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Initial Results of a test survey in the Nechako Basin, B.C. designed to determine the usefulness of the magnetotelluric method in oil and gas exploration

Un nouveau levé dans le bassin du Nechako, CB pour évaluer l'utilité de la méthode magnétotelluriqe appliquée à l'exploration pétrolière

J.Spratt[1,2], J. Craven[1], J. Riddell[3], and F. Ferri[3]

[1]Geological Survey of Canada, [2]Geoscience B.C., [3]B.C. Ministry of Energy Mines and Petroleum Resources

Abstract

The Mesozoic Nechako sedimentary basin, located within the Intermontane belt of the Canadian Cordillera in central British Columbia, is a forearc basin deposited in response to terrane amalgamation along the western edge of ancestral North America. A 1994 estimate by the Geological Survey of Canada suggested that the basin may contain as much as a trillion cubic meters of gas and a billion cubic meters of oil. An important impediment to hydrocarbon exploration, however, is the inability of traditional geophysical methods to see through the thick Neogene volcanic sequence burying the basin. As the magnetotelluric method is not hampered by these volcanics, in the fall of 2007, 734 combined AMT and MT sites were recorded throughout the southern Nechako Basin. The survey was designed to evaluate the technique as a tool in both hydrocarbon exploration, as well as the geological characterization of the basin. Preliminary analysis of these data suggest that they are sensitive to variations in the depth extent of the sedimentary basin and that there are lateral changes in the conductivity structure within the sediments. These lateral variations could be attributed to compositional differences, the presence of fluids, or possibly changes in porosity.

Geological Background

The Mesozoic Nechako Basin, located in the Intermontane Belt of the Canadian Cordilleran, is a basin that includes overlapping sedimentary sequences deposited in response to terrane amalgamation to the western edge of ancestral North America. Regional transcurrent faulting and associated east-west extension, beginning in the Late Cretaceous, were accompanied by the extrusion of basaltic lava in Eocene and Miocence times to form a sheet that covers much of the basin at thicknesses varying between 3 and 200 m. The main geological elements in the southern Nechako area include Miocene basalt, Tertiary volcanic and sedimentary rocks, Cretaceous sedimentary rocks and Jurassic sedimentary rocks (fig. 1).

