

One-dimensional Interpretation of Magnetotelluric Data

- Lab report is **due by 5 p.m. October 30, 2023**
- All late reports require a valid reason to be accepted.
- Include answers to all questions, required figures, and all MATLAB codes.
- **All work and MATLAB scripts should be your own original work. Do not copy someone else's code.**
- **Do not use MATLAB scripts from other classes in this course, unless told to do so.**
- All lab material can be downloaded from the class webpage at:
<https://sites.ualberta.ca/~unsworth/UA-classes/424/labs424-2023.html>

1. Introduction

In this lab you will be using the MATLAB code you wrote in Lab 3 to model and interpret broadband MT data which were collected during field school in 2010 (in southern Alberta). Each station was left to record for about 12 to 24 hours.

There are four MT soundings you will model. The shortest periods sample the conductive Western Canada Sedimentary Basin (WCSB), while the longest periods sample electrical resistivities of the lithosphere and asthenosphere boundary (LAB). The majority of the period range samples the lithosphere, the rigid portion of the earth that sits above the weaker asthenosphere.

The lithosphere below southern Alberta is part of the North American craton. The North American craton has been pieced together through ancient subduction and continental collisions, much of which occurred in Precambrian times. The location of these MT soundings, in southern Alberta, sits above a piece of Archean age craton, pieced together during Paleoproterozoic times and the creation of Laurentia.

The crystalline portion of the lithosphere in Southern Alberta is hidden below the relatively thin WCSB. The crystalline craton below the WCSB represents the extension of the Canadian Shield from the east, which continues to extend as far west as the Rocky Mountain Trench in B.C.

In the MT soundings that you will model, the Canadian Shield rocks constitute the top of a layer whose electrical character is often quite homogenous down to the asthenosphere (although this is not always true). The Moho discontinuity is often difficult to distinguish in the electrical soundings, but has been identified in places such as northern Canada (see Jones & Ferguson, 2001 for a discussion on the electric Moho).

The electrical resistivity can be an indication of lithology, but since a small amount of interconnected fluids can change the bulk resistivity of a rock very significantly (ie: Archie's law), the fluid content is often a larger control on measured electrical resistivity.

Remember that the lithosphere and asthenosphere are defined on the basis of their **mechanical** properties. The crust and mantle have different **chemical** compositions.

QUESTIONS:

- **1.1** Describe two assumptions in one-dimensional magnetotellurics. When would a 1-D approach be valid?
- **1.2** Provide a compositional and physical explanation of the main layers we are interested in (lithosphere, asthenosphere, crust, and mantle). Explain the difference between the Moho and the LAB. What electrical resistivity contrast is expected at the Moho? At the LAB?
- **1.3** What period of electromagnetic signal is required to image 200 km below the surface (i.e. the LAB), assuming an average resistivity of 100 Ωm? Would an overnight recording (12 hrs) be sufficient to obtain an accurate estimate of apparent resistivity for this period?

2. 1D MT Forward Modeling

Use the forward modeling MATLAB codes you wrote in Lab 3 and modify as required.

- Reminder: ensure your plot shows apparent resistivity, phase, and the resistivity model, using *subplot*. Use the periods from the data files. Plot *period in seconds* along the horizontal axis. Include all labels, units, titles, and a legend. Scale your plots appropriately to show the data.
- Use the ‘*stairs*’ function for plotting the resistivity model (makes steps between layers).
- Use the ‘*errorbar*’ function to plot error bars on the apparent resistivity and phase plots. Use the errors found in the data files.
- Include the RMS misfit in the plot.
- Calculate the root mean square (RMS) misfit using the equation below:

$$RMS\ misfit = \sqrt{\frac{\sum_{1:N} \left[\left(\frac{\rho_{dat} - \rho_{calc}}{\rho_{error}} \right)^2 + \left(\frac{\varphi_{dat} - \varphi_{calc}}{\varphi_{error}} \right)^2 \right]}{2N}}$$

ρ_{dat} – measured apparent resistivity

ρ_{error} – error in apparent resistivity measurement

φ_{calc} – calculated model phase angle

N – number of rho (or phase) data points

ρ_{calc} – calculated model apparent resistivity

φ_{dat} – measured phase angle

φ_{error} – error in phase angle measurement

QUESTIONS:

- **2.1** Include your full MATLAB forward modeling script.
- **2.2** Fit all four MT soundings with an **RMS misfit value less than 1.6** (these are found in the *.txt files within the data folder). This is done by creating model text files similar to those used in Lab 3. Use your MT1D code to calculate the data from your created model, then compare to the observed data. Ensure you use enough layers, but not too many (no more than 5 layers), and that they are both shallow and very deep (hint: think about depth to the WCSB and LAB). You can use the values in mod_sample.txt to start. Include your plots (similar to Figure 1).
- **2.3** Save your fitted models as text files and include them with your report.
- **2.4** Note that there is some noise in the data, especially at the longest periods. Can you think of a reason why?

