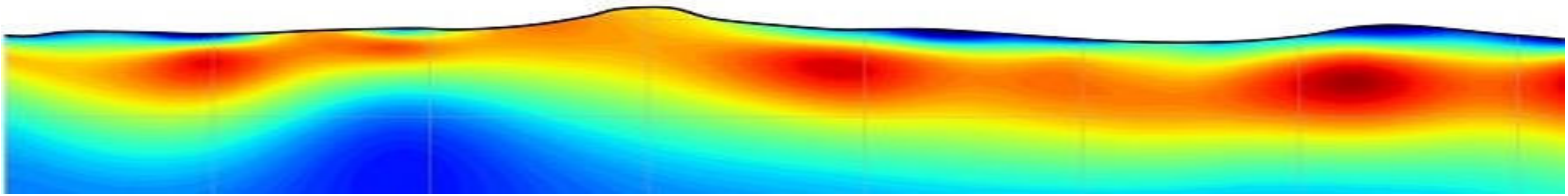
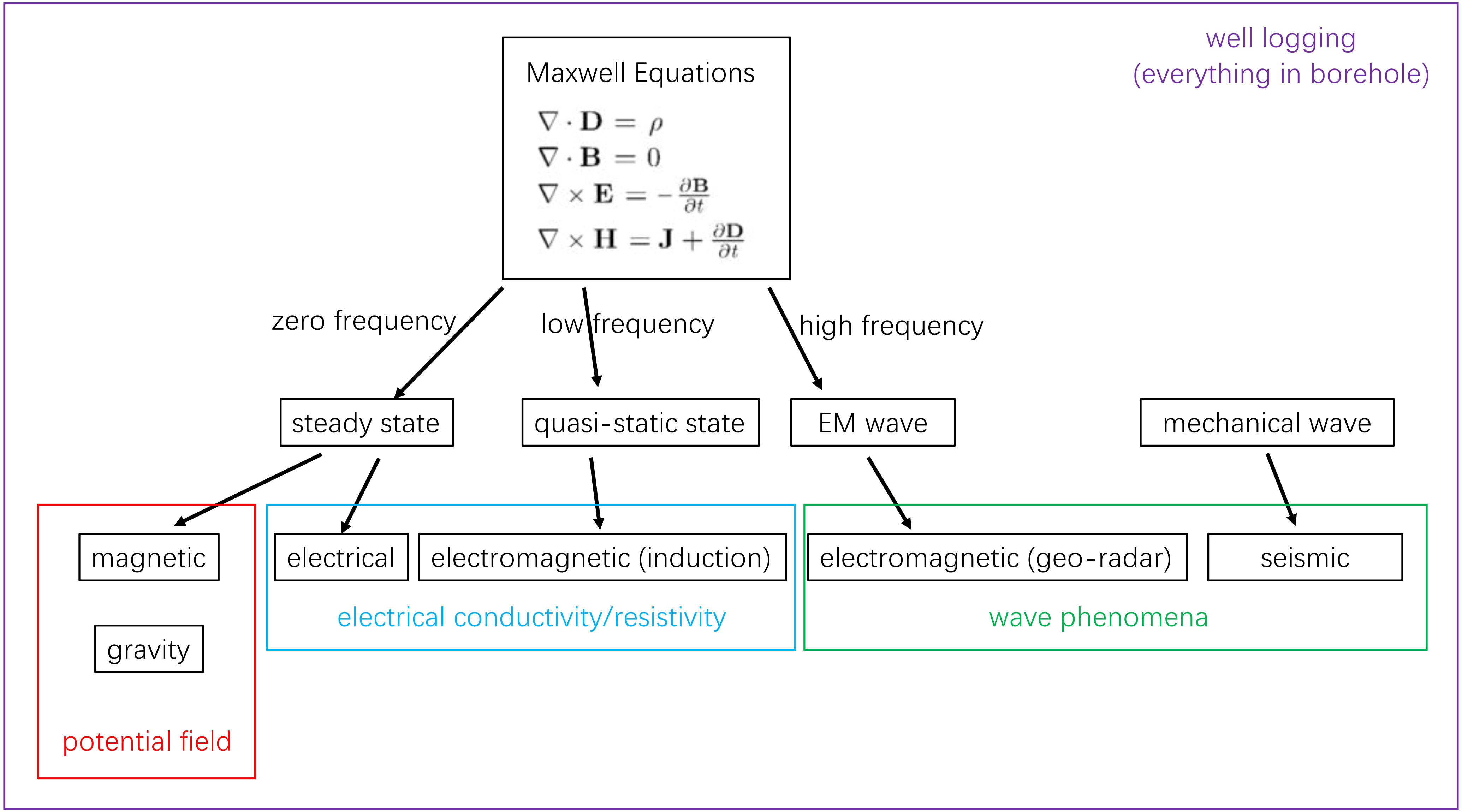
ESS302 Applied Geophysics II

Gravity, Magnetic, Electrical, Electromagnetic and Well Logging

Electrical Wrap-up

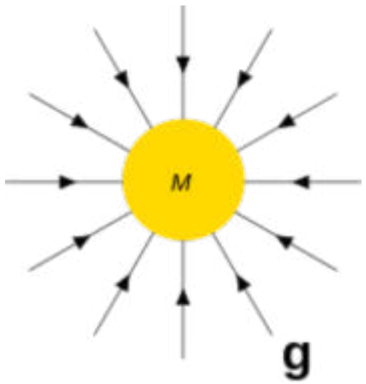
Instructor: Dikun Yang Feb – May, 2020



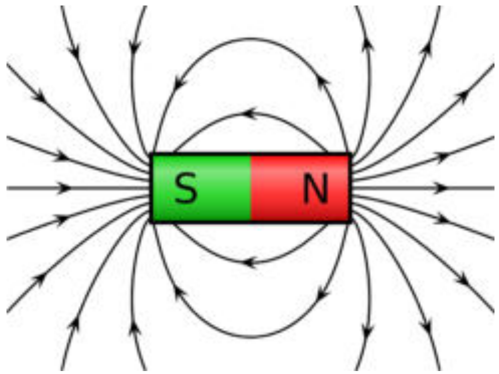


well logging
(everything in borehole)
Maxwell Equations
$\nabla \cdot \mathbf{D} = \rho$
$\nabla \cdot \mathbf{B} = 0$
$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$
$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}$
zero frequency
low frequency
high frequency
steady state
quasi-static state
EM wave
mechanical wave
magnetic
gravity
potential field
electrical
electromagnetic (induction)
electrical conductivity/resistivity
electromagnetic (geo-radar)
seismic
wave phenomena

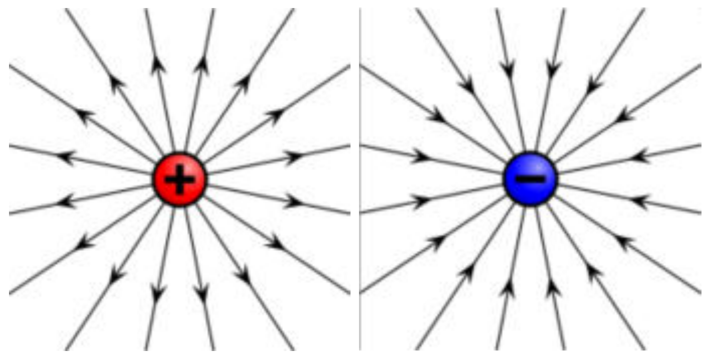
Charge, Force, Field, Potential



- Only positive charge (mass)
- Measure field to infer charge distribution
- External excitation: None (passive)

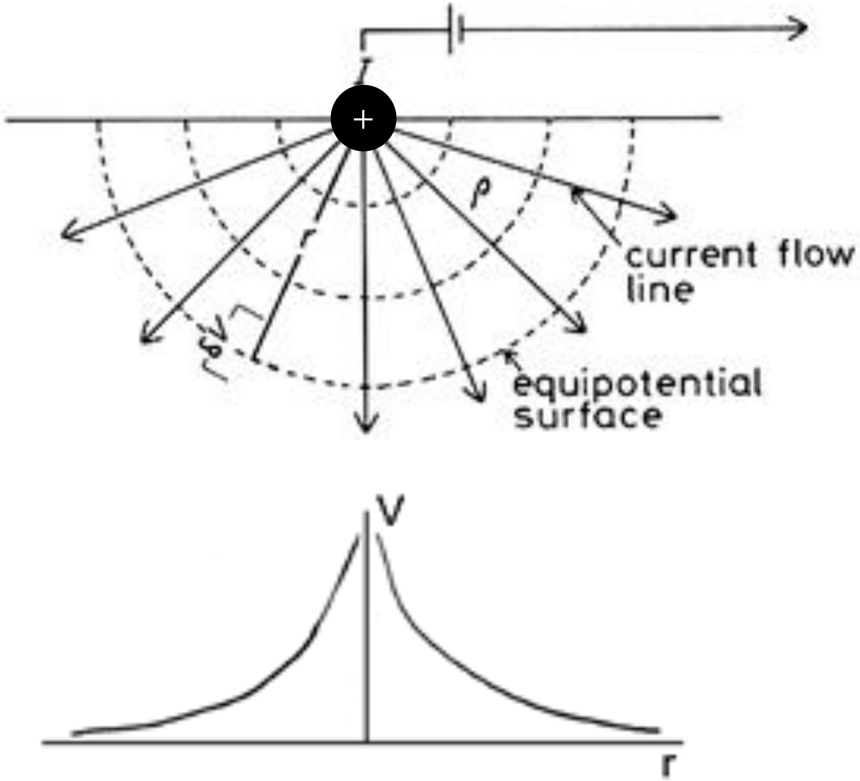


- Positive and negative charge but they have to be bounded as dipole (no monopole)
- Measure field to infer dipole distribution or susceptibility that gives rise to dipole distribution
- External excitation: geomagnetic field (passive)



- Positive and negative charge that can be arbitrarily located
- Measure field/potential to infer dipole distribution or resistivity that gives rise to charge distribution
- External excitation: artificially injected electrical injection (active)

Electrical Potential

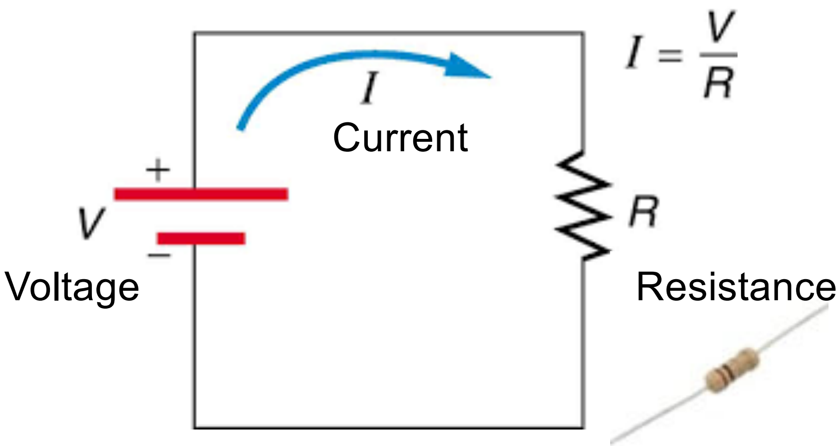


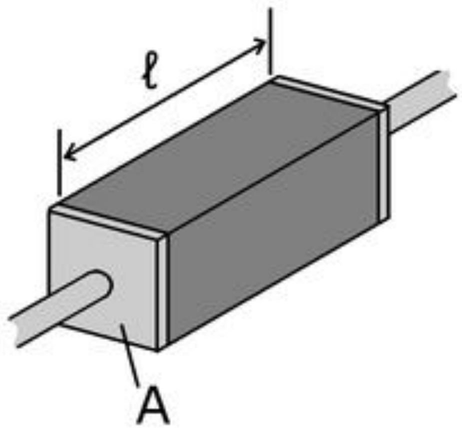
- Current flows radially outwards
- A positive charge at injection point
- Electrical potential decays as 1/r

$$V(r) = \frac{I}{2\pi\sigma r} = \frac{I\rho}{2\pi r}$$

Electrical Resistivity or Conductivity

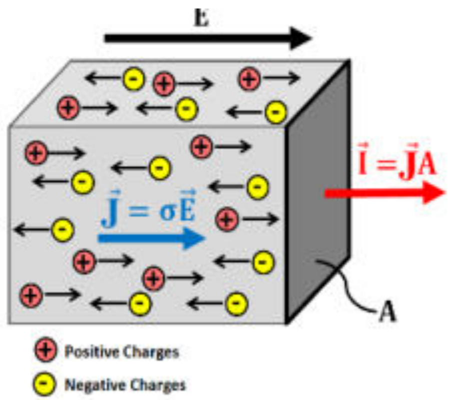
Ohm's law





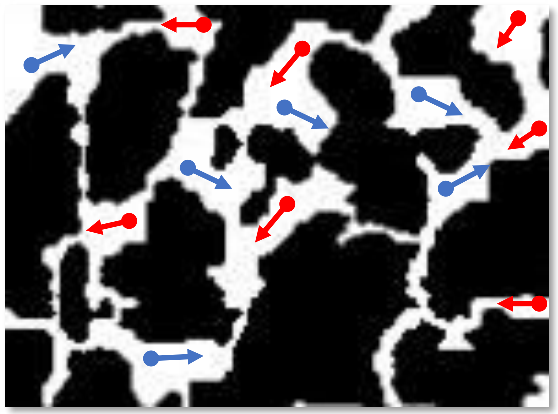
Resistivity (in Ωm) $\rho = R\frac{A}{\ell},$

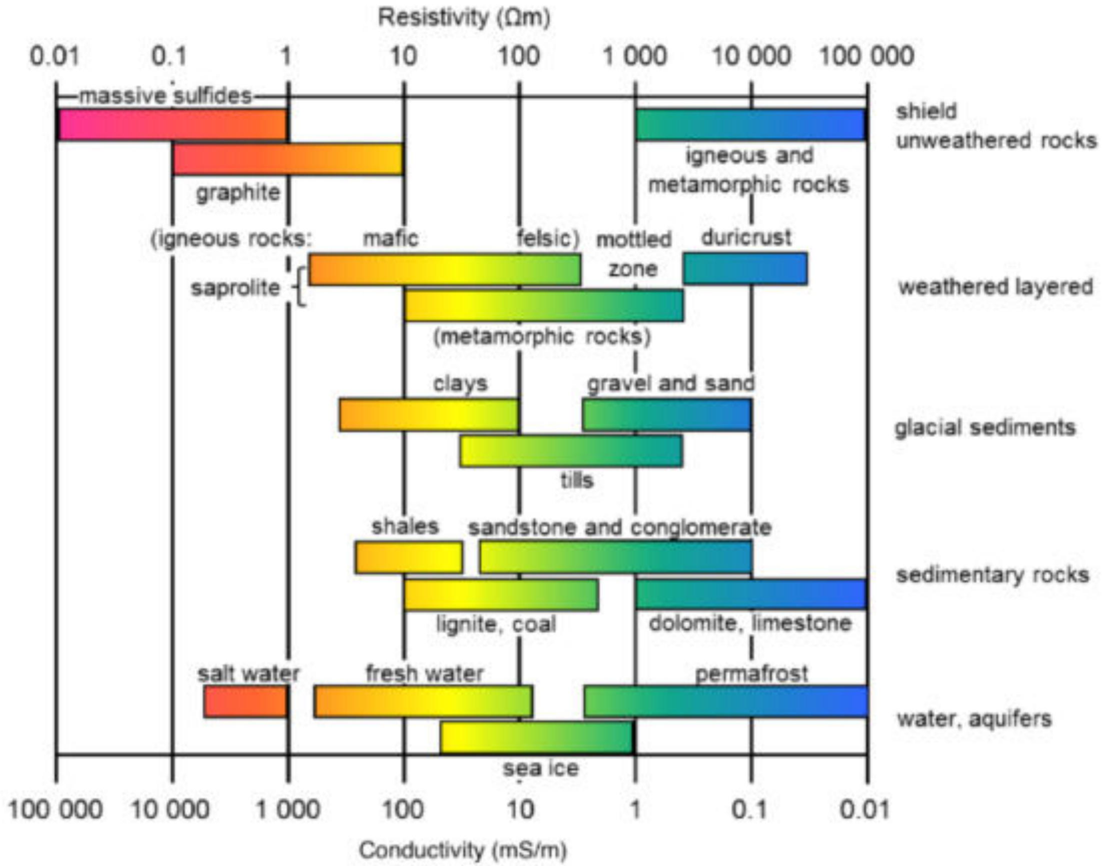
or conductivity (in S/m) $\sigma = \frac{1}{\rho}.$