Location Map for MT Site in the Nechako Basin

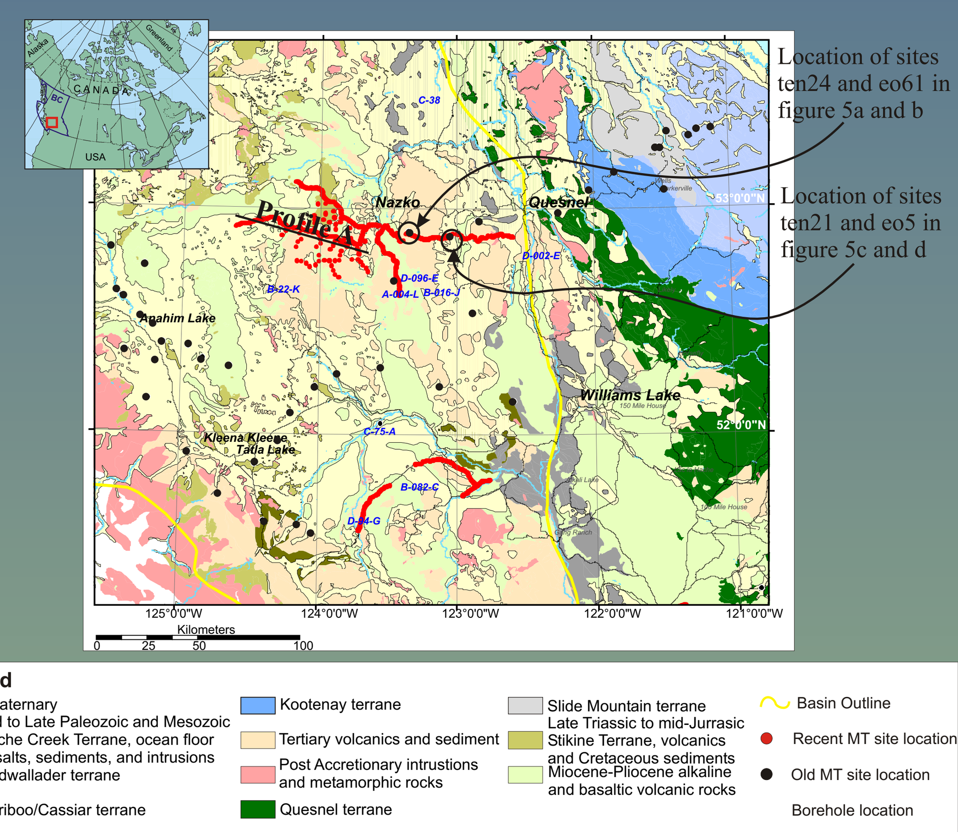

Figure 1

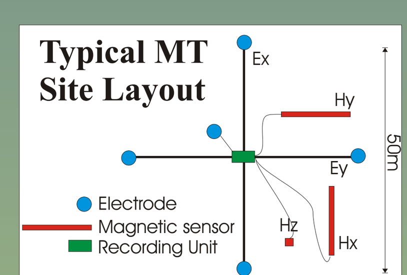

Figure 2

The MT Method

The magnetotelluric (MT) method provides information on the electrical conductivity of the subsurface of the Earth by measuring the natural time-varying electric and magnetic fields at its surface. Figure 2 illustrates the instrumentation and layout for a typical MT site. At low frequencies signal is generated by interaction of solar winds with the ionosphere. At high frequencies the signal is produced from distant lightning storms. The phase lags and apparent resistivities (MT response curves) can be calculated from the measured fields at various frequencies for each site recorded. The depth of penetration of these fields is dependent on frequency (lower frequencies penetrate deeper) and the conductivity of the material (deeper penetration with lower conductivity) and therefore estimates of depth can be made from the response curves beneath each site. The frequency range recorded is therefore dependent on the target depth of interest. AMT (audio magnetotellurics) sensors measure data in the highest frequencies (10,000 - 5Hz), where MT sensors measure lower frequencies (380 - 0.001Hz).

As MT data are sensitive to changes in the resistivity of materials, the method can distinguish between some lithological units. Figure 3 illustrates resistivity values for some common crustal materials and shows how the presence of saline fluids, graphite or interconnected metallic ores can substantially increase the conductivity of rocks.

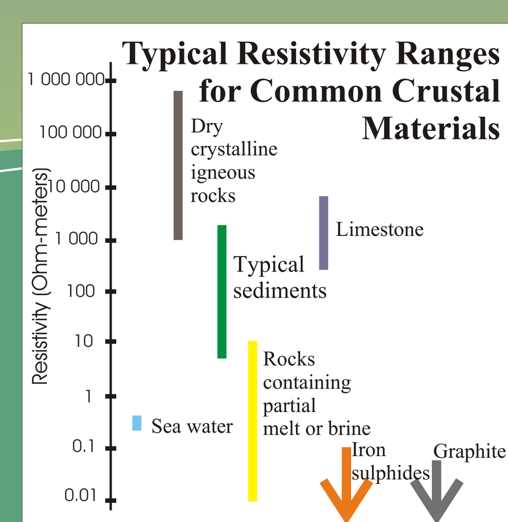

Figure 3

Site Deployment Scheme

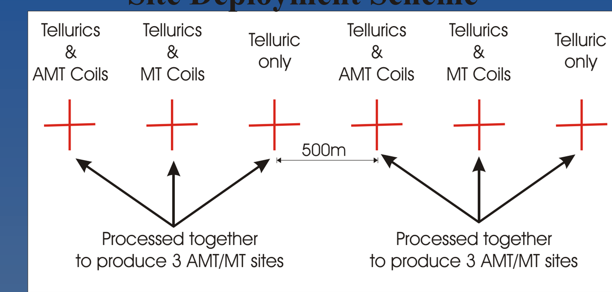

Figure 4

Data Acquisition and Processing

The data were recorded during the fall of 2007 using MTU-5A systems manufactured by Phoenix Geophysics of Toront. In general 3 teams each deployed 6 sites per day where two of the sites were telluric only, two of the sites were 5-channel AMT sites, and the remaining two sites were 5-channel MT sites. The tight station spacing of 500m and the generally layered subsurface conditions mean that the magnetic field recordings (AMT or MT) at the different sites could be used with the telluric channels at all sites (figure 4). The end result was that a total of 734 combined AMT and MT sites were recorded throughout the region (figure 1).

