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Surveys	Geoelectrical Tomography (ERT) and Gradiometric surveys on Quill Creek placers		
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1. Introduction

Between 21 and 28 June 2015, a geophysical campaign was conducted in Quill Creek (Yukon, Canada), in an area located approximately 310 Km NW from Whitehorse, Yukon, and 8 Km up the Quill Creek road. The campaign was constituted by several surveys and aimed at:

- Obtain a reconstruction of the bedrock shape below the Quill Creek alluvial deposits.
- Locate eventual magnetic anomalies correlated with the concentration of magnetite-black sand.
- Distinguish the particularly clay-rich areas (old settings basins) from the clay-poor areas (washed deposits).

The surveys implemented were based on the following methods:

- Geoelectrical Tomographies (Electrical Resistivity Tomography - ERT): five profiles have been implemented in order to characterise the bedrock shape;
- An areal gradiometric survey has been performed to locate the magnetic anomalies;
- Chargeability measures (IP) have been performed contemporary to the resistivity measures (geoelectrical profiling) to identify the clay deposits.

2. Geoelectrical Tomography (ERT) – Method Statement

The objective of Electrical Resistivity Tomography (ERT) is to determine the subsurface distribution in two or three dimensions (2D and 3D) of resistivity, a physical parameter that is related to key geological parameters such as soil or rock type and mineral content, as well as porosity and degree of water saturation.
The basic concept of tomographic inversion was first described by Lytle and Dines as an integration of traditional electrical probing (introduced by Schlumberger). Development of both the theory and practice of ERT occurred mostly in the late 1980s and 1990s. Tomographic inversion added important new capabilities as it provided a more general, accurate and rigorous spatial imaging of geophysical electrical resistance data than earlier pseudo-section or curve fitting methods.

The first system for practical application of geophysical ERT was constructed at Lawrence Livermore National Laboratory by Daily and Ramirez in 1989. Today, there are measurement systems commercially available that are 10-20 times faster (up to a few thousand measurements per hour) and can simultaneously address hundreds of electrodes. Key references are contained in the "References Section" at the end of the report. Loke, 1999, provides an excellent overview.

Resistivity measurements are made by injecting current into the ground through two current electrodes stakes (C1 and C2) and measuring the resulting voltage difference at two potential electrodes stakes (P1 and P2). Such measurement configuration is called a "quadripole" from the current (I) and voltage (V), an apparent resistivity value (ρ_a) is calculated by:

$$\rho_a = kV/I$$

where k is the geometric factor which depends on the arrangement of the four electrodes. Conceptually, ρ_a provides an average resistivity value for the volume of rock sampled by the electrode configuration. By increasing the electrode spacing, the investigated rock volume extends to a greater depth. By moving the electrodes laterally, the rock volume also moves laterally. All resistivity approaches rely on acquiring a number of different average ⍰$_a$ values for different electrode configurations, and using these to deduce changes in the electrical structure of the subsurface with lateral position and depth.

Traditionally, two approaches have been used:

- In soundings, the electrodes spacing is expanded symmetrically about a centre point, allowing the resistivity structure to be investigated directly under this point. The restricting assumption when interpreting sounding data is that the earth resistivity structure only changes with depth (i.e. 1D layering).
- In profiling, the electrode spacing is kept constant, but the electrodes are moved progressively sideward. This approach is able tom point out qualitatively the existence of lateral changes at depth, but cannot indicate precisely how this change is distributed with depth.

ERT combines these approaches and removes some restrictive assumptions made about the subsurface electrical structure. Firstly, an "array" or large number of electrodes, are used and sequential measurements of a large number of different electrode combinations are controlled by a computer. Secondly, this data is inverted in a manner that takes into account changes in both horizontal and vertical resistivity along the profile. In this case it is assumed that the resistivity does not significantly change perpendicularly to the survey line. Typical 1D resistivity sounding surveys involve about 10 to 20 readings, while 2D imaging surveys involve about 600 to 3000 readings.