- Electrons
- Ions

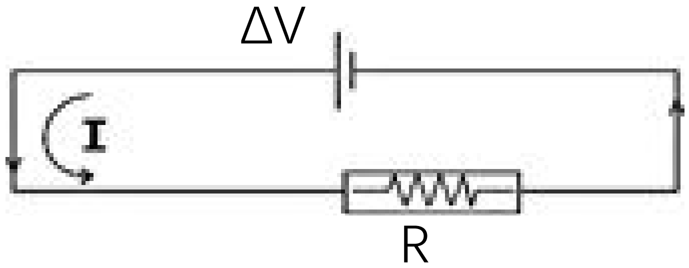
Earth’ s Resistivity





Measurement of Resistance or Resistivity

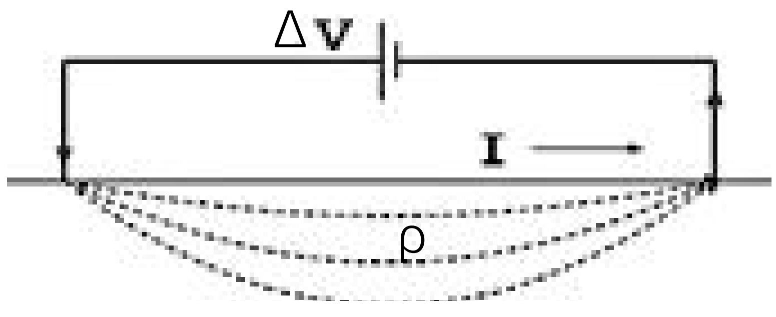
Electrical Circuit



Ohm's Law

$$\Delta V = IR$$

Earth Circuit



For the Earth:

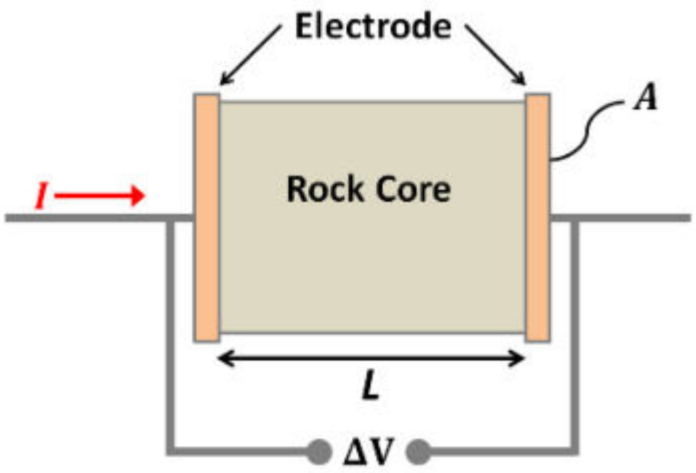
$$\Delta V = I\rho G$$

Depends on:

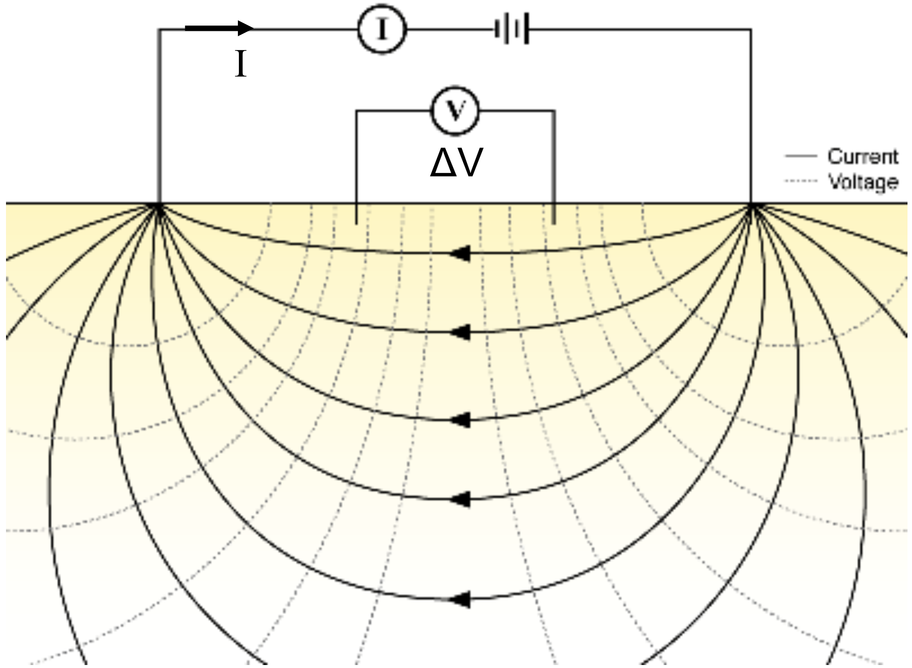
1) Earth' s resistivity (ρ)
2) Geometry of electrodes (G)

Measuring Earth' s Materials

Resistivity measurement in the lab

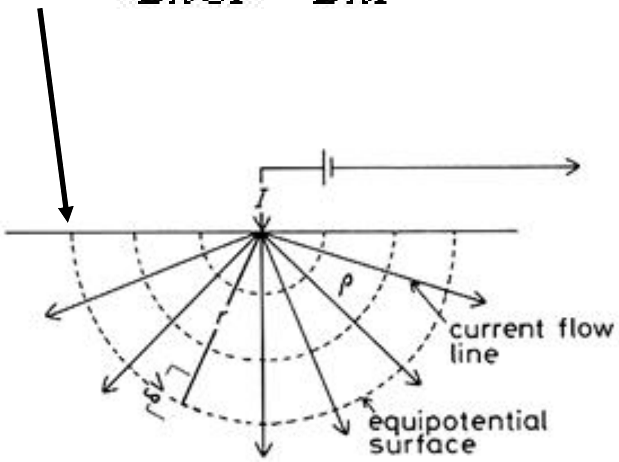


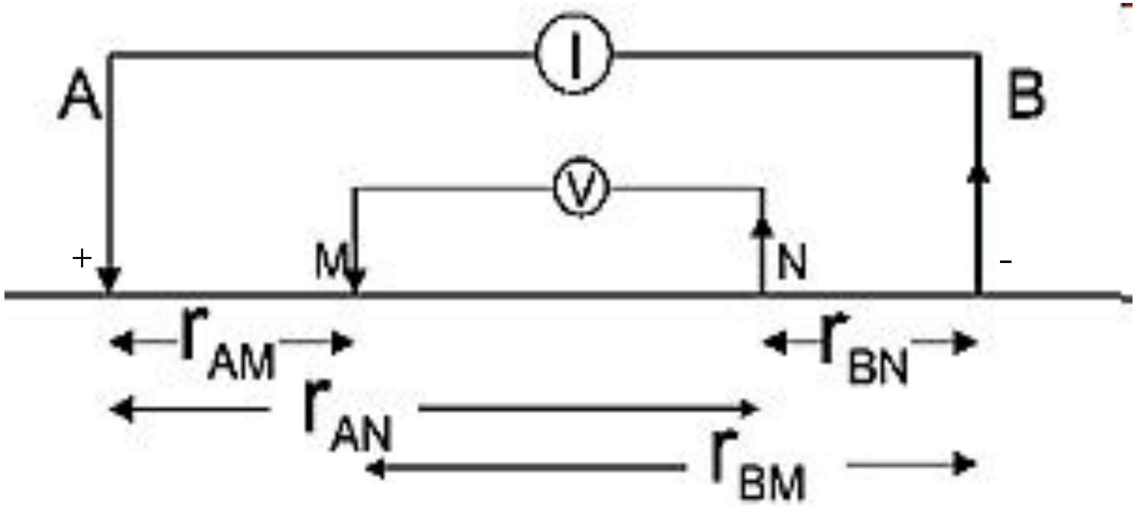
Resistivity survey in the field



Four-electrode Array

$$V(r) = \frac{I}{2\pi\sigma r} = \frac{I\rho}{2\pi r}$$



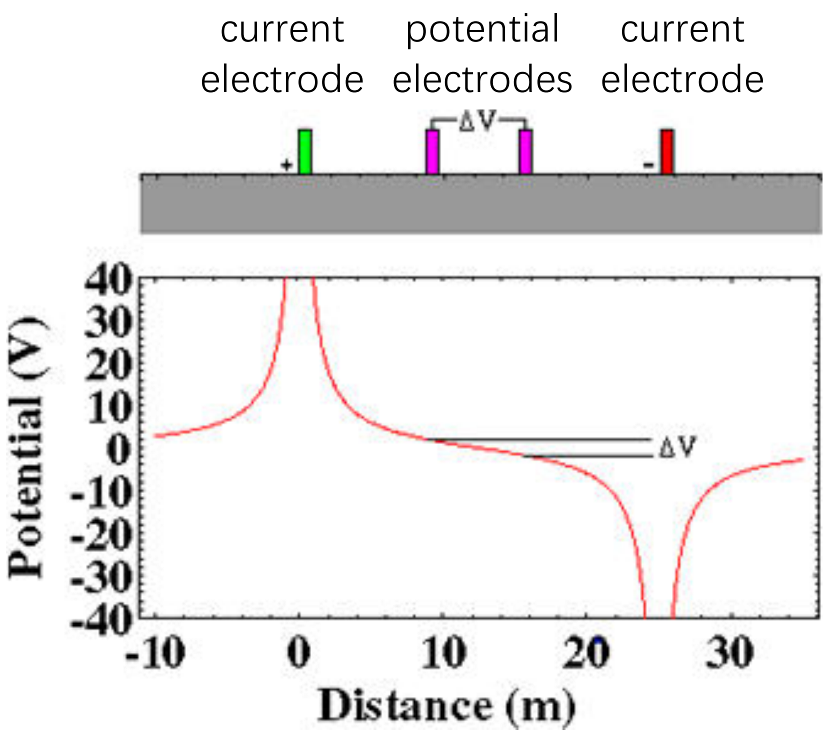


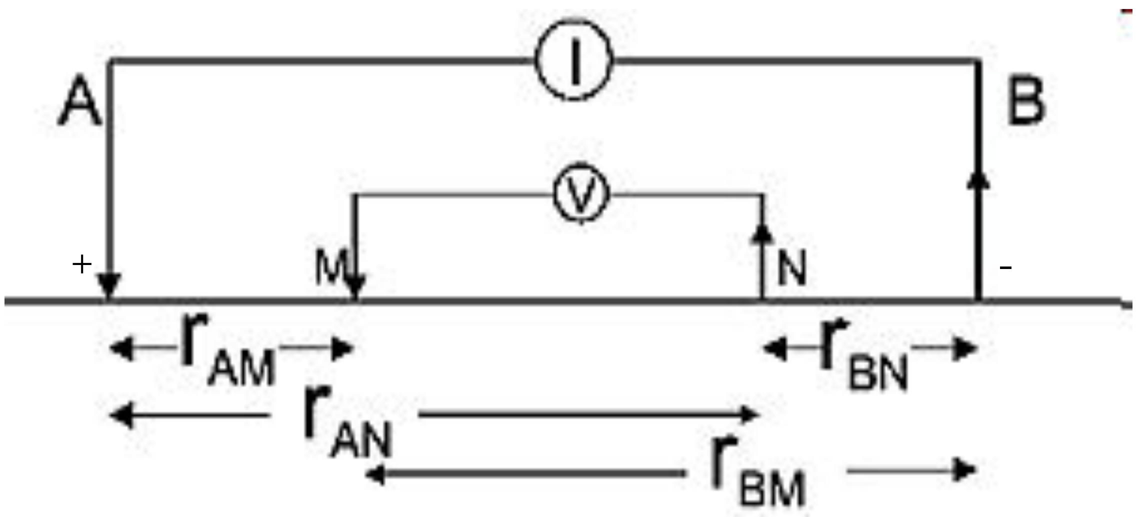
$$\Delta V = I\rho G = \frac{I\rho}{2\pi}\left\{\frac{1}{r_{AM}} - \frac{1}{r_{BM}} - \frac{1}{r_{AN}} + \frac{1}{r_{BN}}\right\}$$

$$\rho = \frac{\Delta V}{IG}$$

Calculated earth’ s resistivity

Four-electrode Array





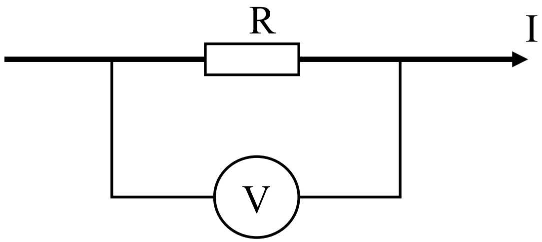
$$\Delta V = I\rho G = \frac{I\rho}{2\pi}\left\{\frac{1}{r_{AM}} - \frac{1}{r_{BM}} - \frac{1}{r_{AN}} + \frac{1}{r_{BN}}\right\}$$

$$\rho = \frac{\Delta V}{IG}$$

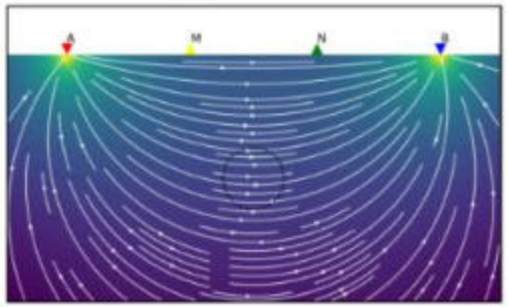
Calculated earth’ s resistivity

Inhomogeneous Earth

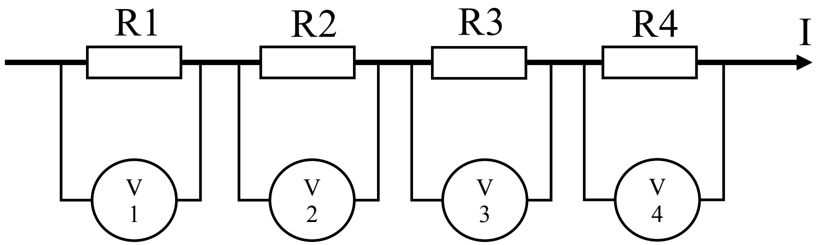
Uniform sample



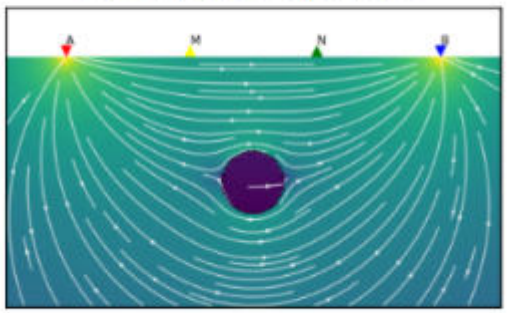
Homogenous earth



Non-uniform sample



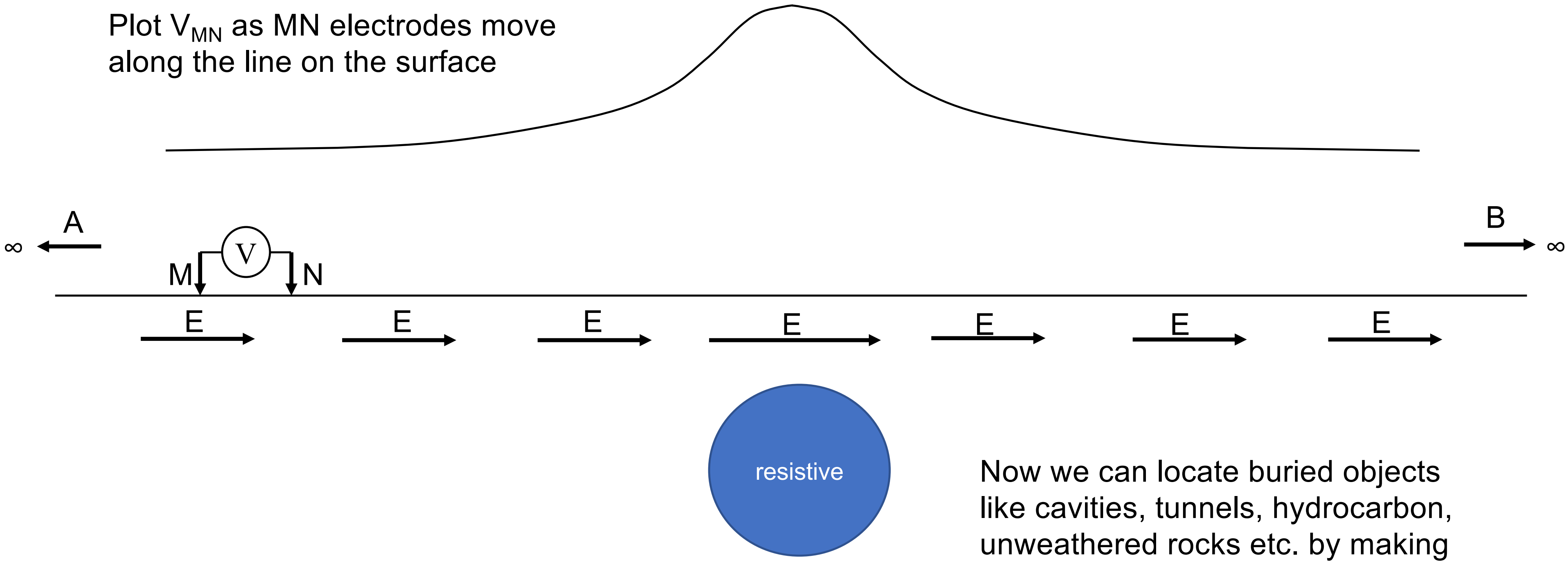
Resistive sphere



How would V_{MN} change if a resistor exists?