The data were processed by Geosystems Canada using robust remote reference techniques as implemented by the Phoenix Geophysics software package Mt2000. Figure 5 shows examples of response curves generated both for sites collected nearly 20 years ago as part of the Lithoprobe project (fig 5a and 5c) and sites collected in the fall of 2007 (fig. 5b and 5d). The response curves for the new sites show significant improvement in data quality over a much larger period range extending from 0.00001 - 1000 s. This, along with a much tighter station spacing will provide better resolution at shallow depths and will allow deeper structures to be modeled.

Examples of Response curves Showing Improved Data Quality Between Old and New Recordings

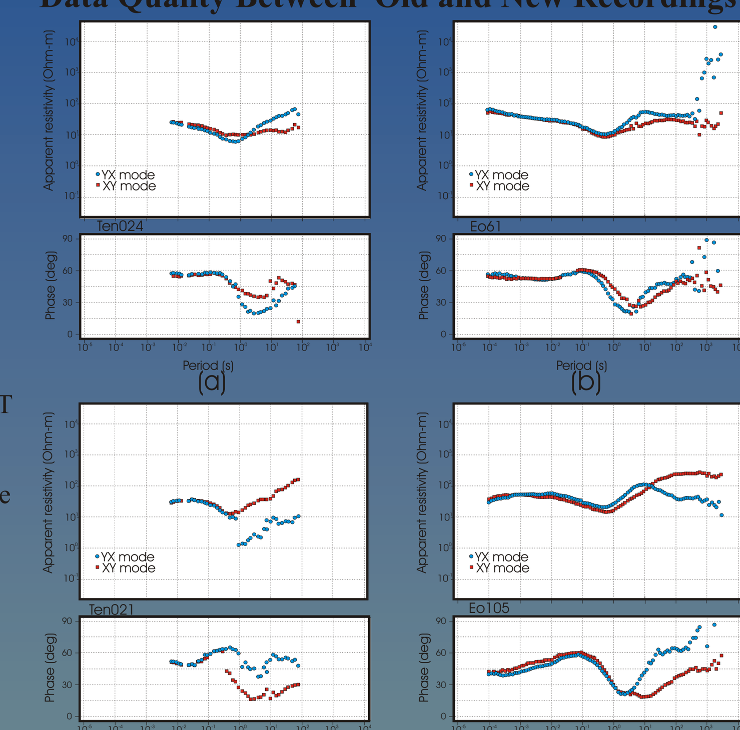

Figure 5

Preferred Strike Directions and Maximum Phase Splits For Each Site Along Profile A at Each Decade Period Band

