Lab 7: DC Resistivity

TA: Thibaut Astic
e-mail: thibaut.astic@gmail.com
office: ESB 4037

DUE: This is an extended lab and assignement. Due Before you next lab session

Overview

DC resistivity surveys are widely used in site-characterization, mineral exploration and geotechnical studies. The purpose of this lab is four-fold:

- Provide an understanding about how currents flow in the ground, the electric potentials that would be measured on the surface, and the secondary fields that result because of charges that occur on a buried structure
- Show how potentials can be converted into an apparent resistivity
- Show effects of buried conductor and resistor
- Provide an opportunity to interpret data on a pseudosection by using an interactive app.

Running Juypter Notebook from gpgLabs

For this lab, you will need to run the appropriate notebook.

- **Shift + Enter** runs the code within the cell (so does the forward arrow button near the top of the document)
- You can alter variables and re-run cells by changing the values and doing **Shift + Enter**
- If you want to start with a clean slate, restart the Kernel either by going to the top, clicking on **Kernel: Restart**, or by **esc + 00**

Resources

- GPG:DC Resistivity
- Jupyter Notebook: DC SurveyDataInversion.ipynb

Note

This is a combination of a lab and a homework assignement. It has been structured to enhance your understanding about the DC resistivity method. Working through this will prepare you for the DC quiz and also for the final exam.

1 Currents, potentials and electric fields

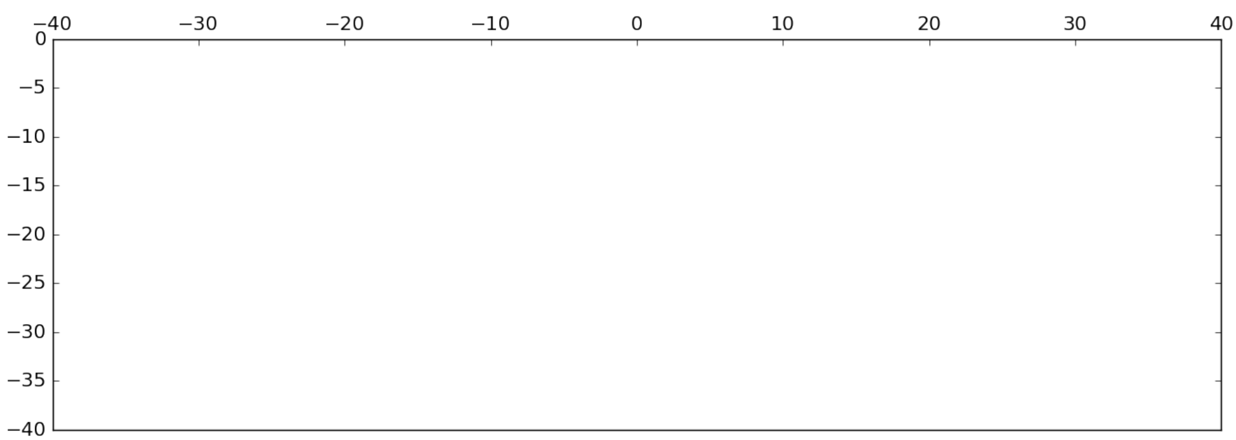
In this section you will use the **cylinder app** to understand how the currents flow in the layered earth, visualize the electric potentials, convert measured potential differences into apparent resistivites.

Q1. Use the default A and B current electrodes locations of -30.25 m and 30.25 m respectively over a half-space.

a. Primary Potentials: A generator is like an electric battery. Look at the map of the electric potentials. Which end of the battery is connected to the A electrode? Which is connected to B? (Comment: Since a battery is a charge storage device, you can think of each current electrode being replaced by a large charge Q.)

b. Why does the potential look like it is positive infinite at the A electrode and negative infinite at the B electrode?

c. Plot the map of electric potentials. In the space below provide a labelled sketch of the lines of equi-potential. In your sketch, include the locations of the A and B electrodes.



d. The electric field is the negative gradient of the potential. On your diagram above, sketch arrows that show the direction of the electric field. Are the electric fields near the current electrodes larger or smaller than the electric fields at depth? Why?

e. What is the relationsip between the electric fields and current density? Sketch some paths on your plot that shows how current travels from the A to the B electrode.

