

September 18, 2023

Lab 1: One-dimensional analysis of DC resistivity data

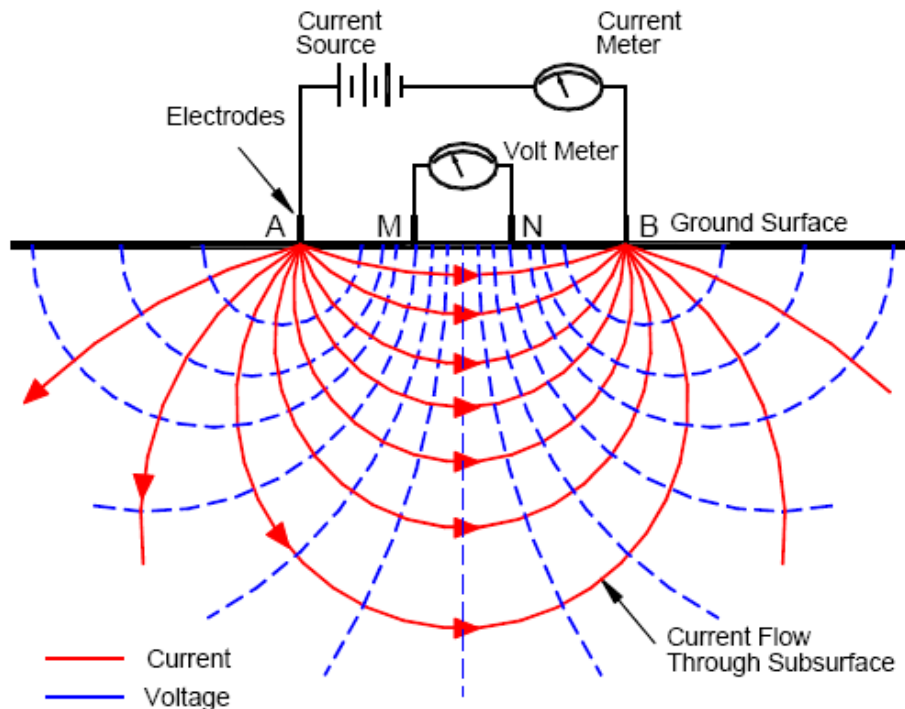
**General Comments:**

- Lab write-up is **due by 5 PM on September 25, 2023** (one week from the lab day).
- Please submit your report by email to the TA
- Write up should include all answers and all relevant figures/plots in a single PDF
- All lab material (codes and data) can be downloaded from the class webpage at: <https://sites.ualberta.ca/~unsworth/UA-classes/424/labs424-2023.html>

**Goal**

The goal of this lab will be to find a 1-D resistivity model of the Earth that fits the measured data, and to interpret the resistivity model in terms of physical properties (porosity, groundwater salinity etc.). We will analyse DC resistivity data collected with a Schlumberger array in 2009 at field school.

**1. Introduction**



**Figure 1** - Schematic of the DC resistivity method.

The DC resistivity technique measures the Earth's electrical resistivity by injecting an electric current into the ground. The electrodes (A and B) are usually metal stakes that are hammered into the ground. Two additional electrodes (M and N) are used to measure the voltage generated by the injected electric current. It is recommended to review your Geophysics 325 notes on DC resistivity.

See : <http://www.ualberta.ca/~unsworth/UA-classes/325/notes325.html>

The electric currents flow in curved lines from A to B as shown in Figure 1. The depth of exploration is proportional to the current electrode spacing, so the greater the spacing, the greater depth the electric currents will flow in the Earth, and therefore the greater the depth of the investigation. We are able to calculate the apparent resistivity, which represents the **average resistivity** of a layered Earth over a hemispherical volume located between the electrodes and with a depth approximately equal to the electrode spacing.

The Schlumberger array is a standard electrode configuration where the current electrodes are moved out some pre-determined distance every measurement while the potential electrodes remain in place. In practice, at some point the current electrodes are at too great a distance and it becomes difficult to measure the potentials so the potential electrodes are moved outwards as well.

There are **FORWARD PROBLEMS** and **INVERSE PROBLEMS** in geophysics.

A **forward problem** begins with an Earth model and makes a prediction about what data would be measured if a geophysical survey was carried out at that location. This is useful in planning a survey to see what parameters are needed to detect a target at a given depth. Forward problems are always unique (i.e. there is only one solution).

