Declining Lawn at Lychee Hills of SUSTech

Name:

Student ID:

1. Setup

The Landscaping Office of SUSTech has noticed the declining health status of the lawn at Lychee Hills. The president was mad about the undermaintained lawn that gradually turned yellow. So, the Landscaping Office has decided to repair. It was known the subsurface beneath the lawn is made of basically two layers - the topsoil that provides moisture and nutritions to the grass and a foundation of loose or consolidated Quaternary sediments. They doubt some yellow patches were caused by topsoils not thick enough, so an investigation on the **topsoil thickness** is necessary.

The Landscaping Office lacks expertise in such problems, so they reached out to the earth science department and asked if geophysics can help. The key information they would like to obtain is the thickness of the topsoil. If possible, they are also interested in the horizontal variability of the top soil layer. Here is a list of their wishes:

1. Estimate an average thickness of the topsoil and see if its overall quality meets the industrial standard
2. Evaluate the variability of thickness
3. Evaluate the uniformity of the topsoil layer
4. Be quick and cheap but with sufficient information for the follow-up repair

---

Questions:

Those requirements are from the Landscaping Office. Do you think their expectations are realistic? Or how confident are you of solving those problems? Why? Provide your answers below. You may come back and revise your answers when you finish this worksheet.

Your answers:

1.
2.
3.
4.

---

2. Properties

Geophysical methods only work if there is a contrast in physical properties.

Questions:

Please list at least three physical properties that you think may be used to distinguish a topsoil layer and the foundation. The topsoil is rich in organic matters and moisture, while the foundation is relatively less porous and less permeable. Also provide comments on whether these properties can be practically used in this project.

Your answers:

1.
2.
3.

In this worksheet, we concentrate on electrical conductivity, or its reciprocal electrical resistivity. Electrical conductivity is a bulk property of material that characterizes the ease that charge carriers flow through the material when an electrical force is applied. In conductive media, free charge carriers usually include ions and electrons. Pure water is resistive, but water in porous earth materials can dissolve salt in minerals and become ionically conductive. Naturally occuring free electrons are often found in metallic mineralizations.

Questions:

The following items are likely to be encountered at Lychee Hills. Please find their conductivity (or resistivity) values. Don't forget to attach the appropriate unit.

Your answers:

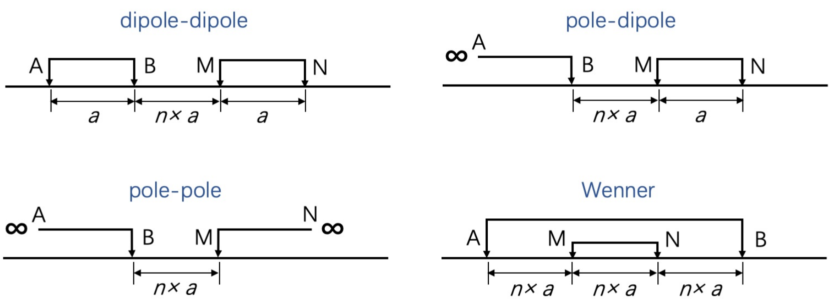
1. Air =
2. Water =
3. Soil =
4. Tills =
5. PVC pipes =

6. Steel pipes =
7. Concrete =

3. Survey

Electrical method, also known as dc resistivity, employs the similar procedure that measures the resistance using Ohm's law. An electrical survey system usually consists of four electrodes. Electrode A and B are current source electrodes, and M and N are potential measurement electrodes. During a survey, an electrical current is transmitted through A and B, and the potential difference between M and N is measured as data. Although it is possible to place the four electrodes at arbitrary locations, some typical inline electrode configurations are often used in practice to provide a sectional view of subsurface conductivity.

Below are four commonly used electrode arrays. All array types are specified by n-spacing and a-spacing. A small spacing has the advantage of higher lateral resolution near surface, while a large spacing can be used to reflect conductivity at depth. In a particular survey, the a-spacing can be fixed and n-spacing varies to achieve different depths of detection.



