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

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Summary

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.

Introduction

In response to the rapid spread and destructive effects of the Mountain Pine Beetle, British Columbia is facing a challenge to try to develop economic diversification opportunities for forestry-based communities in the interior of the province. Although only limited exploration has been carried out, the potential for hydrocarbons has been observed within several interior basins of British Columbia, including the Nechako basin. The Mesozoic Nechako Basin, located within the Intermontane Belt of the Canadian Cordillera, is a basin that includes overlapping sedimentary sequences deposited in response to terrane amalgamation to the western edge of ancestral North America (Monger *et al*., 1972; Monger and Price, 1979; Monger *et al*., 1982; Gabrielse and Yorath, 1991). Regional transcurrent faulting and associated east-west extension, beginning in the Late

Cretaceous, was accompanied by the extrusion of basaltic lava in Eocene and Miocene times that forms a sheet varying between 5 – 200 m in thickness (Mathews, 1989; Andrews and Russell, 2007) and possibly extending up to a maximum of 1 km in isolated places, covering much of the basin. The main geological elements within the southern Nechako area include Miocene basalt, Tertiary volcanic and sedimentary rocks, Cretaceous sedimentary rocks and Jurassic sedimentary rocks (fig. 1).

As magnetotelluric (MT) data is sensitive to changes in the resistivity of materials, it can distinguish between some lithological units. For example basalt and igneous basement rocks typically have electrical resistivity values of >1000 ohm-m, whereas sedimentary rocks are more conductive with values of 1 to 1000 ohm-m. Aside from lithologies, other factors such as saline fluids, changes in porosity, graphite films and interconnected metallic ores are known to affect the overall conductivity of a specific unit in the crust (Haak and Hutton, 1986; Jones, 1992). As the method is sensitive to, but not impeded by, the surface volcanics and can detect variations within the different units, it is expected to be useful in locating the boundaries of the Nechako Basin and define the structure within. In the fall of 2007 a field campaign, recorded over 700 high frequency and broadband MT sites from within the Nechako basin (fig.1), with the primary objective of evaluating the technique as a tool for both oil and gas exploration and geological characterization of the Nechako Basin.

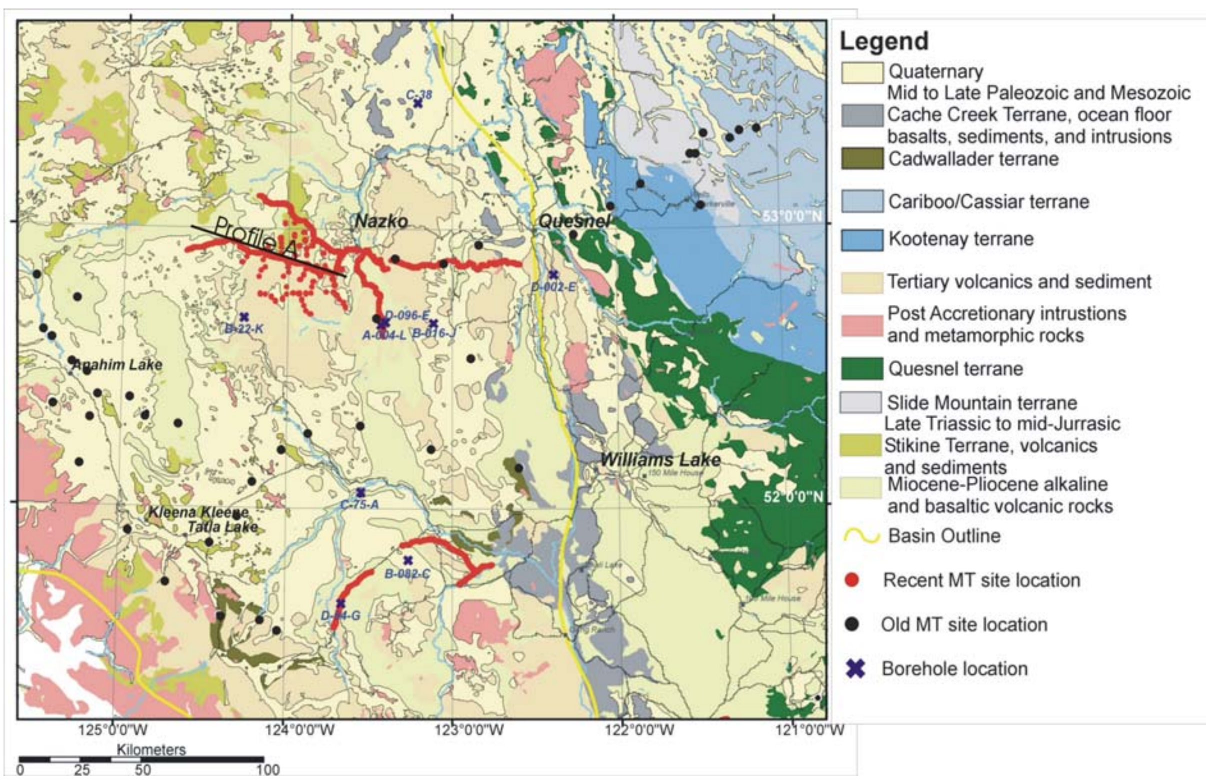

Figure 1: Map showing the location and geology of the Nechako basin along with the location of the boreholes, old MT sites and the newly acquired MT sites.