The standard approach for processing ERT data is to use a numerically calculated (usually finite difference) forward model to define a partial derivative matrix, which is used to iteratively update a starting model (Morelli and Labrecque, 1996). This is a standard approach used for non-linear geophysical problems. The point of departure is that the problem is inherently ill-posed, thus a myriad of different schemes have been implemented to provide better image fidelity. After systematic trialling of different algorithms, we have opted for the approach used in the Geostudi Astier software (Morelli and Labreque 1996).

Another subtle point is that the electrode configuration used can significantly influence image fidelity (Zhou and Greenhalgh 2000). In theory it would be ideal to space electrodes as closely as possible, and to acquire data for every conceivable electrode configuration. In practise, this would take far too long for production surveys and compromises must be made. Tradeoffs must be made between configurations that provide the best signal to noise characteristics, and maximum sensitivity. Our response has been to use, for the surface ERT, the Wenner Schlumberger Array (good signal to noise characteristics) in combination with the Pole Dipole (excellent lateral resolution and depth of investigation). A feature of the Geostudi Astier software is that it can process data from more than one array type, concurrently.

2.1 Equipment

The equipment for data collection was constituted by:

- Resistivitymeter Syscal Pro operating on 10 channels and 72 electrodes;
- two geoelectrical cables with 3 meters spaced takeouts;
- 48 steel electrodes;
- car battery.

2.2 Field operations and data acquisition

The geoelectrical surveys have been carried out on profiles made by 48 electrodes.

Surface ERT requires the same four electrode resistance measurement used for VES soundings or surface electrical profiling (two electrodes to inject current and two other electrodes to measure the resulting potential); however, tomography requires addressing tens or hundreds of electrodes and making hundreds or thousands of such measurements in a timely way.

The basic components of any acquisition system are: transmitter or current source; receiver which measures the resulting electrode potentials; multiplexer for quickness and automatically connecting the electrodes to the transmitter and receiver; and a computer for system control and data archival.

The instruments used for this method are fast multi-channel resistivity meters that allow the acquisition of several thousand data points in a few hours. Under typical conditions, for the *Syscal PRO* operating at 4 Hz and stacking 4-5 times, it is possible to acquire data within roughly 1% error in the magnitude (as determined by comparing reciprocal measurements, see below) at a rate of about 6-7000 measurements per hour. The instrument is powered by external 12 V battery, to avoid the use of AC generator and reduce any external source of disturbance. The maximum power applied is roughly 250 W (500 W with an external DC/DC converter), maximum voltages applicable to the transmitting electrodes are around 800 V, and maximum currents are about 2.5 Ampere.

To obtain the large number of independent impedance measurements necessary for tomographic inversion, all possible linearly independent combinations from an array of electrodes can ideally be used. For N electrodes, there are N (N-3)/2 such combinations that can be obtained using various strategies.

A very large number of measurement schemes are possible, some of which have been found useful. There has been some discussion about the relative merits of these sampling schemes regarding sensitivity patterns for various electrode configurations.

In this case, the schemes named Wenner Schlumberger and Dipole Dipole have been used to achieve a high signal/noise ratio (Wenner Schlumberger) and a very good lateral resolution (Dipole Dipole).

To locate the areas particularly rich in clay (that have to be interpreted as old settings basins) or clay poor ones (interpreted as washed deposits) chargeability measures or Induced Polarization (IP) have also been acquired. The Induced Polarization method is widely applied in this type of research because of the high polarizability of minerals disseminated in the geological environment. Chargeability is defined by the transient potential variable between two points on the transient decay curve normalized by the primary potential. In a dipolar arrangement, the current electrodes form a transmitter pair, while the potential electrodes form a receiver pair. When the current is interrupted, the voltage across the potential electrodes does not drop immediately to zero. After an initial abrupt drop to a fraction of its steady-state value it decays slowly for several seconds. Conversely, when the current is switched on, the potential rises suddenly at first and then gradually approaches the steady-state value. The slow decay or rise of part of the signal is due to induced polarization, which results from two similar effects related to the rock structure: membrane polarization and electrode polarization.

