

SAND AND GRAVEL MAPPING IN NORTHEAST BRITISH COLUMBIA USING AIRBORNE ELECTROMAGNETIC SURVEYING METHODS

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INTRODUCTION

The Ministry of Energy and Mines, as part of the provincial Oil and Gas Development Strategy, recently initiated a regional geological assessment of aggregate resources in northeast British Columbia. The area identified for this project (Figure 1) was selected because subsurface data, collected during seismic shot hole drilling in the region, indicated that gravels were present under one to two metres of overburden. Aggregate deposits are extremely rare in this area, with the closest known deposits occurring many tens of kilometres distant. The study area occurs along the Kotcho winter road, about 40 km east of the Sierra-Yoyo-Desan (SYD) Road.

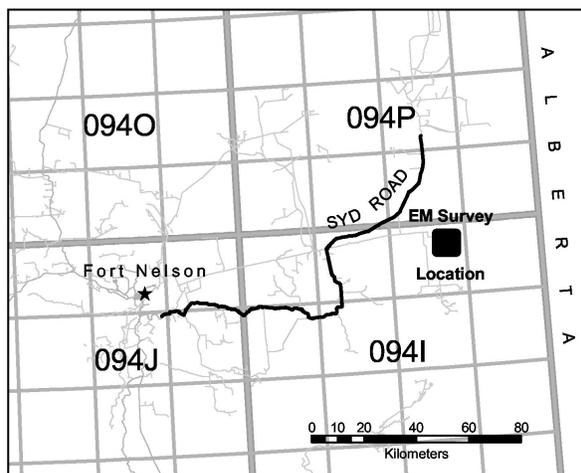


Figure 1. Map of the survey location relative to the Sierra-Yoyo-Desan (SYD) Road.

After initial identification of the area from the shot hole data, the Ministry of Energy and Mines contracted a geotechnical aggregate investigation in the region. The results of the study identified an area approximately 700 m long by 100-400 m wide that contained an estimated 410,000 cubic metres of sandy gravel (Dewer and Polysou, 2003). Excavations in the vicinity of the deposit showed gravels underlying silt rich sediments. The buried sands and gravels were encountered in 10 test pits in an elongated, southwest-trending area, oblique to present surface stream channels. In the core of the deposit, the sands and gravels are at least 5 m thick and in six of the test holes the base of the deposit was not encountered. Surprisingly, the water table was encountered in only one test hole at the south-eastern most edge of the deposit.

The gravel deposit occurs along a gentle south-easterly slope in an area with very little surface topography and there is little or no geomorphic indication that subsurface gravels are present. The sands and gravels are overlain by silts and clays generally 1-2 m thick, but locally up to 5 m thick. These sediments are interpreted to be glaciolacustrine in origin. Even though much of the area has been logged and surface features are readily visible, air photographic interpretation alone would not have detected this deposit.

The present study was initiated to test the effectiveness of using airborne electromagnetic (EM) data for detecting such buried gravel deposits. The objectives of the EM study were threefold: 1) to determine if the buried gravels could be detected remotely, 2) to attempt to trace the extent of the gravel deposit beyond the field tested boundaries, and 3) to locate any other aggregate sources in the area, either directly adjacent to the known deposit or within the general region. To accomplish these objectives, a detailed survey (Figure 1) with a 100 m line

spacing was conducted directly over the known deposit, and a larger area (~25 square kilometres in size – the total black area shown in Figure 1) was covered with a 200 m line spacing (Cain, 2004).

Fugro Airborne Surveys was contracted to carry out a multi-frequency helicopter EM and magnetic survey using the RESOLVE™ EM system. The processed data include five apparent resistivity grids generated from the horizontal coplanar coils at frequencies of 380, 1400, 6200, 25,000 and 115,000 Hz. Fugro also generated apparent resistivity cross sections (differential resistivity) and resistivity inversion cross sections along several lines. The data set includes 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 paper discusses the EM data sets and integrates them into a possible resistivity model of the subsurface within the survey area.

RESISTIVITY OF ROCKS AND GLACIAL SEDIMENTS

Approximate resistivity ranges for sedimentary rocks and glacial sediments are given in Figure 2. Note resistivity has units of ohm-m and conductivity, which is the inverse of resistivity, has units of Sieman per metre (S/m). In some instances these ranges could even be larger than those shown in the Figure. The resistivity range for sandstone overlaps that of sand and gravel and that of till overlaps both sandstone and sand and gravel.

