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# Geoelectrical and IP Imaging Used for Pre-investigation at a Tunnel Project

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## SUMMARY

At a large tunnel project in Southern Sweden a number of geoelectrical and IP imaging were carried out. The tunnel is drilled through a horst with a complex geology which includes fractures, high water content and weathered zones. The measurements where carried out to compile a geologic model to use in the further planning of the project. The resistivity and IP complements each other very well since they focus on different specific characteristics. IP proved to be useful at locating dolerites and resistivity was useful for the general distribution of fractures. An advantage is that with the seven-channel Lund Imaging system both types of data can be measured in a fast and cost efficient way. Magnetic measurements are a good supplement to pinpoint the exact position of the dolerite. Based on the general geologic information, resistivity and IP measurements recommendations can be given on where to drill in order to improve the geological model.

## Introduction

When constructing tunnels and other large rock projects in Sweden the preferred method for the pre-investigations has traditionally been drillings. Drillings gives point information and in a complex geology this is not sufficient for a reliable engineering geological model. Therefore continuous geophysical measurements should be performed prior to drillings with the purpose to make a targeted drilling campaign and perhaps even reduce the number of drillings. Previous research carried out by Dahlin et al. (1999) showed good results from a combination of resistivity imaging, core drilling and geophysical logging used at the Hallandsås Horst, Sweden. Rønning (2003) investigated the usefulness of geophysical methods in the early stages of construction work and concludes that 2D resistivity investigations often is better and more cost efficient than traditional refraction seismic. At a tunnel project in Southern Sweden geoelectrical and induced polarization (IP) measurements has been performed together with ground based magnetic measurements. Based on this information a geological model is compiled to be used in the further planning of the tunnel construction.

## Geological setting

The tunnel is made through the most northern of the Scanian horsts. Gneisses of presumably intrusive origin dominate in the area. Amphibolites of several generations occur where the oldest often is seen as minor layers or schlieren in the gneiss. The bedrock is intruded by a set of young dolerite dykes that run in the same direction as the Scanian horsts. These dolerites are steeply standing dykes which can have a width up to 50 metre (Wikman & Bergström, 1987). The dolerite dykes are seen as very distinct linear positive anomalies on the aeromagnetic map (Swedish Geological Survey, 1981). A substantial deep weathering of the bedrock began under Triassic and periodically continued under Cretaceous. This resulted in a clay-weathering to i.e. kaolin. The weathering is documented in core drillings from the area. In the core drillings is it also clear that there is often secondary mineralization such as chlorite development in the fractures (Wikman & Bergström, 1987).

The horst is an important groundwater reservoir. There are two types of reservoirs; one in the soil layer (< 20 metre thick) and one in the basement. In the bedrock the water flows in a complex web of fractures. The fractures created by the tectonic activity have made it possible for large amounts of water to be stored within the bedrock. The tunnel level is 100-150 metre below the water table resulting in high water pressures and continuous leakage during tunnel construction.

## Method

The geoelectrical and IP measurements were carried out using a version of ABEM Lund Imaging System that allows measuring in 7 channels simultaneously, with Terraohm RIP924b as receiver and ABEM SAS2000 as transmitter (max 400V or 500mA, max 40W). The pole-dipole array was used because of a larger median depth of penetration. A total of 900 metres were measured using the roll along method. Each layout was 400 metres having electrode spacing of 5 and 10 metres. A special technique was used in order to reduce the noise in the IP data. The current was transmitted in one cable and the potential was measured in another. By doing this the capacitive coupling is reduced. The cables were arranged parallel with around one meter distance. The measured data was inverted in the program Res2dinv using robust inversion.

The magnetic data was measured using a GSM858 caesium-vapour magnetic gradiometer manufactured by Geometrics Inc. The sampling rate corresponds approximately to a 10 cm sampling distance. The magnetic profiles covers only 480 metres from x = 400 to x = 880. The data was processed in the MagMap2000 software from Geometrics Inc. and then plotted

in Matlab. An older magnetic dataset, but from the same section, was modelled using the software GMM (Gravity and Magnetic Modelling) from GeoVista AB.

Two existing core drillings (KB5336 and KB5450) as well as geological maps were available as reference data.

## Results

The resistivity, IP and magnetic measurements can be seen in figure 1. The mean residual in the inverted resistivity is 5.1 % and for the IP it is 18.5 %. The first time window (20 ms long) was used for the IP section.