Q2. Use the app to visualize the electric field. The units for electric field is V/m and the scale is $\log_{10}$. You can also visualize the current density. The units for Current Density are A/m^2 and the scale is $\log_{10}$. How does your sketch of potentials and currents match with the computed images?

2 Apparent resistivities

2.1 Computing apparent resistivity

Using the **Two layer app** answer following questions.

Q3. With an 500 Ωm uniform halfspace as a background model, use the slider bars to change the locations of A, B, M, N. For each configuration of A and B, look at the line plot that shows the surface potential, the potentials in the ground, the electric fields and currents. In table 1, there are a few select geometries. Record the potentials that you obtain.

A	B	M	N	V_M	V_N	ΔV_{MN}
-25	25	-10	10			
-25	25	10	-10			
-25	-15	5	15			
-25	0	-10	10			

Table 1: Potential difference measurements over a uniform halfspace.

Q4. Compute in Table 2 the apparent resistivities (ρ_a) for the ΔV_{MN} measurements recorded in Table 1 (Comment: required fomulas are provided in the Jupyter Notebook).

a. Fill in Table 2. In the modelling we assume an input current of 1 A is injected.

AM	MB	AN	NB	ΔV_{MN}	G	ρ_a

Table 2: Calculated apparent resistivities for uniform halfspace.

b. How do these ρ_a values compare with one another and how do they compare with the true halfspace resistivity?

Q5. Now change the earth model to have a 5m thick upper layer with a resistivity of 10 Ωm. Let the lower layer have a resistivity of 500 Ωm.

a. Look at potentials, electric fields and currents to compare them with those from a halfspace. What is the major difference between the current densities? Where are the majority of currents travelling in the layered earth?

b. Use the same electrode locations as in Question 3, but now record the potentials for the layered earth. Fill in table 3. How to your apparent resistivities compare to the apparent resistivity provided by the app (See upper right hand corner of the figure)?

V_M	V_N	G	ΔV_{MN}	ρ_a	ρ_a (app)

Table 3: Measurements from the layered earth model

c. One of the apparent resistivities is 40.89 Ωm; How many other configurations of the four elecctrodes can you find to give you the same apparent resistivity? Is geometric factor, G, the same or different in these cases?

2.2 Soundings

Using the **Two layer app** answer a following question. Use parameters:

- ρ_1: 100 Ωm
- ρ_2: 500 Ωm
- h: 5m

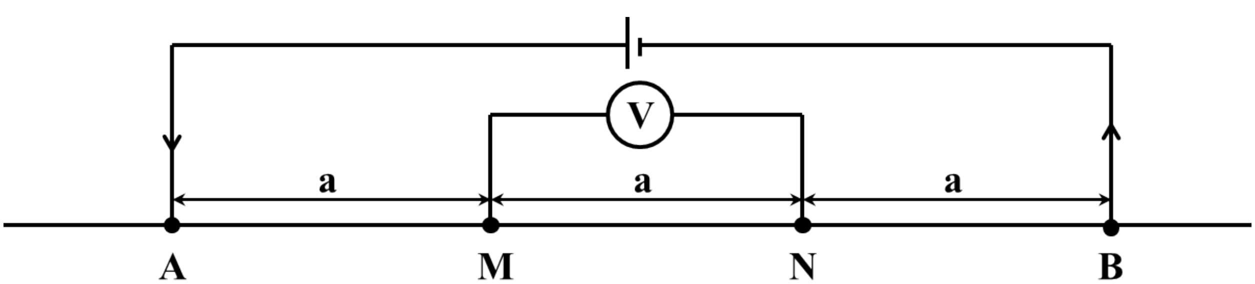


Figure 1: Schematic of a Wenner array.

Q6. Figure 1 shows the electrode layout for a Wenner Sounding. To use this array in a sounding, "a" is successively increased.

a. Choose x=0m as the center of the sounding and use the app to fill in table 4. When $a = 2$m the resistivity is almost the same as that of the upper layer; why is this? Provide a sketch to justify your answer.

a	A	B	M	N	ΔV_{MN}	ρ_a
2	-3	3	-1	1		
4	-6	6	-2	2		
8	-12	12	-4	4		
12	-24	24	-8	8		
20	-40	40	-13	-13		

Table 4: Wenner sounding measurements.

b. At what a-spacing is the Wenner array able to distinguish that the earth is not a uniform halfspace with resistivity 100Ωm? How long is the Wenner array at this point and how does that length compare with the $5m$ thickness of the layer?