The main factors that determine the resistivity of a rock or sediment are 1) porosity, 2) resistivity of pore fluid(s), 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 (Archie, 1942).

$$\rho_b = \rho_f \Phi^m S_w^2 \quad (1)$$

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

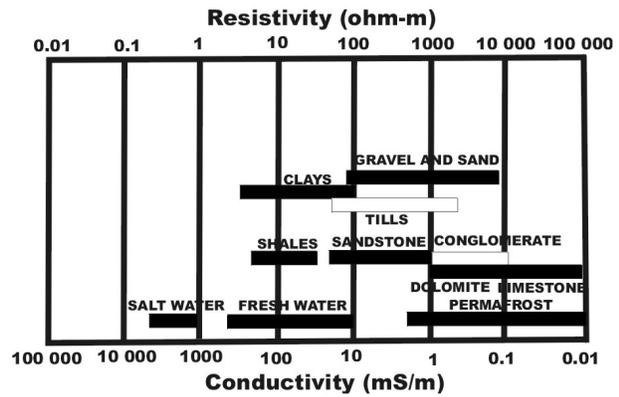


Figure 2. Resistivity ranges for rocks and glacial sediments (modified from Palacky and Stevens, 1990).

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 be almost entirely from conducting clay minerals rather than pore water.

DESCRIPTION OF DATA

Resistivity Sections

Figures 3 and 4 are resistivity sections computed for lines 10110 to 10180. The upper diagram of each line was generated using apparent resistivity data from the horizontal coplanar configurations (differential resistivity). The estimated depth of the differential resistivity sections at each frequency and for 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 the apparent resistivity 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 above ground. As the height increases the in-phase and quadrature values decrease in a predictable way, and hence the apparent resistivity will change accordingly.

