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P04

## Comparison between Geoelectrical Imaging and Tunnel Documentation

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### SUMMARY

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The documentation from the use of a tunnel boring machine (TBM) is used for the evaluation of geoelectrical imaging. Rock type, RQD and weathering are visually compared with resistivity data extracted from different levels in the inversion result. The three types of resistivity, i.e. high, low and intermediate resistivity, can be correlated to certain types of rock mass conditions. The comparison shows that high resistivity corresponds well with good quality gneiss. The tendency is that low resistivity corresponds to a varying lithology with fractured contacts or merely rock with very poor quality (RQD < 25). The intermediate resistivity agrees often with areas with amphibolite having a dominating RQD of 50-75 (good quality). Even though there are exceptions from this tendency the evaluation has given valuable information about how to use the resistivity data in the future work in the tunnel. Previously there has been a large focus on the low resistivity zone in order to find poor rock conditions. But the comparison has shown that the high resistivity areas are interesting because they give a fair chance for good quality rock. This is just as important for the contractor to know as the location of rock with poor quality.

## Introduction

The geoelectrical imaging has with advantage been used in the pre-investigation at several tunnel projects (Cavinato et al. 2006; Dahlin et al. 1999; Ganerød et al. 2006). To get the optimum benefit from the resistivity data certain knowledge of the geological setting is necessary. The ongoing work with a tunnel in the southern Sweden gives a good opportunity to evaluate the measured resistivity data. The documentation from the use of a tunnel boring machine (TBM) is used for the evaluation. The experience from this comparison makes it possible to use the resistivity data in a better way in the future work in the tunnel.

The construction of the tunnel has been heavily delayed because of difficult rock conditions. The tunnel is built through a horst which is uplifted as a part of the Fennoscandian Border Zone. The dominating lithology is gneiss with several generations of amphibolites occurring as minor layers or schlieren in the gneiss. In some parts the bedrock is intruded by dolerite dykes. (Wikman and Bergström 1987) The rock has a poor quality because of deep weathering and water bearing fractures. In some parts the mechanical properties of the rock is like clay. At the contact zone between the different lithologies the conditions are particularly difficult because of heavy fracturing of the rock. Therefore it is of great importance to use the experience from the comparison in the future work with the resistivity data.

## Method

In order to evaluate the result from the geoelectrical imaging the data is compared with the existing tunnel documentation. The resistivity data are measured along the whole tunnel line using CVES. The electrode spacing is 10 meter and the cable layout is 800 meter. Using the Schlumberger-array the penetration depth obtained is 120 meter. The data are measured between 1995 and 1998 but re-processed for this comparison. For the inversion of the data Res2DInv version 3.55.77 is used. At 60 meter above sea level (m.a.s.l.) and 25 m.a.s.l. the resistivity values are extracted from the inversion result. These two depth slices are shown together with the full inversion result.

The tunnel documentation is done at the cutter head of the TBM at every operational stop, e.g. erection of lining. The mapped parameters are lithology, RQD and weathering. The relation between the RQD-value and the rock quality is as seen in table 1. Weathering is given in values from 1 to 5 where W1 is fresh rock and W5 is highly weathered rock.

RQD	Rock quality
90-100	Excellent
75-90	Good
50-75	Fair
25-50	Poor
< 25	Very poor

Table 1. The relation between RQD and rock quality. Modified after Fagerström et al. (1983)

The comparison between the resistivity data and mapped parameters is done merely by visual evaluation. It is expected that water bearing fractures has intermediate to low and clay-weathered rock has a low resistivity whereas the fresh unaltered rock has a high resistivity.

All data is plotted in grey scale in order to give a fast impression of the rock quality. Dark colours are poor quality while light colours are good quality. The only exception is the visualization of rock type where the colour does not have any meaning for the quality of the rock.

The data are visualized in a coordinate system used by the Swedish railroad company.