2.3 Data processing

The processing will be performed using dedicated 2D tomographic software that can perform the inversion of the whole dataset (Pole Dipole and Wenner Schlumberger apparent resistivity data) simultaneously to obtain a tomography with high lateral and vertical resolution (Fig. 2.1).

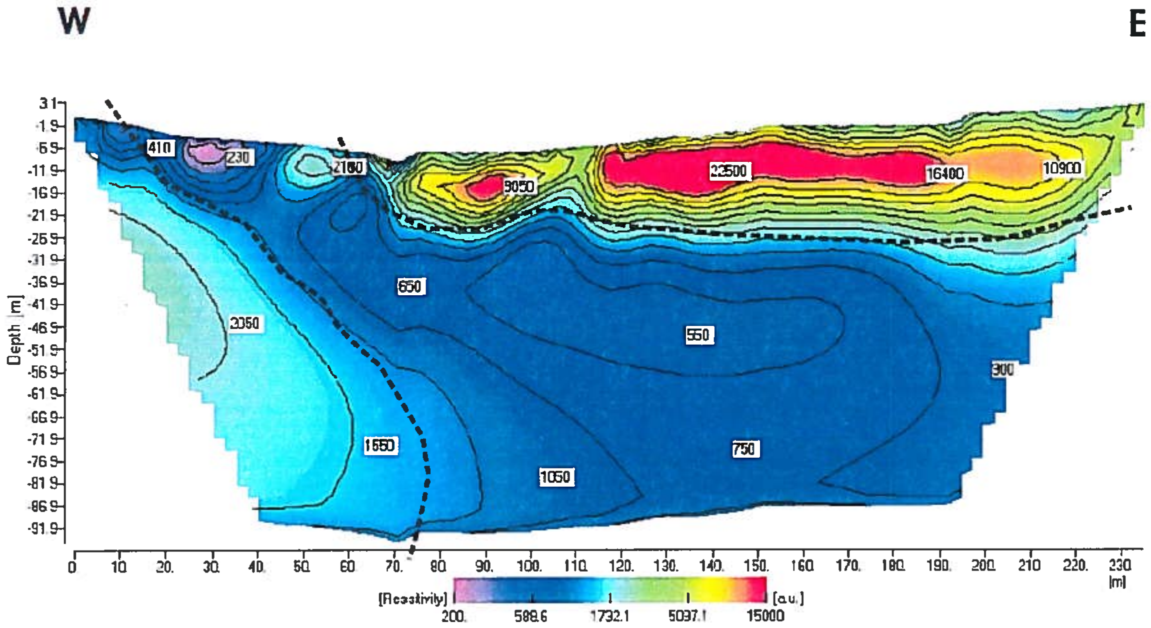


FIGURE 2-1: GEOELECTRICAL TOMOGRAPHY

3. Magnetometric Survey - Method Statement

The magnetometric survey has been performed using a GEM System GSM 19 with Overhauser effect. A "gradiometric" configuration has been used, with two sensors (spaced apart), with simultaneous measurement of the module of the Earth's magnetic field.

The sensors were mounted vertical spacing in order to measure the "vertical gradient" of the Earth's magnetic field. The acquisition of the gradient involves remarkable advantages. The magnetic fields that act in the same way of the sensors are filtered so that the anthropic sources, the fast temporal variations of ionospheric origin and the field of geological nature on regional scale are removed.

Moreover the gradient facilitates the detection of buried objects since the maximum of the gradient anomalies correspond with the edges of the magnetic sources.

The gradient's signal decays much more quickly with the distance in respect to the magnetic module, so that the investigation depth is lower.

This geophysical method is particularly indicated for the detection of isolated objects, which are characterised by high magnetic susceptivity (physical parameter that describes the capability to generate magnetic fields for induction phenomena).

3.1 Equipment

The equipment for data collection was constituted by a GEM System GSM 19 equipped with GPS device.