Finding a Sphere

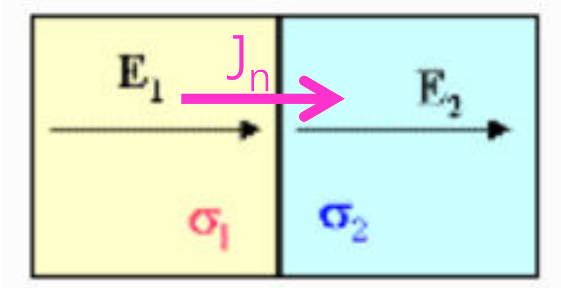
Plot V_{MN} as MN electrodes move along the line on the surface

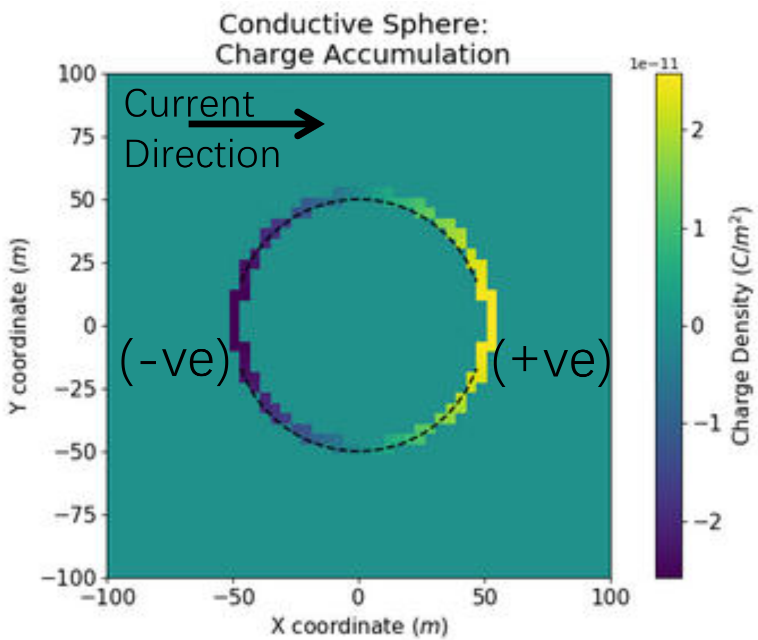


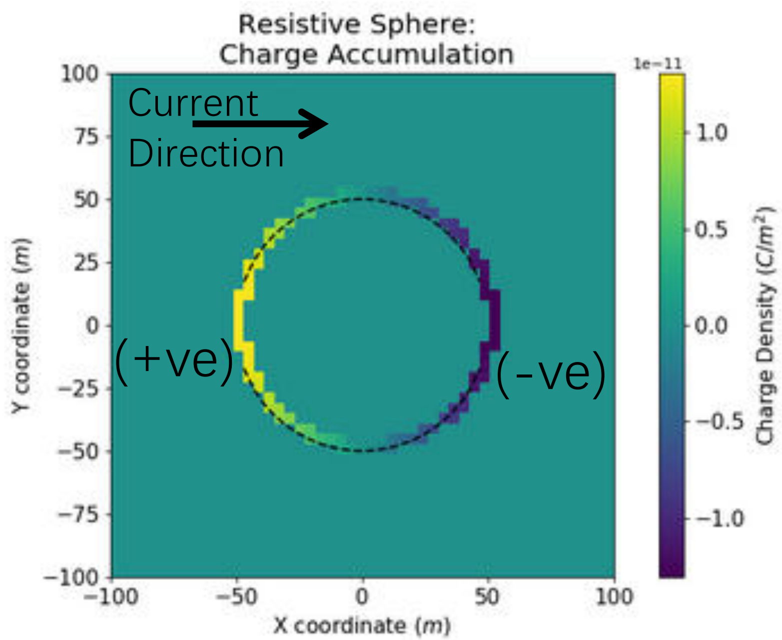
Now we can locate buried objects like cavities, tunnels, hydrocarbon, unweathered rocks etc. by making measurements on the surface!

In Terms of Charges

- Charges build-up on boundaries
  From resistor into conductor → negative charges build-up
  From conductor into a resistor → positive charges build-up

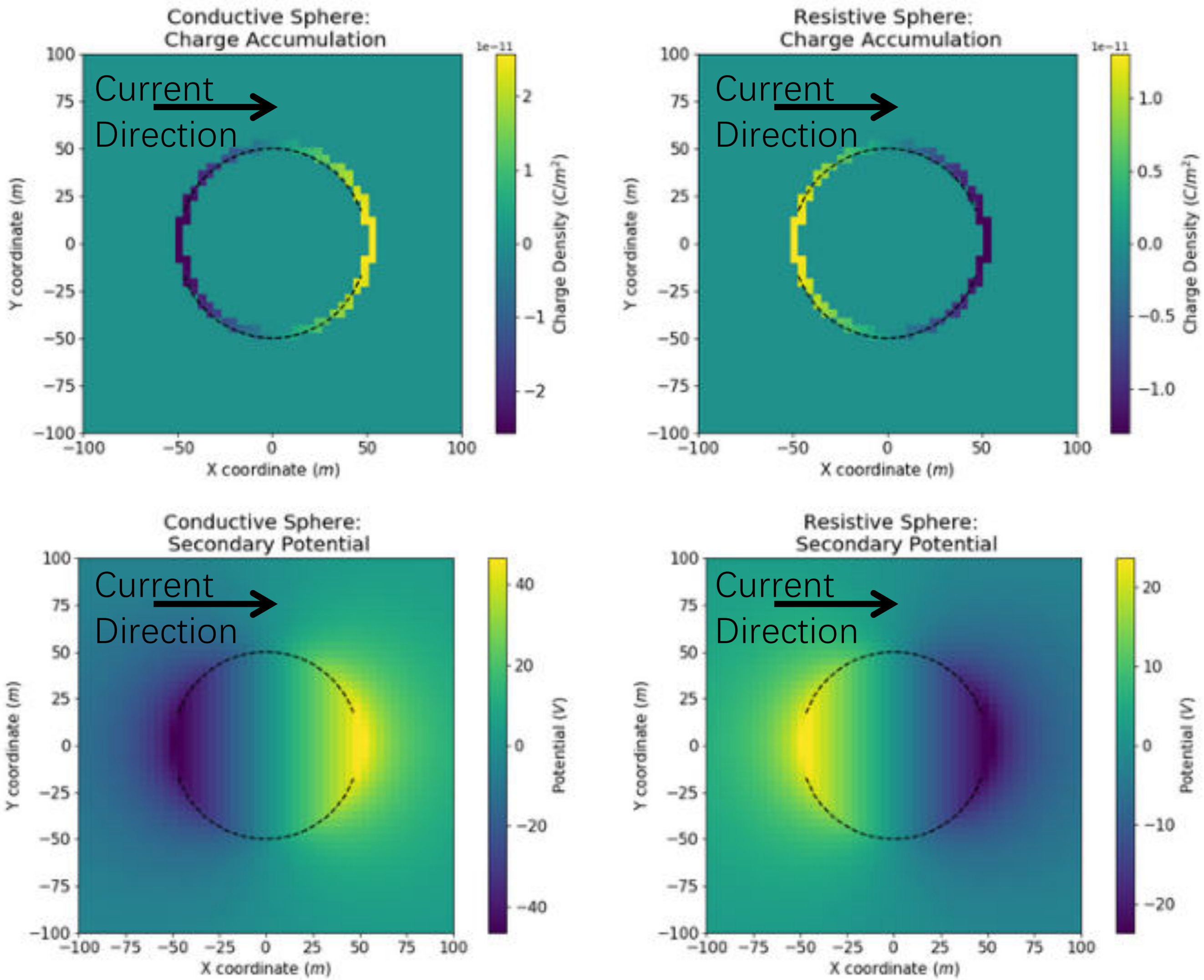




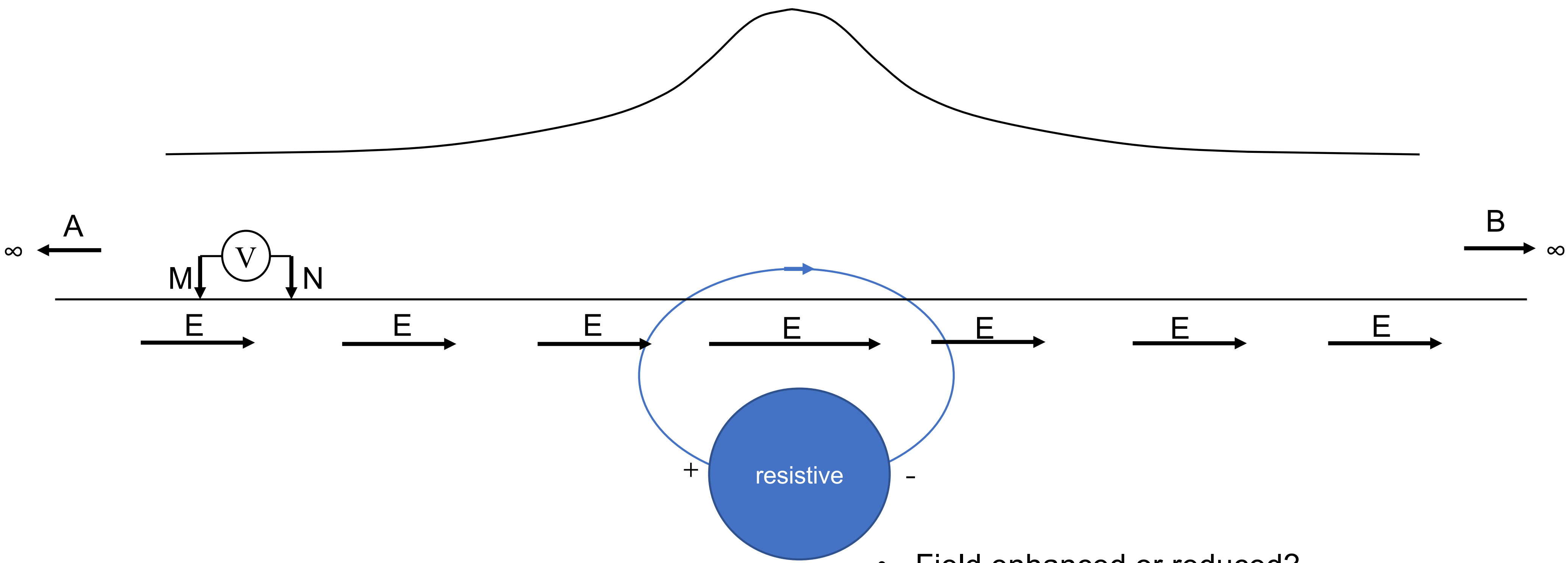


- Charges

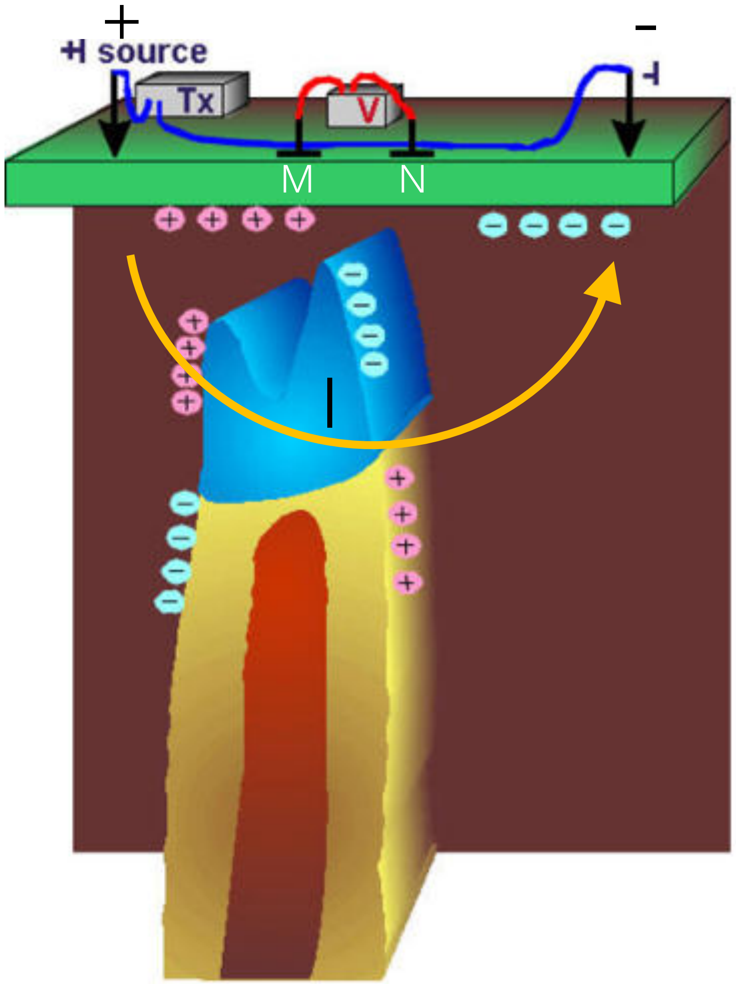
- Secondary Potential



Finding a Sphere



- Field enhanced or reduced?
- Electrodes see more positive or negative charge?

