Lab 2: Two-dimensional analysis of DC resistivity data

General Comments:

- Lab write-up is **due by 5:00 PM on October 2, 2023** (one week from the lab day).
- Write up should include answers to all questions and contain all relevant 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

1. Introduction

In Lab 1 you found a 1D resistivity model from fitting a sounding curve. Multiple 1D resistivity models were stitched together and displayed as a 2-D resistivity section. In this lab you will use the 2D inversion program **RES2DINV** to do something similar. This program was developed by Loke and Barker, 1996).

RES2DINV can be used to invert DC resistivity data collected with an array of electrodes spaced along a profile using a 'smart' cable. This cable is capable of making connections to any of the electrodes along the profile without manually switching the connections.

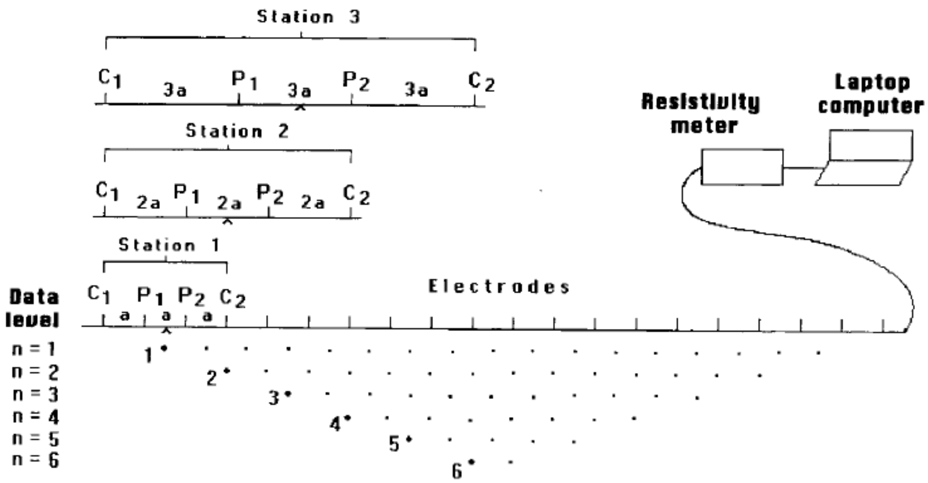

Figure 1 – Wenner array with a smart cable, from Loke and Barker, 1996.

QUESTIONS:

- **1.1** Explain the Wenner Array method. Explain how the Wenner array measures the apparent resistivity (i.e.: where the current flows, and where the electric potential is measured).
- **1.2** Explain the purpose of **RES2DINV** and **RES2DMOD**. Describe the main difference between them.

2: Parameter Information

RES2DINV uses a least squares algorithm to minimize the r.m.s. misfit while keeping the 2D resistivity model relatively smooth. When using the program you will be able to change the control parameters to alter the characteristics of the final resistivity model.

A full explanation of each parameter is described in the **RES2DINV** manual downloadable from http://www.geoelectrical.com/downloads.php. Most of the parameters that can be edited by the user can be found in the menu under *Change Settings*, or *Inversion >> Inversion methods and settings*:

Inversion Damping Parameters:

- The damping parameter controls how closely the data is fit. If you force the inversion to fit the data exactly, the r.m.s. misfit will be small, but the model will be unrealistically rough and the noise will also be fit. Increasing the damping parameter results in a smoother model, but a higher r.m.s. misfit. Therefore a noisy dataset will require higher damping parameters.

- You can change '*Damping factors'*, '*Change of damping parameter with depth*', and '*Optimize damping parameters'*, all of which affect the size of the damping parameter, and how the damping parameter is applied to the data.

Vertical/Horizontal Flatness Filter Ratio and *Diagonal filter*

- Changing this parameter will make the model smooth in either the vertical of horizontal direction. The choice could be the result of *a priori* information that you have about the study area (e.g. in a sedimentary basin you might expect flat structures, and over a kimberlite pipe you might expect to see vertical structures).

Limit Range of Model Resistivity

- Sometimes noise in the data can cause the inversion to produce unrealistically high or low resistivity values in the inversion model. You can use this option to limit the model resistivity.

Mesh Parameters

- In a 2D inversion, the Earth is discretized into a number of rectangular cells. Adding more cells makes the resistivity model smoother, and allows the model to represent more complex resistivity structures. However this also makes the calculations slower, so a compromise must be found.

Other various settings under *Inversion >> Inversion Methods and Settings* can be changed to affect how the mechanics of the least squares inversion operates (their explanation can be found by selecting their option).

PART 3: Forward Modelling (generating synthetic data), with RES2DMOD

We will use the program **RES2DMOD** to generate synthetic DC resistivity data. The RES2DMOD program will calculate the apparent resistivity values that would be measured over a specified 2-D resistivity model.