Below the features of the GEM System GSM 19 are listed:

- Sensibility: < 0.015 nT / √Hz
- Resolution: 0.01 nT
- Abs accuracy: +/- 0.1 nT
- Operating range: 10,000 - 120,000 nT
- Gradient tolerance : > 10,000 nT/m
- Sampling rates: 60+, 5, 3, 2, 1, 0.5, 0.2 sec
- Operating temperature: -40°C +55°C

3.2 Field operations and data acquisition

The measures have been acquired walking on straight lines maintaining a distance of about 2 meters between each line, with a sampling rate of 0.5 seconds and sensors 80 cm spaced.

For a proper understanding of the results be aware that:

- The maximum depth to which it can locate an object is directly proportional to the size of the object itself;
- The depth of the object detected cannot be determined except by comparison with other methods of investigation;
- A shallow object can mask a deeper object.

4. Results

4.1 Geoelectrical Tomography – resistivity and chargeability

In the tomographies two layer are clearly identifiable:

1. The shallower is characterized by lower resistivity values and can be correlated with recent alluvial deposits. Resistivity values variation can be attributed to different contents of clay rich matrix. Tomographies P1 and P2 show, for this layer, resistivity values higher in respect to tomographies P3, P4 and P5. This can be explained with the fact that the tomographies P1 and P2 have been laid on an excavated (washed) area with a lower contents of matrix, while the other on "virgin" areas. Some chargeability anomalies can be observed in the first layer. In some cases these anomalies are well correlated with the "magnetic gradient anomalies" probably due to the presence of magnetite deposits.
2. Below the alluvial deposits an increment of the resistivity values can be observed and a second layer is identified. This is correlated with the bedrock, locally outcropping.

4.1.1. Tomography P1

Resistivity

The alluvial layer in this area has been probably excavated in the past resulting in a low matrix content deposits.

In the first layer (alluvial deposits), two high resistivity anomalies, likely to be correlated with the presence of coarse and washed filling material, can be observed. The thickness of this layer ranges between 10 m and 20 m.

In the first part of the section, between 25 m and 55 m on X axis, the second layer (assumed to be the bedrock) becomes deeper and it is probably fractured by a tectonic structure.

Chargeability

Four chargeability anomalies that have good correlation with the "magnetic gradient anomalies" can be observed. Probably, there is a correlation with the presence of magnetite.

4.1.2. Tomography P2

Resistivity

In the first layer, considering the past digging activities, the evaluations above given to Tomography P1 are valid: this layer shows a thickness of about 10 m, without significant variations. The bedrock doesn't shows relevant variations, in the shape and in the resistivity values.

Chargeability

A chargeability anomaly can be observed starting from 60 m on X axis until the end of the section. In this case also there is a good correlation with the "magnetic gradient anomalies".

4.1.3. Tomography P3

Resistivity

The stratigraphic features are more complicated in this case. In the last part of the section, after 75-80 m on X axis, the bedrock is locally outcropping or very near to the surface. This partially explain the high resistivity values near the surface (coarse and washed filling material is also present in this area).

The alluvial deposits are clearly observable from the start of the section until 75-80 m on X axis, with a thickness that varies from 10 m to about 5 m.

After 60 m on X axis, the bedrock shows some large low resistivity anomalous zones that are probably correlated with tectonic structures.

Chargeability

The last part of the section (where bedrock is outcropping and fractured) there is a large chargeability zone that can indicates a general mineralization of the area.

4.1.4. Tomography P4

Resistivity

The alluvial deposits are characterized by lower resistivity values comparing with those observed for the same layer in the tomographies P1 and P2. This is probably due to the presence of a clay rich matrix indicating that these deposits are "virgin" and not washed during the past activities. The thickness ranges between 5 and 8 meters. The bedrock becomes deeper going to end of the section, with a probable tectonic structure near the profile end

Chargeability

Two main chargeability anomalies are clearly visible between 35 m and 65 m and between 85 m and 95 m on the X axis. These can be correlated with the presence of magnetite but in this area we have no gradiometric data that can confirm.

4.1.5. Tomography P5

Resistivity

This the only tomography that has been laid crossing the valley from a bank to the other.