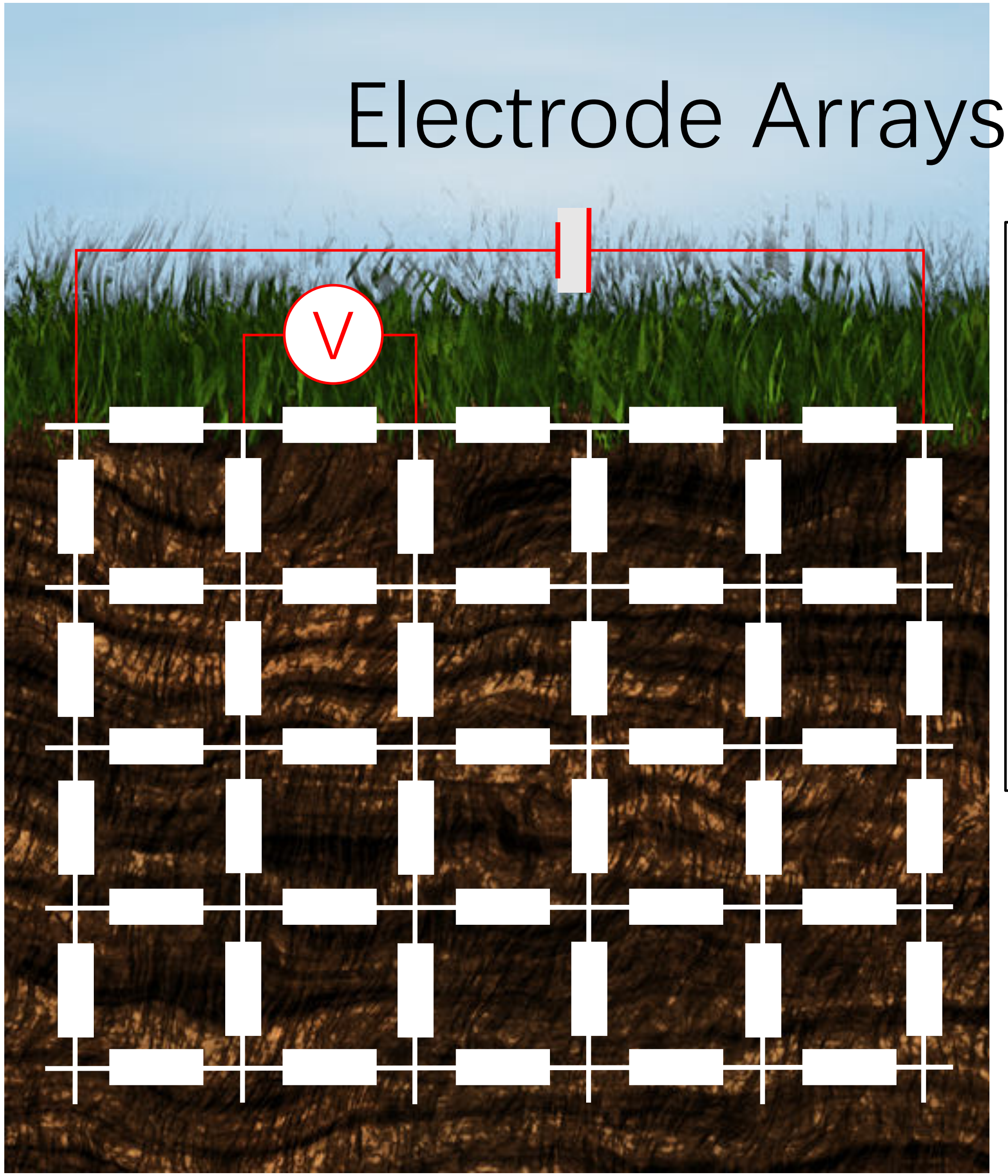


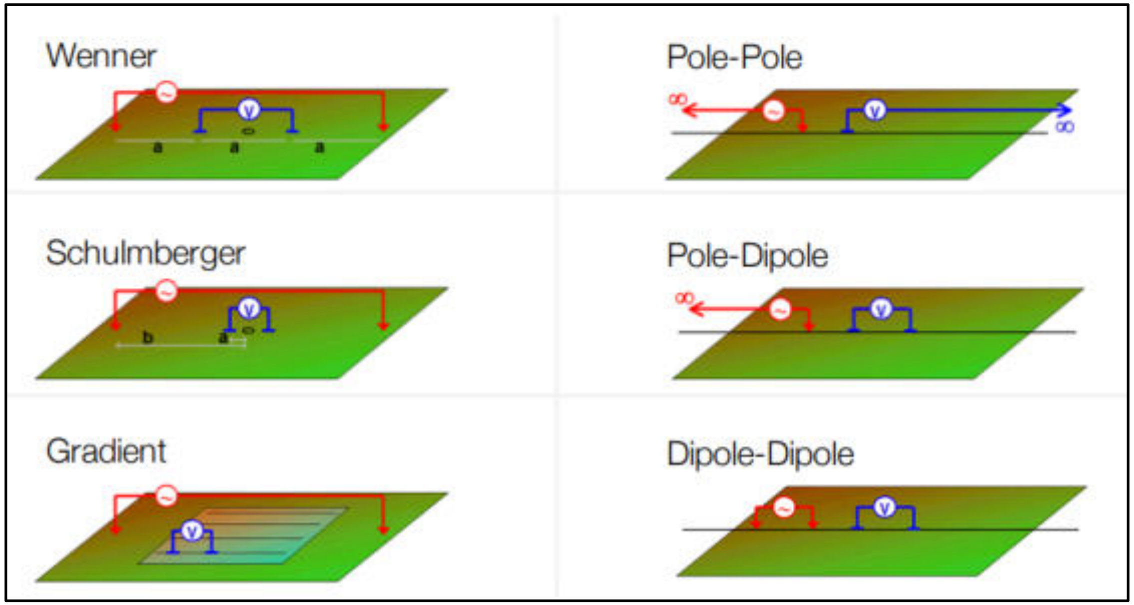
Physical Properties

Rock type	Ohm-m
Overburden	**12**
Host rock	**200**
Gossan	**420**
Mineralization (pyritic)	**0.6**
Mineralization (pyrrhotite)	**0.6**

- Is the anomalous potential positive or negative at location N?

Electrode Arrays: A Circuit Perspective

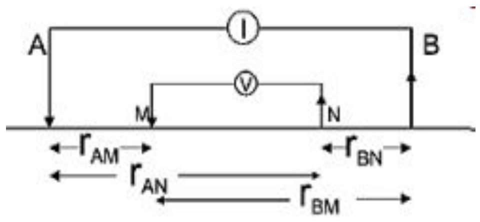




How to gain:

- Lateral resolution - Profiling
- Depth (vertical) resolution - Sounding

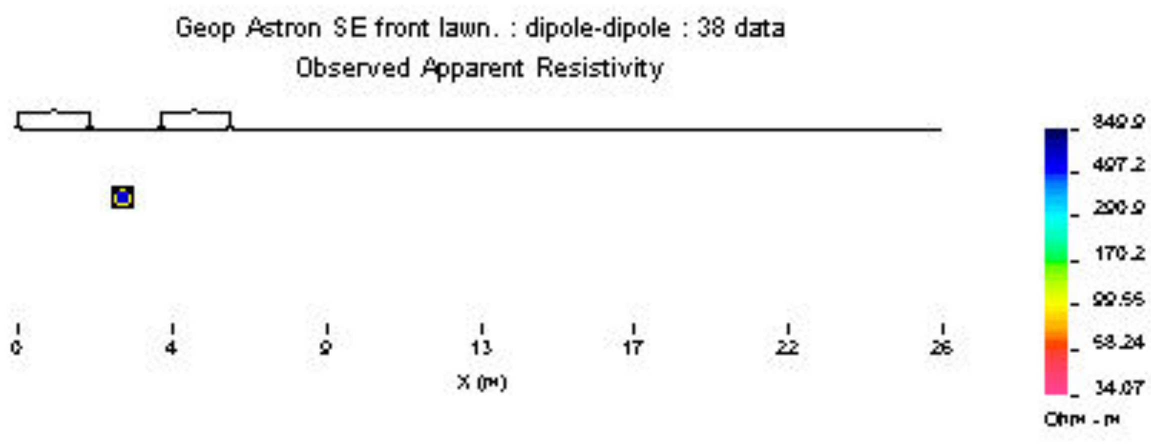
Apparent Resistivity on Pseudo-section



$$\Delta V = I\rho G = \frac{I\rho}{2\pi}\left\{\frac{1}{r_{AM}} - \frac{1}{r_{BM}} - \frac{1}{r_{AN}} + \frac{1}{r_{BN}}\right\}$$

$$\rho = \frac{\Delta V}{IG}$$

True resistivity or apparent resistivity



Useful in revealing lateral and vertical variation in resistivity

Transform of data – Unit in Ωm but still data!

jupyter DC_Building_Pseudosections Last Checkpoint: Last Monday at 12:00 AM (autosaved)

Logout

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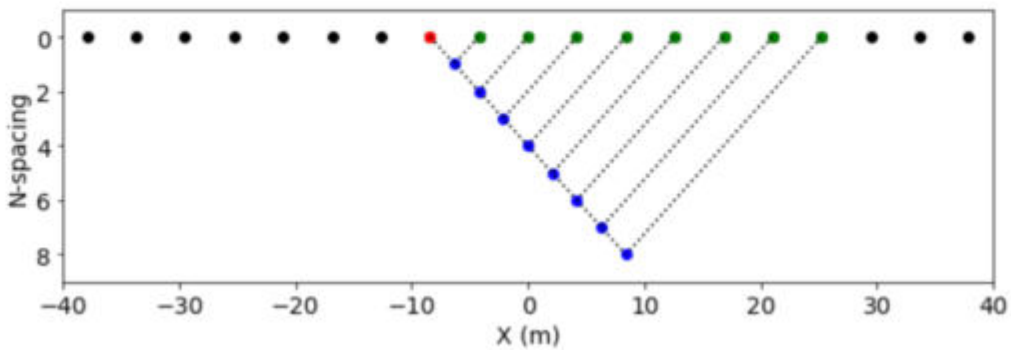
Trusted | Python 3

Run Code

In [5]:
```
out = MidpointPseudoSectionWidget()
display(out)
```

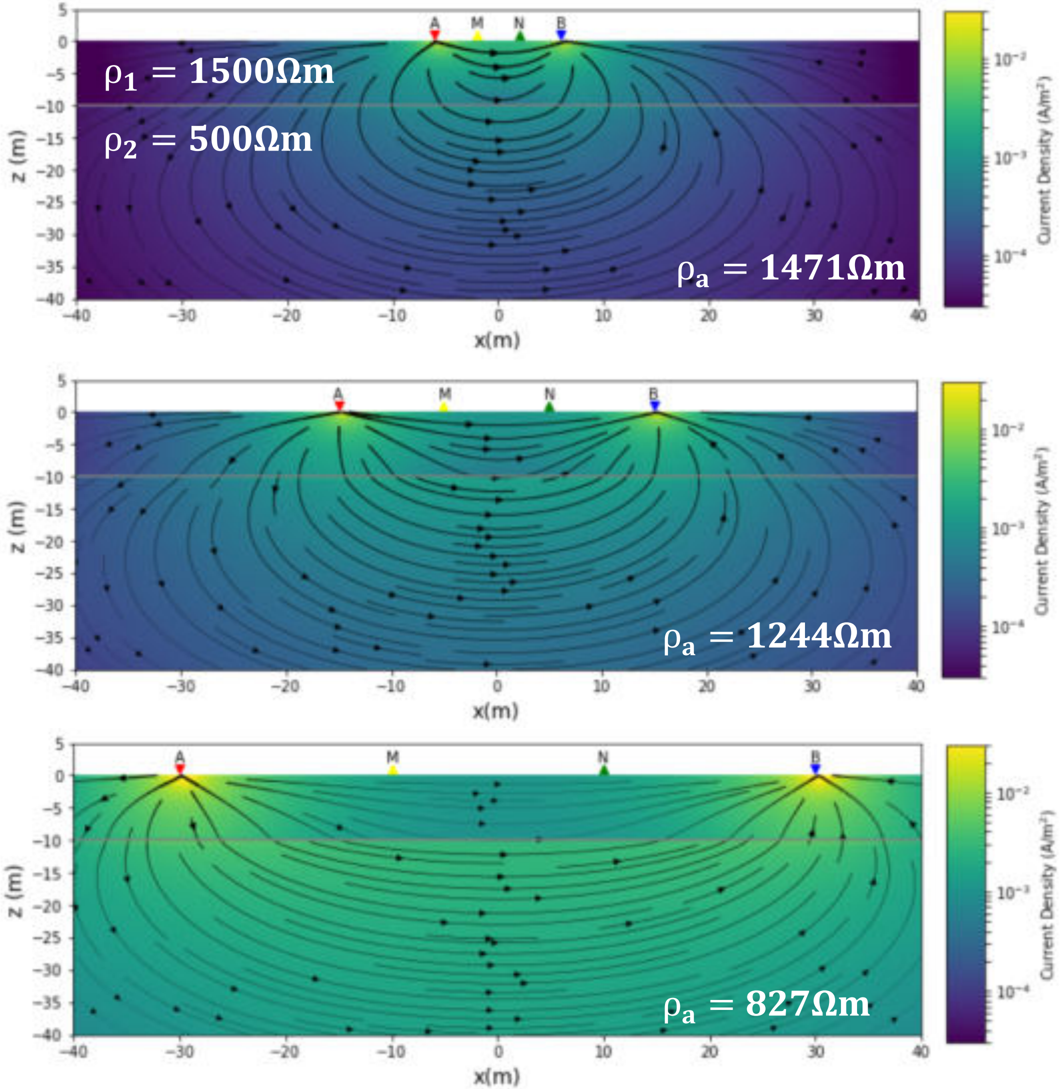
i 7



- ρ_1 : Resistivity of the halfspace
- ρ_2 : Resistivity of the cylinder
- **xc**: x location of cylinder center
- **zc**: z location of cylinder center
- **r**: radius of cylinder
- **surveyType**: Type of survey
- **Run Interact**: Use this button to update your plot

Note: The numerical results shown in this plot are generated from a 2d code such that the source is a line of current. This greatly speeds up the computation. Accurate potentials obtained from point current sources require the 2.5D code.

In [6]:
```
out = DC2DPseudoWidget()
display(out)
```

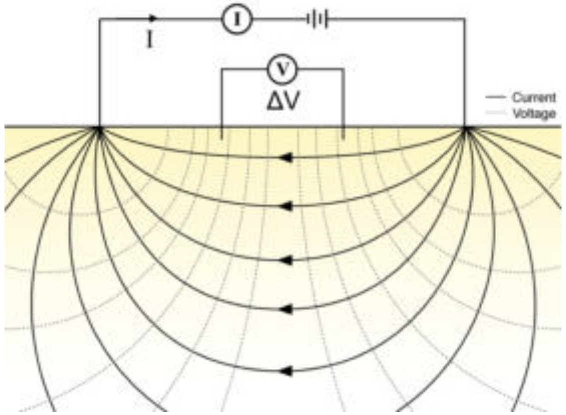


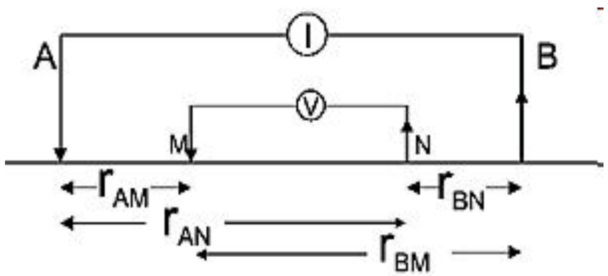
- Most currents near electrodes
- Only sees top layer

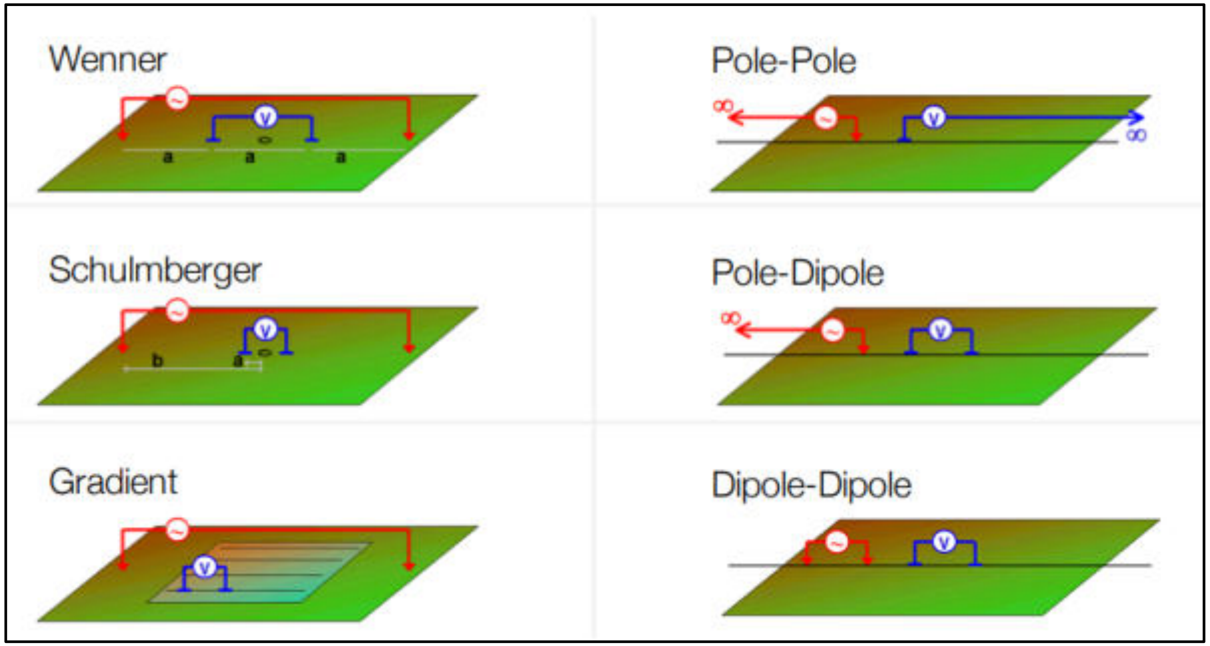
- Currents in lower layer
- Lower apparent resistivity