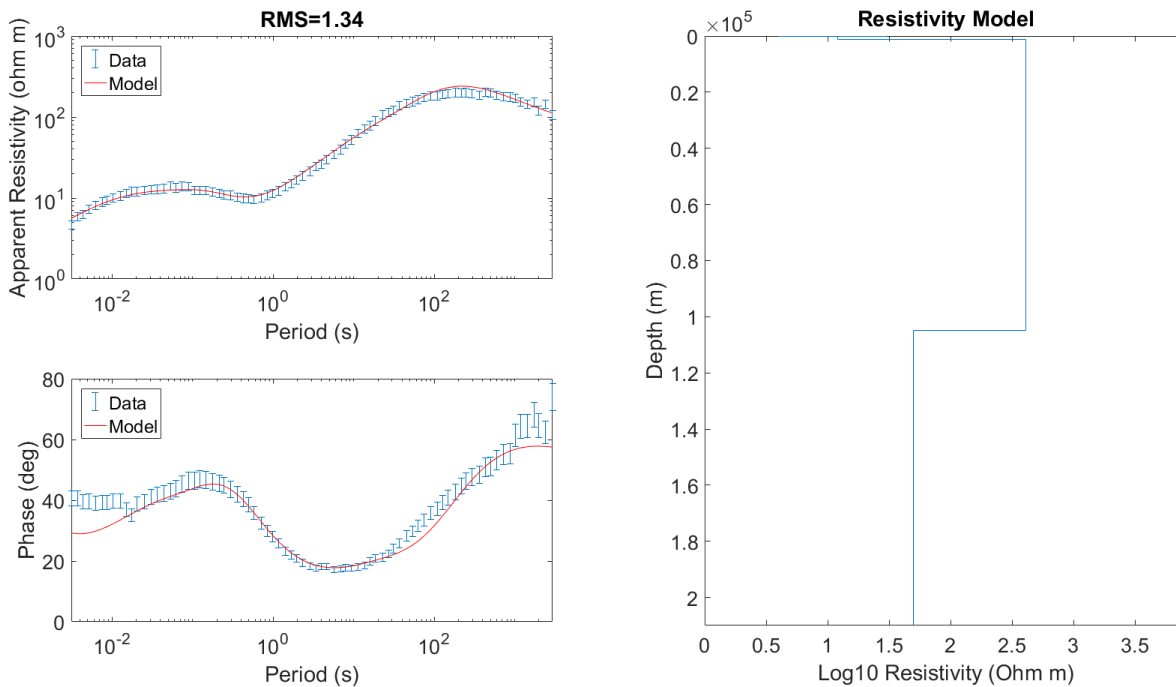


Fig 1: Example of forward modeling code plotting results.

PART 3: Displaying Models as Cross Section

1. Write a MATLAB script to plot the four models you generated as a color image. The horizontal axis should be profile distance, and the vertical axis should be depth. Note that there will be some vertical exaggeration, as the greatest depth is much larger than the profile length. Here are some guidelines:

- Use the `pcolor` function in Matlab [`pcolor (X,Y,C)` for X =distance vector, Y =depth vector, C =resistivity matrix]. See Figure 2 for an example.
- Include a resistivity colorbar. Please use red for conductive and blue for resistive (use greyscale if printing in black/white). Use \log_{10} resistivity values to emphasize the contrasts.
- Use the approximate distances between stations in Figure 2 for your cross section.
- Depth should be shown in metres or kilometres, but do not use a logarithmic scale.
- Do not interpolate! Layers should be discrete.
- Hint: start with a matrix of NaN (using the function '`NaN`') which will plot as white in `pcolor`. Using zeroes will give you an incorrect solid colour (ie: red). Then insert each 1D resistivity sounding into the matrix at the correct distance along the profile (see Fig 2; a31, s02, s03, a30, with 2km, 1km, 4km spacings)
- You need to put each 1D sounding onto a common depth array, so that each row in your plotted matrix corresponds to the correct depth for each sounding. Ensure that you keep the discrete nature of the models!