Cylinder app

- **survey**: Type of survey
- **A**: (+) Current electrode location
- **B**: (-) Current electrode location
- **M**: (+) Potential electrode location
- **N**: (-) Potential electrode location
- **r**: radius of cylinder
- **xc**: x location of cylinder center
- **zc**: z location of cylinder center
- ρ_1 : Resistivity of the halfspace
- ρ_2 : Resistivity of the cylinder
- **Field**: Field to visualize
- **Type**: which part of the field
- **Scale**: Linear or Log Scale visualization

In [1]:

```
from geoscilabs.dcip.DC_cylinder import cylinder_app
from IPython.display import display
%matplotlib inline
app = cylinder_app()
display(app)
```

survey Dipole-Dipole Dipole-Pole Pole-Dipole

Pole-Pole

A -30.25

B 30.25

M -10.25

N 10.25

r 10.00

xc 0.00

zc -20.00

ρ_1 500

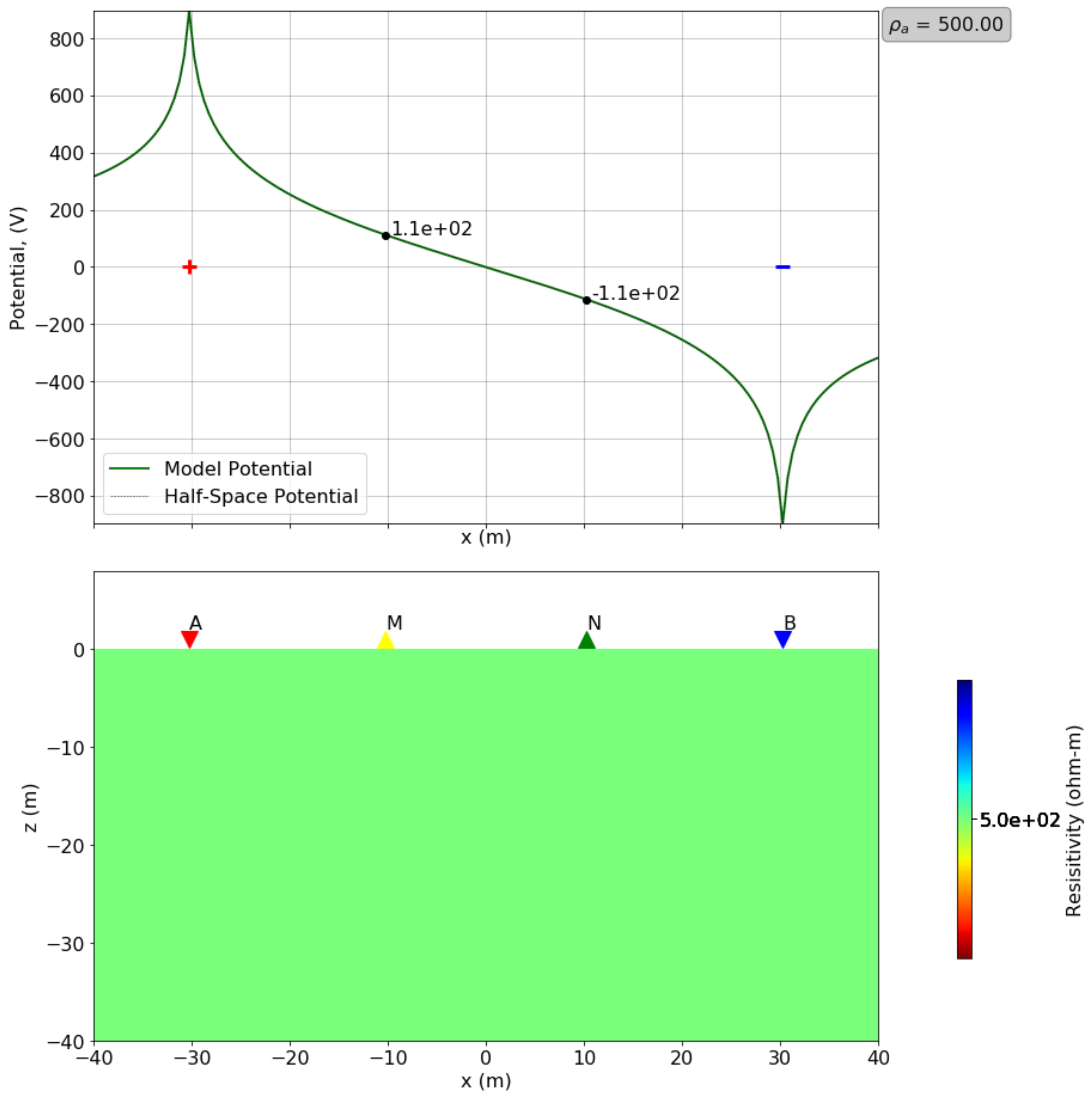
ρ_2 500

Field Model Potential E

J Charge Sensitivity

Type Total Primary Secondary

Scale Linear Log



Questions

1. Is the potential difference measured by a dipole over a conductive (or resisitive) target higher or lower compared to the half-space reference?
2. how do the field lines bend in presence of a conductive (or resistive) target?
3. Compared to the positive and negative sources (A and B), how are oriented the positive and negative accumulated charges around a conductive (or resistive) target?
4. How would you describe the secondary fields pattern? Does it remind you of the response of an object fundamental to geophysics?

Your answers

1.
2.
3.
4.

Layered earth app

- **A**: (+) Current electrode location
- **B**: (-) Current electrode location
- **M**: (+) Potential electrode location
- **N**: (-) Potential electrode location
- ρ_1 : Resistivity of the first layer
- ρ_2 : Resistivity of the second layer
- **h**: Thickness of the first layer
- **Plot**: Choice of 2D plot (Model, Potential, Electric field, Currents)

In [2]:

```
from geoscilabs.dcip import DCLayers
from IPython.display import display
%matplotlib inline
from matplotlib import rcParams
rcParams['font.size'] = 14
out = DCLayers.plot_layer_potentials_app()
display(out)
```