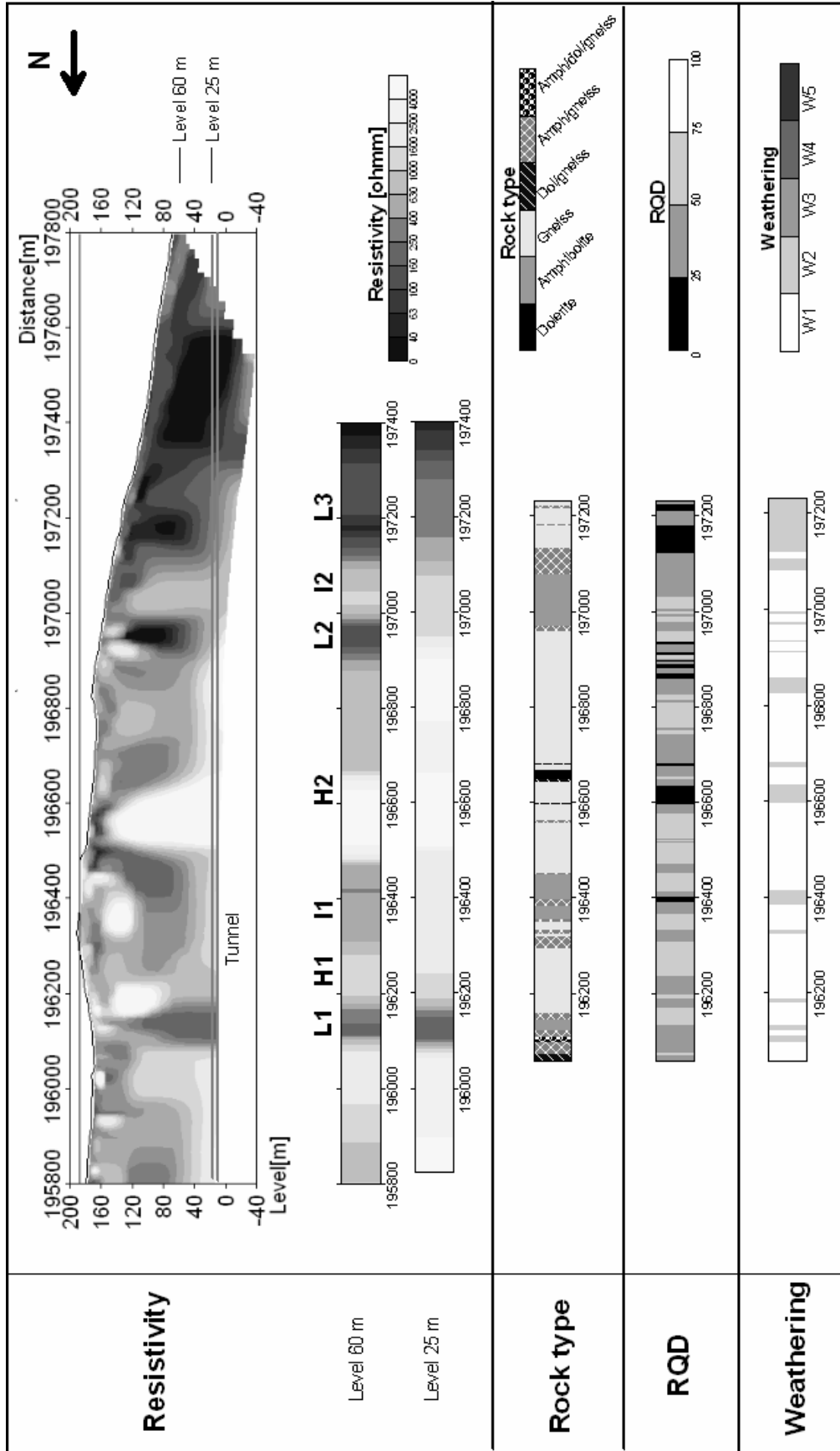


Figure 1. Visualization of resistivity and mapped data from the southern part of the tunnel. The anomalies are marked with L (low), H (high) and I (intermediate). The mapping is done in front of the TBM at every operational stop. The mapped data were rock type, RQD and weathering. The resistivity data are shown as full model and as sub-models extracted at 60 and 25 m.a.s.l. Here the tunnel base is at approximately 15 m.a.s.l.

## **Result**

In figure 1 the resistivity data and mapped parameters are plotted for the comparison. In the figure the areas with the same resistivity are marked with a letter and a number to make the evaluation of the result easier. The resistivity can be divided in three classes for simplicity; low (L), high (H) and intermediate (I).

In the resistivity section at 60 m.a.s.l. three areas with low resistivity are observed, where two are visible at both levels. The first zone, L1, has a resistivity of 160-250  $\Omega\text{m}$ . The full resistivity model shows that it is a steep standing structure. Assuming a displacement of 30 meter towards the north because of discrepancy between the position of the tunnel line and the resistivity profile, this low resistivity zone coincides with the mapped interval from 196050 to 196130. The mapped rock type in this interval is changing between dolerite/gneiss, amphibolite/gneiss and amphibolite/dolerite/gneiss. This rock has a RQD between 25 and 50, where the only exception is a narrow zone with a RQD of 50-75. In the contact between amphibolite/gneiss and amphibolite/dolerite/gneiss the weathering has increased to W2.

The second zone, L2, has a resistivity of 100  $\Omega\text{m}$  and is only seen clearly at 60 m.a.s.l. The full resistivity model shows that it is a steep standing structure which extends to 40 m.a.s.l. At tunnel level the resistivity is higher than 1000  $\Omega\text{m}$ . Considering the displacement to the north this should correspond to the interval where the lithology is gneiss. In the RQD there are many narrow zones with values changing between 0-25 and 25-50. The rock is fresh with W2 in two thin zones.