An **inverse problem** takes geophysical data that was collected in a survey and computes a model of the Earth properties (e.g. seismic velocity, electrical resistivity, magnetic susceptibility) in the survey area. Inverse problems are important because they allow us to analyse field data, but have the unfortunate consequence that they are **non-unique**. This means that more than one model can be found that fits the same dataset, to the same statistical precision.

(See Geophysics 325 notes, section B3 for details and an example from gravity data, <http://www.ualberta.ca/~unsworth/UA-classes/325/B/325B3-2005.pdf>)

In this lab we will solve the inverse problem in DC resistivity surveys using two approaches.

In the first we use **trial-and error approach** to find a 1-D resistivity model that fits the apparent resistivity data to within a given precision. This approach typically gives a single model, and a false degree of confidence that this is the **ONLY** model that fits the data.

In the second, we use a **Monte-Carlo approach**; **many models are generated at random and evaluated statistically**. This has the advantage that we can see the **RANGE** of models that fit the data, to the same precision.

**QUESTIONS:**

- **1.1** Explain (with words and figures) how the DC resistivity method works.
- **1.2** Explain the differences between a forward and inverse problem in geophysics. Give an example of each type.

**PART 2: Trial-and error forward modelling of DC resistivity data**

- Use the files in the folders ‘**fwd**’ and ‘**data**’ for this section. Make sure these folders are in your MATLAB path.
- The MATLAB function ‘**resfwd2012.m**’ computes the apparent resistivity values that would be measured with a Schlumberger array and a specified resistivity model.
- To run the function **resfwd2012.m** you must input both a resistivity model file and an apparent resistivity data file. Data files are in the ‘**data**’ folder. Open the file ‘**mod.txt**’ in the ‘**fwd**’ folder for an example model file. The number of rows corresponds to the number of layers. The first column contains thicknesses [not depth] in metres, and the second column contains actual layer resistivities,
- **resfwd2012.m** accepts the data file and model file as inputs. For example, you can run it with the command: **resfwd2012(‘res04-2009.txt’,‘mod.txt’)**. Alternatively, you can just use the command **resfwd2012** with the files defined as *appresfile=‘res04-2009.txt’* on line 25 and *modelfile=‘mod.txt’* on line 26. For each different data file you will need to edit the name properly.
- The input model does not stop at the bottom of your final layer; instead the code assumes the model goes on to **infinite depth (an infinite halfspace)**. **Therefore the last layer thickness is ignored** by the program and your deepest layer extends to an infinite depth.

>> **Trial-and-error forward modelling** works as follows :

- (1) Run **resfwd2012** to compute the apparent resistivity data predicted for the initial model. To run the function, open MATLAB, add the folders in this lab to the MATLAB path, and follow the instructions above.
- (2) Look at the apparent resistivity data curve and guess an initial resistivity model. Decide how many layers you should need to fit the data (look at the inflections points). You will need to edit your model file each time, save it, and re-run the code.

- (3) Compare the measured and predicted apparent resistivity curves. The agreement between the curves can be evaluated visually, as the predicted curve should be within one standard deviation of each data point.

Numerically this can be expressed as the r.m.s misfit (r.m.s.= root mean square):

$$r.m.s.misfit = \sqrt{\frac{1}{N} \sum_{i=1:N} \left[ \frac{\rho_i^{APP} - \rho_i^{CALC}}{e_i} \right]^2} \quad \text{(Equation 1)}$$

where  $\rho_i^{APP}$  and  $\rho_i^{CALC}$  are the apparent and calculated resistivity, respectively;  $N$  is the number of data points, and  $e$  is the amount of error in each data point.

For example, Figure 2 shows a measured apparent resistivity curve (points), and their associated error bars (above and below each data point). If all of the predicted data (black line) passes through the error bars (red), then the r.m.s misfit value would be below 1.0. The fit in Figure 2 is quite acceptable, with an RMS misfit = 1.03. Notice, however, that a RMS misfit below 1 is not always better because it may mean the data is being over-fit. Always visually inspect the data because you should never rely on one number to validate your data fit!

- (4) If the fit to the measured data is acceptable (ie. r.m.s. is less than 1.5), you can stop. If not, edit the resistivity model to improve the fit and re-run the code. Generally it is best to fit for the shallowest layers first (small AB/2 values), and then move deeper.
- (5) You may need to **change the scale of the plot** in order to see the entire curves. To do this open ‘**rafind2.m**’ in the editor window, and change the window limits set by the variables *ax1* and *ax2* on lines 39 and 40, this changes the apparent resistivity plot and the true resistivity plot respectively.