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

$$\delta \text{ (m)} = 503 (\rho_a/f)^{1/2} \quad (2)$$

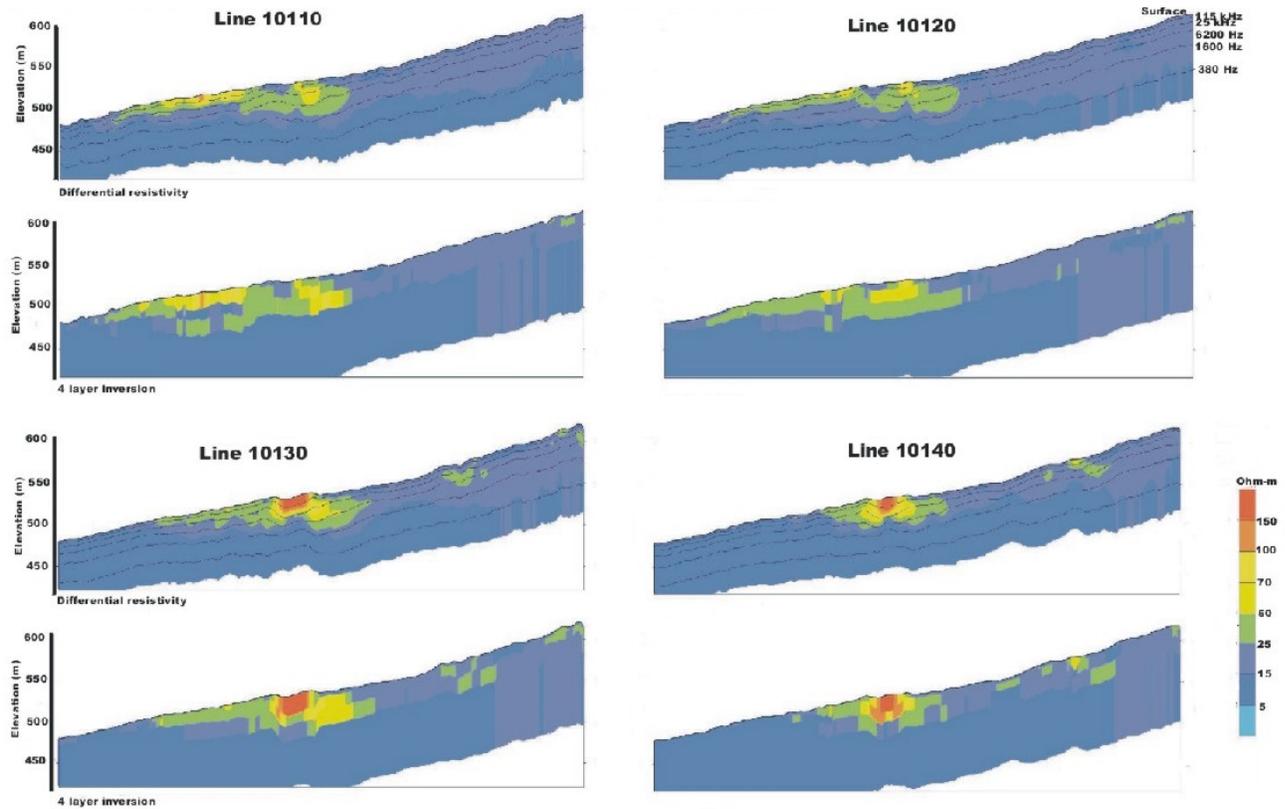


Figure 3. Resistivity cross sections for lines 10110 to 10140. The upper diagram of each line is the differential resistivity and the lower diagram is the 4-layer inversion as described in the text. North is to the right.

For a given resistivity the skin depth decreases as the frequency increases. Consequently the highest frequency of 115,000 Hz represents the average resistivity at the shallow depths while the lowest frequency of 380 Hz represents the average resistivity at the deepest depth the Resolve system can image.

The earth is generally not homogeneous but more complex. This is why the computed resistivity is called an apparent resistivity. As an example consider a two-layer earth with the upper layer resistivity equal to 100 ohm-m and the lower layer resistivity equal to 5 ohm-m. The skin depth of the upper layer at 115,000 Hz and 380 Hz is 14.8 m and 258 m respectively. If the upper layer is 20 m thick then the apparent resistivity at 115 000 Hz will be close to the upper resistivity of 100 ohm-m and at 380 Hz 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 a weighted average of the upper and lower resistivities since the upper layer skin depth is nearly 3 times the layer thickness. The apparent resistivity at 380 Hz would still be approximately equal to 5 Ohm-m.

Notice the similarity between the upper and lower sections in Figures 3 and 4 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 homogeneous (as observed on most of the lines) or is approximately two-layered with the upper layer more resistive.

Apparent Resistivity Maps

The upper resistivity in Figure 5 is the apparent resistivity calculated from the high frequency (115 kHz) horizontal coplanar coils and the lower map is the apparent resistivity calculated from the low frequency coils (380 Hz). These maps illustrate the spatial variability of the average conductivity at shallow (115 kHz) and deep (380 Hz) depths.

INTERPRETATION OF DATA

Apparent Resistivity Maps

As discussed the five apparent resistivity maps represent resistivity values averaged over 5 different subsurface depths, depending on the frequency. These maps exhibit several interesting features worth noting