3.a Install program **RES2DMOD** by **running res2dmod_setup.exe** by double-clicking.

[or download from http://www.geoelectrical.com/index.php. under downloads tab, in the "free software..." section, half-way down the page; unzip the file, and install with setup.exe.]

3.b Open the program. Load model '**Block_one.mod**': ***File*** >> ***Read file with forward model.*** The model can be found in the same directory as Res2Dmod (ie: C:/Res2dmod/).

3.c View the resistivity model: ***Edit*** >> ***Display Model***.

3.d Calculate synthetic apparent resistivity data: ***Model Computation*** >> ***Calculate potential values.***

3.e Display both the resistivity model and the synthetic apparent resistivity data: ***Edit*** >> ***Display Model*** (you may choose a logarithmic scale).

3.f Include this figure in your report. Either ***Print*** >> ***Save Screen*** or use Print Screen to take a screen shot.

3.g Save the model and synthetic data: ***File*** >> ***Save Results in RES2DINV Format*** (the file must have the extension **'.dat'**, i.e. save as "**block_one.dat**"). When saving the synthetic data, **add 5% random noise** to the resistivity.

3.h Repeat these same steps for the model file '**Blocks_up.mod**'.

3.i Repeat for **dyke.mod, fault.mod, thick dyke model**.

QUESTIONS:

- **3.1** Include the forward model figures for the 5 data sets.
- **3.2** Now compare the apparent resistivity sections for '**Block_one.mod**' and '**Blocks_up.mod**'. Explain the features that you see in the synthetic apparent resistivity sections. Compare the data from both models, and explain why the synthetic data sections look like they do.

REFERENCES

1. Loke M.H. and Barker R.D.,1996. Rapid least-squares inversion of apparent resistivity pseudosections using a quasi-Newton method. Geophysical Prospecting, **44**, 131-152.

PART 4: Inverting (synthetic) DC resistivity data, with RES2DINV

4.a Install program **RES2DINV** by **running res2Dinv_setup.exe** by double-clicking on the icon.

[or download from http://www.geoelectrical.com/index.php under downloads tab, in the "Legacy Versions" section, half-way down the page; unzip the file, and install with setup.exe.]

4.b Read in the data: ***File >> Read Data File.*** Start with **block_one.dat**.

4.c Check data quality: ***Edit >> Exterminate bad datum points.*** This is always a good idea before running any inversion. Edit any data points appear to be outliers by clicking on them (changes will save upon exit, but be sure to save to a new name). When finished, click ***Exit***.

NOTE: Multiple bad data points on a diagonal line are probably due to problems a one electrode. All measurements using this electrode will be influenced.

4.d Save inversion parameters: ***Change Settings >> Save inversion parameters***, save as *.ivp file. It is recommended to save this as "**default.ivp**" so you can find it easily later on. We will need to change these later, in Part 5.

4.e *To change parameters you can now open the saved *.ivp file in **wordpad** or **notepad**. All the parameters that can be changed are listed in this file. For an explanation of each of the parameters, look in the manual found in the **RES2DINV** folder, or see Part2.

4.f Read in your parameter file: After ***Change Settings >> Read Inversion Parameters***.

NOTE: When using large damping parameters or unrealistic flatness filter ratios you may need to change the upper or lower resistivity cutoff limit, so the inversion does not use impossibly large or small values.

NOTE: Use the **RMS misfit** as a criterion to compare models. Always remember the ultimate tool in evaluating a model is common sense! Make sure your model not only fits the data, but that the resistivity values are realistic, and the geological structure seems possible.

4.g Run an inversion now: ***Inversion >> Least-Squares Inversion.*** Save these inversions images!

4.h After completing an inversion the results will be shown in 3 panels. If you accidently leave this window, you can see results with: ***Display >> Show inversion results***. Then choose ***Display sections >> Display Data and Model Sections***. This will open a display window showing results for the most recent file. You can also read in an old inversion file.

4.i Do this for **block_one.dat, blocks_up.dat, dyke.dat, fault.dat, thick dyke.dat** (5 total).

4.j For this step, you need the **DONGLE KEY, if not available skip this step.** Save model: ***File >> Save Data in XYZ format***. This creates an **ascii .xyz file** containing your model and other information.

Note: Another approach to running resistivity inversions is to use prior knowledge to constrain an inversion. For example, if you knew there was a large resistivity change from a clay layer to a sand layer at a certain depth constrained by a seismic refraction survey, you can constrain the inversion using that data. This loosens the smoothness constraint at a specified location.