Apply this procedure to **the following Schlumberger soundings** collected at field school in 2009:  
*res04-2009.txt, res07-2009.txt, res08-2009.txt.*

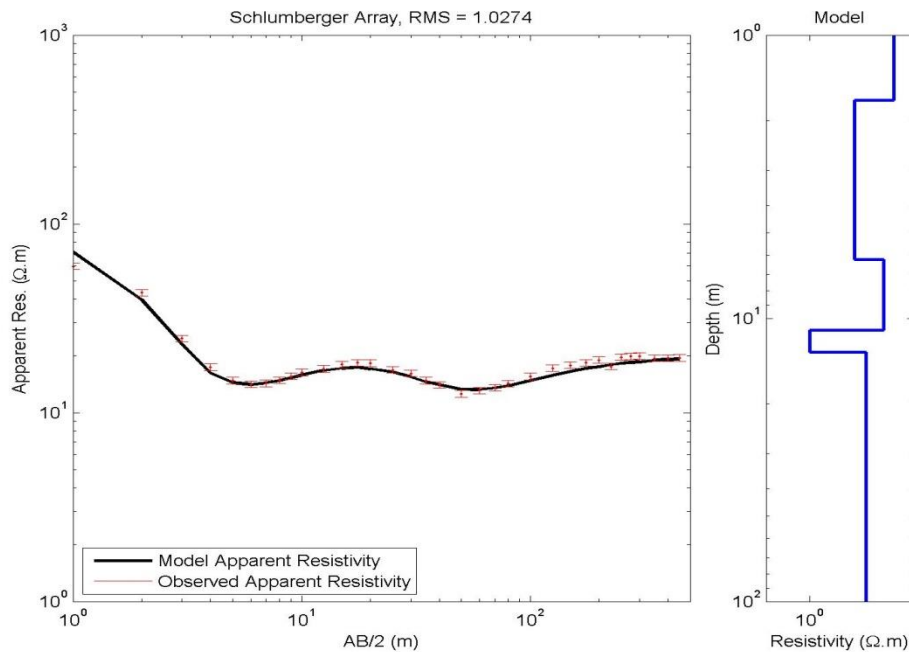
- Use models with **up to 5 layers**, although most of the data can be fit with 4 or less layers,
- The **simplest model is probably the most realistic**. This is expressed in the principle known as Occam's Razor (see [http://en.wikipedia.org/wiki/Occam's\\_razor](http://en.wikipedia.org/wiki/Occam's_razor))
- Fit each Schlumberger sounding within a root mean square r.m.s **misfit < 1.5**
- **Save the model text file**, for later comparison (could rename to *resXX-2009-final.txt*).
- **Save the figure**. In the MATLAB figure window, go to File, Save As, Save as type: .png

- **HINT:** For the *res08-2009.txt* model, start with

<b>2</b>	<b>50</b>
<b>2</b>	<b>400</b>
<b>10</b>	<b>25</b>
<b>2</b>	<b>250</b>
<b>1000</b>	<b>12</b>

**QUESTIONS:**

- **2.1** Discuss non-uniqueness and Occam's Law. How can we use this to choose between several models?
- **2.2** Explain in words what is meant by **root mean square (r.m.s.) misfit**. What does it mean to over-fit data? Is this a good or bad thing to do?
- **2.3** Consider a single data point on a plot of apparent resistivity as a function of electrode spacing. Describe qualitatively where the model response curve is in relation to the data error bars and the data points if the r.m.s. misfit is 2? When it is 0.2? Illustrate your answer with a sketch.
- **2.4** Does a lower r.m.s misfit necessarily mean a better model? Explain.
- **2.5** Include figures for the 3 data sets, showing the model, model response, and fit to measured data. These should have an acceptable fit, as defined above. Identify any outlying points with an arrow.
- **2.6** Submit the model parameters (model thickness and resistivity) for the 3 data sets in individual tables.



**Figure 2** – Output from `resfwd.m` showing a 5 layer fit of a field school data sounding.

### **PART 3: Monte Carlo/Random model Inversion**

Another approach to finding a resistivity model that fits an apparent resistivity curve is by generating many models with randomly distributed thicknesses and resistivities. These models are automatically examined and only those models with an r.m.s. misfit below a certain threshold are kept.

This is a simple form of the **Monte Carlo method** that is often used to solve complex equations (for more details see [http://en.wikipedia.org/wiki/Monte\\_Carlo\\_method](http://en.wikipedia.org/wiki/Monte_Carlo_method)).

