A method for measurement of the electrical formation resistivity while auger drilling

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Introduction

In environmental studies there is often a demand for such detailed and reliable descriptions of the geological strata that geophysical surface methods must be combined with well-log information.

The electrical logging method is a useful tool for providing detailed geological information in the vicinity of a borehole. In the early days of electrical logging, high vertical resolution could only be obtained by using short tools, which were seriously affected by the borehole and the fluids in it. Accurate determination of formation parameters necessitated the use of long tools with deep penetration but poorer vertical resolution. Many attempts have been made to solve this problem, the most successful being the use of focused arrays (e.g. Daknov 1959).

In hydrogeological studies it can be imperative to have precise lithological information with a high vertical resolution. Even very thin layers of clay or silt embedded in sandy saturated formations can drastically alter the flow pattern of groundwater and thereby the dispersion of possible polutes.

To obtain this degree of accuracy in the description of geological strata, a detailed borehole sampling method must be used. Generally, a splitspoon, core barrel or wire-line sampler is required, increasing the cost of the drilling process considerably.

In this article, I describe a new tool for electrical logging which has been developed for use in combination with auger drilling. It provides a detailed apparent resistivity log profile, measured while actively drilling downwards into the formation.

Principles of the method

The method, in the following referred to as the 'Ellog' method, is simple in principle (see Fig. 1), although the implementation presented some interesting technical problems. For example, it was not straightforward to incorporate good electrical insulation near the electrodes with a rugged design to ensure a reasonable tool lifetime under varying drilling conditions (Sørensen 1987).

In the present design, the apparent formation resistivity is measured by means of a tool which is an integrated part of a hollow-stem flight auger. The tool has a steel core with an insulating coating shaped as a flight, allowing the cuttings from the cutter head to bypass the tool sections. The measuring electrodes are embedded in the insulating material with connections to the measuring instrument above ground through cables inside the drill stem. This design has had an average durability per tool of 500 m drilled in moraine, alluvial sand and fine gravel, representing less than 5% of the total cost of the data acquisition.

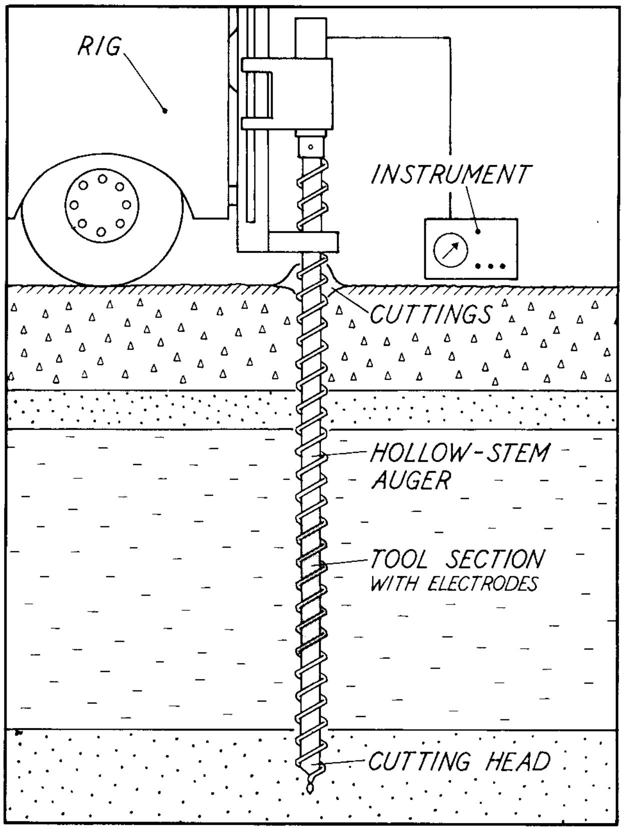

Fig. 1. Principle of the Ellog method. The tool section, with a coating shaped as a flight, is an integrated part of a hollow-stem auger with continuous flighting. The electrodes are placed in a Wenner configuration and connected to the measuring instrument above ground.