A -30.00

B 30.00

M -10.00

N 10.00

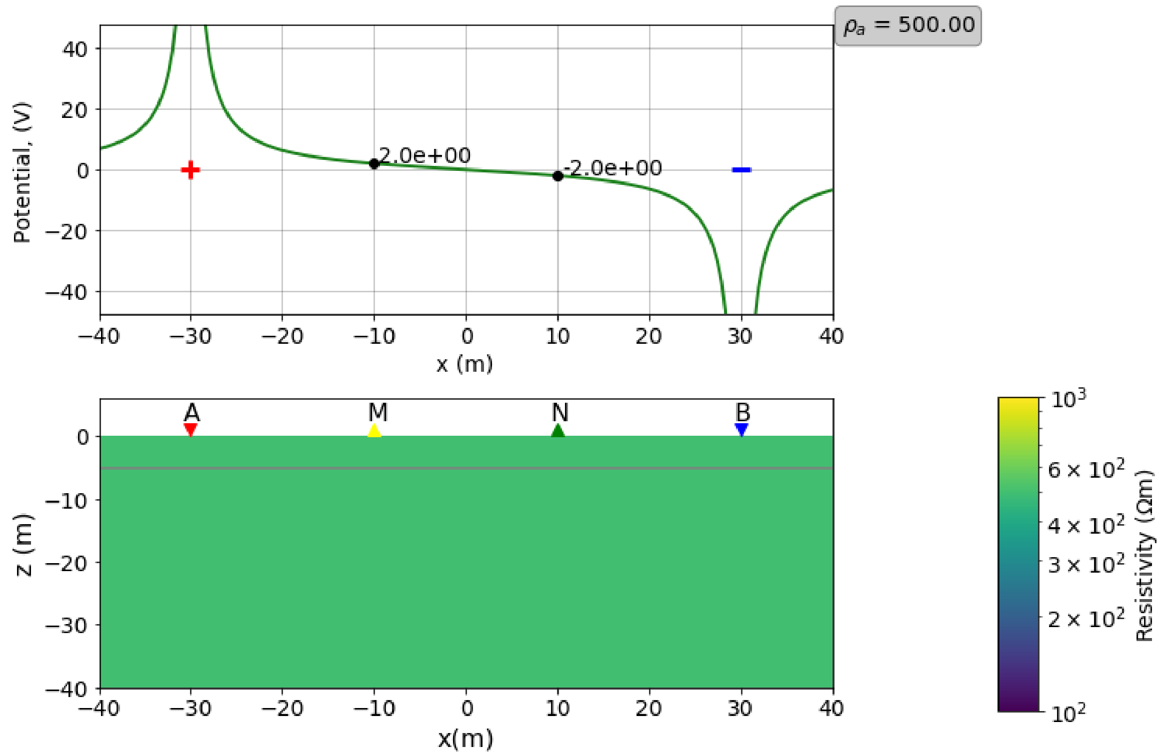
ρ_1 500

ρ_2 500

h 5.00

Plot Model Potential E J

```
/Users/dikun/PythonRepos/geosci-labs/geoscilabs/dcip/DCLayers.py:462:
UserWarning: This figure includes Axes that are not compatible with t
ight_layout, so results might be incorrect.
  plt.tight_layout()
```



4. Data

Apparent Resistivity

In practice we cannot measure the potentials everywhere, we are limited to those locations where we place electrodes. For each source (current electrode pair) many potential differences are measured between M and N electrode pairs to characterize the overall distribution of potentials. In a uniform halfspace the potential differences can be computed by summing up the potentials at each measurement point from the different current sources based on the following equations:

$$V_M = \frac{\rho I}{2\pi}\left[\frac{1}{AM} - \frac{1}{MB}\right]$$
$$V_N = \frac{\rho I}{2\pi}\left[\frac{1}{AN} - \frac{1}{NB}\right]$$

where AM, MB, AN, and NB are the distances between the corresponding electrodes.

The potential difference ΔV_{MN} in a dipole-dipole survey can therefore be expressed as follows,