You can also fix certain resistivity values within a given area. If you have prior geological knowledge from some kind of ground truth, you can fix the resistivity of a given geological body within the model. This forces the inversion to change the model everywhere but where you specified, to fit the apparent resistivity measurements. Since we have no such prior information from these lines, this approach is not possible.

PART 5: Exploring Data Inversions

In this section we will use **RES2DINV** to again invert the synthetic data generated by forward modeling in Section 3. This time we will be changing various parameters and exploring their effects. Synthetic inversions are useful because the model from the inversion can be compared with the true model used to generate the data.

RES2DINV requires a software dongle to run more than three inversion iterations. Three iterations is often enough to see if the inversion will converge. For this lab it is sufficient to use the trial version with three iterations to find a model.

- **5.a** Find the best inversion model for **block_one, blocks_up, dyke, fault, thick dyke** (5). The best model will be the one that gives the model that is most similar to the "true" model used to generate the data in **RES2DMOD.** Make sure to compare depths, distance along profile, and actual resistivity values.
- **5.b** We will use the same models to experiment with the various control parameters in **RES2DINV**. Give detailed comments on what you tried, and why or why it did not help return the original model.
- **5.c** It is not necessary to include every figure in your report. Include only final iteration figures, and those figures which are relevant to your discussion, or help to prove a point.

QUESTIONS:

- **5.1** See if you can generate a model that exhibits both the blocks from **blocks_up.mod**. Can you recover the "true" model with the inversion? Why or why not? Explain in detail, concentrating on the physics.
- **5.2** Include the figure for the best inversion model for **block_one, blocks_up, dyke, fault, thick dyke** (5).
- **5.3** Explain the parameters you changed for each model, and how it changed your models. Include figures to show this. Relate this to the physics.
- **5.4** Would more iterations help improve the model?

- **<u>PART 6: Real Data Inversions : Field School 2011 ERT Data</u>**

- Data were collected across three farm fields in Southern Alberta during Field School in 2011 using a Wenner array with electrode spacing of 1.5 m and profile length of 25 m.
- The surveys were conducted in three types of fields rated by local farmers, based on crop yield, as good, moderate, and bad. The bad field was struggling to grow crops. The survey was carried out to see what electrical resistivity differences existed between these three fields.
- Unfortunately, due to poor record keeping on the data logger machine and the loss of the field note-book, we do not know which data come from which fields.
- The data is saved in *.dat files (lines B, D2, F). Column 1 contains electrode spacing distances, column 2 contains the data level n=1..6 (a pseudo-depth), column 3 contains the resistivity values.
- Now run inversions on the three profiles. Choose appropriate control parameters.

<u>QUESTIONS:</u>

- **6.1** Include the best inversion models for the profiles (3). Be sure to explain what parameters you used and why.
- **6.2** Identify which lines come from the good, moderate, and bad fields. Explain how you determined this, based on the resistivity survey, and other evidence given.
- **6.3** Identify why the poor field is suffering from low crop yields. Explain how you determined this, based on the resistivity survey, and other evidence given.
- **6.4** Briefly **interpret your results.** Give a simple geological model for the three fields. Add a sketch for each profile. What is changing in the geology?

PART 7: Real Data Inversions: Wagner Natural Area

- Three profiles of data were collected in the **Wagner Natural Area** between Edmonton and Spruce Grove using a Wenner array with **electrode spacing of 5 m**. The lines range in length from **600m to 2000m**, and have electrode spacings in the range from 5-80 m. The lines were collected from south to north, as shown on the map in Figure 2.

- A brief overview of the hydro-geological setting of the Wagner Natural Area can be found in the Appendix (see more info at the website: **http://wagner.fanweb.ca**).

7.a Consider **Line 3**, and compare the inversions obtained by changing the following parameters.

7.b For example, how does changing the **damping factor** change the resistivity model. Choose a value that (a) is obviously too large, (b) a value that is obviously too small and (c) a value which seems to represent the most realistic tradeoff between (a) and (b).

7.c Adjust the **vertical/horizontal smoothing ratios** to find which values are required to smooth the model. Choose a value that (a) is obviously too large, (b) a value that is obviously too small and (c) a value which seems to represent the most realistic tradeoff between (a) and (b).

7.d Try changing more than just these settings, look through the manual at the various settings you can change, and if it makes sense to change something, try it. Clearly document what you have tested, and comment on why or why it did not produce a better model. Include both written explanations and figures. Show your results.

7.e Use what you have discovered from the last two steps, and other experiments, to choose appropriate parameters making the best inversion model you can for **Line 3**. This means finding a model with a low RMS, resistivity values which make sense given the geological setting, and structure which also seems realistic. Give best inversion result.

7.f Next, try to find suitable inversion parameters for **Lines 1 and 2**, starting with the best values you found for Line 3. If you think this model looks unrealistic, try changing the parameters. Give best inversion result.