The folder '**Monte\_Carlo**' contains a MATLAB function '**resinv2012.m**' that does this type of inversion on Schlumberger array data. This function generates random thicknesses and resistivities to make a model, and then calculates the apparent resistivity that would be measured from the random model.

The function keeps any models which have an RMS misfit value less than *mtol* (the RMS tolerance level) specified within the MATLAB script file, and generates the number of models specified by *num\_it*. The final resulting figures are printed, and the best fitting model is saved to a text file with the name '*mod\_SoundingName.txt*' (ie: *mod\_res01-2009.txt*).

Start by trying to fit *res04-2009.txt* or *res08-2009.txt* with this function, since you have already done the forward model for this data. Within the function '**resinv2012.m**', you should change the number of models generated *num\_it* (try about 5000 or more), the r.m.s tolerance level *mtol* (remember you want an r.m.s below 1.5), and the *z\_scale* (this linear scale controls whether you want layer thicknesses on the order of 10m, 5m, 1m, etc.).

You will need to do this for all of the data files in Profile 1 (7), Profile 2 (7), and *res5beach.txt*.

>>**Monte Carlo modelling** works as follows :

- (1) To run the function, open Matlab, navigate to the proper current folder "**Monte Carlo**" where the code is stored, type **resinv2012** in the Matlab window.
- (2) Select the number of layers in the model from the menu. Remember it is often better to use as few layers as possible to fit the model, as in the forward model section.
- (3) Select the resistivity data file from the menu.
- (4) **Save the final figures** and include all information in your report.

Figure-1 has 3 windows, it will show the lowest r.m.s misfit achieved amongst many models. All of these models meet your criteria (ie. r.m.s misfit tolerance level).

Figure-2 has 2 windows showing the lowest-r.m.s. model which fits the data, and shows the corresponding resistivity model with depth.

Figure-3 has 2 windows showing the first model found to fit the data, and shows the corresponding resistivity model with depth.

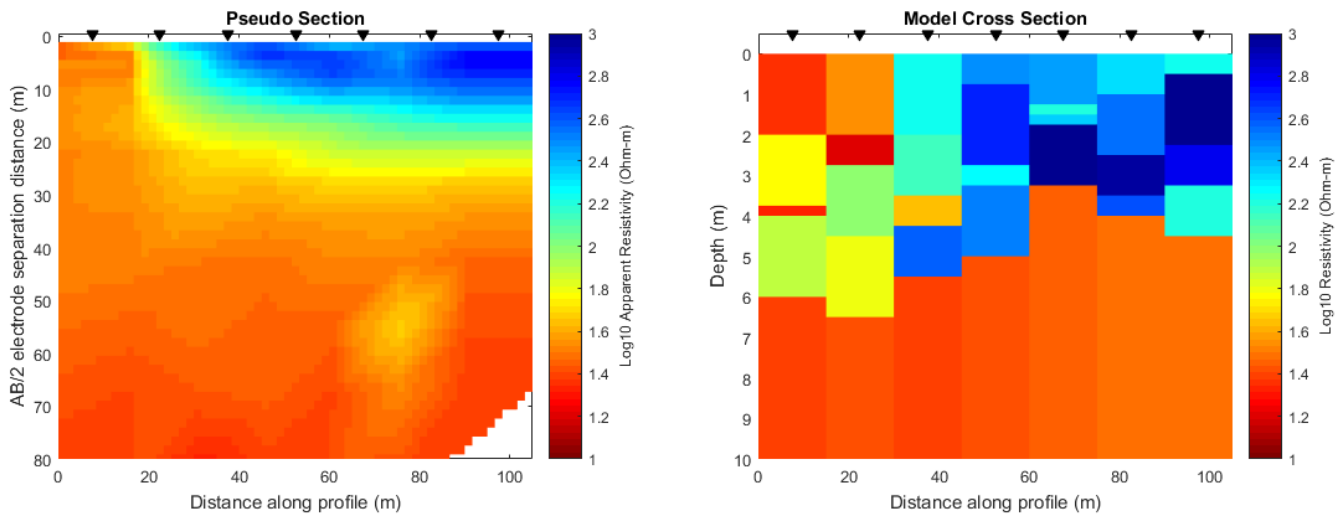
Remember to choose the best model based on fit.

Save these figures. The model file itself will be saved in the current folder (ie: as 'mod\_res01-2009.txt').

