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Application of Joint Inversion and Fuzzy C-means Cluster Analysis for Road Pre-investigations

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SUMMARY

Collated DC resistivity and seismic profiling has become a popular method when doing pre-investigations for infrastructural projects such as roads and tunnels. The motivation behind the usage of two methods is that combined usage of both of these methods can decrease the ambiguity inherent to the individual use of these methods. Several software packages for inversion exist, but possibilities to combine several geophysical methods are limited; research algorithms that have this functionality exists and are evaluated herein. Joint inversion and fuzzy c-means cluster analysis are potentially ways to get the most of the collated data; thus enabling the methods to enforce each other is such a way that interpretation could be improved. These methods were applied on a field dataset from a pre-investigation of a new road. The joint inversion did not result in any major changes in the inverted models for this example, probably due to the very complex geology. The cluster analysis provides an additional tool for interpretation; highlighting for example a dolerite dyke, which can have strong influence on the construction and planning process.

1. Introduction

Collated DC resistivity and seismic profiling has become a popular method when doing pre-investigations for infrastructural projects such as roads and tunnels. The motivation behind the usage of two methods is that combined usage of both of the methods can decrease the ambiguity inherent to the individual use of the methods. Ambiguities could for example be that resistivity could fail to detect a low contrast boundary between two low resistivity layers such as clay and shale, but seismics could register this due to different velocities. Similarly, a low velocity layer under a higher velocity layer could be a problem for refraction seismics, but could be detected by resistivity. An improved interpretation of the subsurface may be achieved by letting the measured data from each method influence each other's models via structural coupling, as shown by Gallardo and Meju (2004) for both synthetic and real datasets.

There are several available software packages for geophysical inversion of both DC resistivity and refraction data individually, but there are limited possibilities to combine results of the two types of investigation in the same inversion. In this study, algorithms developed by Günther and Rücker (2006) were used. This study aims to test the algorithms on a field dataset and evaluate if the method is viable, thereby yielding an improved and more transparent interpretation of the geology.

The study area is situated in Norway and is investigated as a part of the pre-investigations for a new international E-road. The bedrock in the area consists mainly of Precambrian Gabbro that has partially been transformed into Amphibolite and Soapstone, intrusive dolerite dykes can also be expected in the area. The bedrock is overlain with quaternary glacial till ranging from half a meter to about ten meters in thickness, the glacial till is compacted, well graded and may contain everything from clay to cobbles and boulders[1].

2. Methodology and materials

2.1 Data acquisition

The DC resistivity data was acquired using an ABEM Terrameter LS, refraction seismics data was acquired using Geode seismic recorders from Geometrics. The coordinates for the geophones were collected using a differential GPS with ground corrections. The electrode separation was 10 meters, and the geophone separation was 5 meters, both measurements were made using roll-along methods. The length of each profile is 740 meters, resistivity data was measured using 74 electrodes and contains 859 data points, refraction seismics originates from 41 shots with a maximum geophone count per shot of 44 geophones, yielding 1526 data points for refraction seismics.

2.2 Mesh generation

Mesh generation needs to be done prior to inversion since both inversions are running on the same unstructured triangle mesh. First, a unified position list is created from both measured positions. Very short spacing is avoided by combining the average of both points. The list is refined successively until no distance larger than a certain amount exists. It defines how fine the mesh is at the surface. Next, a box for the inversion domain and a much larger box for the DC resistivity forward calculation are added around and a quality constrained mesh is created using the triangle algorithm. Since we use a triple-grid approach (Günther et al., 2006) for the inversion, primary potentials are calculated on another; spatially refined mesh, using quadratic shape functions and are interpolated on the forward mesh.

2.3 Inversion

The inversion scheme is described by Günther and Rücker (2006). For every method a starting model is generated and a first iteration is done independently. In subsequent iterations, structural information is exchanged by mutually deriving smoothness weights from the roughness of the image. Thus,

[1] www.ngu.no, accessed on 11 April 2012

common gradients in the models are preferred over individual ones without forcing them. For the coupling, the blocky-model scheme is sometimes too selective; therefore we used an alternative method based on the logarithms of the properties, which also allows for coupling three models (Günther et al., 2010).

2.4 Cluster analysis

Cluster analysis is used to automatically combine different parameters, cluster the parameters and minimizing the distances to the centre of each cluster represented by mean values. The approach used here involves a suitable pair of inverted data sets (here resistivity vs. velocity) that is grouped into statistically significant clusters, as they would appear in a cross-plot, by utilizing the fuzzy c-means method. Instead of unambiguously allocating each data point to one cluster only, the fuzzy c-means method will create a "membership" for the data points, where memberships close to unity implies a high degree of similarity between the sample and a cluster, while memberships close to zero means little similarity between the sample and the particular cluster (Bezdek et al., 1984). The membership functions for each cluster is used to compute a reliability factor (Paasche et al., 2006, The reliability factor (0-1) is derived from membership functions, and is used as opacity when the cluster model is visualized (so called alpha shading); in order to visualise how well the individual cells are represented by the clustered model with its cluster centres. For computing the distances, the values are usually normalized; instead, we used logarithms, thus the distance being a relative deviation.