The inverted resistivity section in figure 1A shows that the first 500 meters from northeast have a top layer where the resistivity is higher than 3000 Ωm. Below this the resistivity is between 1000 and 2000 Ωm. Between x = 400 and 450 there is a zone with resistivity higher than 300 Ωm 60 metres below the surface. In the last 400 metre of the profile the resistivity

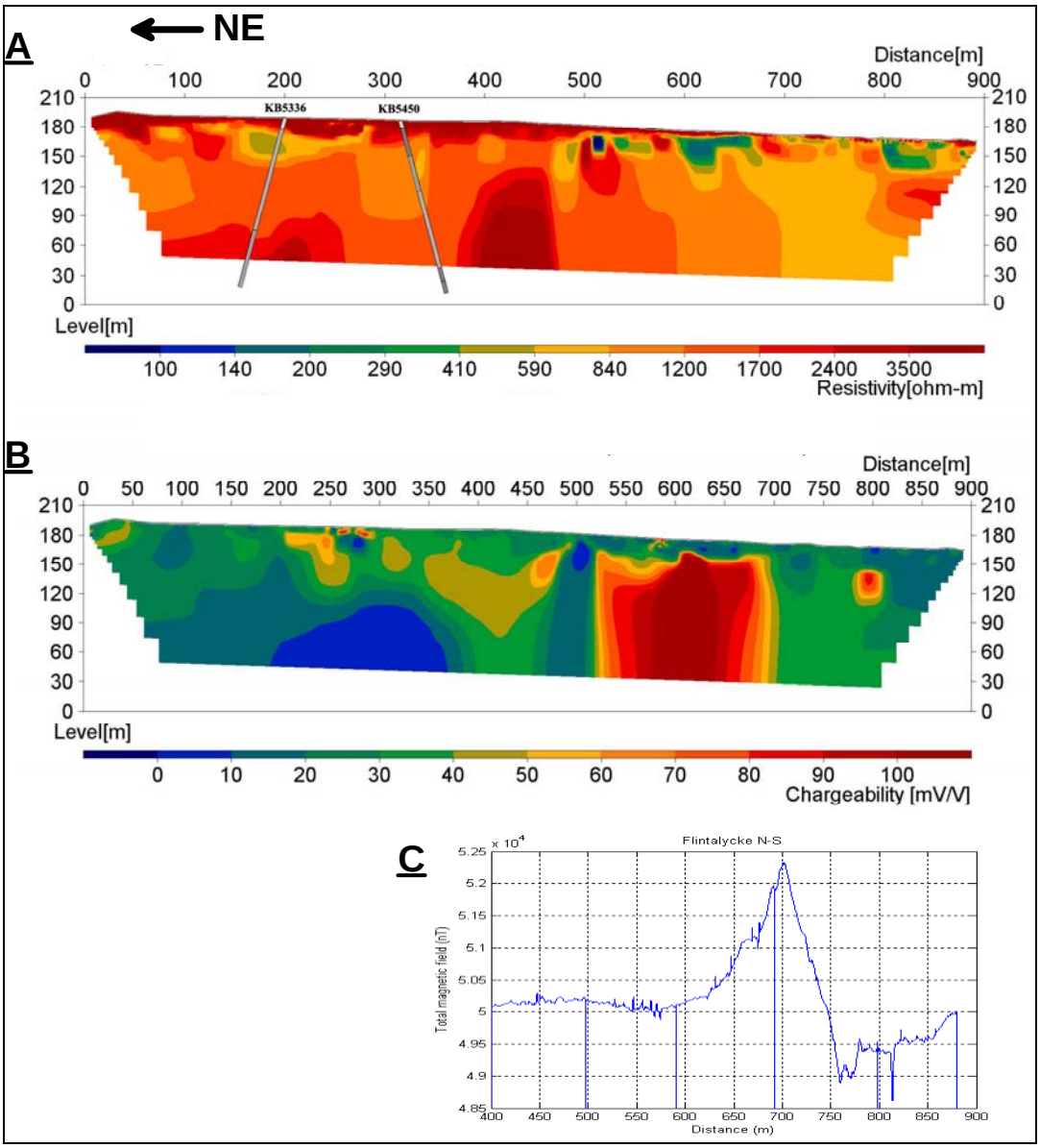

Figure 1. *(A) Inverted resistivity results for the 900 metre profile. The positions of two existing core drillings are marked in the profile. In (B) the inverted IP can be seen and in (C) the result from the magnetic measurement is shown.*

section changes character. There is no high resistive top layer. Instead there is a low resistive (200-400 Ωm) 40 metre thick layer. Below this the resistivity is between 600 and 2000 Ωm.

The inversion result of the IP data is seen in figure 1B. The profile is dominated by a 200 meter wide zone with an IP effect higher than 100 mV/V. This zone starts 10 to 20 metre below the surface. In the north eastern part of the profile there seems to be an upper layer with a thickness of 60 metre and an IP effect between 20 and 60 mV/V. Below this the IP effect is less than 10 mV/V.

The magnetic data is shown in figure 1C. A previous modelling of the same anomaly and the used parameters are seen in figure 2. The modelling result and the general knowledge about the geological setting suggest that the dyke is dolerite.