**QUESTIONS:**

- **3.1** Discuss the trial-and error approach and the Monte-Carlo approach. Which one do you prefer? Why? Do you think that one gives better results?
- **3.2** Discuss the parameters you changed in the Monte-Carlo code. What happened when you increased or decreased the number of iterations (num\_it), the r.m.s misfit tolerance level (mtol), and the scaling factor (z\_scale)?
- **3.3** Include model figures for the 15 data sets. These should have an acceptable fit, as defined above. Identify any outlying points with an arrow.
- **3.4** Include model parameters (model thickness and resistivity) for the 15 data sets in individual tables.

**PART 4: Display data and resistivity models**



**Figure 3** – Pseudo Section and Cross Section of resistivity data from profile 1.

For this section you will use the MATLAB function '**profile2012.m**' in the **profile\_sections** folder to read in both the measured apparent resistivity, and your resistivity models generated in the previous sections.

This function displays a pseudosection of apparent resistivity, and a cross-section of your resistivity models from previously. The figures should look similar to what you see in Figure 3. The models from each data file are in the **monte\_carlo** folder, seven files for profile1 and for profile2. Start with the data from profile1.

- (a) First make sure your data is in the correct format within the folder:
  - a. Model files: mod\_X.txt, (ie: 'mod\_res01-2009')
  - b. Data files: X.txt, (ie: 'res01-2009')
    - i. You must make sure that the corresponding model and data files from each sounding are called the same name, and all soundings have the same number of characters.
- (b) Then edit the MATLAB function '**profile2012.m**' so that your sounding names will be used, this will have to be done for each separate profile. See lines 27-43 in the code.
- (c) Run '**profile2012.m**' by typing **profile2012** in the MATLAB window. Make sure all files are in your MATLAB path.
- (d) Do this for both profiles, saving the created figures of the profile pseudo-section and cross-section.

**Note** you should also look through the function '**profile2012.m**' to change the scale on these figures when they are plotted. We may expect a maximal depth of about 10 – 15 m for this data. Data spacing is 15m.

**Use colour versions of the figures in the report.** Print in grayscale only if printing on a black and white printer (make sure the colorbar is light to dark). Marks will be deducted if we can't distinguish the different regions.

Notice that the pseudosection is 'pseudo' - it does not give a true measure of depth! The relationship of the electrode spacing and depth is non-linear, however, we are able to get a general idea of how the resistivity varies beneath the electrode array.

### **QUESTIONS:**

- **4.1** Discuss the information shown in the pseudo-section plot, and explain how it is different than the model cross-section.
- **4.2** Include the pseudo-section plots for the 2 profiles.
- **4.3** Include the cross-section plots for the 2 profiles.



**PART 5: Interpretation**

Collecting and analysing data does not make you a geophysicist! The interpretation is often the most important part of a project. Thinking about both the data and the geology as you answer the questions below.

**QUESTIONS:**

- **5.1** Comment on the change in resistivity along each profile. Make sure you understand the colorbar values!
- **5.2** Make a brief interpretation of the geology beneath the two profiles. Is there a difference between the two profiles? Explain clearly why this geological structure might give the resistivity values you see in the data. See Figure 4 for more information.
- **5.3** Use **Archie’s law** to estimate the porosity of the **near surface layer** in your model for *res5beach*. Make sure to fully **justify the values** you choose for the cementation factor and fluid resistivity. Do this where water exists in the pores (not where there is air in the pores, i.e. the very high resistivity surface layer).
- **5.4** Does your porosity value make sense? Is it as you expected? Why or why not? See Geophysics 424 notes on the resistivity of rocks for reference.

<b>Profile 1</b>		<b>Profile 2</b>	
Name	Distance from start of profile (m)	Name	Distance from start of profile (m)
res01-2009	0	res08-2009	0
res02-2009	15	res09-2009	15
res03-2009	30	res10-2009	30
res04-2009	45	res11-2009	45
res05-2009	60	res12-2009	60
res06-2009	75	res13-2009	75
res07-2009	90	res14-2009	90

Table 1: Location of soundings on each profile. The location is the center point of the Schlumberger array.



**Figure 4** – Map showing the location of the two profiles near the Milk River and the DC Resistivity sounding *res5beach*.

NOTE: Profile 2 is closer to the Milk River, on sandier soil. Profile 1 is higher on the bank, in shrubs and vegetation. The location of sounding *res5beach* is on a sandy beach, a low and flat area, very close to the river.

NOTE: The profiles in your pseudosection and cross-section go from left to right (N to S). As shown above, Profile 1 starts with *res01* on the left and goes to *res07* on the right, Profile 2 starts with *res08* on the left and goes to *res14* on the right.