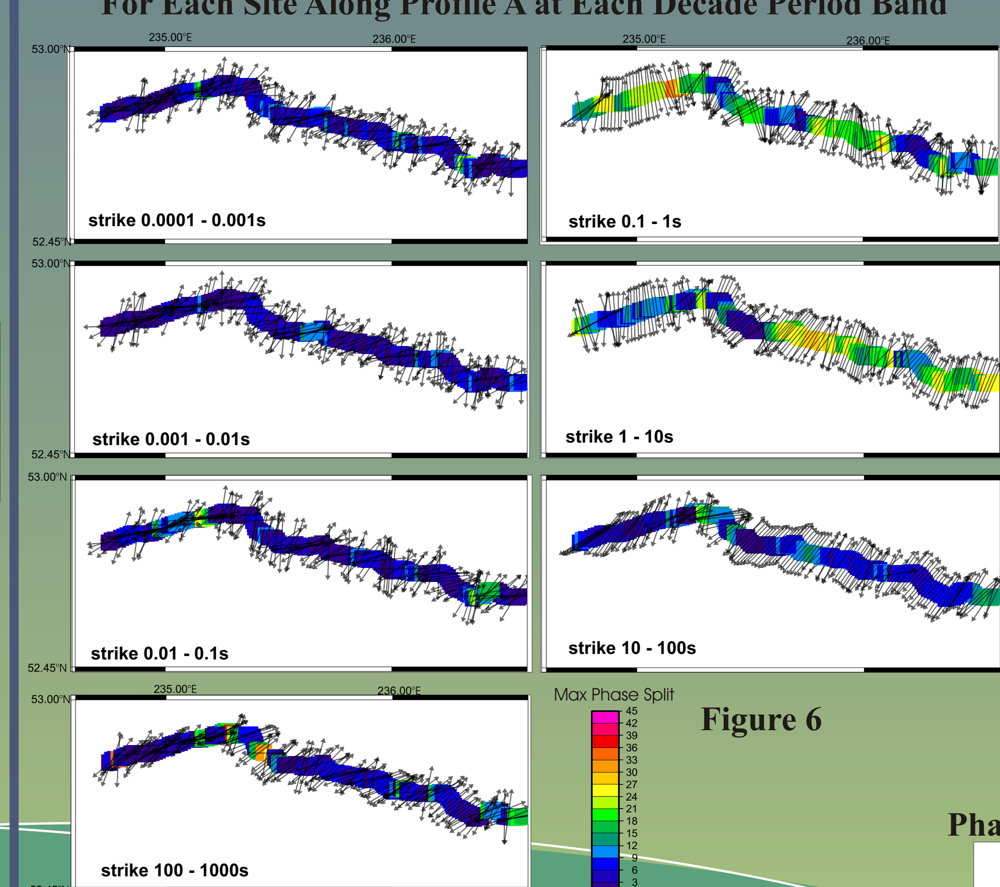

Figure 6

Pseudosections of the observed phase values with increasing periods in both the XY- and YX-modes were generated along profile A (fig. 7). Where the phases of the two modes are the same, the data are independent of the geoelectric strike angle and are considered 1-dimensional. The red line in figure 7 illustrates the maximum period to which the phases are similar, below which the data are either 2- or 3-dimensional. The 1-D models generated are therefore only accurate to periods of 0.1 - 1 seconds at most of the sites along profile A. Schmucker's c-function analysis was applied to each site providing a depth estimate at these periods by calculating the depth to maximum eddy current flow. These indicate that the 1-D models should accurately represent the conductivity structure of the subsurface to depths of 1000 to 2500m.

Analysis

Single site and multi-site Groom-Bailey decompositions were applied to each of the MT sites along profile A in figure 1, in order to determine the most accurate geoelectric strike direction and analyze the data for distortion effects. Figure 6 illustrates the results of single site strike analysis for each decade period band recorded at each site along the profile. The direction of the arrows shows the preferred geoelectric strike direction with a 90 degree ambiguity and the colour scale represents the maximum phase difference between the two modes.

Nearly all the sites along the profile show a maximum phase difference that is less than 10 degrees, at periods below 0.1 seconds, and maximum phase splits are observed between 0.1 and 10s. The westernmost sites along the profile consistently indicate a preferred geoelectric strike angle of approximately 5 degrees between 0.1 and 10s, whereas the eastern half of the profile prefers an angle of 30 - 35 degrees. Special analysis and model appraisals will need to be undertaken to account for this change in strike angle when generating 2-dimensional models of the profile.