$$\Delta V_{MN} = V_M - V_N = \rho I \underbrace{\frac{1}{2\pi}\left[\frac{1}{AM} - \frac{1}{MB} - \frac{1}{AN} + \frac{1}{NB}\right]}_{G}$$

and the resistivity of the halfspace ρ is equal to,

$$\rho = \frac{\Delta V_{MN}}{IG}$$

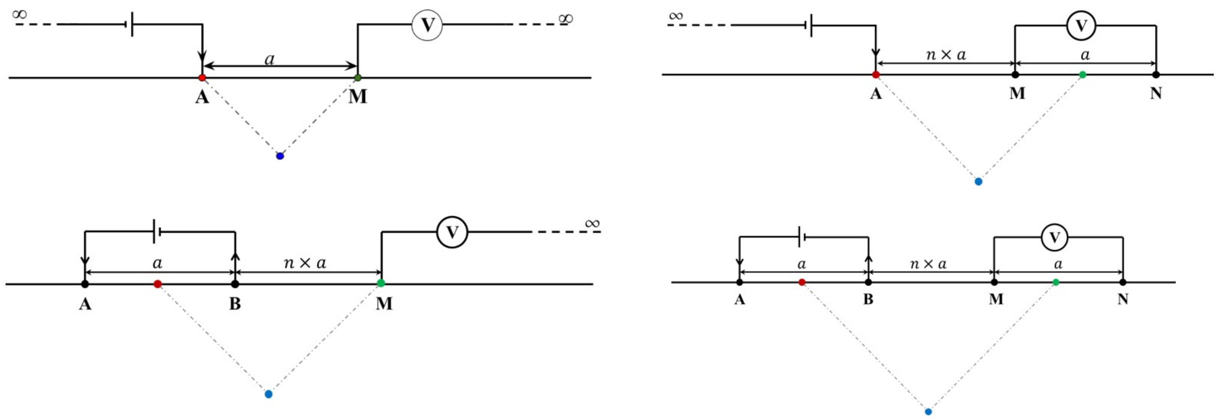
In this equation G is often referred to as the geometric factor.

In the case where we are not in a uniform halfspace the above equation is used to compute the apparent resistivity (ρ_a) which is the resistivity of the uniform halfspace which best reproduces the measured potential difference.

Pseudo-section

2D profiles are often plotted as pseudo-sections by extending 45° lines downwards from the A-B and M-N midpoints and plotting the corresponding ρ_a value at the intersection of these lines as shown below. For pole-dipole or dipole-pole surveys the 45° line is simply extended from the location of the pole. By using this method of plotting, the long offset electrodes plot deeper than those with short offsets. This provides a rough idea of the region sampled by each data point, but the vertical axis of a pseudo-section is not a true depth.