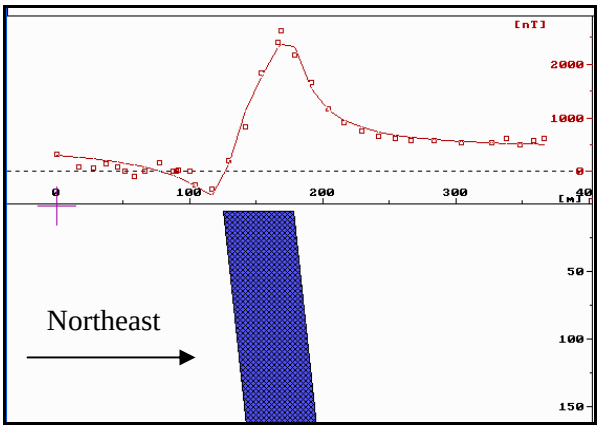


*Figure 2. Suggested model and parameters suiting the magnetic data. Notice the reversed profile direction.*

| Parameters | Value |
|---|---|
| Susceptibility, dyke | 0.1 [SI] |
| Susceptibility, surrounding | 0.022 [SI] |
| Q-factor | 1.2 |
| Inclination of remanence | -10 |
| Declination of remanence | 220 |
| Depth to top of body | 5.6 metres |
| Width of the body | 50 metre |
| Strike angle from y-axis | 10.3° |
| Strike length | 820 metre |

## Discussion

For the locations with access to drilling data (table 1) it can be seen that changes in both the resistivity and the IP coincides well with the core drillings. For example between x = 0 and 370 metres there is low resistivity and high IP effect from 186-120 m.a.s.l. which coincides well with the fractures observed in the core drillings.

KB5336

| Depth (m) | Rock material |
|---|---|
| 0-12 | Till and weathered bed rock |
| 12-118 | Moderately fractured gneiss/amphibolite with raw fractures |
| 118-177 | Moderately fractured gneiss/amphibolite with fractures covered with chlorite |

KB5450

| Depth (m) | Rock material |
|---|---|
| 0-9 | Till and weathered bedrock |
| 9-38 | Gneiss with varied fracture frequenzy |
| 38-74 | Gneiss/amphibolite with varied fracture frequenzy, fractures covered with chlorite |
| 74-155 | Moderately fractured gneiss/amphibolite |
| 155-169 | Moderately fractured granite amphibolite with chlorite covered fractures |
| 169-181 | Moderately fractured gneiss |

*Table 1. The geologic information from the core drilled boreholes KB5336 and KB5450.*

Between x = 260 and 390 metres there is an area where the resistivity is slightly lower than its surrounding. It is likely that this is a zone where fractures are present. From the

core drilling KB5450 it can be seen that the fracture frequency is locally higher. The large volume of solid gneiss in combination with the small amount of fractures can explain the quite high resistivity value. At x = 500 metres and at 180 m.a.s.l. there is a section where both resistivity and IP is low. This might be explained by fractures where no weathering has occurred.

The magnetic mapping and modelling located the dolerite with high precision. At the same location but over a larger area there are also high IP effects. The dolerite's high IP effect can be explained by increased mineralization due to contact metamorphosis. In the surrounding rock there is also an increased fracturing which is highly water bearing giving slightly lower resistivity.

In the southern part of the resistivity profile a plume shaped section of low resistivity can be seen. The surface area above this plume is very wet with bogs and even a lake. The IP data show no effect in this zone which can be interpreted as water bearing fractures.

The geological interpretation of the 900 metre profile can be seen in figure 3 and is based on resistivity, IP and magnetic data combined with reference data from core drillings geological maps.

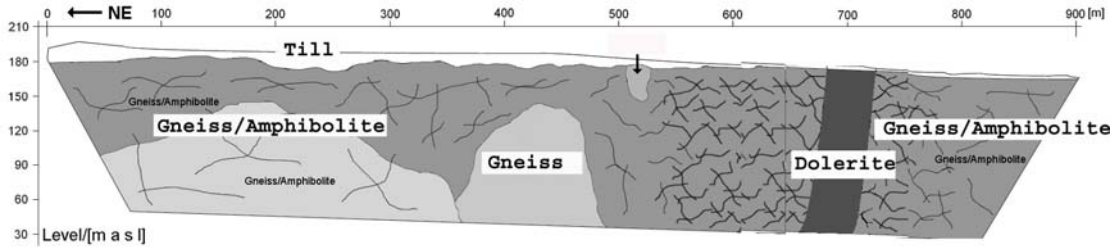


Figure 3. *Detailed geological interpretation of the 900 metre profile.*

## Conclusion

Based only on the resistivity data the area can be divided into two sections. The northern most has a higher resistivity due to less fractures and the southern most has slightly lower resistivity and a higher amount of fractures. The IP data then adds information about the dolerite dyke and the magnetic data locates the dolerite with high precision.

The resistivity and IP complements each other very well since they focus on different specific characteristics. IP proved to be useful at locating dolerites and resistivity was useful for the general distribution of fractures. An advantage is that with the seven-channel Lund Imaging System both types of data can be measured in a fast and cost efficient way. It is notable that good quality IP data was achieved with as little as 40W transmitter power despite the relatively large depth of investigation. Magnetic measurements are a good supplement to pinpoint the exact position of the dolerite.

Reference data, e.g. core drillings and pumping test, is important for a detailed interpretation. In an early stage of the pre-investigations no information from drillings is usually available. But based on the general geologic information, resistivity and IP measurements recommendations can be given on where to drill in order to improve the geological model. It is clear that in this specific case the model would be improved by making drillings at x = 250 and x = 600. So based on the geophysical data the two drillings actually performed (KB5336 and KB5450) are not positioned optimally. One should ideally been placed so that information could be obtained about the zone with high IP effect.

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