3. Results and discussion

A possible difficulty when trying to collect data optimized for joint-inversion, is the collation of surface data collection points (electrodes and geophones). We used a technique to merge the electrode coordinates with the geophone positions from differential GPS. Simplified data handling could be achieved by considering this when planning the data acquisition.

The results of the resistivity inversion seen in figure 1, shows a high (1250-3980 Ωm) resistivity strip close to and at the surface, below this layer there is a low (25-1249 Ωm) resistivity layer. The underlying resistivity layer is protruded by vertical strips at 300 and 450 meters. The horizontal stratification that is apparent in the resistivity section would suggest that there are horizontal geological structures. This coincides with expected horizontal volcanic rock structures. The vertical high (1250-3980 Ωm) resistivity strip at 300 meters could indicate a dolerite dyke; there is dolerite visually detectable at the surface.

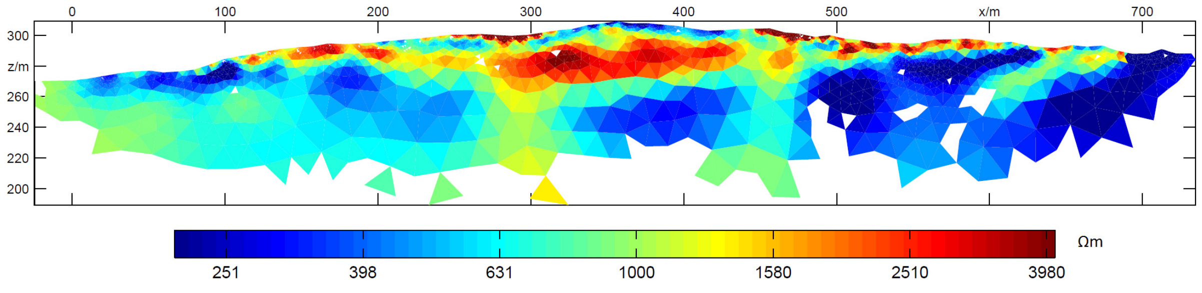

Figure 1 *Inverted resistivity section, note that some areas inside the section are blanked; this is because of the lack of reliable values in these positions.*

The results of the seismic inversion seen in figure 2, shows one or two low (1000-3500 m/s) velocity layers overlaying a high (3501-5200 m/s) velocity layer that is split in three parts at approximately 100 and 450 meters where the outer parts demonstrates a higher velocity (4500 m/s and up). The suggested dolerite dyke that is showing in the resistivity profile is indicated by a high velocity (4500-5200 m/s) area just below the surface at 300 meters. The left side of the suggested dyke shows lower (3500-4000 m/s) velocities that may indicate a weathered zone present here.

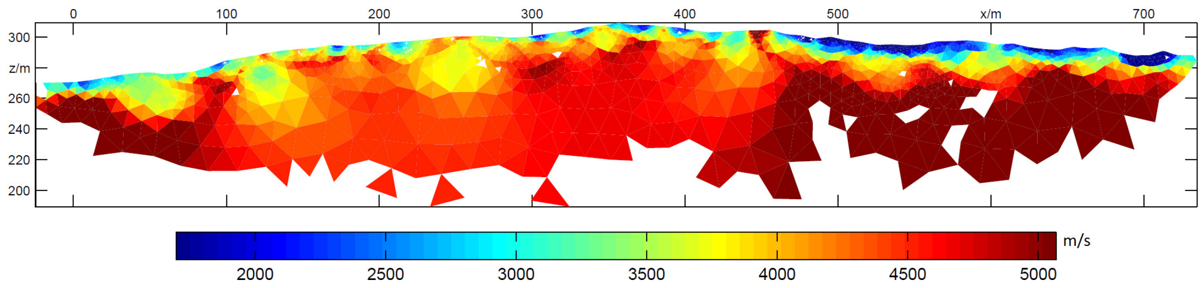

Figure 2 *Inverted velocity section. Note that the depth to high velocity layers averages at 15-20 meters, not much information is attained below this level.*

The result of the cluster analysis as seen in figure 3, yields a model consisting of two main clusters (blue and turquoise), two smaller clusters (green and yellow) are also formed. The number of clusters selected was done so that the clusters yields a gathered view of both resistivity and seismics, the use of too few clusters seems to oversimplify the interpretation of the results and too many clusters makes it very difficult to interpret the results and explain the existence of each cluster on the basis of a geological frame of mind. The separation between the clusters can be viewed in figure 4. The two main clusters formed (blue and cyan) dominates, and it now becomes very clear that there is a vertical anomaly at 300 meters; this is the suspected dolerite dyke. The possible dyke seems to have some horizontal near surface parts.

