A preliminary look at magnetotellurics as a tool to examine the geology beneath the Chilcotin Group basalts

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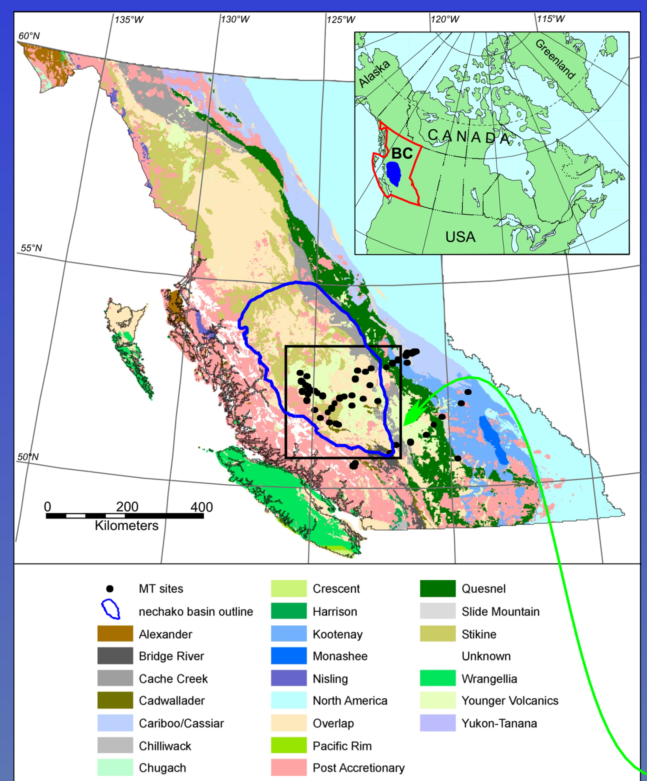
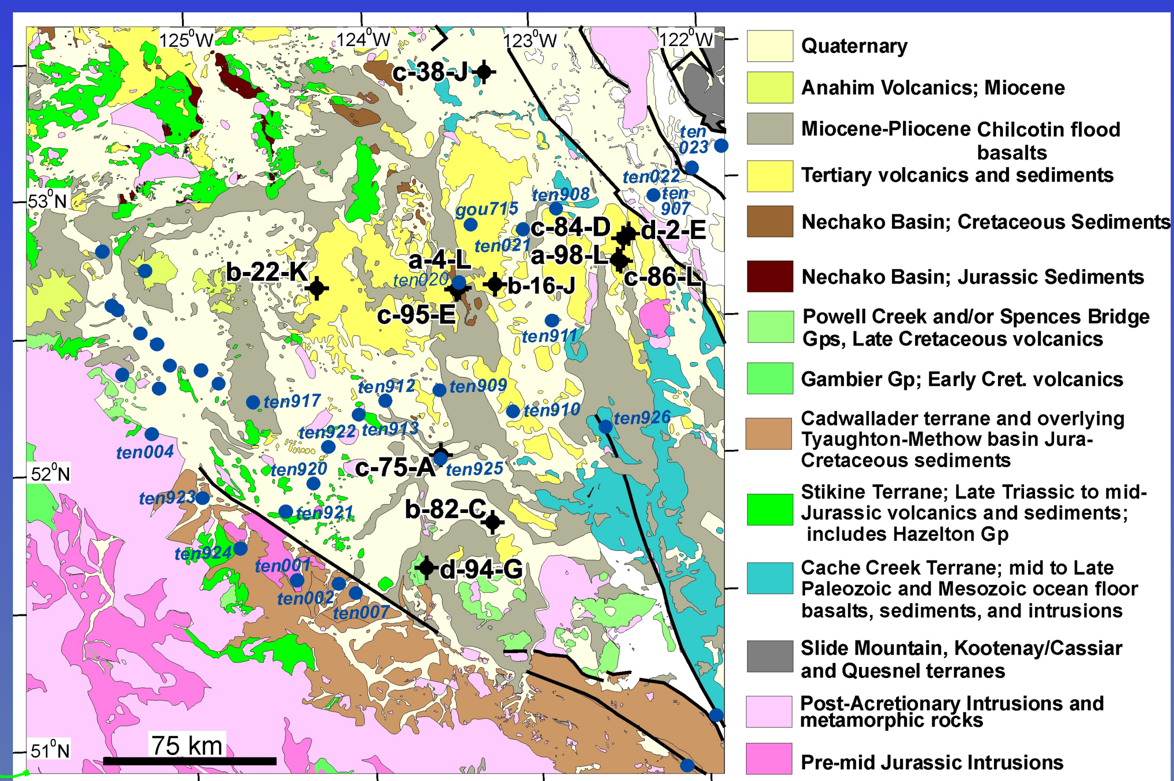
Abstract