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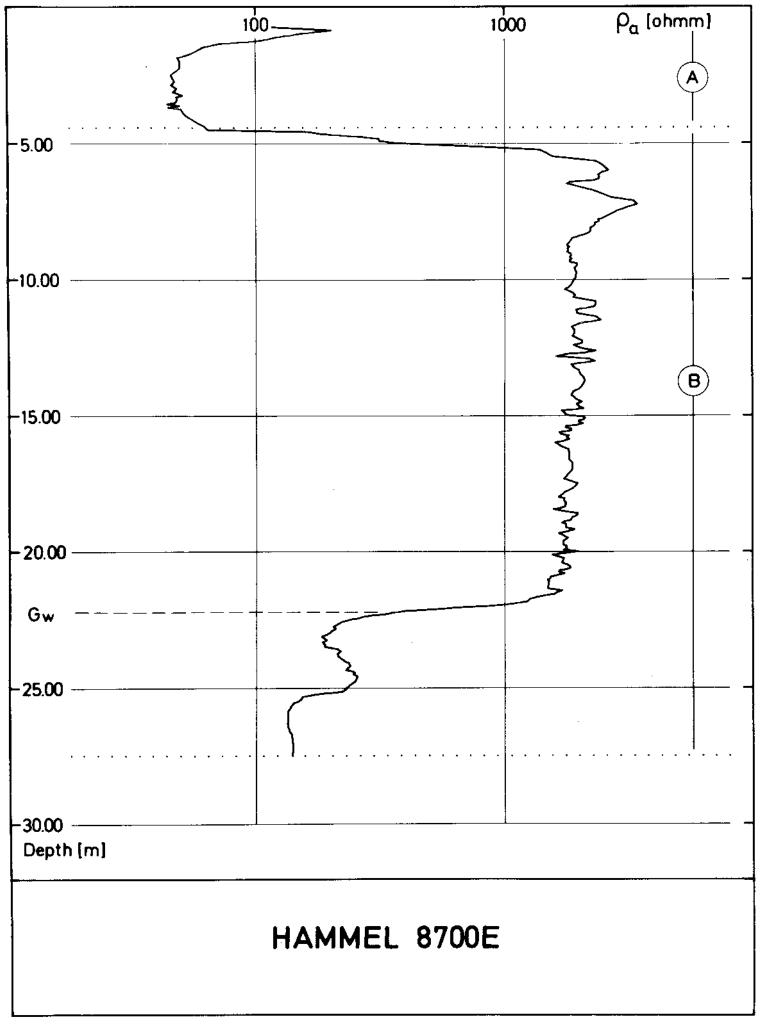

Fig. 2. An Ellog profile of 27 m through clay and sandy gravel. Section A of the profile indicates moraine clay whereas section B is a comparatively homogeneous sandy layer with an unsaturated and a saturated zone. The ground water level is at G_w.

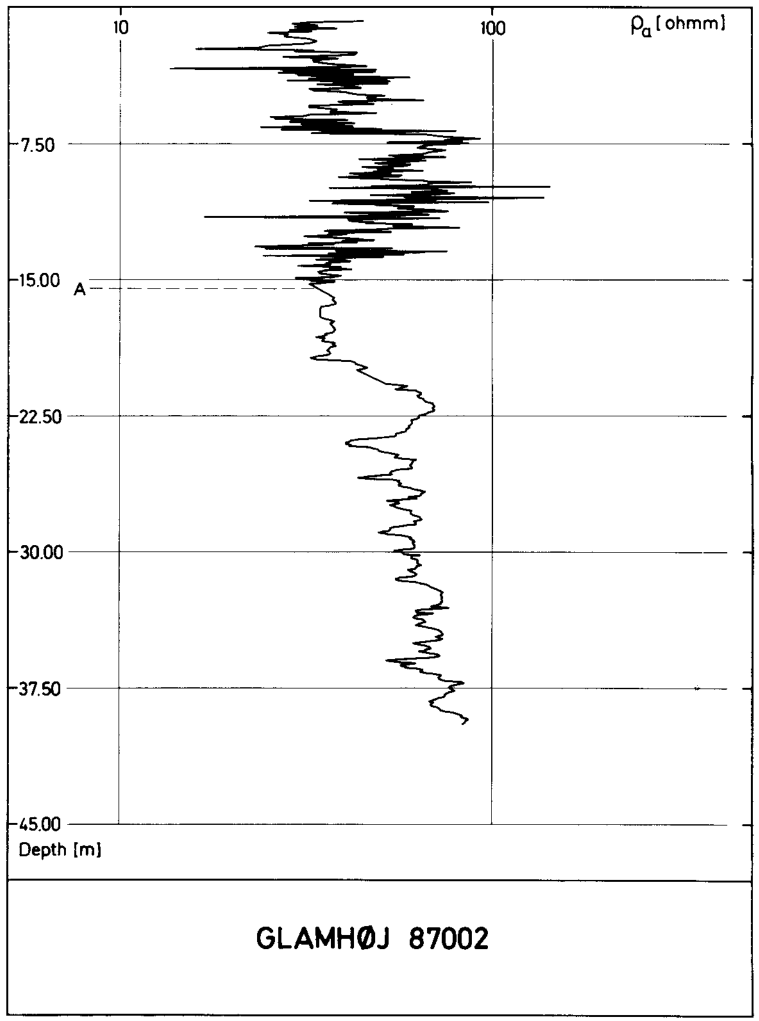

Fig. 3. An Ellog profile of 39 m through inhomogeneous moraine clay underlain by saturated alluvial sand. The boundary between the two layers is situated at A.