Phase Pseudosections in the XY- and YX-Modes

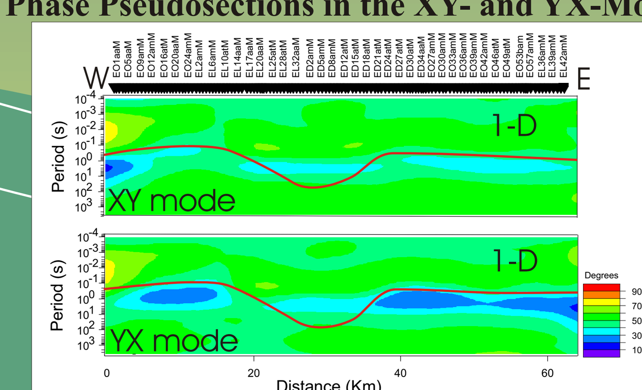

Figure 7

Modeling

One-dimensional layered earth resistivity Occam models were generated for each site along profile A using the WinGLink software package. These models are shown in figure 8 where the warm colors illustrate conductive regions, and the cold colors reveal more resistive material. For some sites, there appears to be a very thin (~100-200m) resistive layer (>1000 Ohm-m) near the surface, that thickens towards the east. This most likely represents the surficial volcanic rocks, as the geology strip at the top of figure 8 shows more volcanic cover in the eastern half of the profile. The data are not sensitive to the extremely shallow structures and may not reveal a volcanic cover that is less than 50m thick. Nearly all of the sites reveal a significant decrease in resistivity (from 10-100 Ohm-m to >1000 Ohm-m) at depths ranging between 1000 and 3000 m, shown by the black line in figure 8. These depths are consistent with those of the Nechako basin, suggesting that the data are imaging the base of the sediments and penetrating into the deeper basement units.

