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INTERPRETATION OF APPARENT RESISTIVITY MAPS AND RESISTIVITY CROSS SECTIONS FROM THE KOTCHO REGION, N.E. BRITISH COLUMBIA

by

BEMEX CONSULTING INTERNATIONAL
5288 CORDOVA BAY ROAD
VICTORIA, B.C. V8Y 2L4

for

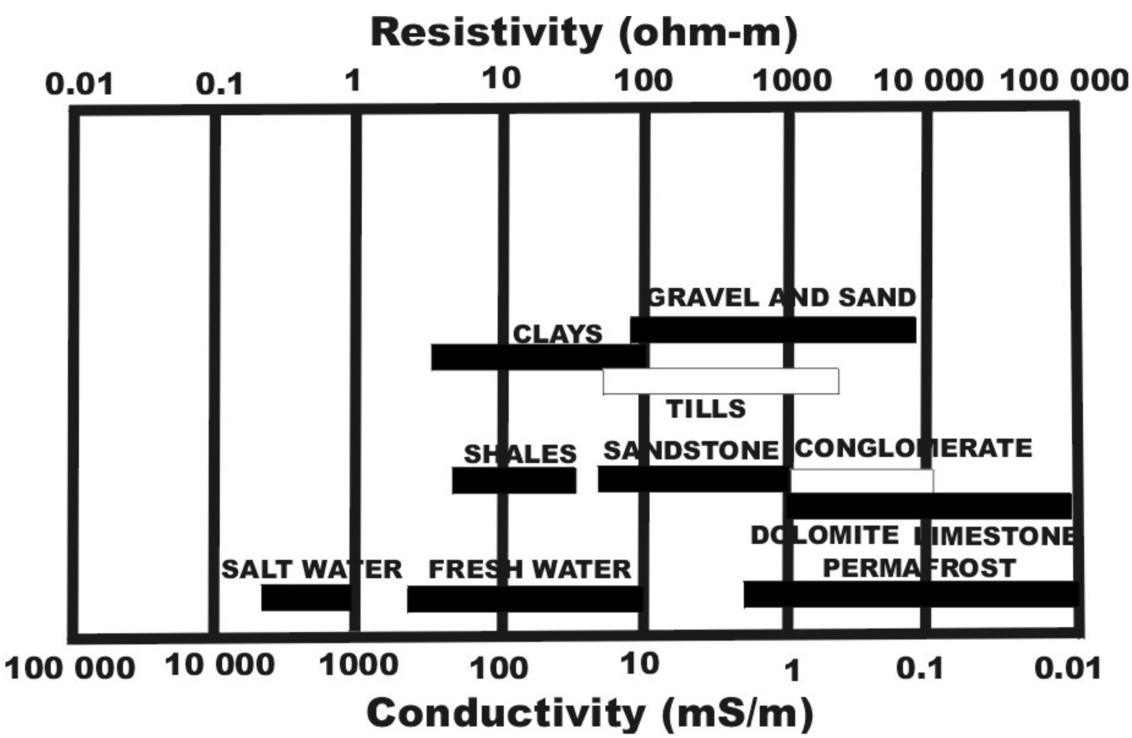
NEW VENTURES BRANCH
BRITISH COLUMBIA MINISTRY OF ENERGY AND MINES

Introduction:

A helicopter electromagnetic (EM) survey was carried out over a test area in the Kotcho area of northeast British Columbia to determine if airborne EM could be used to locate shallow gravel deposits within this region. The test survey covered an area that contained a shallow gravel deposit initially discovered from seismic shot hole data. The deposit was subsequently delineated, at least partially, by trenching.

Fugro Airborne Surveys was contracted to carry out a multi-frequency helicopter EM and magnetic survey using the RESOLVE™ EM system. The final processed data included 5 apparent resistivity grids generated from the coplanar coils at frequencies of 380, 1400, 6200, 25,000 and 115,000 Hz. Fugro also generated 8 apparent resistivity cross sections and resistivity inversion cross sections alonglines 10110, 10120, 10130, 10140, 10150, 10160, 10170 and 10180. The final data set included a series of magnetic grids as well (total field magnetic, vertical derivative, several high pass filters, with and without reduction to the pole, i.e. RTP).

This report discusses the various data sets and integrates them into a potential resistivity



model of the subsurface within the survey area.

Resistivity of rocks and unconsolidated sediments:

Approximate resistivity ranges for sedimentary rocks and glacial sediments are given in Figure 1. These ranges may be larger than shown in the Figure under some circumstances. Note the resistivity range of sandstone and sand and gravel overlap. The resistivity range for till also overlaps that of sandstone and sand and gravel to some extent.

The main factors that determine the resistivity of a rock or sediment are 1) porosity, 2) pore fluid(s) resistivity, and 3) percentage of conducting minerals (clays, graphite, sulphides) contained within the mineral grains. The influence of pore water on the resistivity of a rock or sediment can be determined from Archie's Law.