QUESTIONS:

- **7.1** Clearly show your experiments with many different parameters, as discussed above. For full marks you should try changing the damping factor, the smoothing ratios, and one more parameter. Give both detailed explanations and figures.

- **7.2** Include the best inversion models for the profiles (3). Be sure to explain what parameters you used and why.

- **7.3** Try heavily editing Line 3. Does this affect the inversion result?

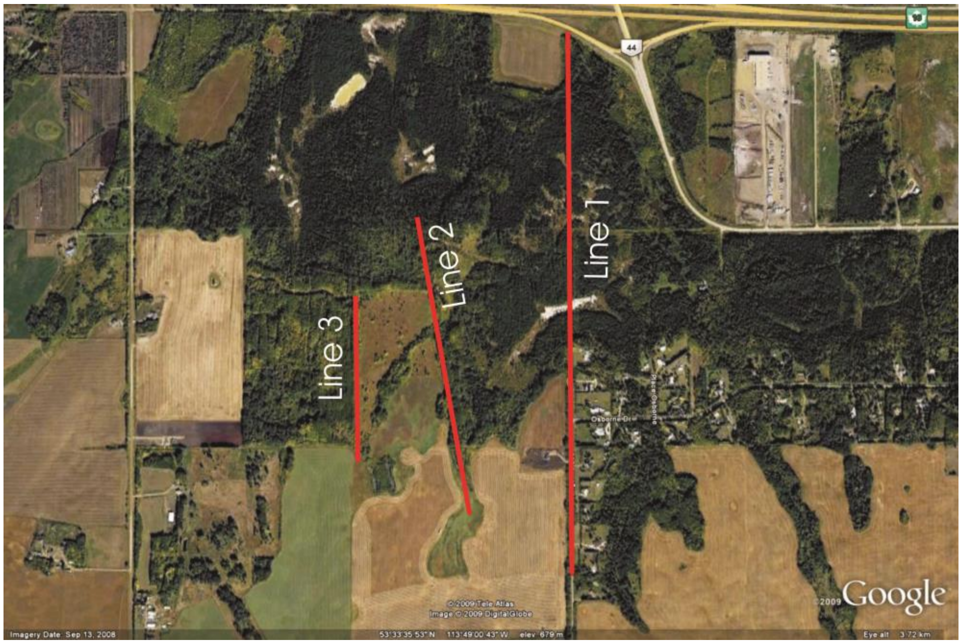

Fig 2: Map of survey lines across Wagner Natural Area. Data were donated by Dr. Ben Rostron and Dr. Carl Mendoza from the Department of Earth and Atmospheric Sciences.

PART 8: Interpretation of Wagner Natural Area

- In the questions below, include a relatively detailed interpretation of the real data inversion models from the Wagner Natural Area. Be sure to give a consistent, concise, realistic, and clear geological interpretation. Remember to relate the geology of your interpretation to the resistivity values you found. Use the Appendix to help guide your interpretation.

QUESTIONS:

- **8.1** How does the subsurface resistivity change throughout the Wagner Natural Area? Comment on the changes both along the lines (from south to north) and between the lines (from east to west).
- **8.2** Make a geological interpretation of what each layer could represent given the geological background, and the resistivity values you found. Give detailed explanations as to why.
- **8.3** Also include a figure/sketch of the geological model you propose. A plan view and section view would be useful to illustrate this.

APPENDIX

Hydrogeology

Wagner Natural Area

Hydrogeology of Wagner Natural Area

Wagner Natural Area is underlaid by sand and gravel deposited at the end of the last ice age, approximately 10,000 years ago. These constitute an **aquifer**, allowing groundwater collected from catchment areas to the south of the Natural Area to flow down-slope through Wagner to the valley bottom in Big Lake, west of St. Albert. In low lying places where the ground dips below the water table, springs well up and the water flows overland.

Much of this spring water is rich in calcium carbonate, typical of glacial gravel in the area. Other springs coming from deeper down contain sodium and sulfate. It is this abundance of mineral-rich water that creates Wagner's most distinctive type of (?plant community?), the **fens**. Within the fens the water-filled hollows grade into larger marl ponds, so-called because in their shallow waters calcium carbonate precipitates from a supersaturated solution and is deposited as a whitish sludge or **marl**.

Aquifer: An underground layer of permeable rock, sediment (usually sand or gravel), or soil that yields water. The pore spaces in aquifers are filled with water and are interconnected, so that water flows through them.
Fen: A type of wetland fed by ground water and runoff, containing peat below the waterline.
Marl: a loose or crumbling earthy deposit (as of sand, silt, or clay) that contains a substantial amount of calcium carbonate.