- Apparent resistivity sensitive to lower layer

Typical Electrical Surveys along Lines





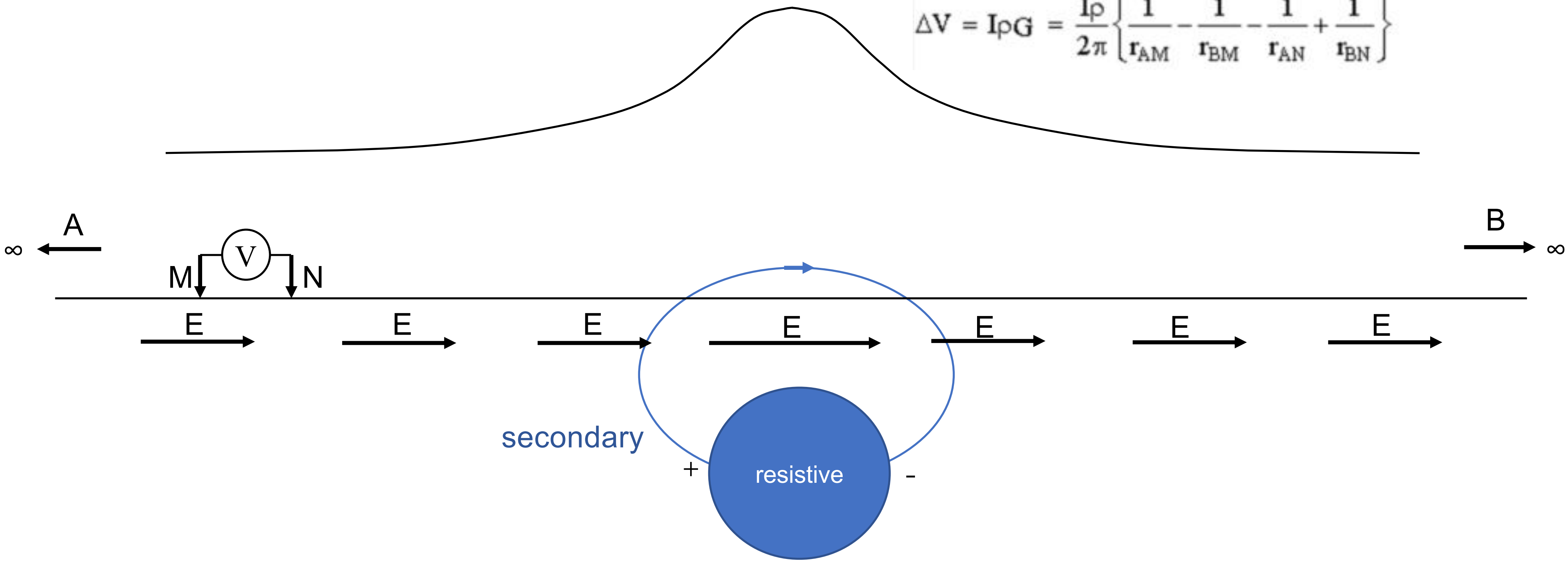


$$\Delta V = I\rho G = \frac{I\rho}{2\pi}\left\{\frac{1}{r_{AM}}-\frac{1}{r_{BM}}-\frac{1}{r_{AN}}+\frac{1}{r_{BN}}\right\}$$

$$\rho = \frac{\Delta V}{IG}$$

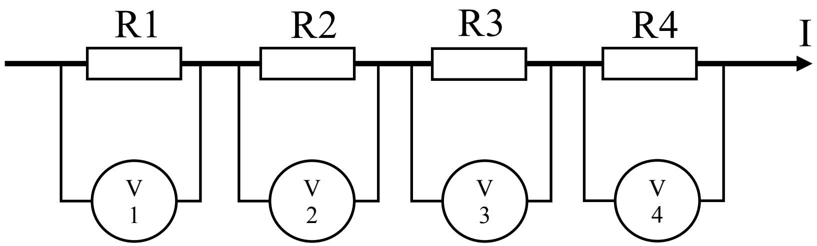
Physical Intuition of Electrical Anomaly (1)

$$\Delta V = I\rho G = \frac{I\rho}{2\pi}\left\{\frac{1}{r_{AM}} - \frac{1}{r_{BM}} - \frac{1}{r_{AN}} + \frac{1}{r_{BN}}\right\}$$

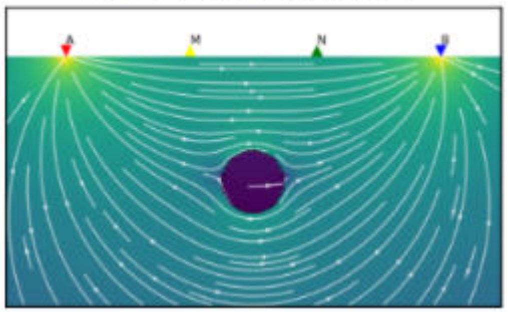


Physical Intuition of Electrical Anomaly (2)

Non-uniform sample

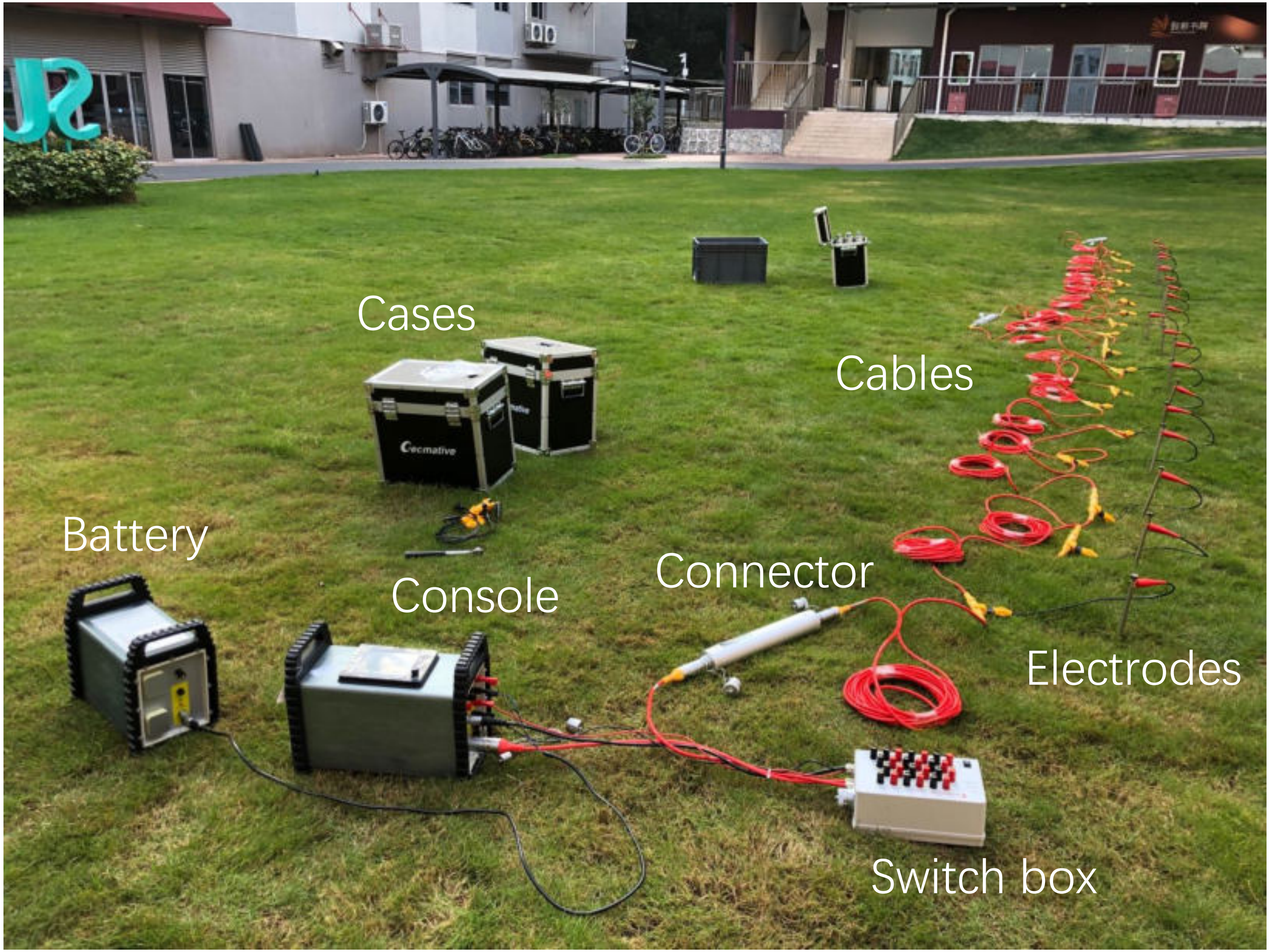


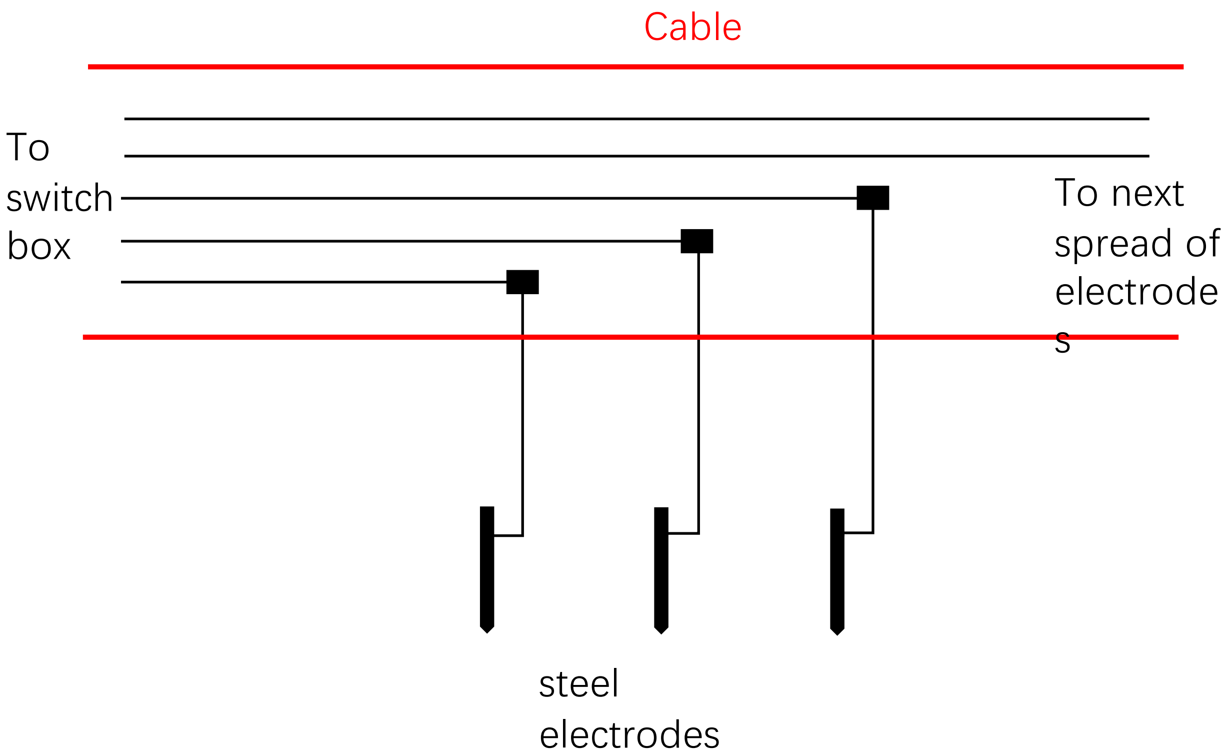
Resistive sphere



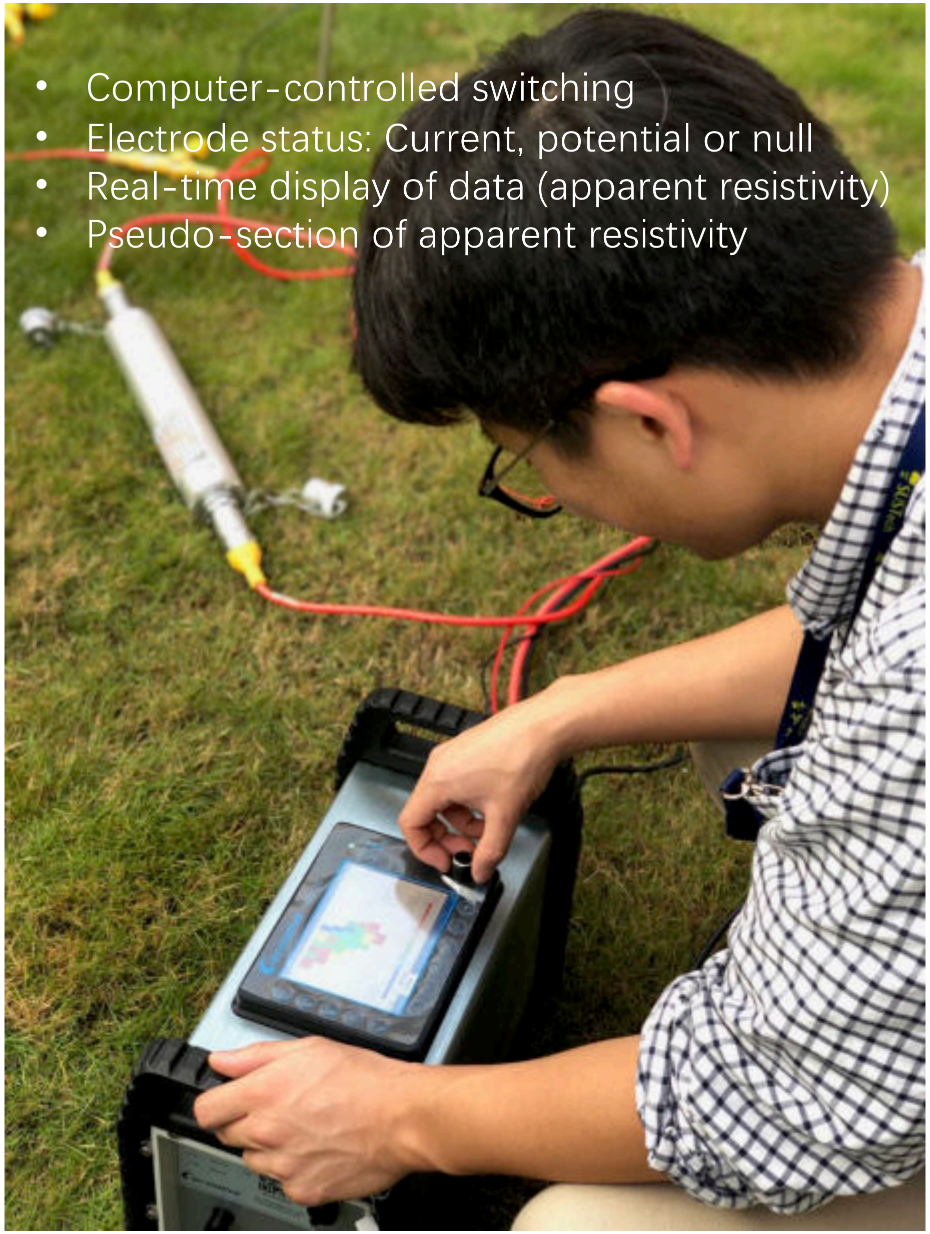
$$\Delta V = I\rho G = \frac{I\rho}{2\pi}\left\{\frac{1}{r_{AM}} - \frac{1}{r_{BM}} - \frac{1}{r_{AN}} + \frac{1}{r_{BN}}\right\}$$