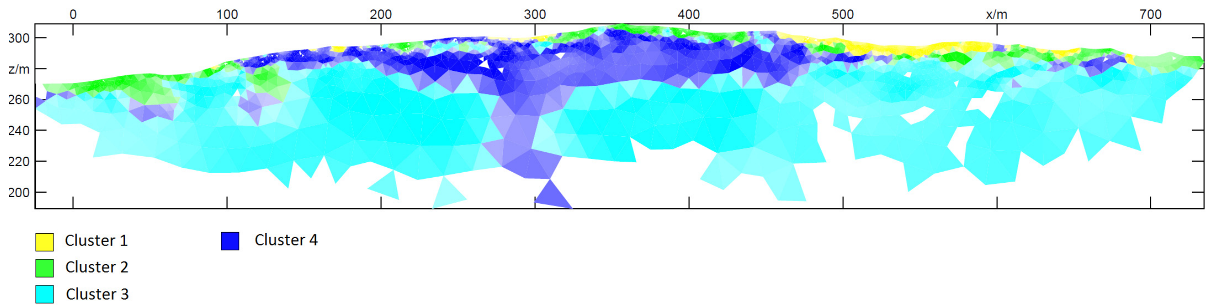

Figure 3 *Cluster model derived from resistivity and seismic velocity, 4 clusters. Alpha shading represents the reliability factor as discussed in the text.*

4. Conclusions

The use of joint inversion was in this case not apparently beneficial due to the highly complex geology of the area investigated. The cluster analysis provided an additional tool for interpretation, highlighting for example a dolerite dyke which can have strong influence on the construction. The use of joint inversion does require the data to be processed in such a way that cluster analysis is very much simplified, especially when using the same mesh for both datasets. Interpretation of the resistivity and refraction seismics profiles separately can yield results that are similar to the results when doing interpretation with the aid of the cluster analysis. The cluster analysis however does confirm what an experienced interpreter could deduce; this implies that cluster analysis could be a very useful tool for interpretation which has potential for further development.

5. Acknowledgements

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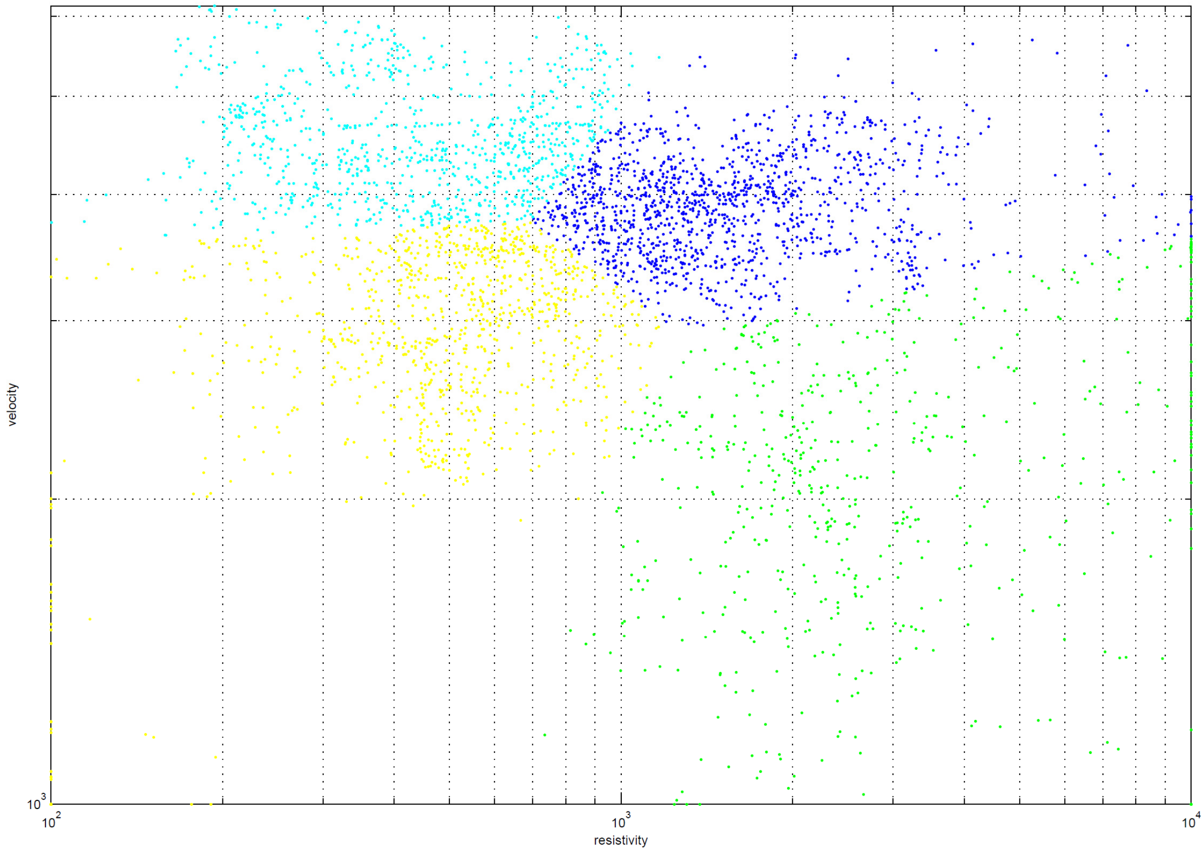

Figure 4 *Cluster cross-plot for the inverted sections in figure 1 and 2; this figure illustrates how the respective clusters are formed in respect to their resistivity and velocity.*

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