On the edges of the section the slopes deposits are clearly visible and characterized by higher resistivity values comparing with the alluvial deposits. As for P4, the alluvial deposits show lower resistivity values comparing with tomographies P1 and P2 and are characterized by a thickness that ranges from 5 m and about 10 m.

The bedrock has a very irregular shape probably due to the presence of paleo-channels that engraved the rock.

Chargeability

Some chargeability anomalies are clearly visible and in this case also, can be correlated with the presence of magnetite even if we do not have gradiometric data for this area.

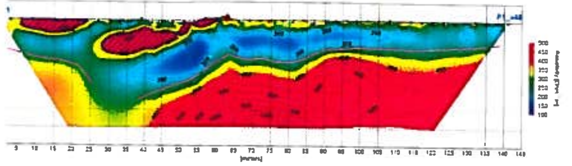
4.2 Gradiometric survey

The results of this survey are recapped in two maps:

- Magnetic anomalies map (vertical gradient): this map shows the acquired measures. The anomalies have a typical dipolar shape and are generated by ferromagnetic objects;
- Analytic signal map: this map shows the results of the signal elaboration, which takes place in two steps: in order to achieve a more correct localization of the anomalies, the gradient modulus is analytically transformed in the three directions. This step is needed to free the anomalies from the dipolar form; later the anomalies with a greater intensity (that is significance) are identified and result much more visible on account of the full scale colour (in our case magenta). On these, a close attention is then paid.

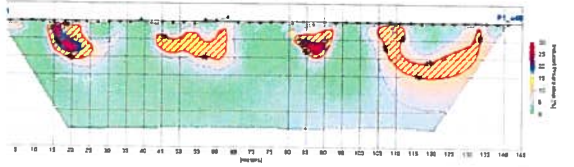
In both cases red-purple anomalies are clearly visible, most of them are elongated in the direction of the Quill Creek flow and are probably correlated with the presence of magnetite deposits.

Geoelectrical Profile P1 - Resistivity



scale 1:500

Geoelectrical Profile P1 - Induced Polarization



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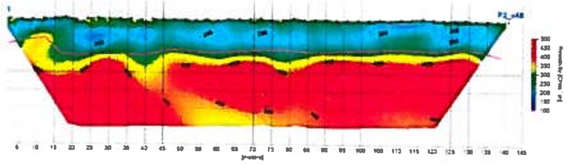
Geoelectrical Profile P2 - Resistivity



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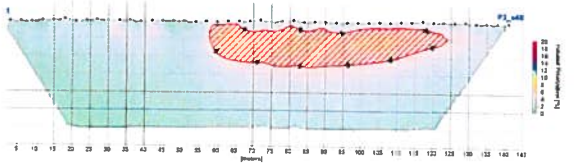
Geoelectrical Profile P2 - Induced Polarization



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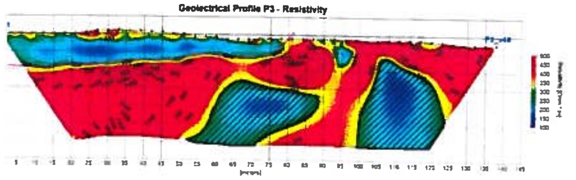
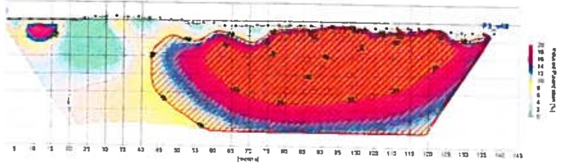
Geoelectrical Profile P3 - Resistivity



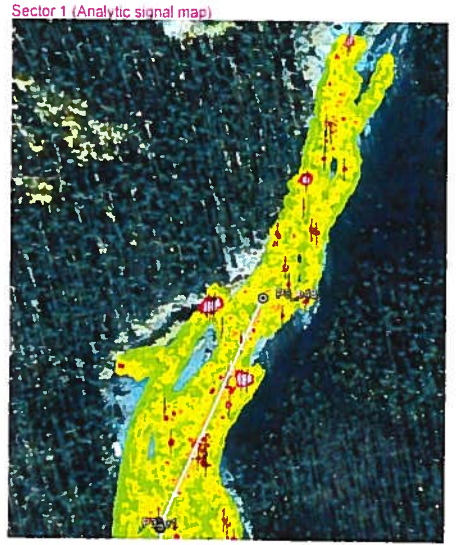
scale 1:500

Geoelectrical Profile P3 - Induced Polarization



scale 1:500

Sector 1 (Analytic signal map)