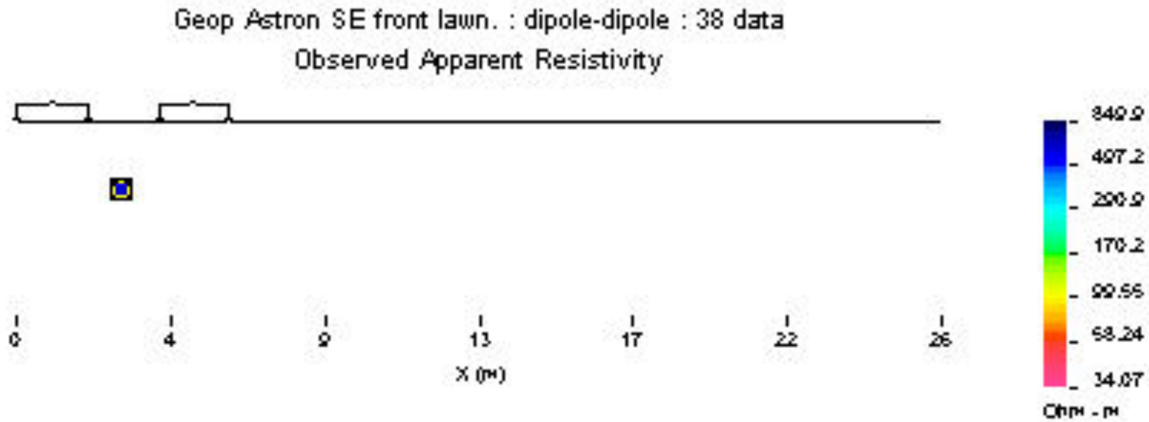
Instrument

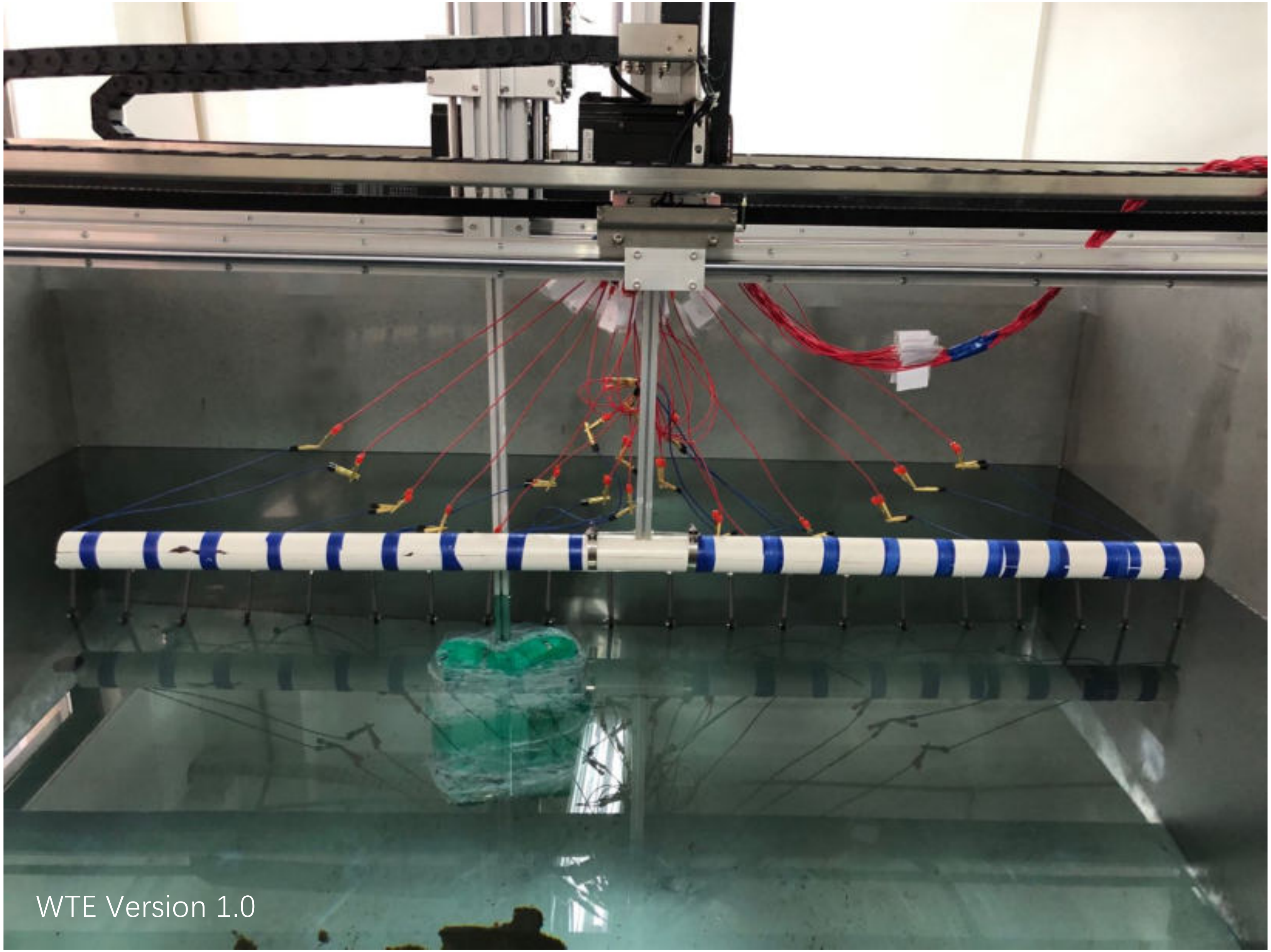

Cases
Cables
Battery
Console
Connector
Electrodes
Switch box


Cable
To
switch
box
To next
spread of
electrode
s
steel
electrodes

- Computer-controlled switching
- Electrode status: Current, potential or null
- Real-time display of data (apparent resistivity)
- Pseudo-section of apparent resistivity







Water Tank Experiment

- Known targets
- Validation of numerical solutions
- Optimization of arrays

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Logout

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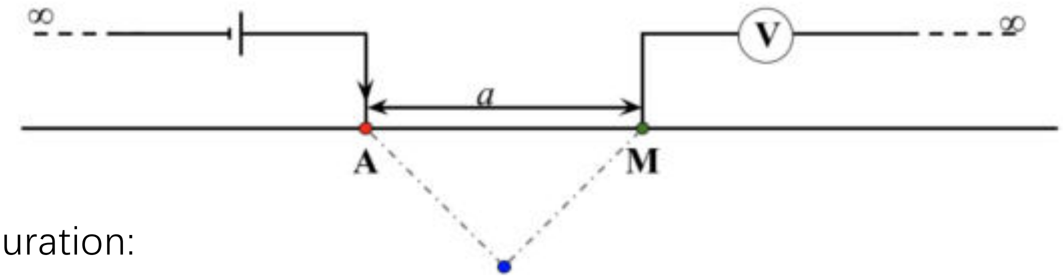
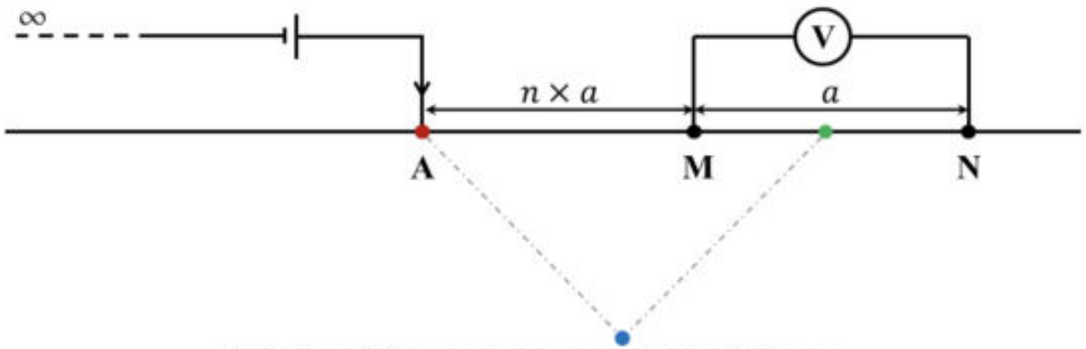
Run Code



Basic skematic for a uniformly spaced pole-pole array.

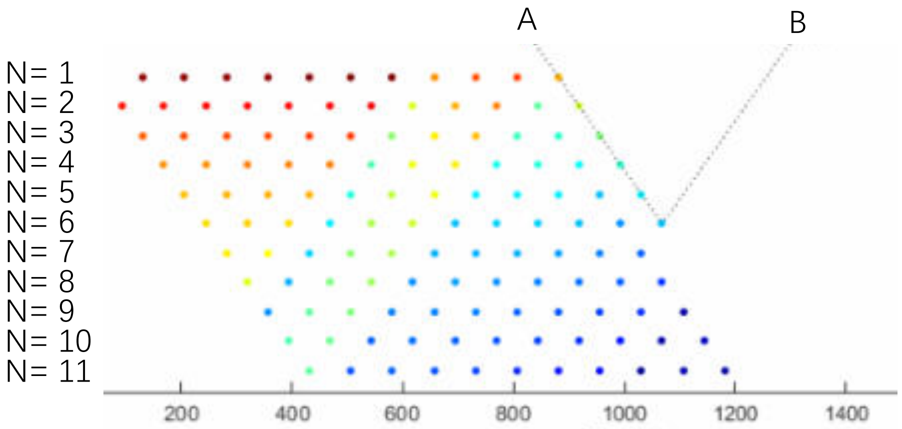
Pole or dipole array configuration:
a – basic spacing
n – multiplier



Basic skematic for a uniformly spaced pole-dipole array.

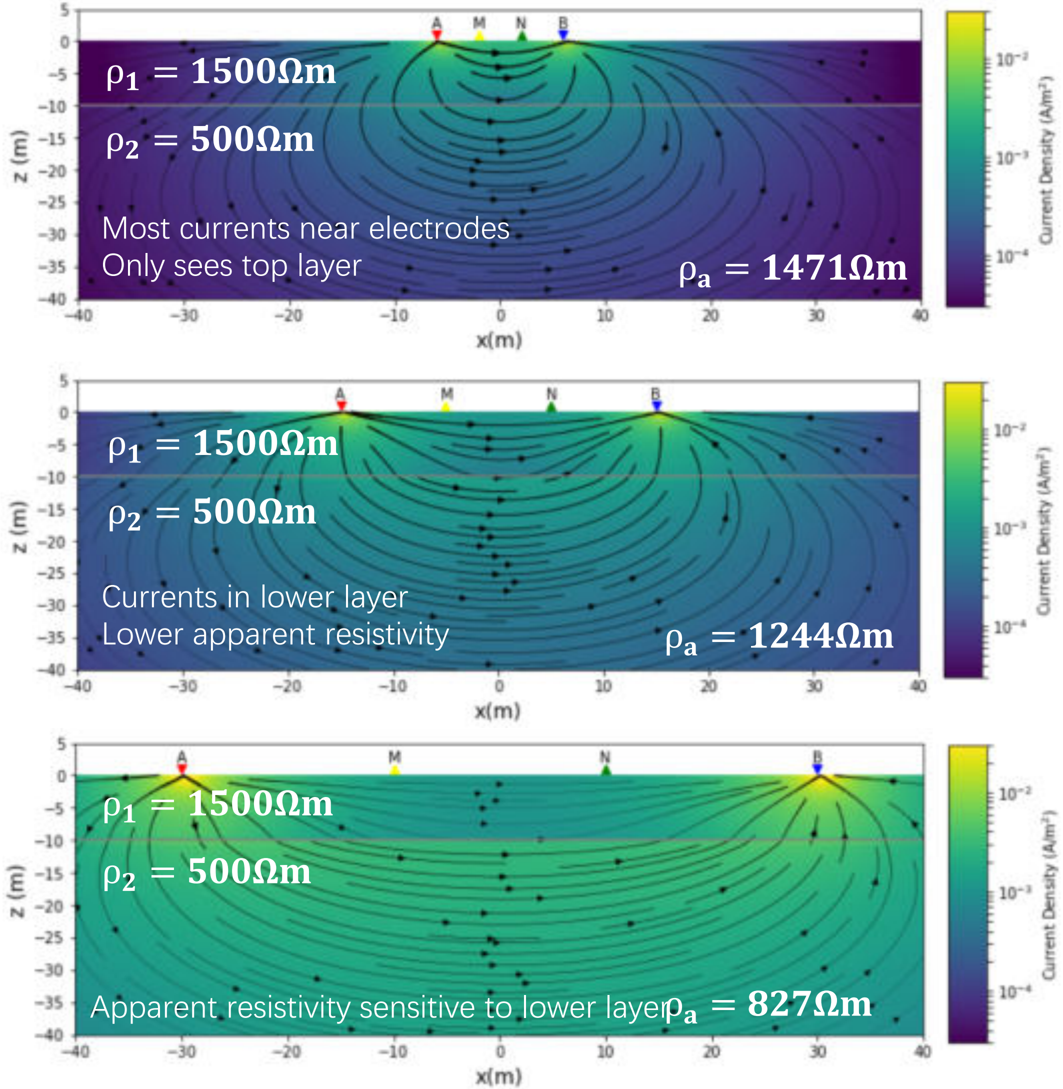
Geosci-labs/notebooks/dcip/DC_Building_Pseudosections.ipynb

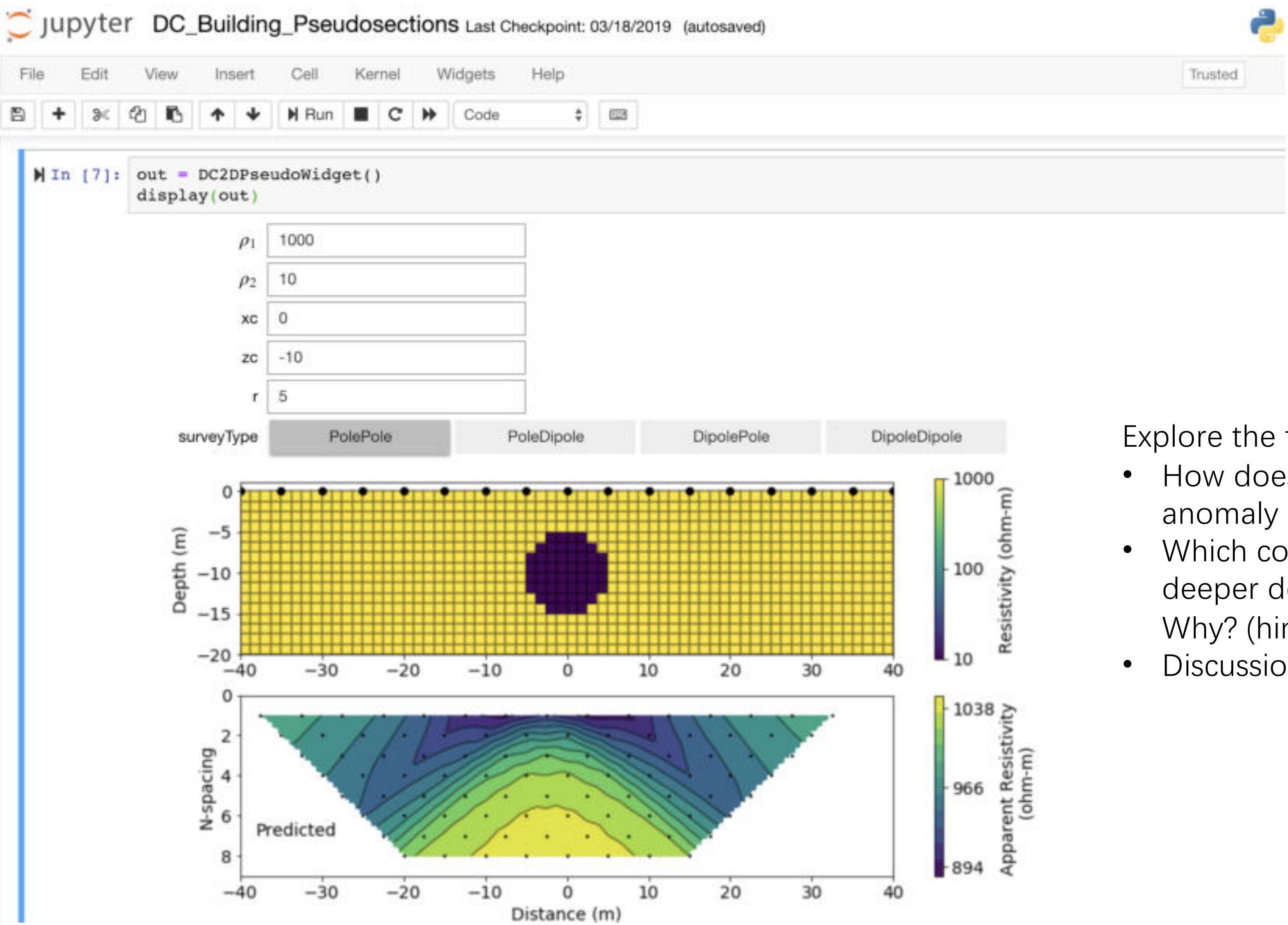
Spacing and Depth



Apparent resistivity is a weighted average of the earth’ s resistivity as a distributed parameter (volume effect)

- Shallow always has higher weight
- Small spacing enhances weights for shallow
- Large spacing enhances weights for deep