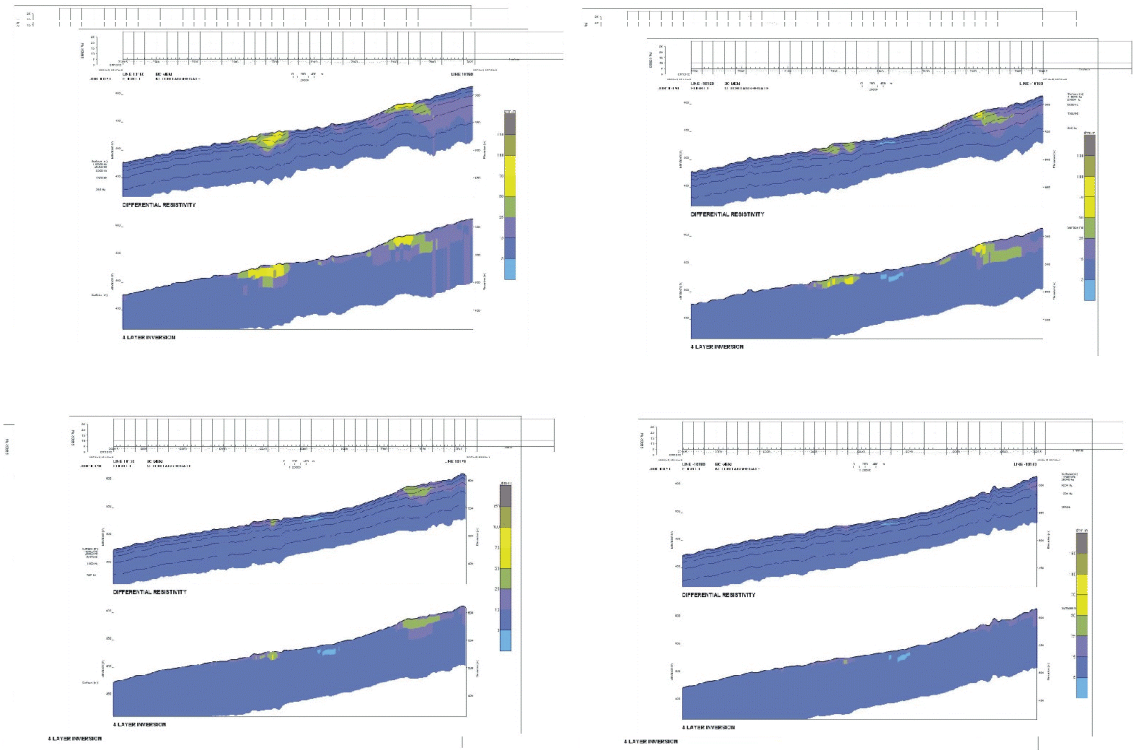
$$\rho_b = \rho_f \, \varphi^{-m} \, S_w^{\,2} \qquad (1)$$

where ρ_b and ρ_f are the resistivity of the bulk material and fluid respectively, φ is the porosity and m is the cementation factor (usually between 1.5 and 2.0). The water saturation within the pores is S_w (assuming the other fluid in the pores is resistive, for example oil or air). $S_w = 1$ when the pores are filled with 100% water.

Archie's Law implies that for a given pore fluid the larger the porosity the larger the bulk resistivity. This equation does not take into account conducting mineral grains such as clay, graphite and sulphides. Such conducting grains, if they are electrically connected, will lower the bulk resistivity of a rock or sediment from that predicted by Archie's Law. When the conducting mineral grains are isolated from one another no current will flow within the mineral grains. In this case the current will flow through the water in the pores and the bulk resistivity is determined from Archie's Law. On the other hand if there are continuous conducting pathways within the mineral grains some of the current will flow within the pore water and some of the current will flow within the conducting mineral grains. The bulk resistivity of the material will therefore be less than that predicted by Archie's Law. Indeed, in the case of clay, the bulk resistivity can come almost entirely from conducting clay minerals rather than pore water.

Description of resistivity sections

Figures 2 and 3 are resistivity sections computed for lines 10110 to 10180. The upper section of each line was generated from the apparent resistivity data for the 5 horizontal coplanar coil configurations (frequencies of 380, 1400, 6200, 25,000, and 115,000 Hz) of the Fugro Resolve™ system. The estimated depth of the apparent resistivity for each frequency at a given position along a line is equal to the skin depth computed from the apparent resistivity value at that position. The lower section on each line is a layered earth inversion (in this case 4 layers)



computed using the in-phase and quadrature data at all 5 frequencies.

The apparent resistivity is calculated from the normalized in-phase and quadrature values of the secondary magnetic field by assuming the earth is homogeneous with a resistivity equal to ρ_a. For a given frequency f and transmitter-receiver separation S, the apparent resistivity computed from the in-phase and quadrature values depends on the height of the Resolve system above the ground. As the height above ground increases the in-phase and quadrature values decrease in a predictable way, and hence the apparent resistivity will change as well.

The apparent resistivity is therefore considered to be an approximate measure of the average resistivity of the earth to a depth δ (skin depth)

$$\delta \text{ (metres)} = 503 \, (\rho/f)^{1/2} \qquad (2)$$

where ρ is the resistivity and f is the frequency. For a given resistivity the skin depth decreases as the frequency increases. Consequently the apparent resistivity values at the highest frequency (115,000 Hz) represents the average resistivity at shallow depths while the apparent resistivity values at the lowest frequency (380 Hz) represents the resistivity averaged over a deeper depth.

