DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2002/107

Evaluation of the applicability of geophysical methods in the Swan River area, Manitoba Canada

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G E U S

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Introduction

During the summer 2001 a ground penetrating radar (GPR) survey was carried out in the Swan River area, Manitoba, Canada. The GPR method was chosen, because it had shown great potential in mapping heavy mineral enriched sand deposits in Denmark. However, in the Swan River area the sand deposits were found to be covered with plastic clays that attenuates the GPR signal, so that the underlying sand could not be mapped by GPR.

This report evaluates the most commonly used geophysical methods applicability to map the heavy mineral enriched sand deposit in the Swan River area. The evaluation is based on a geological model described in the following section.

The evaluation is carried out using knowledge obtained from field work in Denmark supplemented by literature studies of Danish and international case histories.

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Geological setting in the Swan River area

The geological knowledge of the Swan River area is relatively sparse. The geological information about the Swan River area reported here is provided in a drilling campaign carried out by Richard Gunter in 2001. The drillings are carried out to a maximum depth of 25 m. Figure 1 and 2 show cross-sections compiled by Richard Gunter from the lithological drill logs.

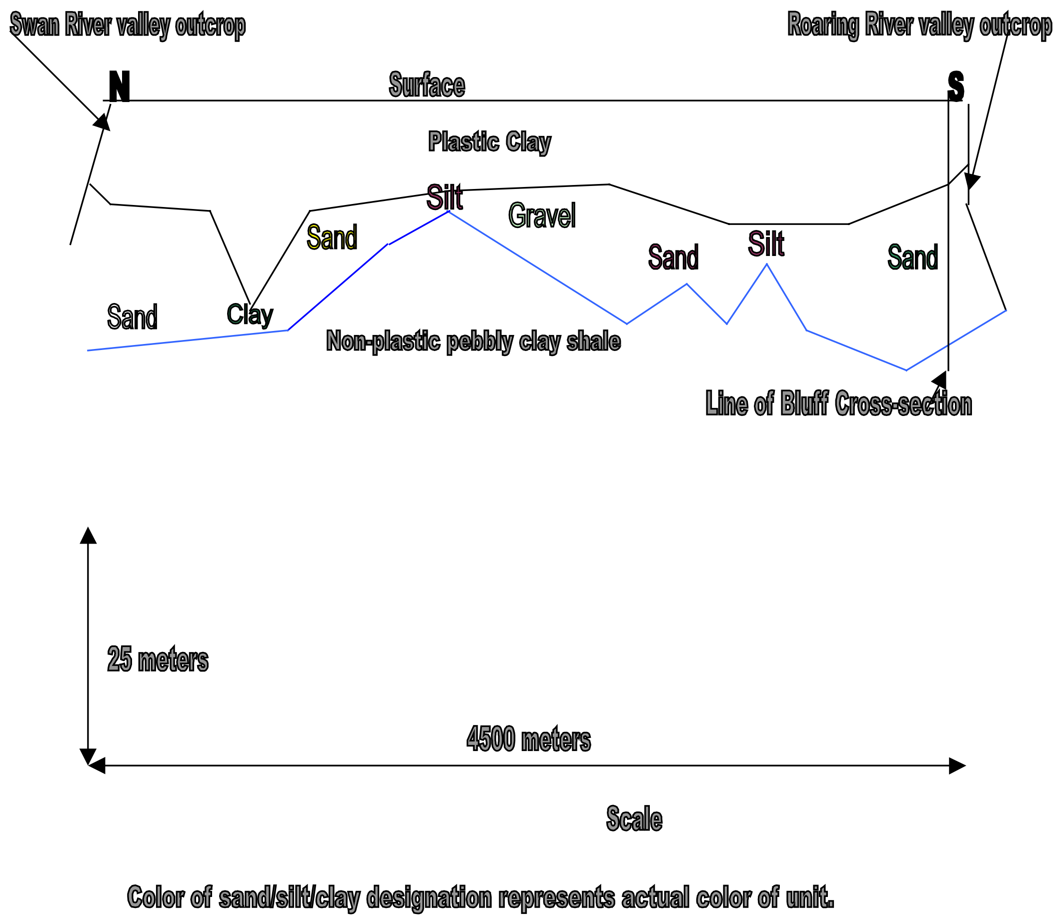

Figure 1: North-south cross-section from the Swan River valley outcrop to the Roaring River valley outcrop.

Based on the drill logs, following geological model is set up and used for the evaluation of the geophysical methods.