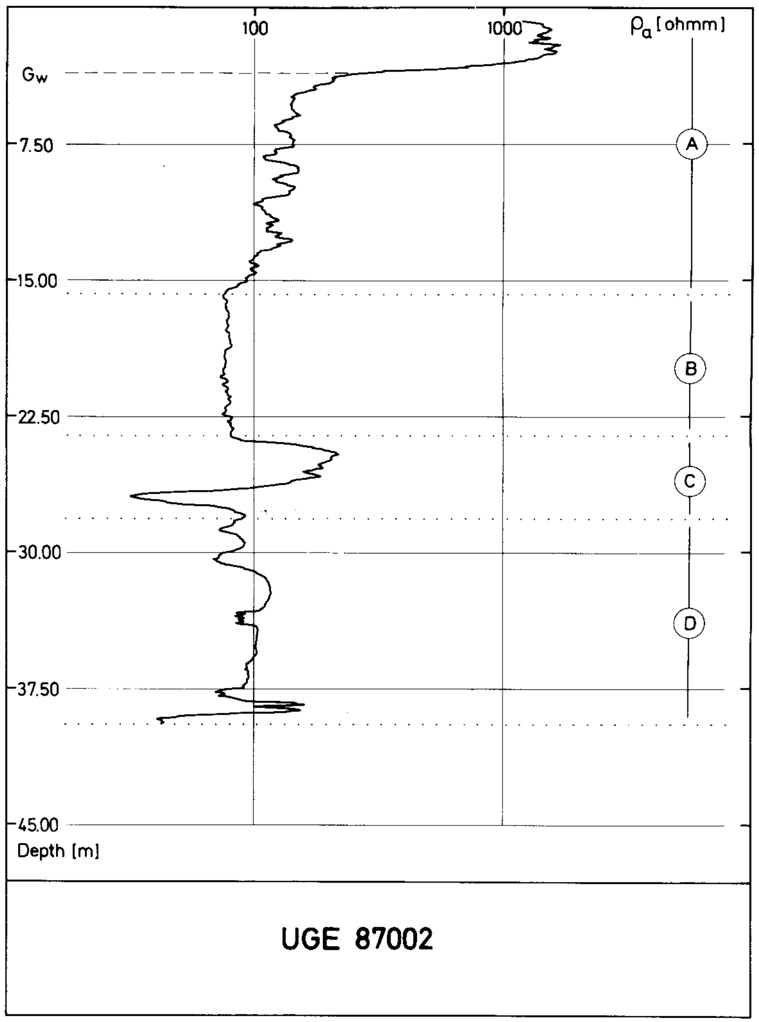

Fig. 4. An Ellog profile of 39 m through mainly saturated alluvial sandy strata with thin layers of clay and gravel. The groundwater level is at G_w. Section A of the profile shows a series of layers with different sorting whereas section B is a homogeneous layer. Section C is composed of a layer of gravel underlain by a thin layer of clay. Section D is a sandy layer with thin layers of clay, silt and gravel.