The earth is generally not homogenous but more complex. This is why the computed resistivity assuming the earth is homogeneous is called an apparent resistivity. As an example consider a two layer earth with the upper layer equal to 100 ohm-m and the lower layer equal to

5 ohm-m. The skin depth of the upper layer at 115,000 Hz is 503 x $(100/115{,}000)^{1/2}$ = 14.8 m and at 380 Hz is equal to 258 m. If the upper layer is 20 m thick then the apparent resistivity at 115,000 Hz will be very close to the upper resistivity of 100 ohm-m and at 380 m would be approximately equal to the lower layer resistivity of 5 ohm-m. On the other hand if the upper layer is only 5 m thick the apparent resistivity at 115,000 Hz would be between 100 and 5 ohm-m, in other words an average of the upper and lower resistivity values since the upper layer skin depth is nearly three times the layer thickness. The apparent resistivity a t 380 Hz would still be approximately 5 ohm-m.

Notice the similarity between the upper and lower sections in Figures 2 and 3 for each of the lines, even though the upper resistivity section is computed assuming the earth is a homogeneous half-space at each frequency. The reason why this happens is because the resistivity structure of the earth is either homogenous (as observed on most of the lines) or is approximately two-layered with the upper layer more resistive.

Interpretation of data

<u>Apparent resistivity maps</u>

The 5 apparent resistivity maps for horizontal coplanar coils at frequencies of 380, 1400, 6200, 25,000 and 115,000 Hz therefore provide resistivity values averaged over 5 different depths depending on the frequency. These 5 maps exhibit several interesting features worth noting, . There is a resistivity high near the northern boundary of the survey area between lines 10130 and 10180 at frequencies between115,000 and 6200 Hz. At lower frequencies the resistivity of this feature merges with the background resistivity values. There is another resistive feature between lines 10060 and 10160 that starts near the southern boundary of the survey area and continues to the middle of the north-south survey lines. The resistive feature is most prominent on the three higher frequencies similar to the first feature we discussed In both these examples the apparent resistivity values are within or close to the resistivity range of sands and gravels and/or sandstone (Figure 1).

An approximately north-south boundary (with an east-west jog at approximately the mid point of the survey) separates higher resistivity values to the west from lower resistivity values to the east. This boundary is located between lines 10180 and 10120 and is visible on all 5 apparent resistivity maps. The eastern edges of the two resistive features discussed above are coincident with this boundary. It is not clear what this boundary represents geologically since it is observed near the surface (115,000 Hz) and also at depth (380 Hz). If this boundary is a bedrock contact, say between sandstones to the west and shales to the east, then there should not be such a sharp boundary in the overburden material. Similarly if it is a surficial feature then there not be such a sharp boundary at depth.

In addition to the above features there is one other resistive zone that can be seen at higher frequencies along the northern boundary of the survey area between lines 10050 and 10120. It is more diffuse than the other two resistive features discussed earlier but the resistivity values are comparable.

Resistivity sections

The resistivity sections for lines 10110 to 10180 provide information on the depth extent of the resistive features discussed above (Figures 2 and 3). The northern-most anomalous feature is most prominent on lines 10050 to 10100, although there is a hint of it on lines 10110 and 10120.

The background resistivity values (away from the resistivity features and at depth under the resistive features) are very low, most likely associated with shale or clay. The resistivity of the resistive features computed from the layered earth inversions generally have values greater than 50 ohm-m, although the outer fringes are somewhat less resistive (greater than 25 ohm-m). These values could correspond either to sand and gravel or to sandstone. Sandstone bedrock is known to exist in the area so there could be knobs of sandstone protruding through shale and/or tills. The only way to confirm the presence of shallow sand and gravel is to trench or drill

Once drilling or trenching confirms the presence of sand and gravel in these resistive features the entire area containing the resistive anomaly will almost certainly be composed of sand and gravel. The thicker regions of the resistivity features are estimated to be between 25 and 35 m deep but do thin towards the edges. This is deeper than the trenching that has been carried out on these features. The depths from the resistivity cross sections can be used in conjunction with the apparent resistivity maps to estimate the total volume of sand and gravel in place.

Summary and conclusions

The Resolve EM system was effective in mapping sand and gravel deposits in the Kotcho area of British Columbia. The areal extent of the known deposit (from seismic shot hole data and trenching) was mapped and the total area was even extended. The resistivity cross sections provided an estimate of the depth of the sand and gravel deposit as well.

The survey outlined two other resistivity features as discussed above. Unfortunately the resistivity range for sand and gravel overlaps the resistivity range for sandstone. Since sandstone may outcrop in this area follow up drilling or trenching is required to determine te material causing these anomalous resistivity features. Recent trenching of the larger feature to the south has shown that it, at least the part of the feature sampled, consists of sand and gravel. Further delineation is required to make sure the entire area of the resistive feature consists of sand and gravel.