The third low resistive area, L3, is visible at both levels throughout the rest of the resistivity profile. This is the Southern Marginal Zone which is a problematic zone with weak rock. The rock type shows a change in lithology from amphibolite/gneiss to gneiss with narrow zones with amphibolite/gneiss. The RQD is 0-25 in the first part and 25-50 in the last part of the anomaly. In the whole interval the weathering is W2.

At 60 m.a.s.l. there are three zones with high resistivity. At 25 m.a.s.l. there is one large high resistive area (H2). If focusing on the areas visible in both levels the first high resistive zone is H1. The resistivity is 1600-2500  $\Omega\text{m}$  at both levels. This equals gneiss with a dominating RQD of 50-75 but with zones with RQD between 25 and 50. The rock in the section is fresh rock without any alteration.

Considering the full resistivity model it is obvious that the high resistive body H2 (>4000  $\Omega\text{m}$ ) which is visible at 60 m.a.s.l. is extending towards the south at tunnel level. In the tunnel documentation the dominating lithology is gneiss but with narrow zones that differs. In these zones the lithology is dolerite, a combination of amphibolite and gneiss, and a combination of dolerite and gneiss. The area between the zones with dolerite, the gneiss has a RQD lower than 25. Here there is a slight weathering of the rock (W2). In the interval where both resistivity depth slices show high resistivity the rock quality is good, with a dominating RQD of 50-75. In the intervals where the high resistivity is only visible at 25 m.a.s.l. the rock quality is changing, having narrow zones with RQD less than 25. The rock is fresh but with three zones which to some extent are weathered (W2).

A zone with intermediate resistivity (400-630  $\Omega\text{m}$ ) is marked with I1. This resistivity is only occurring at 60 m.a.s.l. At the same location the rock type is dominated by a combination of amphibolite and gneiss in the first 50 meters and by amphibolite in the last 100 meters of the zone. In a small zone the lithology is gneiss. This interval is on the other hand dominated by several contacts between different lithologies. The RQD is 25-50 in the first 25 meter of the combined amphibolite/gneiss. In the pure gneiss the RQD increases to be between 50 and 75. In the pure amphibolite the RQD has decreased to 25-50. In the 20 meter wide zone with the amphibolite/gneiss the RQD is lower than 25. In the last part of the pure amphibolite the RQD has increased to 50-75. In the zone with the poorest rock quality the weathering is W2 whereas it otherwise is fresh rock.

At I2 the resistivity is intermediate (630-1000  $\Omega\text{m}$ ) in both depth slices. This corresponds well with the zone with amphibolite. Here the RQD is alternating between 25-50 and 50-75 with the dominating being 25-50 in the last part of the interval. Primarily the rock is fresh with four narrow zones with W2.

## **Discussion and Conclusions**

The three types of resistivity, i.e. high, low and intermediate resistivity, can be correlated to certain types of rock mass conditions. The comparison shows that high resistivity corresponds well with the dominating rock type being good quality gneiss. The tendency is that low resistivity corresponds to a varying lithology with fractured contacts or merely rock with very poor quality (RQD < 25). The intermediate resistivity agrees often with areas with amphibolite having a dominating RQD of 50-75 (good quality).

Even though there is a clear tendency to a correlation between the resistivity and the rock conditions there are also exceptions. The RQD at H2 shows a relatively large area with a value of less than 25. It is expected that such a large area with poor rock quality would give low resistivity. Instead there is quite high resistivity. Another example is at L2 where the RQD shows many narrow zones with values lower than 25. There is no clear indication of this problematic area because the resistivity data at tunnel level does not show any low resistivity whereas at 60 m.a.s.l. it does.

A reason for the divergence between the tunnel documentation and the resistivity data might be that the resistivity data are measured as 2D profiles while the subsurface is 3D. This might create 3D effects in the resistivity data; especially in this case where the geology changes relatively fast. Another issue is also that there is a difference in the scale of the data. The resistivity data are measured at the ground surface 120 meter above the tunnel. Therefore these data has a lower resolution at tunnel level than the detailed tunnel documentation. In addition the mapping of RQD, weathering and lithology is a subjective assessment done by different geologists at the tunnel site under difficult conditions inside the TBM.

The evaluation of the resistivity data and the mapped parameters has given valuable information about how to use the resistivity data in the future work in the tunnel. Previously there has been a large focus on the low resistivity zone in order to find poor rock conditions. But the comparison has shown that the high resistivity areas are interesting because they give a fair chance for good quality rock. This is just as important for the contractor to know as the location of rock with poor quality.

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