The Mesozoic Nechako 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 the basin may contain as much as a trillion cubic metres of gas and a billion cubic metres 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. A comparison between borehole resistivity data, gravity anomalies, and MT responses, collected in the 1980s by D.I. Gough, allows us to test the utility of MT as a tool in mapping the structure of the Nechako basin beneath the surface basalts. We conclude that MT may be a useful tool in the exploration of oil and gas and indicate the need for further data acquisition in this region.

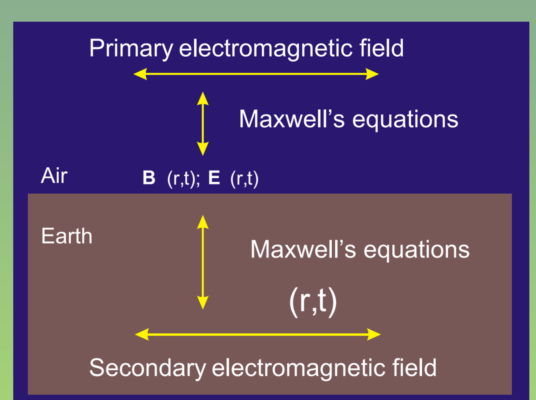


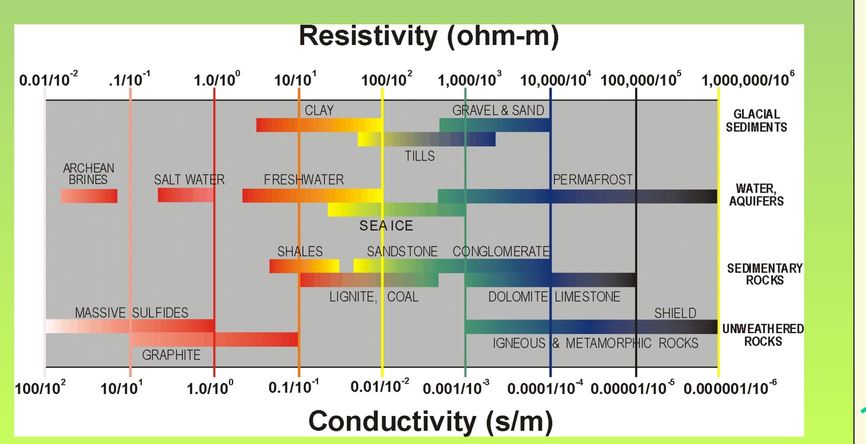


INTRODUCTION

The Canadian Cordillera, where the Juan de Fuca oceanic plate is currently being subducted beneath the North American continent, is comprised of oceanic and island arc terranes accreted to the western edge of ancestral North America since the Neoproterozoic. The Mesozoic Nechako Basin, located within the Intermontane belt of the Canadian Cordillera, is a forearc basin deposited in response to this terrane amalgamation. East-west extension at ~ 30 Ma resulted in the extrusion of basalts that form a variably thick sheet, up to 2 km in thickness, covering much of the basin. The main geological elements within the southern Nechako area include the Chilcotin flood basalts, Tertiary volcanics and sediments, Cretaceous sediments, and Jurassic sediments. Understanding the structure of these different units at depth is vital for assessing possible resources.