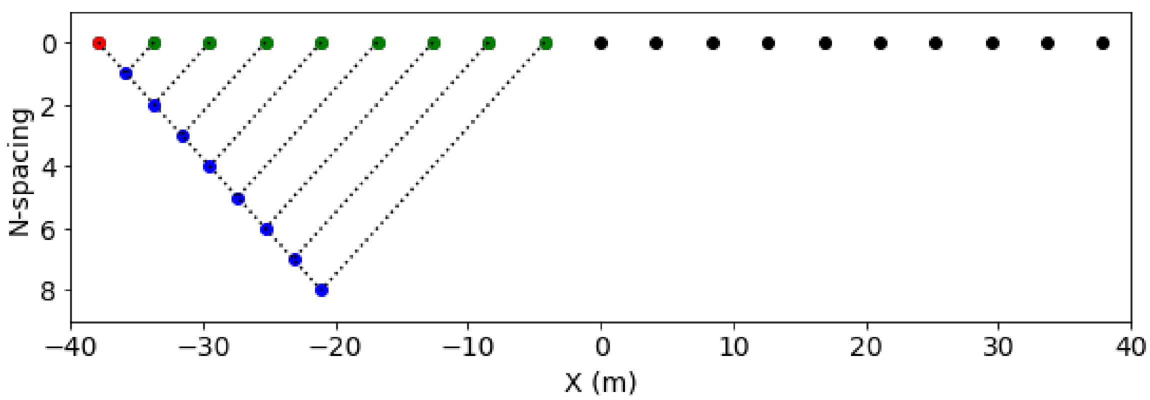
In the widget below the red dot marks the midpoint of the current dipole or the location of the A electrode location in a pole-dipole array while the green dots mark the midpoints of the potential dipoles or M electrode locations in a dipole-pole array. The blue dots then mark the location in the pseudo-section where the lines from Tx and Rx midpoints intersect and the data is plotted. By stepping through the Tx (current electrode pairs) using the slider you can see how the pseudo-section is built up. The figures below show how the points in a pseudo-section are plotted for pole-dipole, dipole-pole, and dipole-dipole arrays.



In [3]:

```
from geoscilabs.dcip.DC_Pseudosections import MidpointPseudoSectionWidget, DC2DPseu
from IPython.display import display
out = MidpointPseudoSectionWidget()
display(out)
```