Layer 1: Plastic clay with the thickness of 8-15 m. Close to the Roaring River bluff, the thickness can be thinner. A ground penetrating radar survey carried out in 2001 showed that the plastic clays cover the entire area between the Roaring River and the Swan River as well as the area just north of Swan River.

Layer 2: Sand with a thickness from 3 m to at least 15 m. A few drillings are stopped before the bottom of the sand layer is reached. In the geophysical mapping the sand layer can appear as two layers, if the ground water table is present in the layer (see the table below).

Layer 3: Shale or clay of unknown thickness.

Geophysical properties found in the literature for the three layers are listed in the table below.

Geophysical property	Clay	Sand	Shale
Density (kg/m^3)	1500 – 2600	1400 – 1700 (dry) 1600 – 2000 (wet)	2000 – 2700
Seismic velocity (P-wave) (m/s)	1100 – 2500	300 – 1000 (dry) 1200 – 1900 (wet)	2000 – 5000
Electrical resistivity (Ωm)	5 – 20 (plastic clay)	60 – 200 (wet) 100 –10 000 (dry)	5 – 50

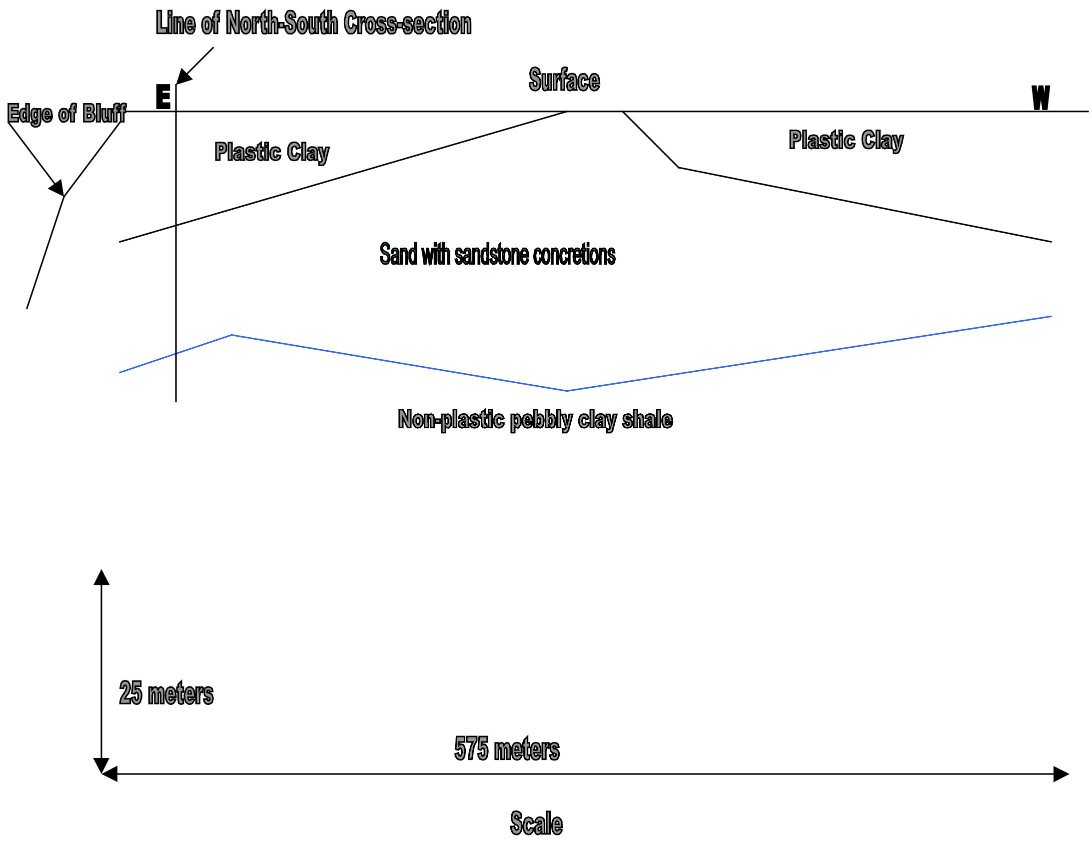

Figure 2: Bluff cross-section, east-west, at the Roaring River valley outcrop, north of the Highway # 10 over the Roaring River.