An assessment of the hydrocarbon potential based on geological information and well data was performed by the Geological Survey of Canada in 1994, suggesting that the Nechako basin may contain as much as a trillion cubic metres of gas and billion cubic metres of oil. The thick volcanic cover limits resolution of reflection seismic data and has made it difficult to determine the physical boundaries of the basin, impeding exploration. Magnetotellurics (MT) can distinguish between these units, as flood basalts and igneous basement rocks have typical electrical resistivity values of >1000 Ohm-m, and sediments are more conductive with values of 1 - 1000 Ohm-m. In the 1980s, Majorowicz and Gough (1991) recorded MT data across the Nechako basin between 52° and 53° latitude using SPAM (short period automatic MT system) instruments that recorded data in the frequency range of 0.016 to 130 Hz. These data have been re-examined using modern analysis techniques to assess the usefulness of undertaking MT in the Nechako region and to determine specific data acquisition techniques for future MT surveys that will provide higher resolution results.





MT BACKGROUND

Magnetotellurics is an electromagnetic geophysical technique for imaging the deep structure of the Earth. It images conductors in the Earth and as such it is relatively unhampered by resistive material such as volcanics and glacial overburden. It is useful to delineate contacts between crystalline and sedimentary units at depth as they have dramatically different electrical characteristics. It can also be useful to directly detect deeply buried sulphide mineralization and to provide estimates of porosity and other features of sedimentary rocks. The novel feature of MT is that it uses the Earth's natural magnetic field as a transmitter of energy into the earth. This enables almost an infinite depth of investigation; however in practice the depth of investigation is limited to the asthenosphere.

MT SOURCE FIELDS

At high frequencies (>1Hz) the Earth's magnetic field is affected by thunder storm activity world wide. Guided waves between Earth Surface and Ionosphere circle the globe and can be used to infer resistivity structure down to ~1 km depth.

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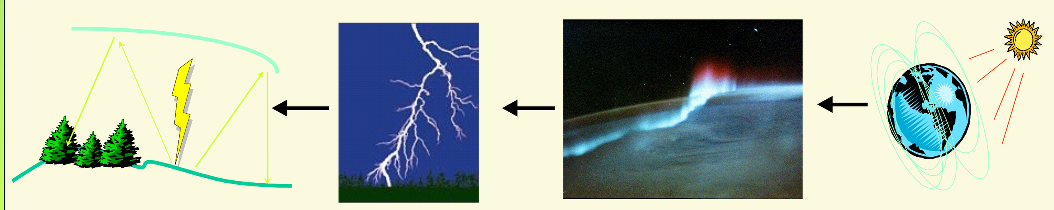
At frequencies <1Hz the magnetic field is affected by interactions with the solar wind. Measurement of the electric and magnetic fields at frequencies as low at .0001 Hz (period=10000 s) permits investigation of depths into the upper mantle and beyond.



STRIKE ANALYSIS

Single site and multi-site Groom-Bailey decompositions applied to the MT sites along the profile show much of the data to be 1-dimensional with maximum phase differences below 10 degrees, particularly at frequencies above 1 s. For the sites with a strong 2-dimensionality, exhibiting larger phase differences, the preferred strike angle was determined to be -35 degrees, i.e., approximately the geological strike of the belts. The models generated in the distortion analysis show that the data fit well within 3.5%, equivalent to a 2 degree error floor in phase. This geo-electric strike angle is consistent throughout the data set and appears to correlate well with structures revealed in the gravity data (fig. GRAVITY/STRIKES) indicating that the strike is likely to be dominated by regional large-scale structures.