i 0



2D pseudo-section for a sphere model

In [4]:

```
out = DC2DPseudoWidget()
display(out)
```

ρ_1 1000

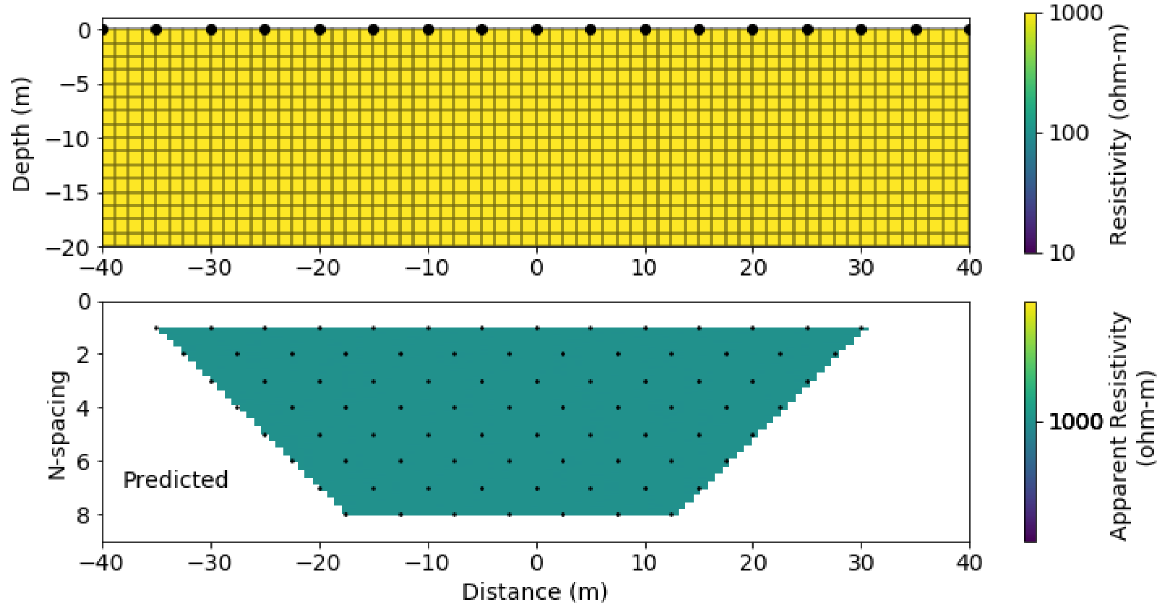
ρ_2 1000

xc 0

zc -10

r 5

surveyType PolePole PoleDipole DipolePole DipoleDipole



Questions

Click through different types of electrode array. Which survey type is more suitable for deep exploration? Which survey type is good at resolving small features? Why?

Your answers

-
-

Lychee Hills data

Two datasets were acquired at the same location on the Lychee Hills lawn using dipole-dipole and Wenner arrays respectively.

- T190424009.xlsx : data file of the dipole-dipole array
- T190424015.xlsx : data file of the Wenner array

Questions

Open the data files and understand the survey specifications. Write your own code to import the data and plot apparent resistivity pseudo-sections.

Your answers

In [5]:

```
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
%matplotlib inline

# dipole-dipole array
df = pd.read_excel('T190424009.xlsx', sheet_name='DAT', header=0) # specify file nan
df.describe() # show contents of data frame

# plot apparent resistivity pseudo-section
```

Out[5]:

	A(C1)	B(C2)	M(P1)	N(P2)	Stacking	K	I(mA)	
count	127.000000	127.000000	127.000000	127.000000	127.0	127.000000	127.000000	127
mean	7.929134	6.606299	13.070866	14.393701	1.0	295.456374	247.631701	331
std	4.053572	4.242935	4.053572	4.242935	0.0	267.398365	51.363877	581
min	2.000000	1.000000	3.000000	4.000000	1.0	9.424800	172.516449	17
25%	5.000000	3.000000	10.000000	11.000000	1.0	37.699100	193.775055	45
50%	7.000000	6.000000	14.000000	15.000000	1.0	272.140411	246.783783	75
75%	11.000000	10.000000	16.000000	18.000000	1.0	505.403503	279.533539	280
max	18.000000	17.000000	19.000000	20.000000	1.0	1055.574951	375.097260	2787

In [6]:

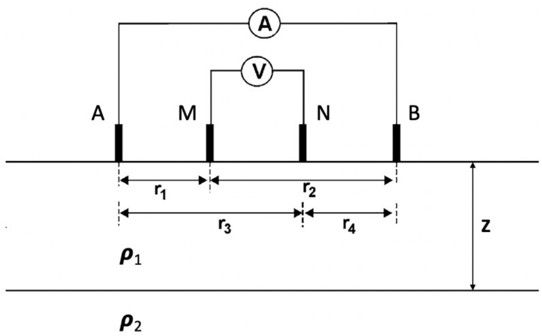
```
# Wenner array
df = pd.read_excel('T190424015.xlsx', sheet_name='DAT', header=0) # specify file nam
df.describe() # show contents of data frame

# plot apparent resistivity pseudo-section
```

Out[6]:

	A(C1)	B(C2)	M(P1)	N(P2)	Stacking	K	I(mA)	V(mV)
count	57.000000	57.000000	57.000000	57.000000	57.0	57.000000	57.000000	57.00000
mean	6.631579	14.368421	9.210526	11.789474	1.0	8.102021	257.722502	3088.35327
std	4.357389	4.357389	3.843997	3.843997	0.0	4.558312	56.590795	1741.57922
min	1.000000	4.000000	2.000000	3.000000	1.0	3.141600	160.114426	1263.34033
25%	3.000000	11.000000	6.000000	9.000000	1.0	3.141600	209.587311	1883.27917
50%	6.000000	15.000000	9.000000	12.000000	1.0	6.283200	257.461273	2512.35034
75%	10.000000	18.000000	12.000000	15.000000	1.0	12.566400	298.880920	3878.464111
max	17.000000	20.000000	18.000000	19.000000	1.0	18.849600	431.244629	7776.385254