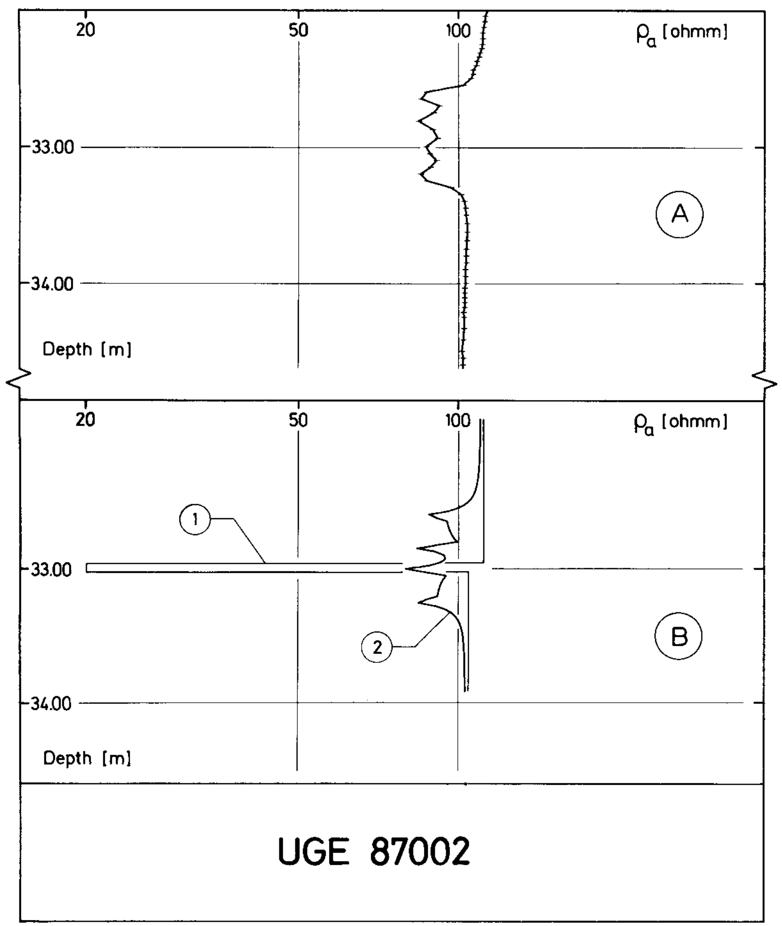

Fig. 5. An interval of the Ellog profile shown in Fig. 4. Section A shows the measured profile, with each data point marked by a tick. Section B displays the theoretical response, curve 2, from the layering indicated by curve 1. The response is calculated for a horizontal layered model and the influence of the borehole is neglected.

A true measurement of the formation resistivity is in principle impossible, because disturbances will always arise from the presence of the measuring tool. Model experiments have shown only a negligible effect from the steel parts of the drilling stem and the cuttings in the flight passing the tool (Sørensen 1989). Furthermore, there can be no disturbances from drilling fluids in an auger drilling procedure.

Thus the apparent resistivity, as measured by this method, is expected to be a close estimate of the actual *in situ* formation resistivity.

The remaining part of the drill stem is an ordinary hollow-stem auger with continuous flighting, which permits the drilling process to be continuous as the cuttings are removed from the bit. Furthermore, the measurements are performed during the rotation of the stem, which makes the drilling process fast.

The measurements

The method has already established itself in environmental studies in Denmark, and around 8000 m of log profile have been acquired during the first year of service.

In order to obtain adequate vertical resolution a Wenner electrode configuration with adjacent electrodes spaced 20 cm apart has been chosen, and the apparent resistivity is measured at a sampling interval of about 5 cm.

Figure 2 displays 30 m of an Ellog profile penetrating three layers, each showing a comparatively homogeneous resistivity structure. The boundaries between the layers are resolved so accurately that a sampling interval of less than 5 cm could be useful! Thus the method yields an estimate of the resistivity of the main geological formations, which could provide valuable constraints in the interpretation of geoelectrical soundings in the region.

Moreover, the fine scale fluctuations of the resistivity log profile carry additional useful information. The Ellog profile presented in Fig. 3 penetrates a layer of electrically inhomogeneous moraine clay underlain by a saturated sandy gravel formation, which is more homogeneous electrically. The trend in the profile is a gradual, featureless increase with depth, whereas the spectral content of the profile reveals the position of the boundary rather accurately.

As mentioned above, a detailed description of the layer sequence is crucial in hydrogeological studies. This is illustrated by Fig. 4, which presents another example of the ability of the method to resolve the formation resistivity and thereby the geology. The electrical profile is measured in a diluvial sequence. As the formation resistivity is closely related to the porosity, especially in sand and gravel, the changes in apparent resistivity can be interpreted as changes in the porosity related to the sorting. This may give important clues to the understanding of the geological processes active during deposition.

The resolution of thin layers plays an important role in hydrogeological studies. To indicate the possibilities of the method, Fig. 5 displays an interval of the Ellog profile shown in Fig. 4. For comparison, the theoretical response of a thin conductor embedded in a resistive layer is presented. The agreement with the details of the measured resistivity pattern is quite satisfactory (Yang and Ward 1984).

Future work

The Ellog method is a new method for detailed studies of the electrical formation resistivity.

A research programme has been started for simultaneous *in situ* determination of the conductivity of the pore fluid and the formation resistivity in order to study the variation in the formation factor. The experiments are carried out using a screened hollow-stem auger in combination with an Ellog tool.

For interpretation and understanding of the detailed structure in the formation resistivity, Ellog tools with several electrode spacings producing different penetration depths have been designed for simultaneous measurements. The resistivity profile will be interpreted by an iterative inverse procedure based on the assumption of horizontal layering. This technique 'sharpens' the apparent resistivity log profile, thus allowing the study of details, macroanisotropies and inhomogeneities (Yang and Ward 1984).

Conclusion

The Ellog method is at an early stage in its development, but offers wider scope than has previously been possible for detailed studies of the electrical formation resistivity.

The measurements have high resolution which should enable a deeper understanding of the nature of the formation resistivity to be acquired. Among other problems, the question of macroanisotropic layers may now be addressed in a quantitative manner, which has previously been practically impossible. This is of the utmost importance for surface electrical and electromagnetic methods.

Furthermore, as the technique is based on a fast hollow-stem auger drilling, the method offers an alternative to detailed borehole sampling methods and the deployment of pipes for test sampling of pore fluid, by describing the geological strata with a high-resolution electrical log profile.

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