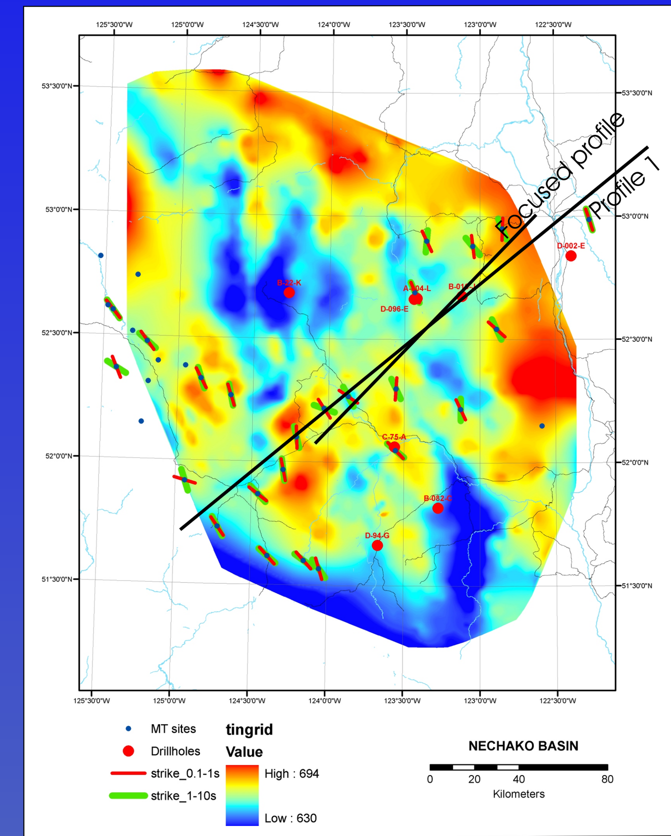
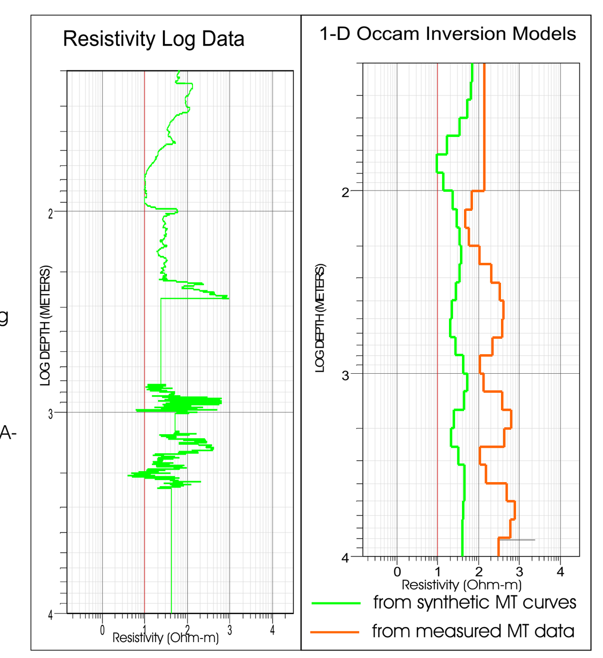


Fig - Gravity/Strikes Map of Bouguer gravity for the Nechako region and strike directions obtained using multi-frequency McNeice-Jones decompositions for period bands 0.1 - 1 s, and 1 - 10 s. The black lines mark the profile traces of the MT models. Cold colours represent areas of low gravity and warm colours areas of high gravity.

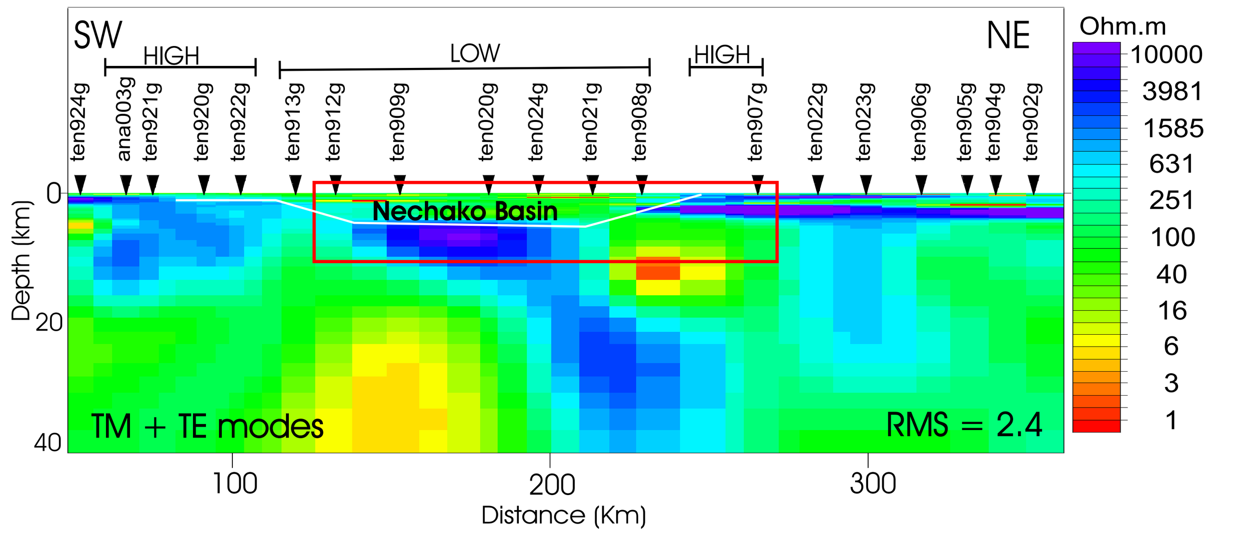
Fig. BOREHOLES vs MT: One-dimensional models of synthetic data from borehole log A-004-L and MT site ten020g at the same location. The far left shows the resistivity log data recorded at well A-004-L.