1-D Resistivity Models with Geological Variations Along Profile A

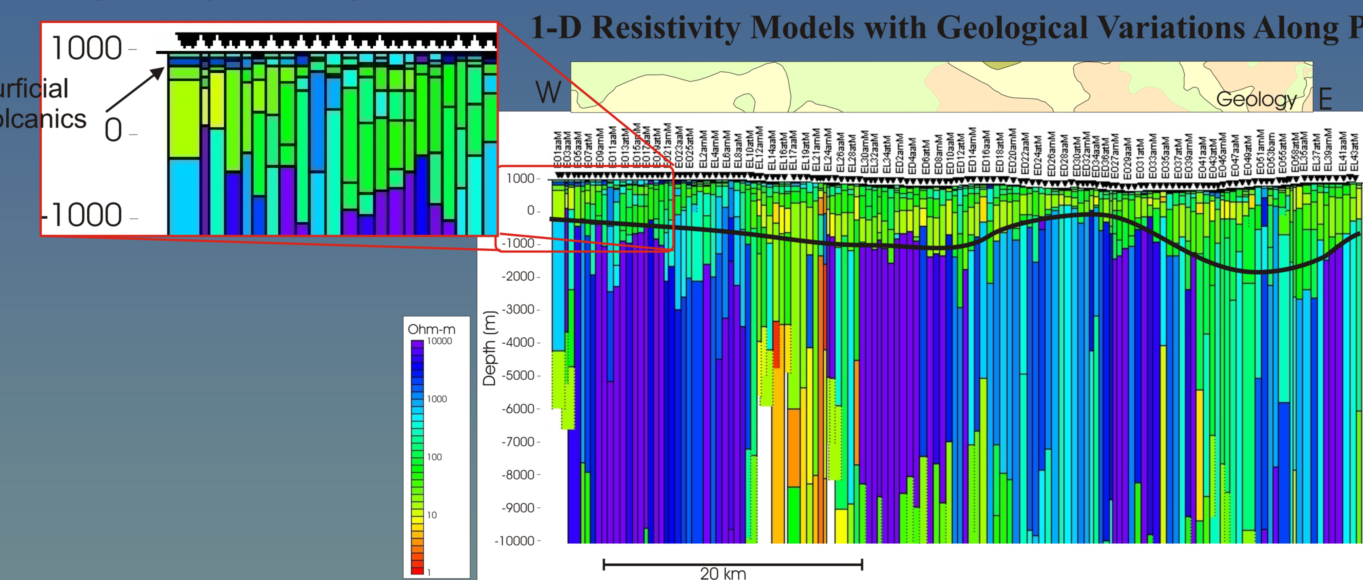

Figure 8

Smoothed Stitched 1-D Models with Gravity Variations Along Profile A

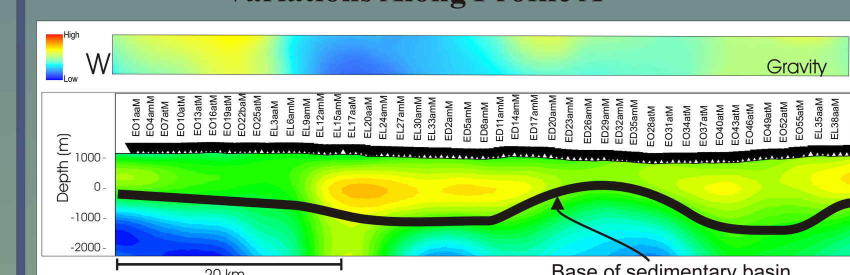

Figure 9

The 1-D models were stitched together with a smoothing parameter applied resulting in figure 9. The colour scale is the same as that used in figure 8. The black line illustrates the variations in the depth of the boundary between the upper sediments and the lower basement rocks along the profile. Additionally there are lateral variations in the conductivity structures within the sediments that could be attributed to compositional changes, the presence of fluids, or possibly changes in the effective porosity of the material. These variations appear to correlate with results from a regional gravity survey that was collected by Canadian Hunter in the 1980's, seen at the top of figure 9.

Laboratory Measurments

More than 100 rock samples collected throughout the Nechako basin have been sent to the Geological Survey of Canada's petrophysical laboratory in Ottawa for measurement of the resistivities and porosities of key lithological units. The intent of these tests are to provide information on the primary electrical conduction mechanisms and level of electrical anisotropy of the different units. Although a limited number of samples have been analyzed for percent effective porosity and electrical conductivity in the horizontal direction only, preliminary results show a direct correlation between these properties (figure 10). This is indicative that the MT method is sensitive to porosity changes in the sedimentary units and suggests a cause for the link between areas of low density observed in the gravity data and areas of low resistivity in the MT data.

Relationship Between Resistivity and Porosity

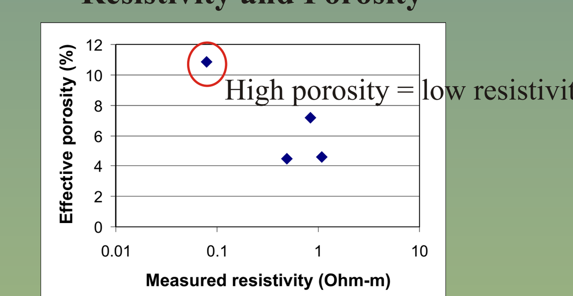

Figure 10

Discussion and Conclusions

Magnetotelluric data, in the AMT and MT frequency ranges, were collected at 734 sites within the Nechako basin. Initial results of the data analysis reveal a shallow resistive layer in some areas, that is interpreted as the surficial volcanic rocks. Also the data show a significant decrease in the apparent resistivity values at depths corresponding to the approximate boundary between the sedimentary basin and the underlying basement rocks. These results indicate that the MT method is sensitive to thicker regions of volcanic cover and that it is able to penetrate these volcanics and image the deeper structure. A cross-section of the stitched 1-dimensional MT models, indicate variations in the depth of this boundary from east to west. Additionally, at shallow depths within the sedimentary basin, changes in the conductivity values of up to 1 order of magnitude are observed. This suggests lateral changes in the physical properties of the basin that could be attributed to compositional difference, or the presence of fluids. However, preliminary results of laboratory tests on rock samples, along with a correlation between high conductivity and low gravity, suggests that these changes may be related to changes in the effective porosity of the material.

Future work on this data will include 2-dimensional modeling and model appraisals of the presented profile, 3-dimensional modeling of the northernmost sites, and integrated modeling and interpretations of various geophysical data sets including new seismic and gravity information..

Acknowledgments

Financial support for this work comes from the Geological Survey of Canada, Geoscience BC and the BC Ministry of Energy Mines and Petroleum Resources. Additional instrumentation was provided by the Polaris consortium and a special thanks is given to the Geosystems Canada crew for collecting the data.