3 The effects of buried conductive or resistive cylinders

Use the **Cylidner app** to answer the following questions.

3.1 Conductive Cylinder

Use the default options. View the model, electric fields, potentials and currents for the $500\Omega m$ halfspace. Some of images will differ from those of the layered earth app. To make the app fast and easy to run, we simulate 2D data assuming a 2D line source rather than a 3D point source. Change the cylinder resistivity, ρ_2, to $10\Omega m$.

Q7. View the total current density. How does the presence of the cylinder impact the current path?

Q8. Look carefully at the boundary of the cylinder. Are the secondary currents on the outside of the cylinder flowing in the same direction as the currents inside? Any change in direction is attributed to charges that are built up on the boundary.

Q9. Look at the plot for total charge. Do you see the expected charge buildup of the cylinder? What do you see and why?

Q10. Now examine the secondary charges associated with the cylinder. What is the sign of the charges on either side of the cylinder? Is this in agreement with the formula for charge buildup (eq. $(\tau/\varepsilon = (\rho_2 - \rho_1)J_n)$?

Q11. The app also provides you with the total amount of positive and negative charge on the cylinder. We can think of this as being concentated at the dots inside the cylinder. The effects of the cylinder, referred to as the secondary potential, are approximately represented by this electric dipole. What is the sign of the secondary potential at the two locations: $x = -10m$ and $x = 10m$? and why?

Q12. What is the apparent resistivity for this measurement? How does it compare with the resistivity of the cylinder and that of the background?

3.2 Resistive Cylinder

Now change the resistivity of the cylinder (ρ_2) to $5000\Omega m$.

Q13. How have the currents changed?

Q14. View the secondary charges on the cylinder.

a. How have they changed compared to having a conductive cylinder? Does the sign of the charges agree with that predicted by the formula? What are the values of the cumulative positive and negative charges on either sice of the cylinder?

b. What is the sign of the secondary potential at the two locations: $x = -10m$ and $x = 10m$? and why?

Q15. What is the apparent resistivity for this measurement? How does it compare with the resistivity of the cylinder and that of the background?

4 Pseudo-Sections

Using the slider in the **Pseudo-section app** step through the different transmitters to see how the points in the pseudo-section are built up. While pseudo-sections are often useful for identifying outliers or noisy data they should never be directly interpreted since the shape and location of anomalies can be highly distorted based on the survey geometry.

In the **DC pseudo-section app** the background is fixed to be $1000\Omega m$. Electrodes are spaced 5m apart over the complete survey area. The electrode locations are shown in Figure 2. These electrodes can be used as current or potential electrodes and therefore used for any of the survey types.

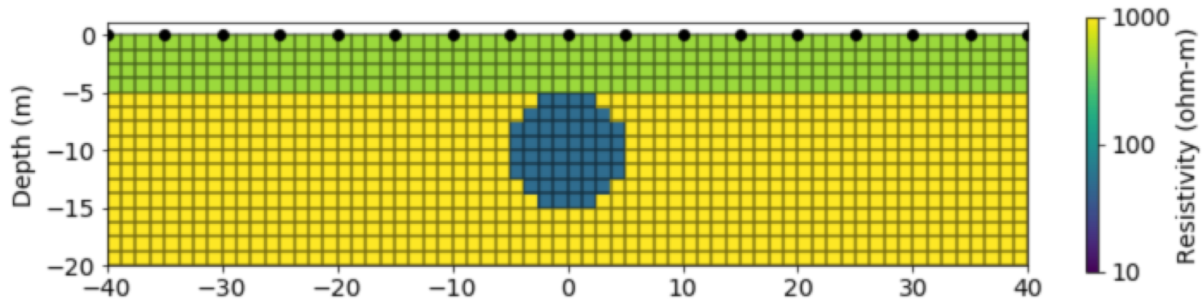


Figure 2: Earth conductivity model with electrode locations marked at the surface.

Q16. Set the resistivity of the cylinder and of the overburden to be $1000\Omega m$. Generate pseudo-sections of the apparent resistivities for dipole-dipole, pole-dipole, and dipole-pole and pole-pole surveys. What do you conclude?