5. Processing

An analytic solution of a layered earth model exists for an arbitrary four-electrode array. In this exercise, we examine a two-layer model characterized by two resistivity values ρ_1 , ρ_2 and a thickness of the first layer z as shown below. The current and potential electrodes ABMN can be at any locations on the surface and their mutual distances are r_1, r_2, r_3 and r_4 respectively. According to Telford et al. (1990), the measured potential difference ΔV between M and N is shown in the figure below, where m is an integer sufficiently large.



$$\Delta V = \frac{I\rho_1}{2\pi}\left[\left(\frac{1}{r_1}-\frac{1}{r_2}\right)-\left(\frac{1}{r_3}-\frac{1}{r_4}\right)+2\sum_{m=1}^{\infty}k^m\left\{\frac{1}{(r_1^2+4m^2z^2)^{1/2}}-\frac{1}{(r_2^2+4m^2z^2)^{1/2}}-\frac{1}{(r_3^2+4m^2z^2)^{1/2}}+\frac{1}{(r_4^2+4m^2z^2)^{1/2}}\right\}\right]$$

$$k = \frac{\rho_2-\rho_1}{\rho_2+\rho_1}$$

Questions

Make two computer programs:

1. A function that calculates the potential difference data in a four-electrode electrical survey. The two resistivities, thickness of the top layer and the electrode locations should be adjustable.

2. A function that convert the calculated potential difference data to apparent resistivity values.

Your answers

In [7]:

```
# function Potential Difference
```

In [8]:

```
# function Apparent Desistivity
```

Questions

A simple method of validation is to assign the two layers the same resistivity (as a uniform half-space) and verify if the calculated apparent resistivity is the same as the assigned resistivity. Note the solution in the potential difference equation involves an infinite series. In practice, you must choose an m that is sufficiently large to achieve a stable and accurate solution. In the blank below, report the value of your choice and describe how you chose it.

Your answers

- Your m =

Questions

Use the program you made to calculate the electrical data from a two-layer earth model, in which the top layer is 1500 Ω·m and 10 m thick and the basement layer is 500 Ω·m. Here we consider four types of arrays: dipole-dipole, pole-dipole, pole-pole and Wenner as shown below. The arrays are specified by a-spacing (in meter) and n-spacing (integer). Calculate the potential difference and apparent resistivity for the four arrays based on the two layer model with a = 1 m and n varying from 1 to 20. Plot curves of apparent resistivity versus n-spacing for each type of array. And answer the following questions.

1. Which type of array has better resolution for the near-surface property? And how can you tell?
2. Which type of array has better depth of penetration with the least n-spacing (less expensive field operation)? And how can you tell?
3. Which type of array has the best balance between near-surface resolution and depth of penetration? And why?

Your answers

1.
2.
3.

In [9]:

```
# Your code plotting curves of apparent resistivity versus n-spacing for each type (
```

---

6. Interpretation

Now you have the codes that compute the potential difference of an electrical survey and the corresponding apparent resistivity for a two-layer model. Manually adjust the two-layer model to fit the Lychee Hills field data and make interpretation. Hint: a pseudo-depth versus apparent resistivity plot may be helpful.

Questions

What model (ρ_1, ρ_2, z) has the best overall fit to the field data? Support your claims with data and figures.

Your answers

-

In [10]:

```
# Make plots to find the model that has the best overall fit to the field data
```

Questions

How do the thickness and uniformity of the topsoil vary along the survey profile? Support your claims with data and figures.

Your answers

-

In [11]:

```
# Make plots to study the thickness and uniformity of the topsoil
```

7. Synthesis

Questions

1. What are the limitations of the two-layer model used in your interpretation?
2. Is the interpretation models you obtained compatible with your general expectation?

3. If a steel pipe is buried under the lawn, how would it impact the data and your interpretation?

Your answers:

1.
2.
3.

End of Worksheet

In [ ]:

```

```