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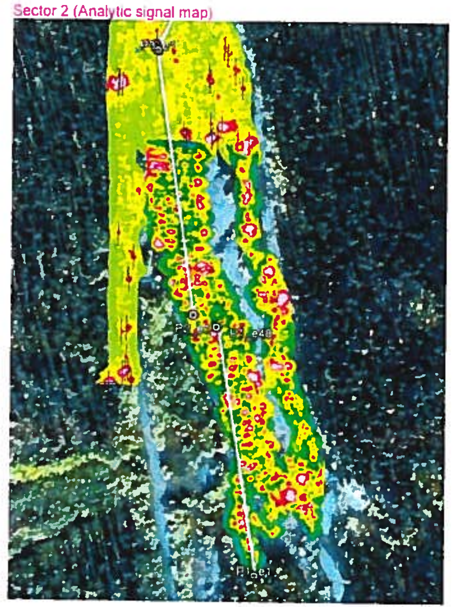
Sector 2 (Analytic signal map)



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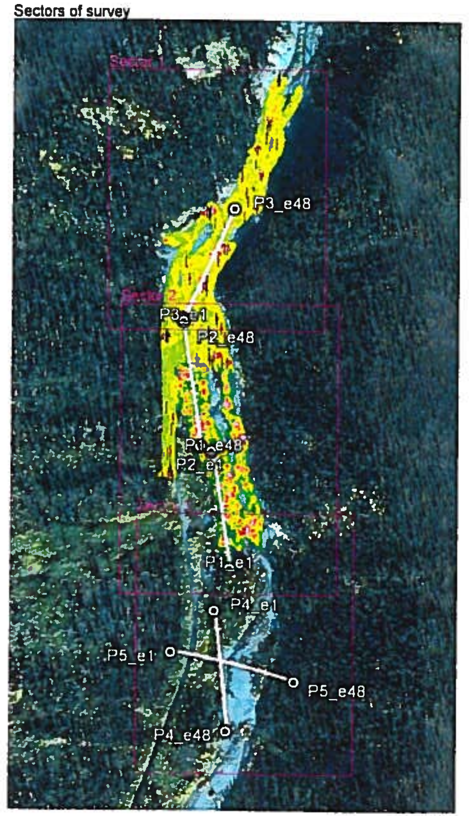
Sectors of survey



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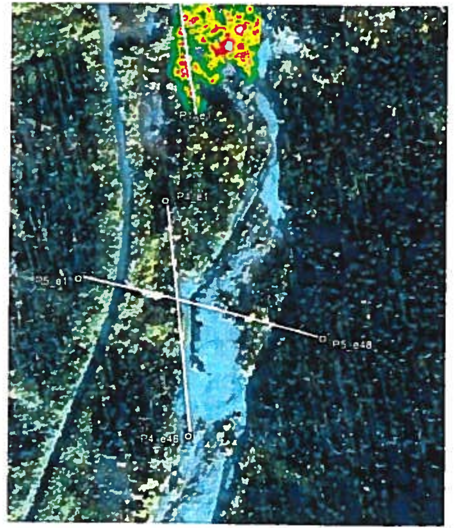
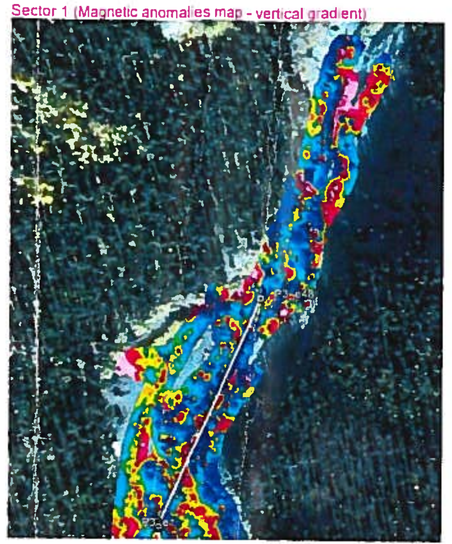
Sector 3



scale 1:1000

Sector 1 (Magnetic anomalies map - vertical gradient)