The MT Method

Magnetotellurics (MT) is a method that provides information on the electrical conductivity of the subsurface of the Earth by measuring the natural time-varying electric (E) and magnetic (H) fields at its surface (Cagniard, 1953; Wait, 1962; Jones, 1992).   The measurement of these mutually perpendicular electric and magnetic fields allows us to calculate phase lags and apparent resistivities at various frequencies, know as MT response curves, for each MT site recorded. Since the depth of penetration (or skin depth) of these fields is dependent on frequency (lower frequencies penetrate deeper) and the conductivity of the material (the lower the conductivity, the greater the depth), estimates of depth can be made from the response curves beneath each site (Kearey and Brooks, 1991).

Examples

One-dimensional layered earth resistivity Occam models were generated from the response curves for each site along profile A in figure 1. 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 (fig. 2). This most likely represents the surficial volcanic rocks as there is 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 (fig. 2). 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.

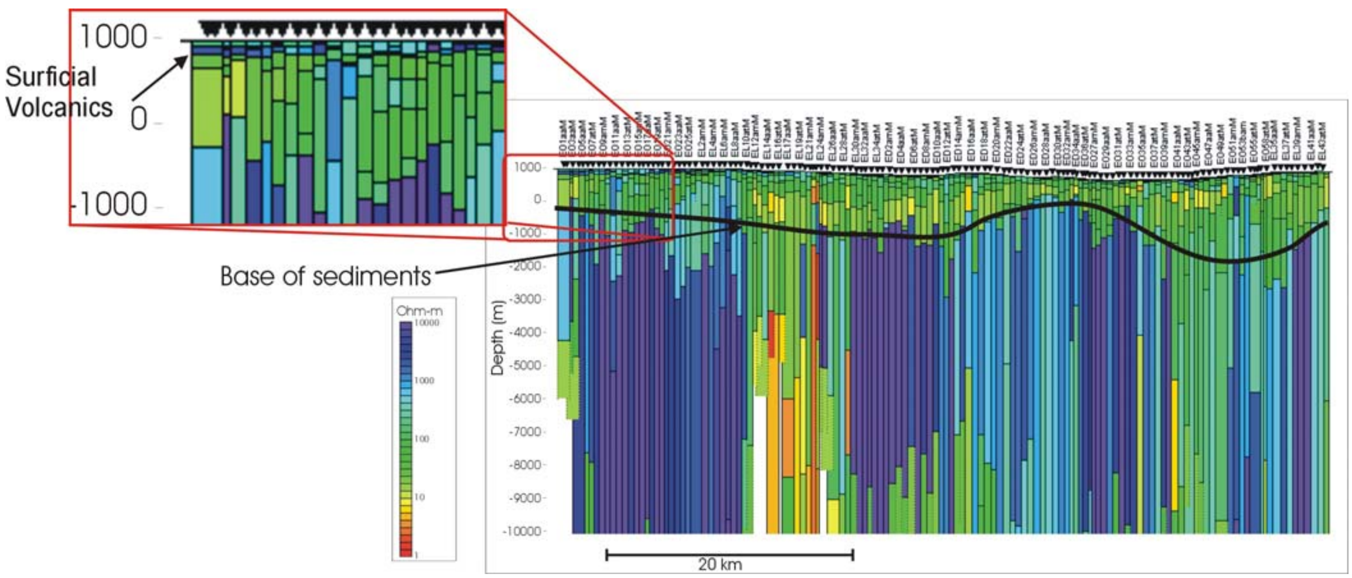

Figure 2: 1-D models for all of the sites as well as the surface geology along profile A. The warm colours represent conductive regions and the cooler colours resistive areas.

The 1-D models were stitched together with a smoothing parameter applied and show that, in addition to undulations in the depth of the conductive unit, 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 (fig. 3).

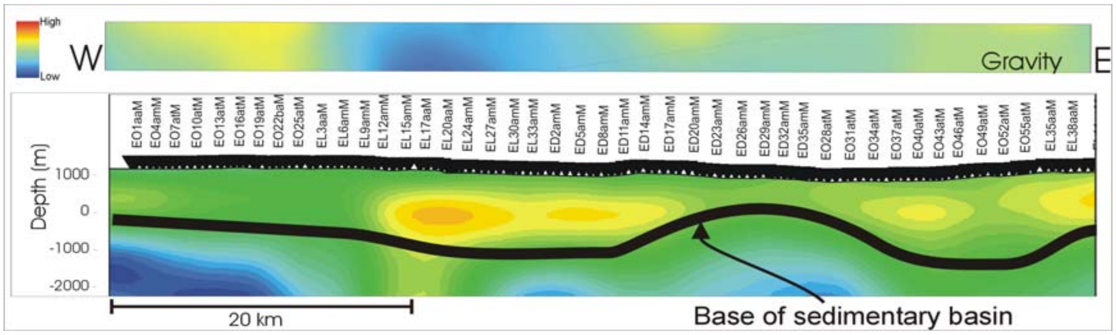

Figure 3: Stitched, smoothed 1-D models as well as gravity information along profile A.
The conductivity colour scale is the same as that in figure 2.

More than 100 rock samples collected throughout the Nechako basin have been sent to the Geological Survey of Canada's petrophysical laboratory in Ottawa in order 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. 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.

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.

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