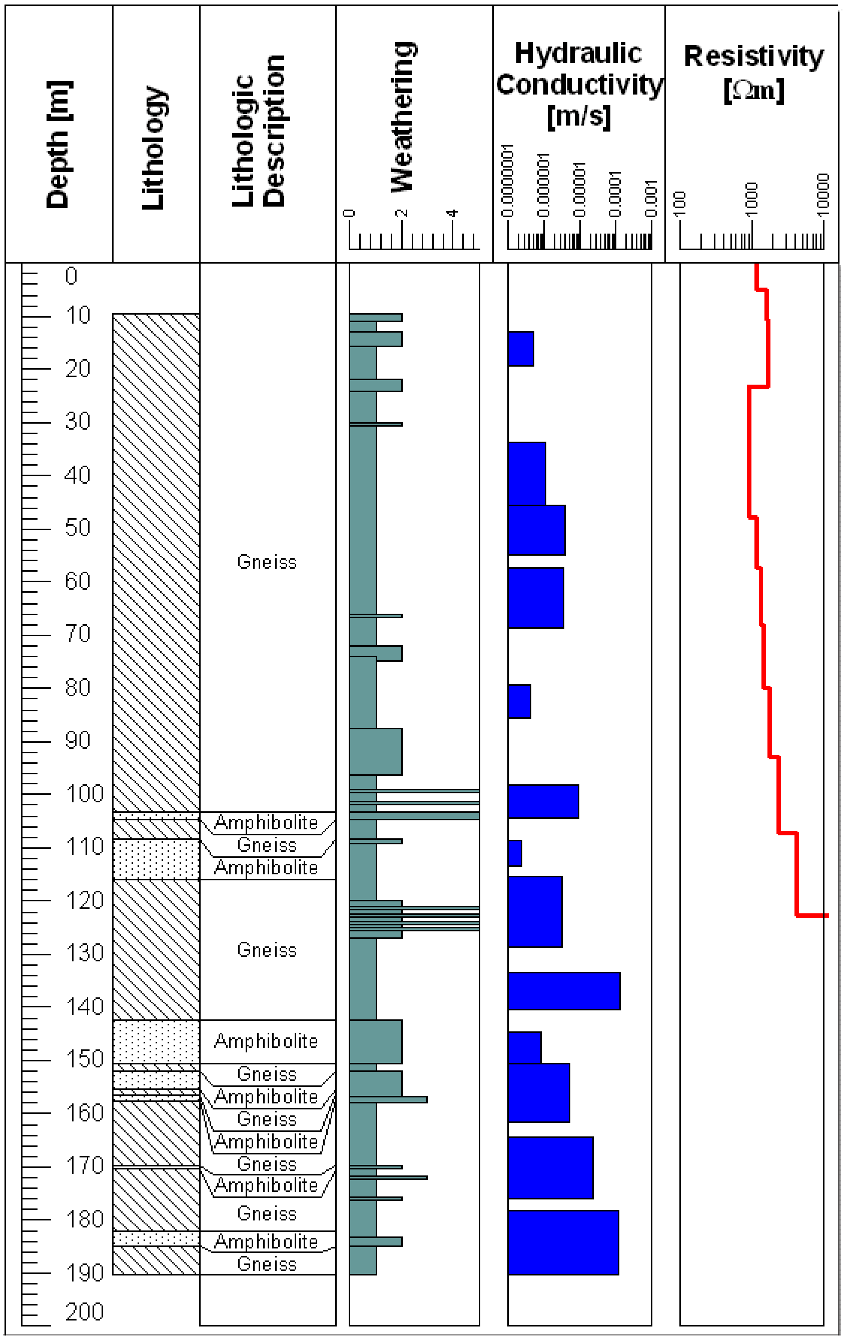

Figure 3. Data from core drilling KB3728 and extracted resistivity model at 193728.

meter and from 120 to 125 meter there are thin layers with strong weathering (class 5). The hydraulic conductivity increases with depth from values of $5 \cdot 10^{-6}$ m/s to $1 \cdot 10^{-6}$ m/s. To the right in figure 3 the resistivity is shown. The first 25 meters the resistivity is 1600 Ωm. In the depth of 25 meter the resistivity decreases to 900 Ωm. With increasing depth the resistivity increases to a value of more than 10.000 Ωm at a depth of 120 meter.

Discussion and Conclusions

The results presented are not easy to interpret. KB6375 has low resistivity in the intervals with high weathering. This is expected because clay weathered rock has a lower resistivity then fresh rocks. KB3728 has an increasing resistivity even though the rock is weathered and there is an increased inflow of water. This result does not agree with the expectations. Examination of the seven other core drillings (not shown here) shows that some lives up to the expectations and some do not. There is no obvious connection between the information from the core drillings and the resistivity soundings. The problem might be that the resistivity measurements have a too low resolution compared to the very detailed observations from the core sample. It should also be taking into consideration that there is likely to be 3D effects in the resistivity measurements. Another problem could be that the core drilling and resistivity most likely are made at positions close to each other but not the exact same place. The geology being so complex with fractures and weathered rock makes these feasible explanations.
As expected this type of investigation is too simple for a complex relationship as the one that might exist between geophysical and hydraulic properties. It shows the importance of further investigations of existing and new data. For the further investigations within the area an additional field campaign with a combination of methods is planned in the summer 2006.

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