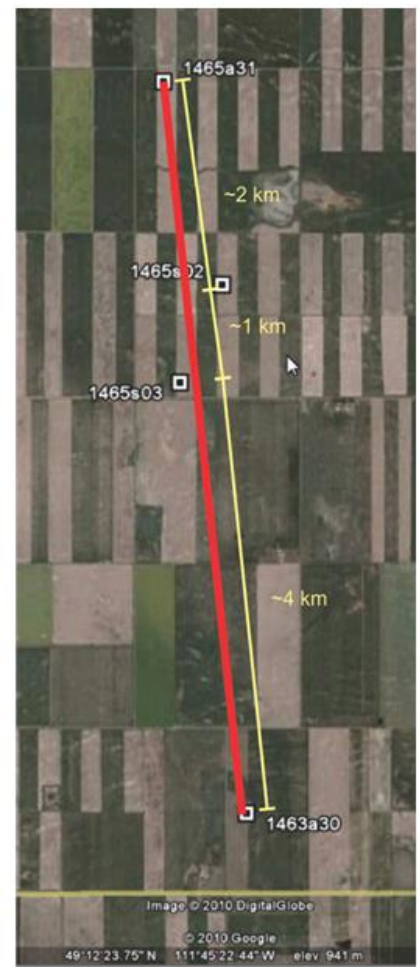
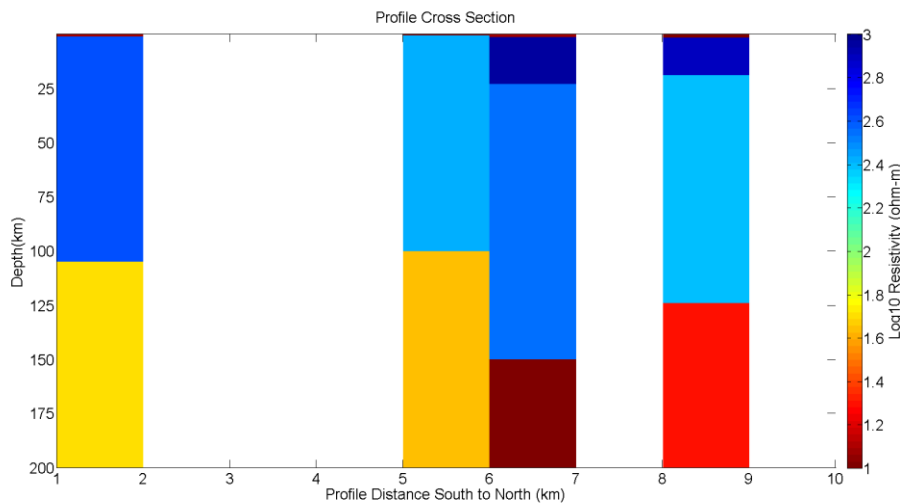


Fig 2: Example cross section of the four 1-D resistivity models. Make sure to include a colorbar and properly labeled axes. Map on right of the 2010 field school data.

QUESTIONS:

- **3.1** Include your full MATLAB script.
- **3.2** Include two cross-sections: one showing only the shallow structure (top ~5km, which is the sedimentary basin) and one showing all model layers.

PART 4: Cross Section Interpretation

- Your cross-sections should show two main areas of interest:
 - Small scale structure within the sedimentary basin (scale <5 km)
 - Large scale structure defining the lithosphere beneath southern Alberta (scale ~200km)

QUESTIONS:

- **4.1** Looking at the **large-scale cross-section**, identify the main layers below the sedimentary basin, and explain what the electrical soundings show deep below the subsurface. Reference these layers to known layers in the Earth, and comment on how these depths compare to global averages.
- **4.2** Does the depth to the asthenosphere match global averages, if not, can you think of a reason why? See Eaton et al. (2009) for a discussion on the lithosphere-asthenosphere boundary below cratons.
- **4.3** Can you see the Moho in your cross-section? Explain in detail why or why not? At what depth would you expect to find the Moho in this area? See Jones & Ferguson (2001) for a discussion on the electrical Moho.
- **4.4** Compare and contrast the advantages of various geophysical methods to identify the location of the LAB and the Moho beneath Alberta. See Bouzidi et al. (2002) for a discussion on the structure of the crust below Alberta.
- **4.5** Comment on any **changes in depth and resistivity you see along the profile**. Do the layer depths and resistivities match from station to station? Do you think these changes are reasonable and real? If not, why? Discuss data and modeling limitations.
- **4.6** Next look at the **electrical structure of the sedimentary basin**. Describe how the basin changes over the length of the profile in terms of depth and resistivity character. It is difficult to make a good interpretation without any other information, but try to make inferences on what broad changes in the sedimentary basin could be causing these changes.
- **4.7** To help your explanations, illustrate your interpretation by drawing a **cross section sketch including the basin and much deeper structure**. This does not need to be to scale but please be detailed and clear. Label approximate depths and distances. Use labels to relate the resistivity measurements to the geology.

References

- Bouzidi, Y., Schmitt, D. R., Burwash, R. A., & Kanasewich, E. R. (2002). Depth migration of deep seismic reflection profiles: crustal thickness variations in Alberta. *Canadian Journal of Earth Sciences*, **39**(3), 331-350.
- Eaton, D. W., Darbyshire, F., Evans, R. L., Grütter, H. S., Jones, A. G., & Yuan, X. (2009). The elusive lithosphere–asthenosphere boundary (LAB) beneath cratons. *Lithos*, **109**(1-2), 1-22.
- Fischer, K., Ford, Abt, & Rychert. (2010). The Lithosphere-Asthenosphere Boundary. *Annu. Rev. Earth Planet. Sci.* doi 10.1146/annurev-earth-040809-152438
- Jones, A. G., & Ferguson, I. J. (2001). The electric Moho. *Nature*, **409**(6818), 331-3.