Evaluation of geophysical methods

DC-resistivity

(ABEM Instruments AB: Lund Imaging System; Advanced Geosciences Inc.: Sting System)

In a DC-resistivity survey the vertical and lateral resistivity variations are mapped along profiles. The measurements are carried out by placing many steel electrodes equally spaced on a line connected to the instrument by multicore cables. The number of electrodes used varies from system to system and the unit electrode spacing is varied to obtain a certain investigation depth. Any electrode configuration can be used, however normally only one type of electrode configuration is used in the same dataset. Traditionally in mining, the dipole-dipole electrode configuration is used. In environmental and groundwater applications where less powerful instruments are used, the preferred electrode configuration is the Wenner configuration, because this electrode configuration has a higher signal-to-noise ratio and therefore is more robust to noise.

The investigation depth is primarily dependent on the electrode configuration and the maximum electrode spacing. Using the Wenner configuration the investigation depth is about half the maximum electrode spacing. So, if the required investigation depth is about 40 m the maximum electrode spacing should be 80 m for a Wenner configuration.

The survey setup should use about 10 different electrode spacings to ensure that the three layers can be resolved.

DC-resistivity data are routinely interpreted using a 2D inverse modelling to obtain a 2D resistivity structure.

The DC-resistivity method is well suited mapping the clay and sand layer in the Swan River area.

OhmMapper

(Geometrics Inc.: OhmMapper)

The OhmMapper maps laterally and to some extend vertically resistivity structures. The recently developed system uses capacitively coupled electrodes. Therefore, the investigation depth obtained by the system is highly dependent on subsurface resistivities (because of the skin depth effect). The higher subsurface resistivity the larger investigation depth. The plastic clays assumable with resistivities about 5-20 Ωm just below surface in the Swan River area limit the investigation depth to less than 10 meters.

The OhmMapper will not be able to map the extension and thickness of the sand layer in the Swan River area.

Ground conductivity meters

(Geonics Limited: EM38, EM31, and EM34-3)

Ground conductivity meters typically maps lateral resistivity variations. The ground conductivity meter is frequency domain electromagnetic systems operating at so called low induction numbers. At low induction numbers the instrument readings are linearly proportional to the ground conductivity. However, this is only true for a moderate to high resistive ground. Furthermore, at low induction numbers the penetration depth only depends on coil separation and coil orientation. Dependent on coil orientation the penetration depth is 0.75-1.5 times the coil separation.

The EM38 system with a 1 m coil separation and the EM31 system with maximal 4 m coil separation have penetration depths in the interval of 0.75-1.5 m and 3-6 m, respectively, which is too shallow for investigations in the Swan River area.

The EM34-3 using coil separations of 10, 20 and 40 m provide the required investigation depth. However the low resistive plastic clays may cause unreliable conductivity readings.

The ground conductivity meters are primarily used as a qualitative tool for mapping. Soundings carried out using both different coil separations and coil orientations may be interpreted using 1D inverse models, but 2D inverse modelling, as carried out routinely for DC-resistivity data, are not routine for EM34 data.

The EM34 system is applicable to the Swan River area. The method has the potential of indicating, where the sand layer thickness increases and decreases, but not the potential of estimating layer thickness for all layers. Furthermore, the excepted problems with unreliable reading caused by low resistive clay have to be taken into account.

Other ground frequency domain methods

There are other frequency domain methods on the market. If they have a required investigation depth, they may have a potential of indicating changes in the sand layer thickness, but not the potential of estimating the thickness of the layers.

Helicopter borne frequency domain electromagnetic method (HEM)

(Fugro Airborne Surveys: DIGHEM)

The HEM method maps lateral and to some extend vertical resistivity variations. A frequency domain electromagnetic system with 5-6 frequencies between about 100 Hz to 100 kHz with coil separations of about 8 m is mounted in a “bird” and carried around by a helicopter in about 30 m high above the ground surface. Data are typically collected with a speed of 100 km/h.

The HEM method is developed to regional mapping for minerals placed in conductive veins in an otherwise resistive host rock. The method is sparsely used in “stratigraphy” mapping in sedimentary area, for instant in Germany.

The method has a limited depth resolution and is usually only capable of resolving two layers and at the most 3 layer. A layer has to be thicker than the depth to it to be detected. The investigation depth is typically about 50-80 m dependent on the subsurface resistivities.

HEM data can be interpreted using 1D inverse modelling. However, that is not necessarily part of the standard data interpretation carried out by the survey company.

In the Swan River area the sand layer will assumable only be detectable, if it is thick compared to the plastic clay above it and that it is thicker than at least 20 m.

Transient electromagnetic method (TEM)

(Geonics Limited: PROTEM)

The TEM method maps the vertical resistivity structure. TEM data is collected as single soundings located either along profiles or arbitrarily over an area. Commonly, a central-loop configuration is used with the receiver coil located in the middle of a 40 m by 40 m transmitter loop.