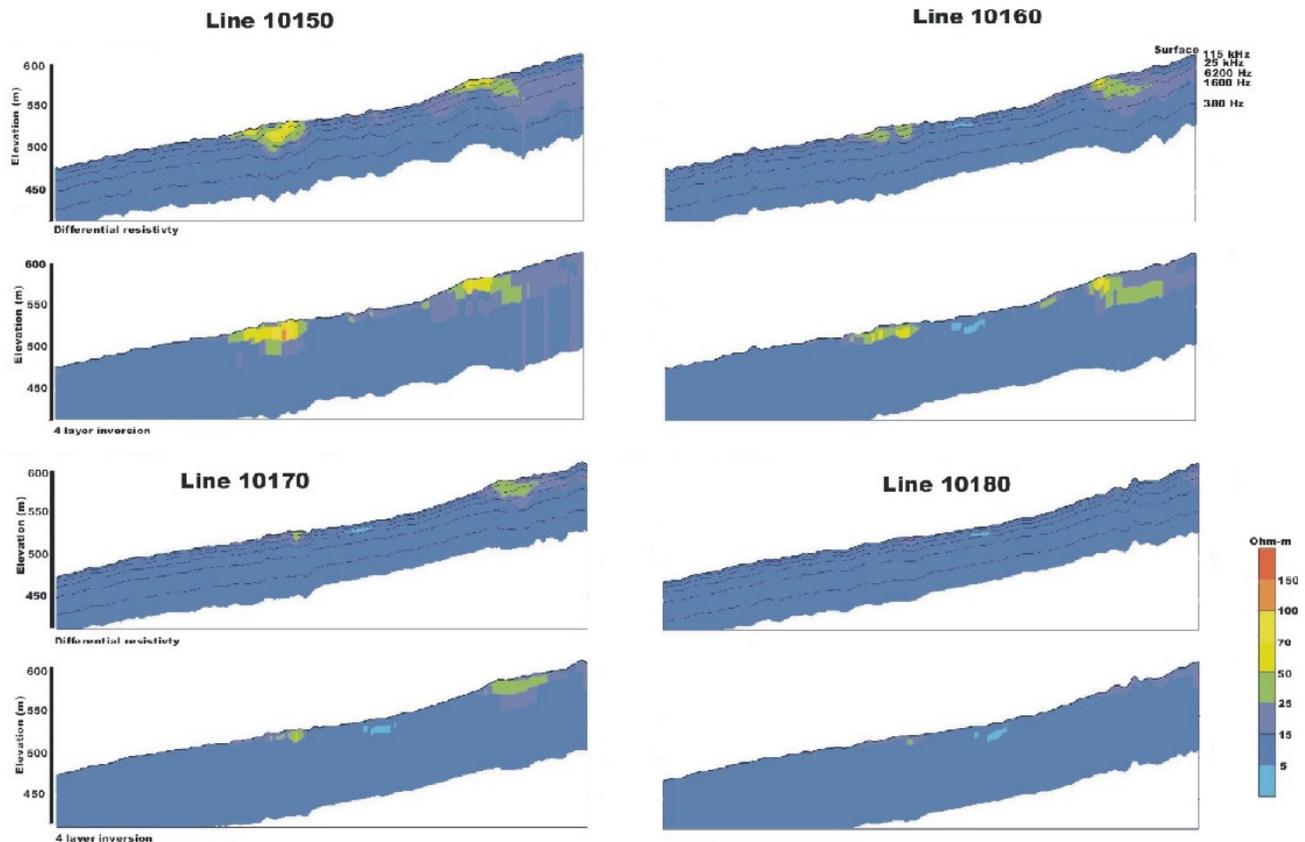


Figure 4. Resistivity cross sections from lines 10150 to 10180. The upper diagram of each line is the differential resistivity and the lower diagram is the 4-layer inversion as described in the text. North is to the right.

(Figure 5). There is a resistivity high (Zone A) located in the northern part of the survey area between lines 10130 and 10180 that is prominent at frequencies between 115,000 and 6200 Hz. At lower frequencies the resistivity of this feature merges with the background resistivity values. This feature is related to the sand and gravel deposit outlined by trenching.

There is a resistive feature (Zone B) between lines 10060 and 10160 that starts near the southern boundary of the survey area and continues north to the middle of the survey. This resistive feature is most prominent on the three highest frequencies, similar to Zone A.

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 (figure 5) and is visible on all 5 apparent resistivity maps. The eastern edges of Zones A and B are coincident with this boundary. It is not clear what this boundary represents geologically since it is observed on all 5 frequencies.

In addition to Zones A and B there are two other resistive zones that can be seen on the higher frequencies (Figure 5). Zone C is along the northern boundary of the survey area between lines 10150 and 10110 and Zone D lies between lines 10240 and 10280. Both these features

are more diffuse than Zones A and B but the resistivity values are comparable.

Resistivity Sections

Resistivity sections between lines 10110 and 10180 provide information on the depth extent of Zones A and B (Figures 3 and 4). Zone A appears on lines 10130 to 10170 and zone B appears on lines 10110 to 10170. Zone C is most prominent on lines 10060 to 10100, although there is a hint of this resistive feature on lines 1010 and 10120. Zone D does not appear on any of these processed lines.

The background resistivity values (away from the resistivity features and at depth under the resistive features) are low (< 15 ohm-m), 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 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 till.

Once drilling or trenching confirms the presence of sand and gravel in any of these resistive features we can