SYNTHETIC VERSUS MT RESPONSE CURVES

Several wells have been drilled within the Southern Nechako region since the 1950s and resistivity well-log data were acquired down some of them. Unfortunately there are few good quality MT sites that recorded data within reasonable proximity to these wells. Although the well log data at a-4-L has significant gaps, site ten020 was recorded nearby. A comparison between synthetic response curves and measured data can therefore be made (Fig. BOREHOLE vs MT). Synthetic apparent resistivity and phase curves were calculated using the Geotools MT interpretation package from long normal and deep induction logs measured at well a-4-L (Fig. MAP). From these synthetic curves, as well as from the data recorded at site ten020, Occam inversions were run to generate 1-dimensional models (Fig. BOREHOLE vs MT). The 1-D models for both sets of curves, in general, are quite similar with two major differences: The first is that the starting resistivity value is nearly 1 order of magnitude higher in the MT data, and the second is that the different resistivity layers appear to be downshifted. These differences are mostly likely a result of static shift effects on the measured MT data and need to be accounted for in further models.

Fig. 2D Model: Two-dimensional resistivity model obtained from MT data across the Nechako basin. The model was generated using both TE and TM mode distortion-decomposed apparent resistivity and phase data, and an RMS misfit of 2.4 was achieved. The red box indicates the region of localized modelling shown in Fig. LOCAL MODEL. The black bars above the model illustrate the regions of high and low gravity data as seen in fig. GRAVITY/STRIKES.



TWO-DIMENSIONAL MODEL

Two-dimensional models along profile 1 (Fig. MAP) were determinedfor the distortion-corrected MT responses at a strike angle of -30° of both the TM and TE-modes, as well as TE-mode only. Inverse modelling using Rodi and Mackie's (2001) RLM2DI code, as implemented in Geosystem's WinGlink software package, was run for 100 iterations for models with varying smoothness parameters (tau). From the L-curve trading off fit (smallest RMS value) against roughness (largest tau value) the best tau was determined to be 3. To account for static shift effects, the data were inverted to fit preferentially the phase data, with high error floors set for the apparent resistivities. The data were also inverted with error floors for both the phase and apparent resistivities equivalent to 2 degrees (as determined acceptable from the distortion analysis) and after 100 iterations a static shift correction was applied to the model parameters. The structures of the different models and the associated conductivity values were very similar and the final model (Fig. 2-D MODEL) was generated using a tau setting of 3, phase error floor of 2°, an apparent resistivity error floor of 25%, and achieves an RMS misfit of 2.4. A comparison between the calculated forward response of the apparent resistivities and phases, and the original data shows a reasonable fit at most sites along the profile, particularly at shallow depths (Fig. SITE FITS).