Q17. Set the resistivity of the cylinder to be $100\Omega m$. Generate pseudo-sections for the different array types.

a. Which surveys yield symmetric pseudo-sections, Which yield asymmetric pseudo-sections. For each survey, what is the minimum resistivity value that is obtained.

b. How are the data affected by the resistivity of the cylinder?

Q18. Select the dipole-dipole survey. Find the location of the electrodes that give the maximum anomalous response (In this case the minimum value of resistivity).

a. Fill in the table below. How does the response change when the resistivity of the cylinder is very small?

ρ_2	990	300	100	30	10	3	1	0.3	0.1
min (ρ_a)									

b. How are the data affected by the depth of burial?

Q19. Reset the resistivity of the cylinder to be $100\Omega m$. Fill in the table below and compile the minimum resistivity value obtained as the cylinder is buried deeper? A reasonable estimate for noise is 5 percent. Assuming this noise level, at what depth do you no longer have good indications that there might be a buried conductor at depth?

zc	-6	-8	-10	-20	-30
min (ρ_a)					

Q20. How does your value of the maximum depth of burial found in the previous question compare with a rule-of-thumb estimate of depth-of-investigation (DOI) ~L/3 where L is the length of the survey. To estimate L, show on Figure 2 the location of the current and potential electrodes and use the distance between the first and last electrode for the observation as an estimate for L. From the plot, the maximum length corresponds to "n=8". Show on your electrode diagram what this means.

Q21. Add a conducting overburden by altering the ρ_1 with different resistivities: (500, 100, 50, 10); here use zc=-10m, Examine the output pseudo-sections.

a. How does conductivity of the overburden change the detectability of the conductive cylinder in our DC data?

Self-learning:

- Repeat the above questions but this time make the cylinder resistive. (Imagine that you have an air-filled tunnel.)
- As you work through the apps, always attempt to anticipate what will happen when parameters are changed.

5 Parametric Inversion

The above work provides insght about how observed data (plotted as pseudo-sections) will change when the parameters of the earth are variable. To make the DCR technique useful however, we need to extract information about the resistivity from the observed data. That is, we need to invert the data. This question is designed to illustrate the fundamentals of inversion and introduce the concept of non-uniqueness. Your goal is to adjust the parameters of the model so that you have a good match between your simulated data and the observations.

The problem, the survey and your task are illustrated below:

- A buried tunnel is sought. (Maybe its terrorists building tunnel under the border of your country or maybe it's a natural tunnel)
- The resistivity of the tunnel is unknown. It might be filled with air or saline water.
- The horizontal location of the tunnel (xc) and depth (from the surface to the center of the tunnel are unknown). So is the radius of the tunnel.
- The earth consists of two layers. The top layer is $5m$ thick but it's resistivity is unknown. The region below the layer is uniform and has a known resistivity of $1000\Omega m$.

- An array of electrodes is put on the earth and four DCR surveys are carried out. No noise is added to the data.
- You have 5 items that can be adjusted
  - ρ_1: resistivity of the upper layer
  - cylinder: (r, xc, zc, ρ_2)
- Compare your predicted data with the observations. Do they match? To quantify the fit, you can plot the normalized misfit. which is defined as

$$\text{normalized misfit} = \frac{d^{pred} - d^{obs}}{d^{obs}} \times 100\ (\%)$$

So a value $mis = 1.0$ is one percent. You should be able to fit the data so that the maximum normalized misfit is less than 5 for all the surveys.

Q22. As you experiment and find solutions that "look" good (just by using your eyes), or by determining a value for the maximum misfit, record your numbers in the table below.

a. List your best estimate for the parameters in the table at the end along with some uncertainty. The uncertainties can be obtained from your table that lists parameters of "acceptable" solutions.

	1	2	3	4	best	uncertainty
ρ_1						
ρ_2						
xc						
zc						
r						

Q23. In many inverse problems a fundamental non-uniqueness exists in which multiple parameters can be changed and yield the same result. In magnetics we saw that a change the size of the cylinder could be compensated by changing the susceptibility. Do you see any equivalent tradeoffs here. (say between the radius of the cylinder, depth of burial and its resistivity?)