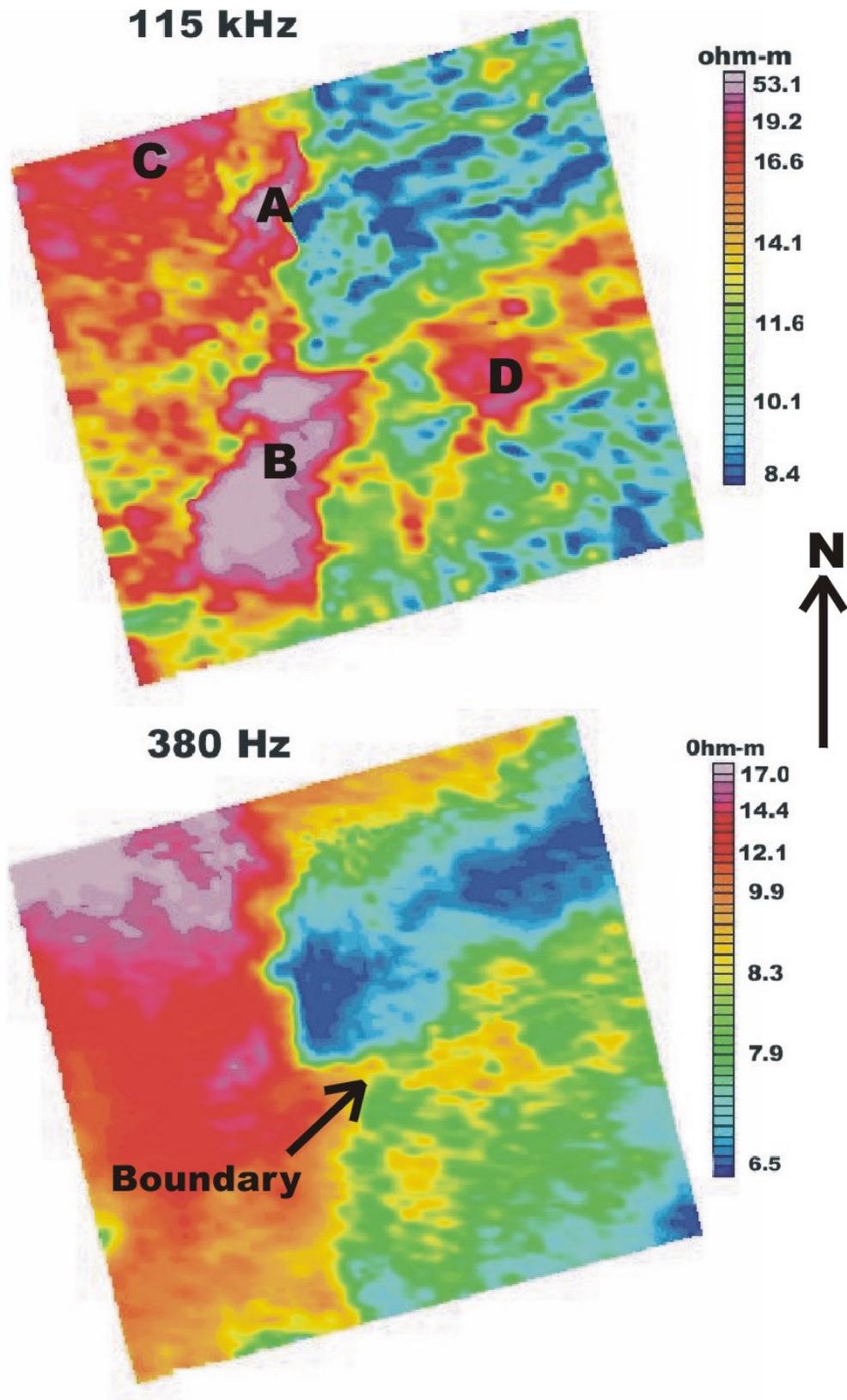


Figure 5. Apparent resistivity maps for frequencies of 115 kHz (upper diagram) and 380 Hz (lower diagram). The four resistivity areas discussed in the text are labeled A to D in the upper diagram.

assume that the entire area containing the resistive anomaly will most likely be composed of sand and gravel. The thicker regions of resistive Zones A and B are estimated to be between 25 and 35 m deep but do thin towards the edges. This is deeper than the trenching carried out to date. 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.

RESULTS

On the high frequency data reflecting the shallow geology, four main areas of high resistivity were identified in the survey. Zone A coincided remarkably well with the area of shallow buried gravels as mapped out by the field investigations. The northern and southern areas of Zone B are much larger and became the focus of recent reconnaissance-scale ground investigations. During these recent studies, both areas were found to contain sand and gravel. At least 4 m of sand and gravel, under 1-2 m of overburden, were encountered in test pits in the centre of these areas. Further work is required to outline these deposits in detail and to investigate the potential of Zones C and D. The results strongly indicate that high resolution EM surveys can be an effective tool for mapping buried sand and gravel deposits.

SUMMARY AND CONCLUSIONS

Airborne EM 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 containing sand and gravel was extended. The resistivity cross sections also provided an estimate of the depth of the sand and gravel deposit.

The survey outlined two other resistivity features as discussed above (Zones C and D). 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 the material causing these anomalous resistivity features.

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