The model shows distinct variations in the conductivity structure along the profile and reveals a moderately conductive layer (40 Ohm-m) that varies in depth up to ~5 km. There is a good correlation between the gravity lows, which are assumed to represent sedimentary sequences, and the high conductivity layer (< 100 Ohm-m) where it thickens between sites 922 and 908 in the 2-D model along Profile 1 (Fig. MODEL). Where the MT model shows resistive structure near the surface at both ends of the profile, there are gravity highs that have been interpreted to represent volcanic basements. This indicates consistency between the two datasets, and suggests that the MT data are capable of distinguishing the different stratigraphic units at depth and defining the boundary of the Nechako basin.

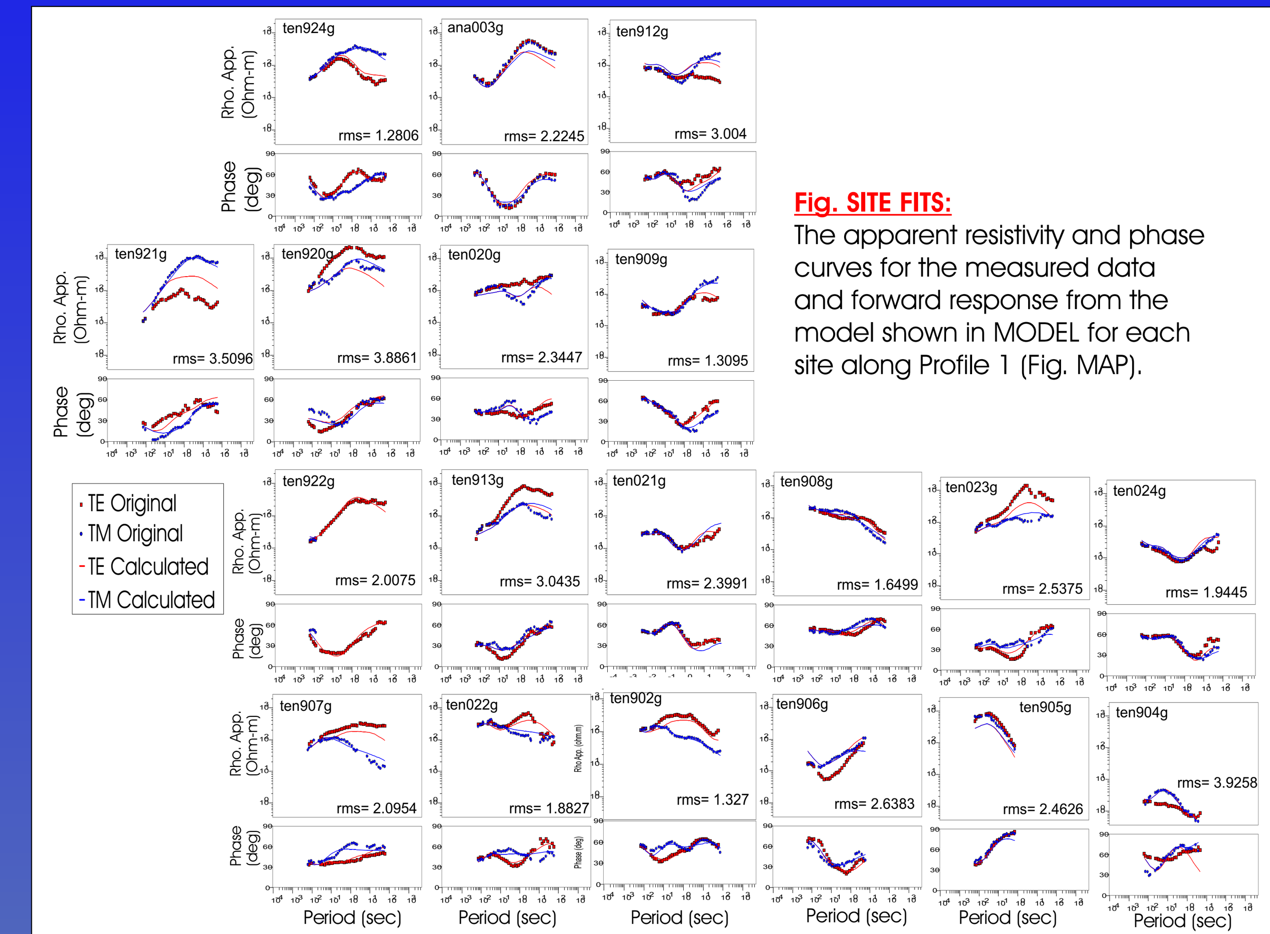


Fig. SITE FITS: The apparent resistivity and phase curves for the measured data and forward response from the model shown in MODEL for each site along Profile 1 (Fig. MAP).