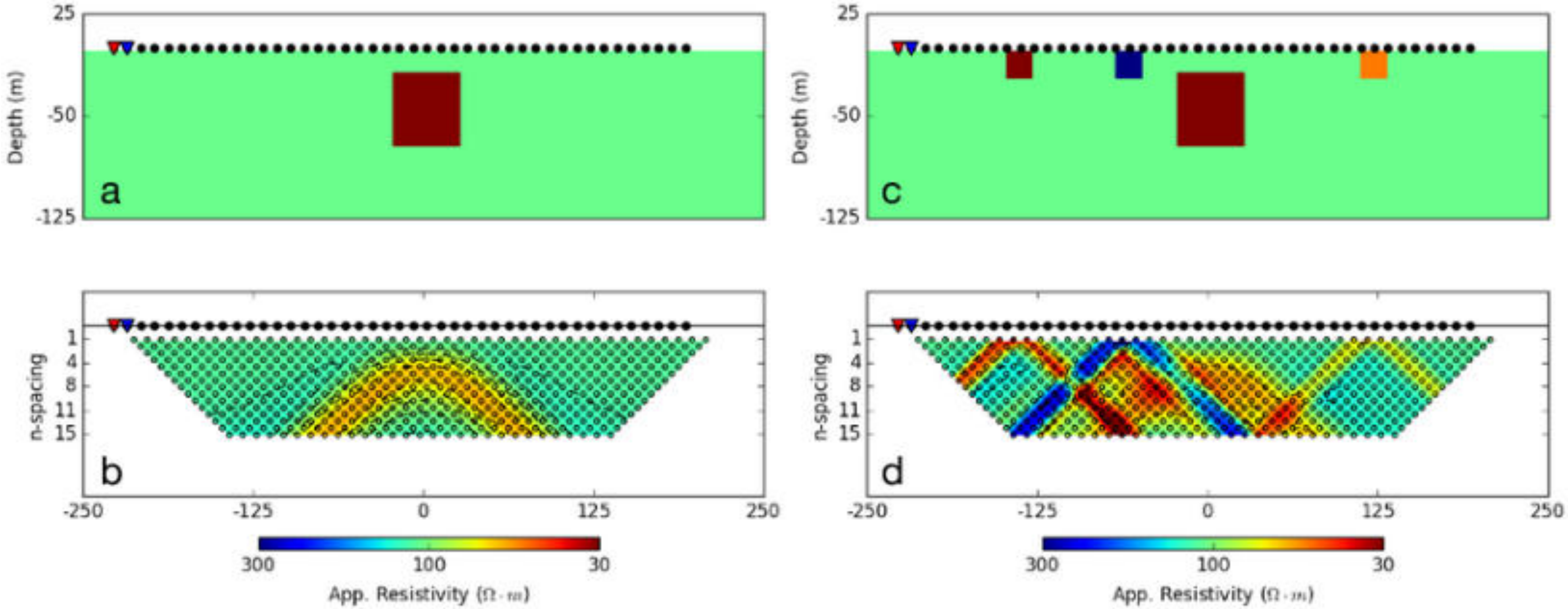




Explore the following:

- How does a sphere manifest its anomaly on a pseudo-section?
- Which configuration has deeper depth of penetration? Why? (hint: adjust zc)
- Discussion: Use dipole or pole?

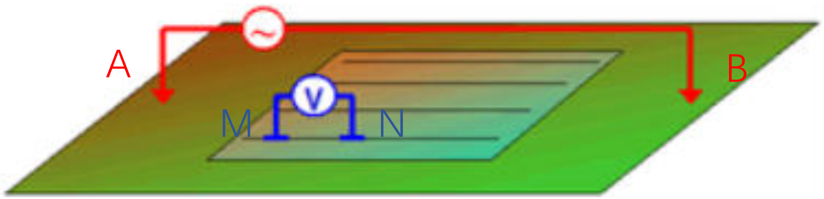
Anomaly of Compact Targets

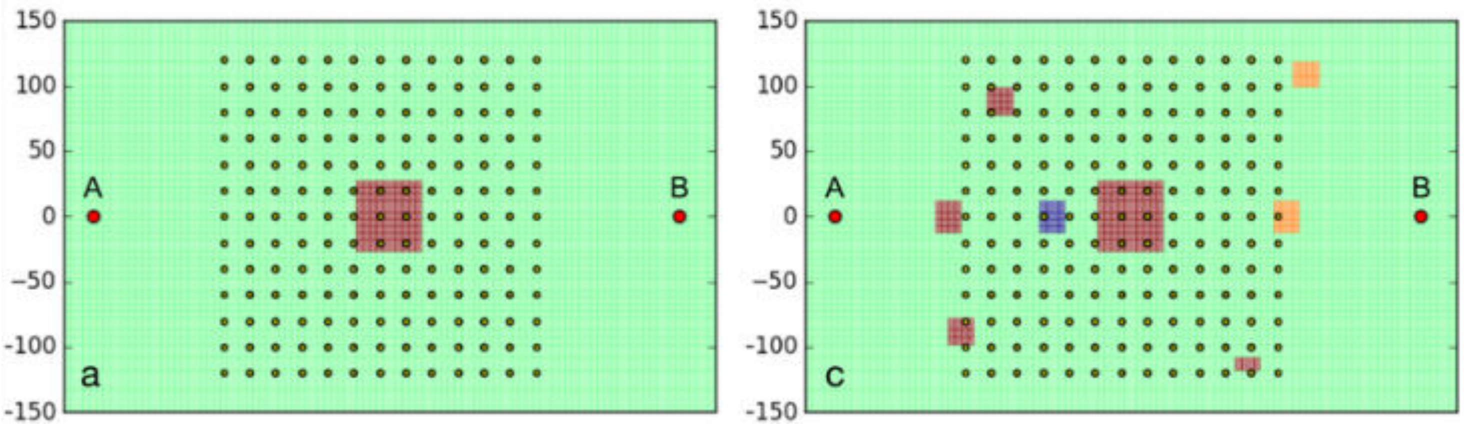


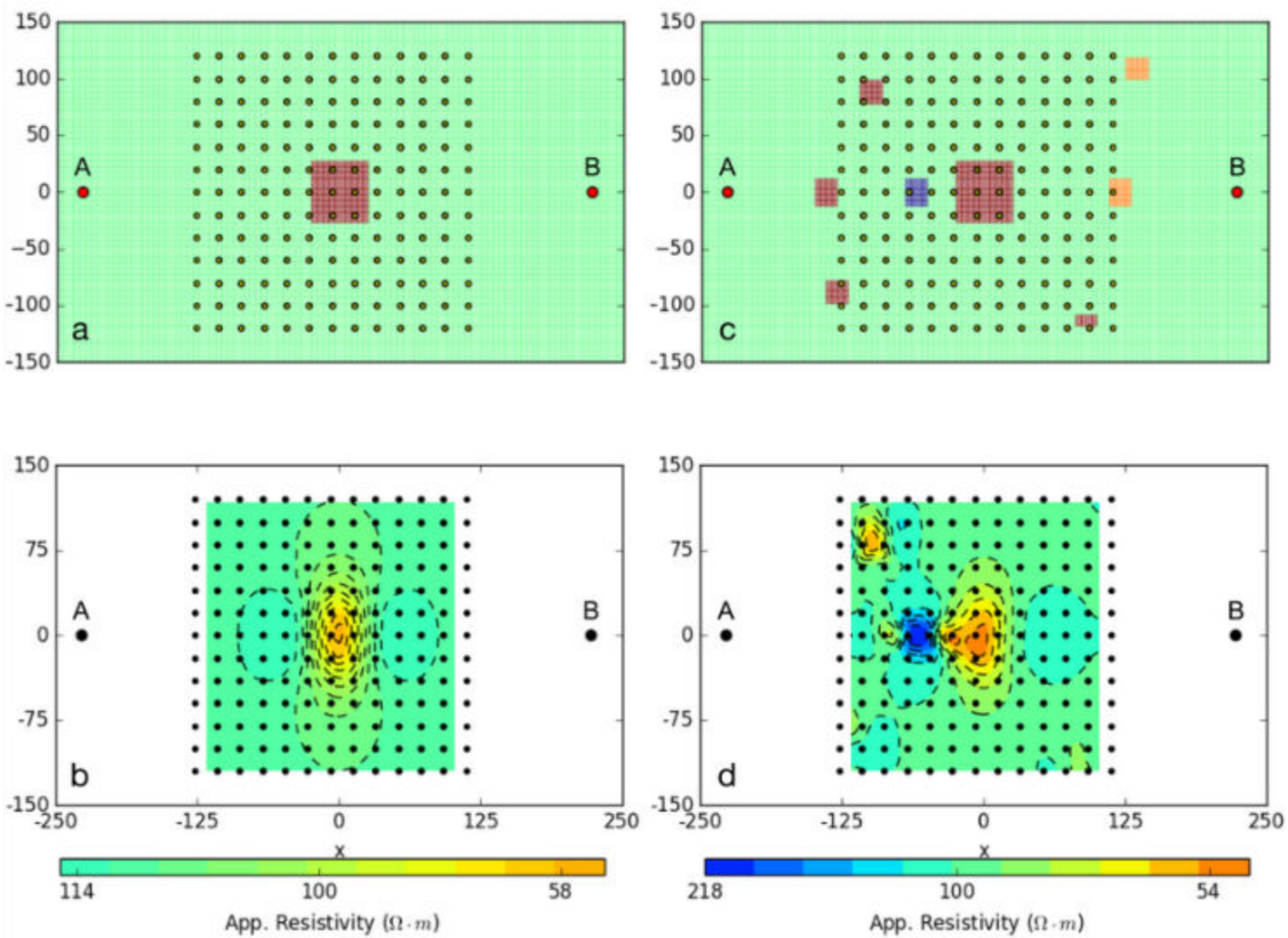
- Compact bodies: arc signature
- Depth of arc signature: depth of target
- Thickness of arc: size of target
- One block (left): easy to interpret
- Shallow blocks (right): geologic noises mask large buried conductor; hard to interpret

Gradient Array (A and B at infinity)

- Detects lateral variations in resistivity
- Fixed A and B: rapid acquisition of large areas
- Potential field problem



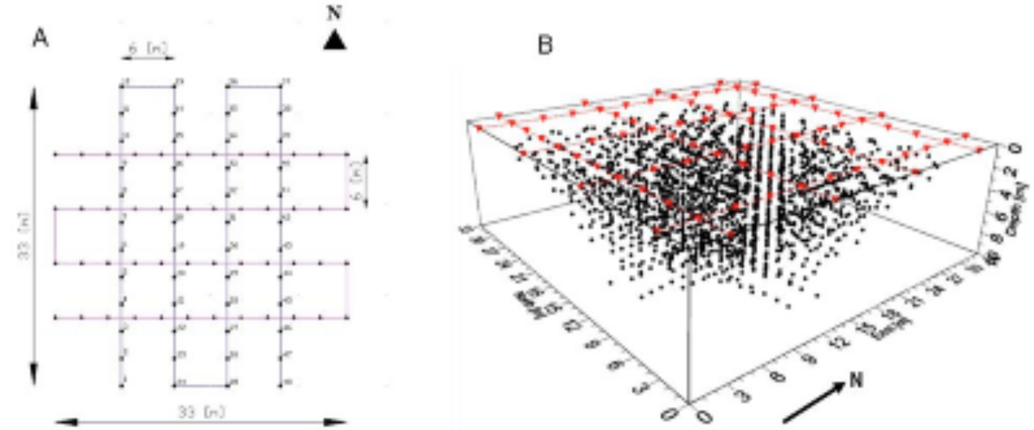


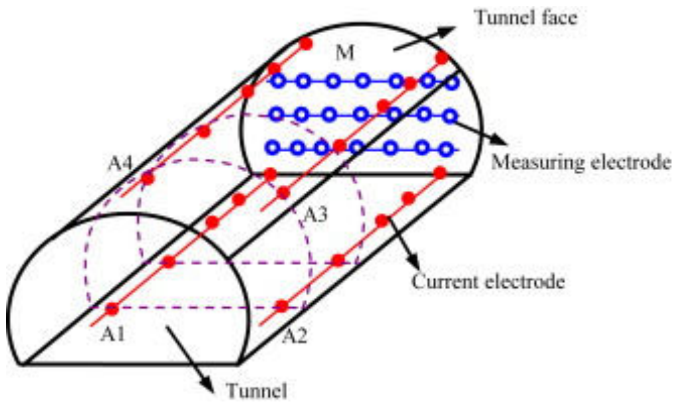


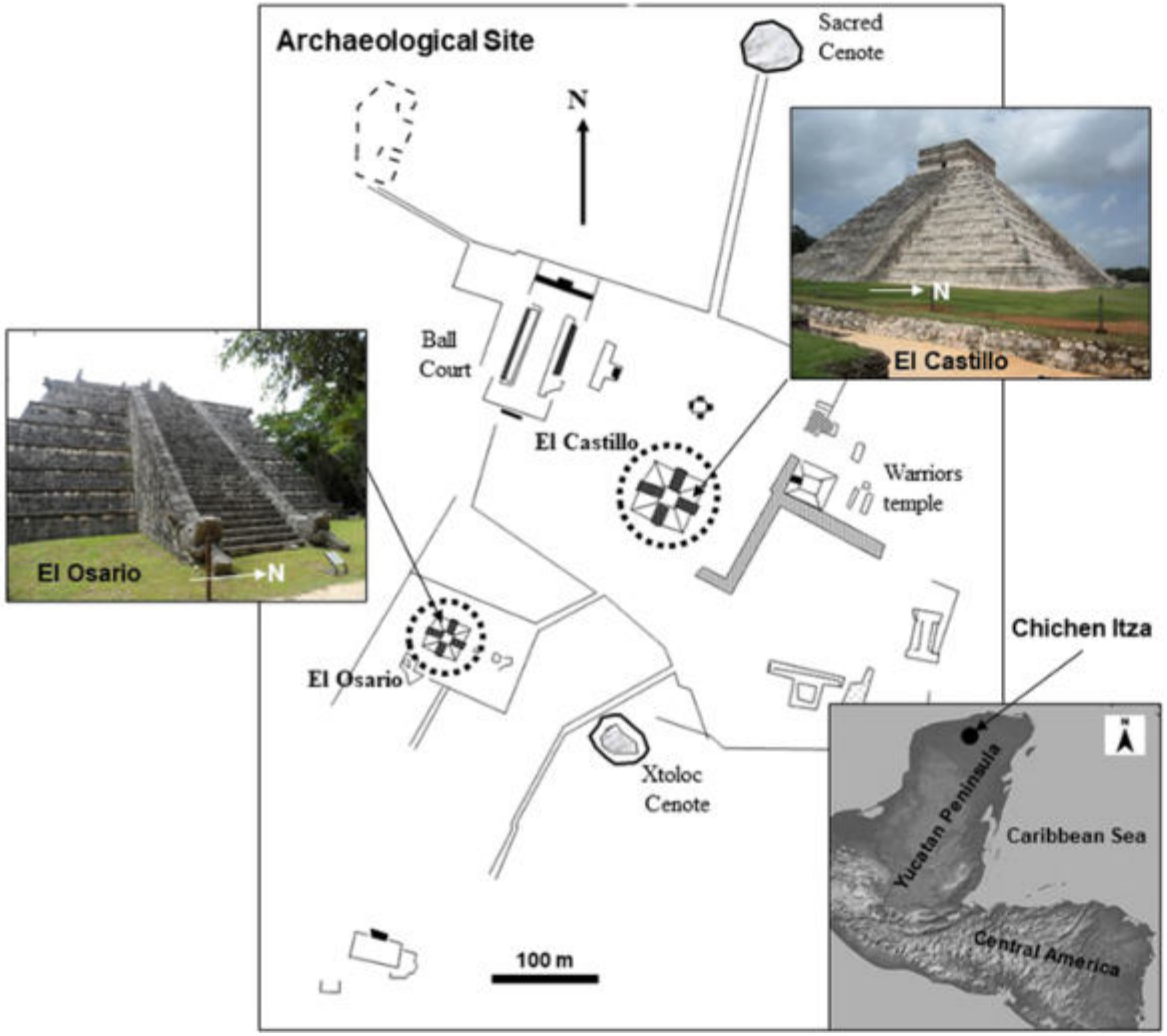
Recall induced magnetic anomaly at equator and discuss:

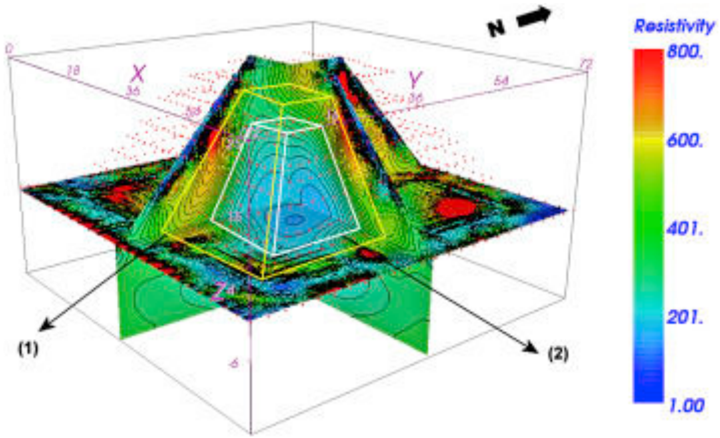
- Data are the most sensitive to the edges in ____ direction.
- The anomaly from a single block has the pattern of ___ anomaly.