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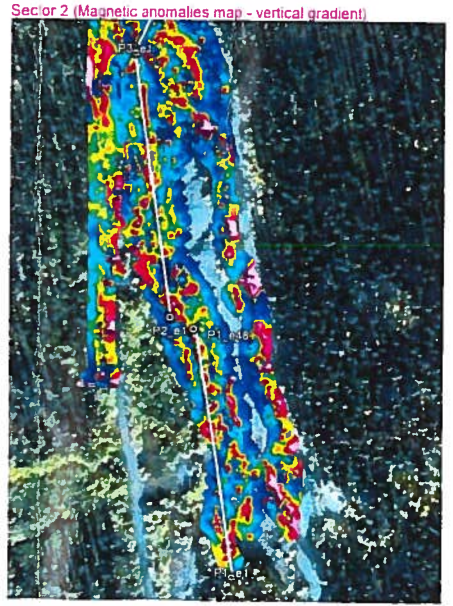
Sector 2 (Magnetic anomalies map - vertical gradient)



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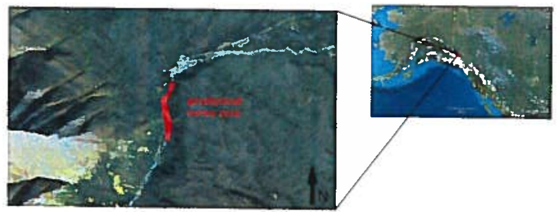

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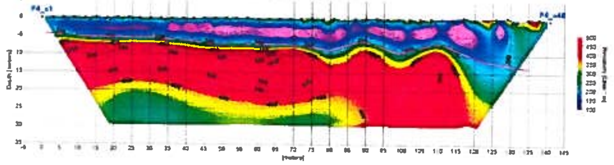
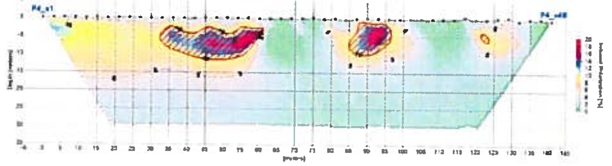
Geoelectrical Profile P4 - Resistivity



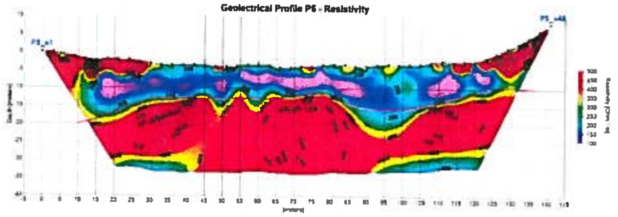
scale 1:500

Geoelectrical Profile P4 - Induced Polarization



scale 1:500

Geoelectrical Profile P5 - Resistivity



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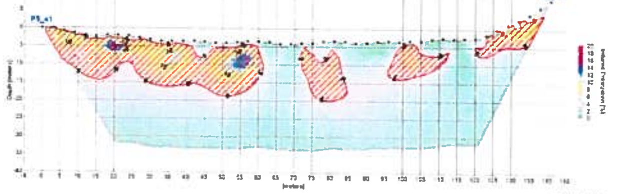
Geoelectrical Profile P5 - Induced Polarization



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LEGEND

〰	low limit of alluvial deposits
▨	chargeability anomalies
▨	conductivity anomalies
▨	resistivity anomalies
P5_e48	geoelectrical profile number and electrod number

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Geoelectrical and Gradiometry surveys

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