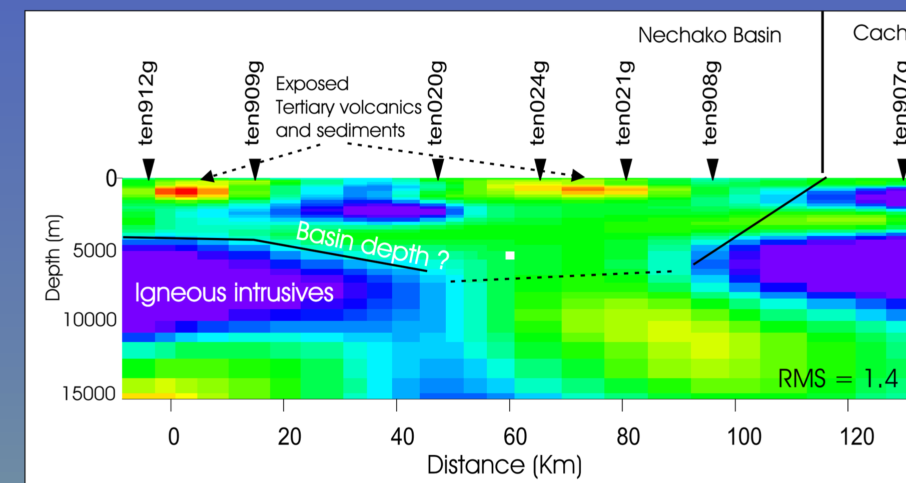


Fig. LOCAL MODEL: A two-dimensional model focussing on the shallow structures crossing the eastern boundary of the Nechako basin. The model was generated using high frequency data (1-130 Hz) for both the TE and TM-modes and an RMS misfit of 1.4 was achieved. The colour scale is the same as Fig. MODEL.

MODEL FOCUSED ON SHALLOW BASIN STRUCTURE

A new model was generated for the eastern edge of the Nechako basin using the high frequency data (1-130 Hz) only in order to determine how sensitive the data are to the shallow structures in this region. Fig. LOCAL MODE shows significant conductivity changes at shallow depths along to profile. To the south-west, there is a conductive (~100 Ohm-m) region overlying resistive (>1000 Ohm-m) material; Majorowicz and Gough (1991) interpreted this to represent Nechako sediments overlying granitic intrusions. To the north-east the conductive region becomes resistive across the boundary between the Nechako basin and the Cache Creek Terrane. The model also shows two very conductive features (<10 Ohm-m) that correlate with the surface mapped Tertiary volcanics and sediments (Fig. MAP). Hypothesis testing of these features was undertaken by replacing these features with a higher resistivity value and running a forward response. The RMS values increased dramatically (from 1.4 to 8.2) and a comparison of the calculated versus measured pseudosections of both the TM and TE modes, in both the apparent resistivies and phases showed distinct differences. This indicates that the shallow conductive structures are required by the measured data and are not artifacts of the inversion algorithm. These SPAM MT data recorded a maximum frequency of 130 Hz (0.007 s), additional data with modern AMT instruments can reliably acquire data to 10,000 Hz and would be useful in determining the shallow structure of the Nechako region.

CONCLUSIONS

MT data collected 2 decades ago are capable of penetrating the Chilcotin volcanics and imaging the shallow features of the Nechako Basin. The two-dimensional models show a good correlation between along-strike conductivity variations and mapped geological units as well as observed gravity anomalies. A comparison with measured borehole resistivities allows us to quantify static shifts effects and indicates the need to account for these effects. Additional MT data acquisition, using modern high frequency and broadband instrumentation, would be a highly cost-effective method to determine the thicknesses and boundaries of the Nechako sediments, and would be an important tool in mapping out potential resources in the region.

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