The investigation depth is dependent on the ground resistivity structure. I relative resistive ground investigation depths down to 130 m are obtained; conductive layers decrease the investigation depth. A layer has to be thicker than the depth to it to be resolved. The method is brilliant in mapping the depth to a good conductor.

TEM data is interpreted using 1D inverse modelling.

In the Swan River area the TEM method can be used mapping the sand layer if it is thick compared to the overlaying layer of plastic clay and that it is thicker than 10-15 m. The TEM method should be able to detect the boundary between the sand layer and the underlying shale/clay.

Controlled source audio magnetotelluric method (CSAMT)

(Geometrics Limited & EMI: Stratagem)

The CSAMT method maps vertical (and lateral) resistivity variations.

The CSAMT method is a frequency domain method. However it is comparable to the TEM method if data are collected at frequencies up to 100 kHz.

The CSAMT method is applicable in the Swan River area with the same limitations as the TEM method.

Ground penetrating radar (GPR)

GPR maps changes in the dielectrical constant laterally and vertically.

The signal attenuation depends on the ground resistivity. The more conductive ground the higher signal attenuation; i.e., clay layers attenuate the signal.

In the Swan River area the sand layers can not be mapped by GPR as the signal can not penetrate down through the overlying clay layer.

Reflection seismics

Reflection seismics maps structures in the ground that are caused by changes in acoustic velocity and/or density. A “shot” generates seismic energy that penetrates into the ground, where it is reflected back to the ground surface at boundaries with seismic velocity and/or density contrasts. The reflected energy is detected at ground surface.

In a shallow seismic survey it is usually possible to detect reflections in a depth interval from 10-30 m to a few hundred meters.

To ensure that the seismic energy can penetrate into the ground, the sediments have to be well consolidated or water saturated. For instants, dry loose sand will absorb the seismic energy.

If a reflection seismic survey in the Swan River area should be successful it has to be a “best condition” case. The layer boundaries lie in the interval of 10-30 m, which usually is on the upper limit of detectable reflections.

Refraction seismics

Refraction seismics maps lateral and vertical seismic velocity variations. Seismic energy is transmitted into the ground by a “shot”. A fraction of the seismic energy is converted to refracted waves where the seismic waves hit a layer with a higher velocity at critical angle. At a certain distance (about critical distance) away from the shot, geophones detect the refracted waves as first arrivals.

The best condition for a successful refraction seismic survey is at locations, where the seismic velocity increases with depth. Although low velocity zones or layers can be found, if a velocity model is constructed from the data by inverse modelling (seismic tomography).

In the Swan River area the plastic clay is assumed to have a higher velocity than the underlying sand layer. A refraction seismic survey is assumed to run into a “hidden layer” problem, i.e., the top of the sand layer with an assumed lower velocity creates no refracted wave and is therefore not directly observed in the data.

Gravity

A gravity survey detects density contrasts in the ground.

In a microgravity survey anomalies down to 0.001 mGal can be detected. However, to achieve such accuracy the horizontal position and the vertical position have to be known better than 1.2 m and 4 mm, respectively.

If qualitative information, such as layer thickness or shape of the anomalous body, solely should be obtained from a gravity survey, the geological setting has to be so simple that it only consists of two different materials.

In the Swan River area, a microgravity survey will only be able to predict the thickness of the sand layer, not the depth to it and it will only be the case if following conditions are obtained. 1) The density of the plastic clay above and the shale/clay below the sand layer has to have the same density. Otherwise a change in gravity readings can either be caused be changes in the thickness of the plastic clay or the sand. 2) The ground water table must not lie within the sand layer. The density is dependent on water saturation. 3) The density contrast has to be known. 4) Each layer has to be homogeneous.

Magnetics

In magnetic prospecting changes in earth magnetic field due to changes in magnetic susceptibilities or remanent magnetization in the ground are measured.

A magnetic survey is assumed not to be able to provide any information about thickness of or depth to the sand layer.

Conclusions

The DC-resistivity method (profiling with about 10 different electrode spacings) is best suited to map the Swan River area. The method can provide 2D resistivity models from which the sand layer thickness can be estimated.

The EM34-3 system used with all three coil separations can indicate changes in layer thickness.

The TEM and CSAMT methods have only the potential of mapping the sand layer, where the sand layer is at least 10 m and thicker than the overlying clay layer.

A reflection seismic survey can under the best conditions detect the sand layer.