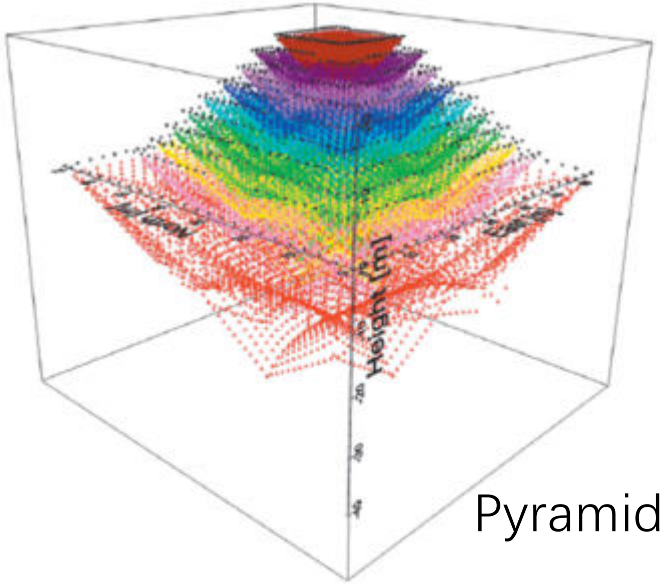
Non-2D Arrays







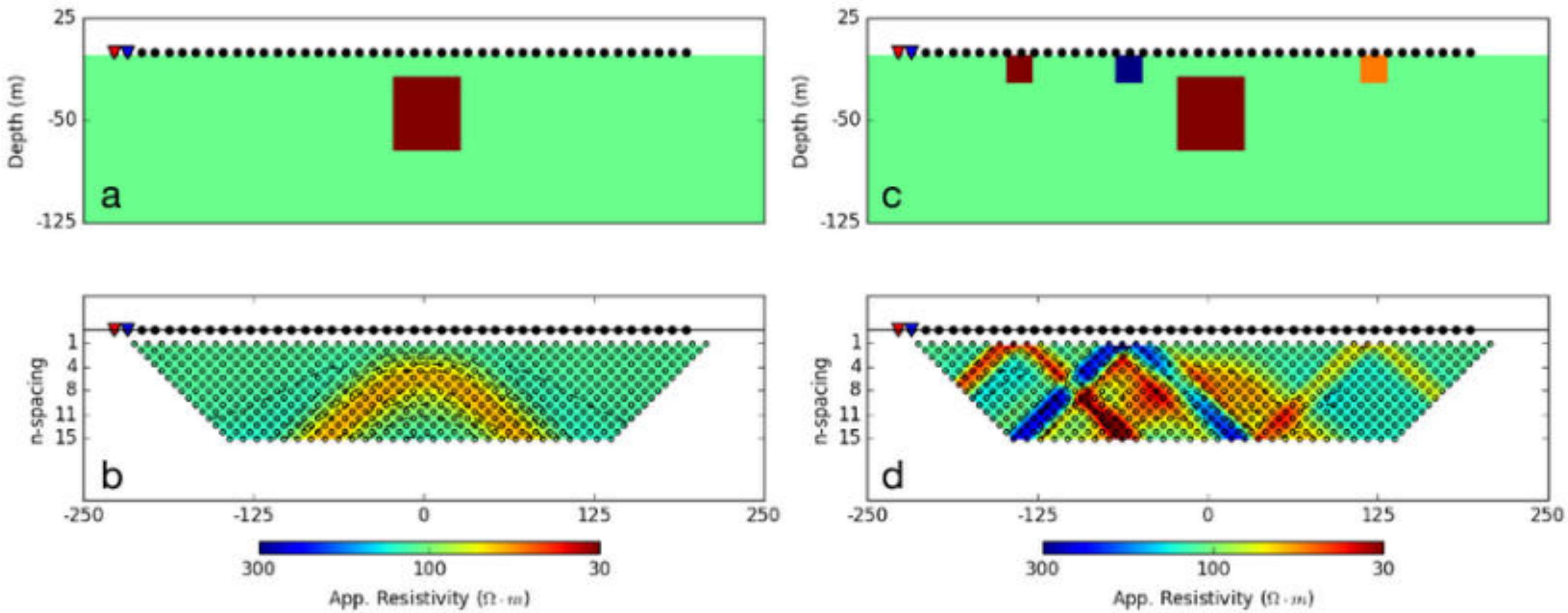




Pyramid array

Rethink Pseudo-sections

- Advantage: Why use apparent resistivity instead of raw voltage?
- Disadvantage: Can horizontal/vertical position of buried conductors/resistors be inferred directly from pseudo-section?

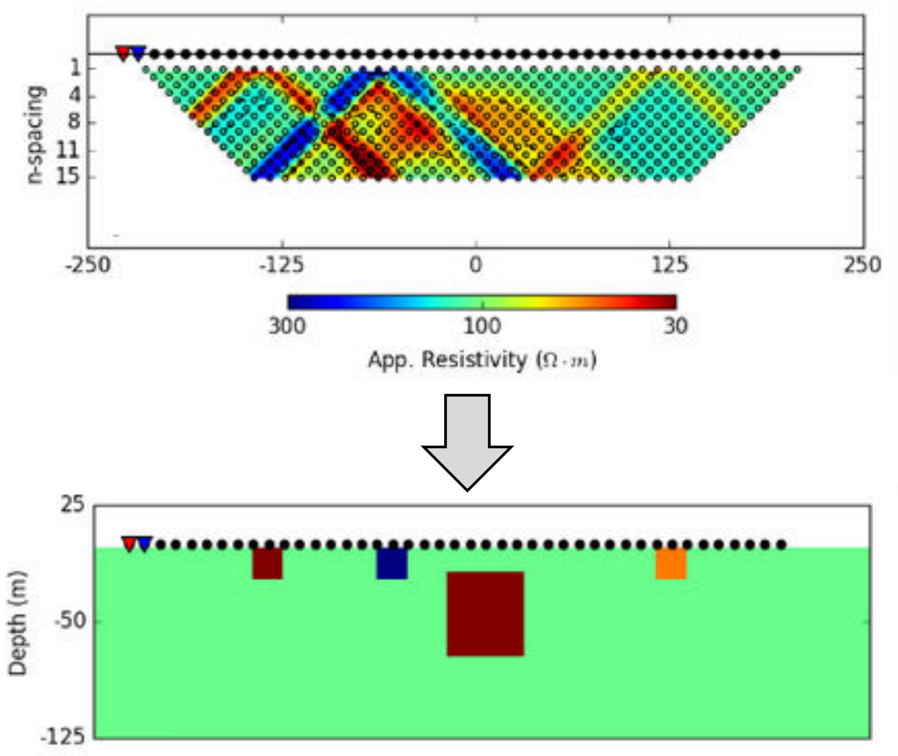


Quantitative Interpretation – Inversion

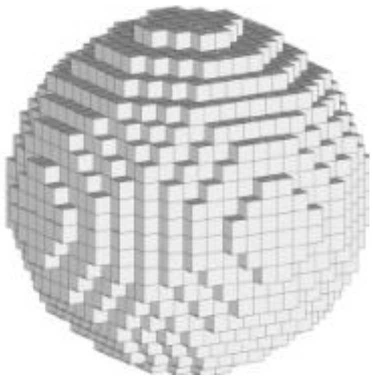
Goal of **Inversion**:

Find a resistivity (conductivity) model which:

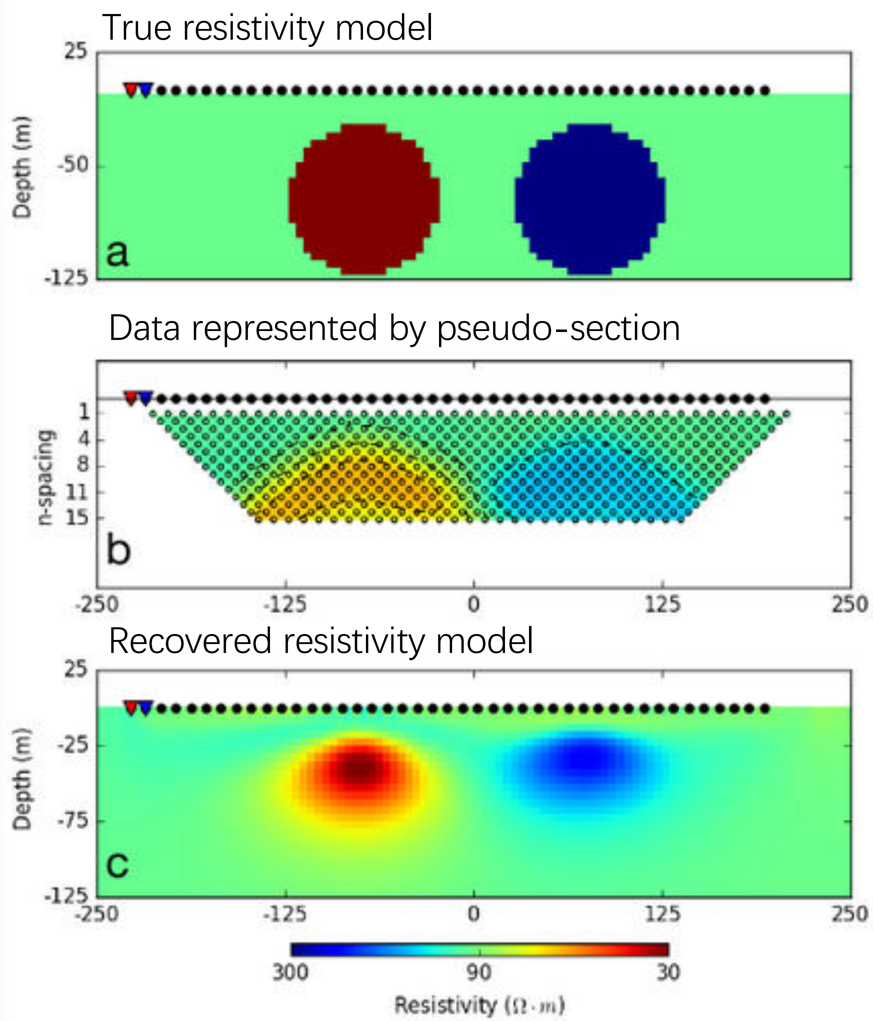
- Explains all the data
- Is representative of the true geology



Pixel/Voxel Inversion



- The earth consists of many small uniform elements
- Resistivity in cells allowed to vary
- Versatile but high ambiguity (volume effect)
  - Does not recover the true model
  - Recovers a geologically approximate model
  - Recovers structures represented in the data

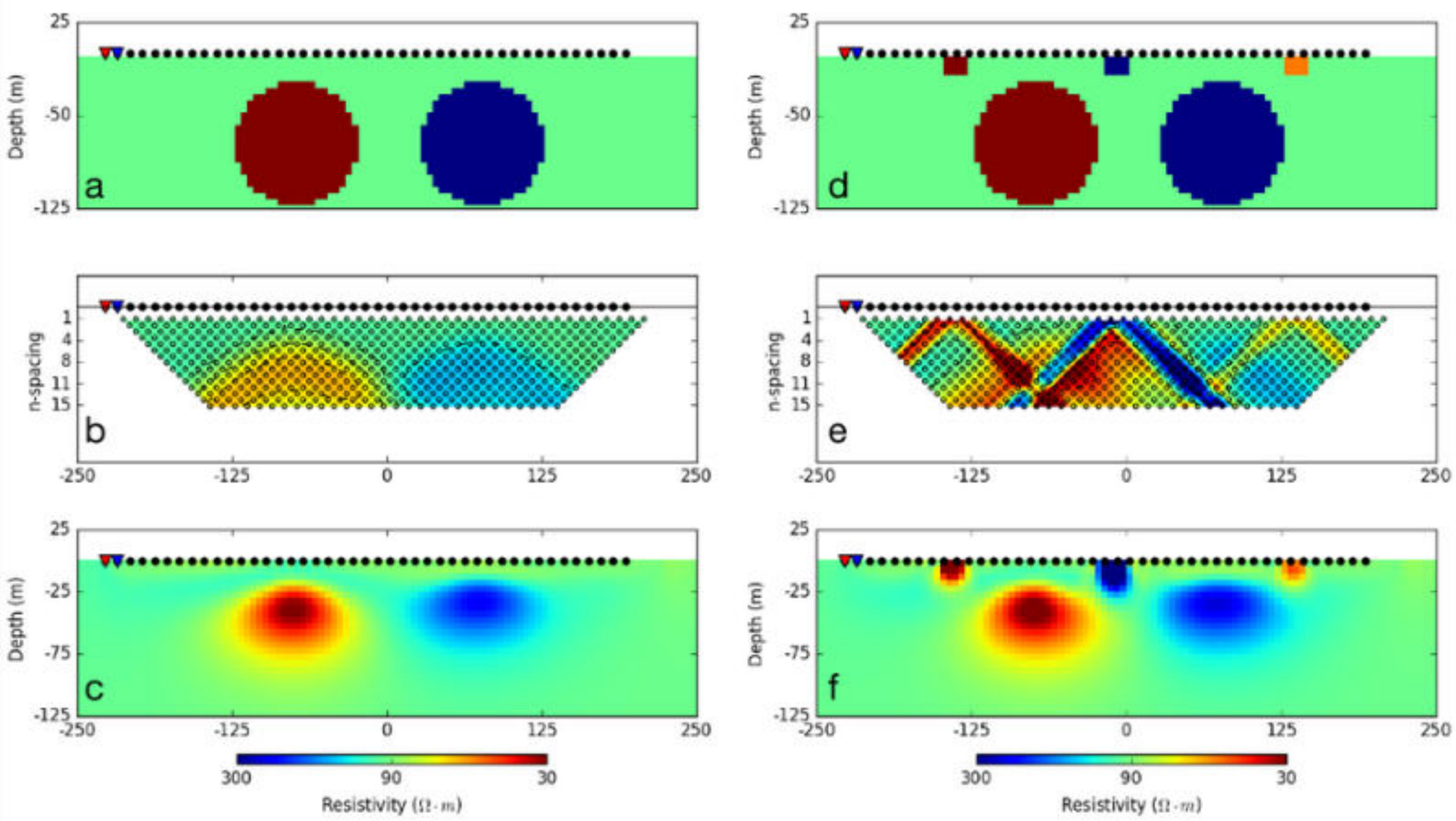


Pseudo-section vs. Inversion

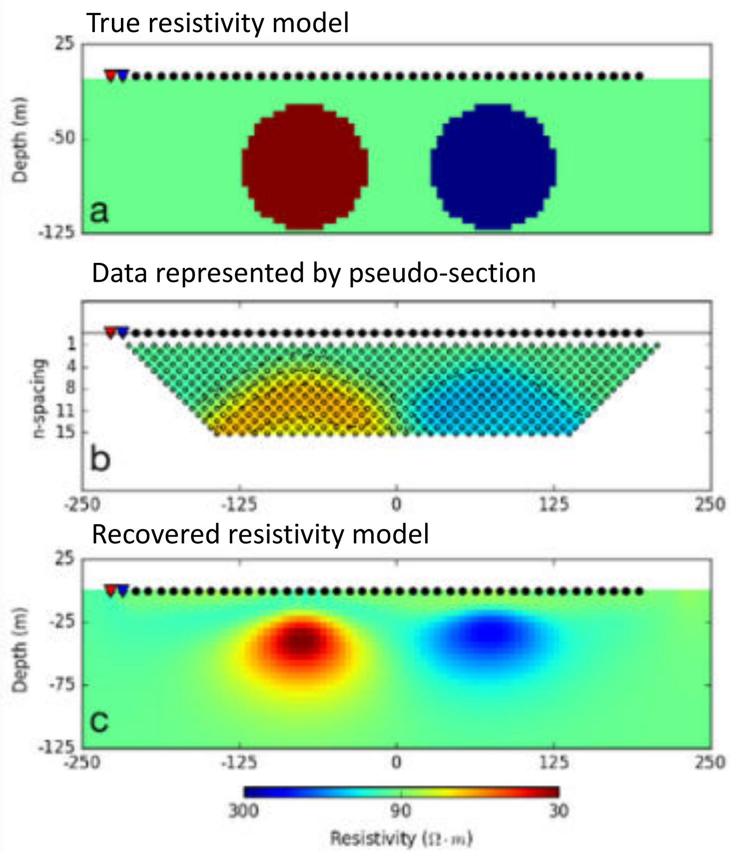
True model

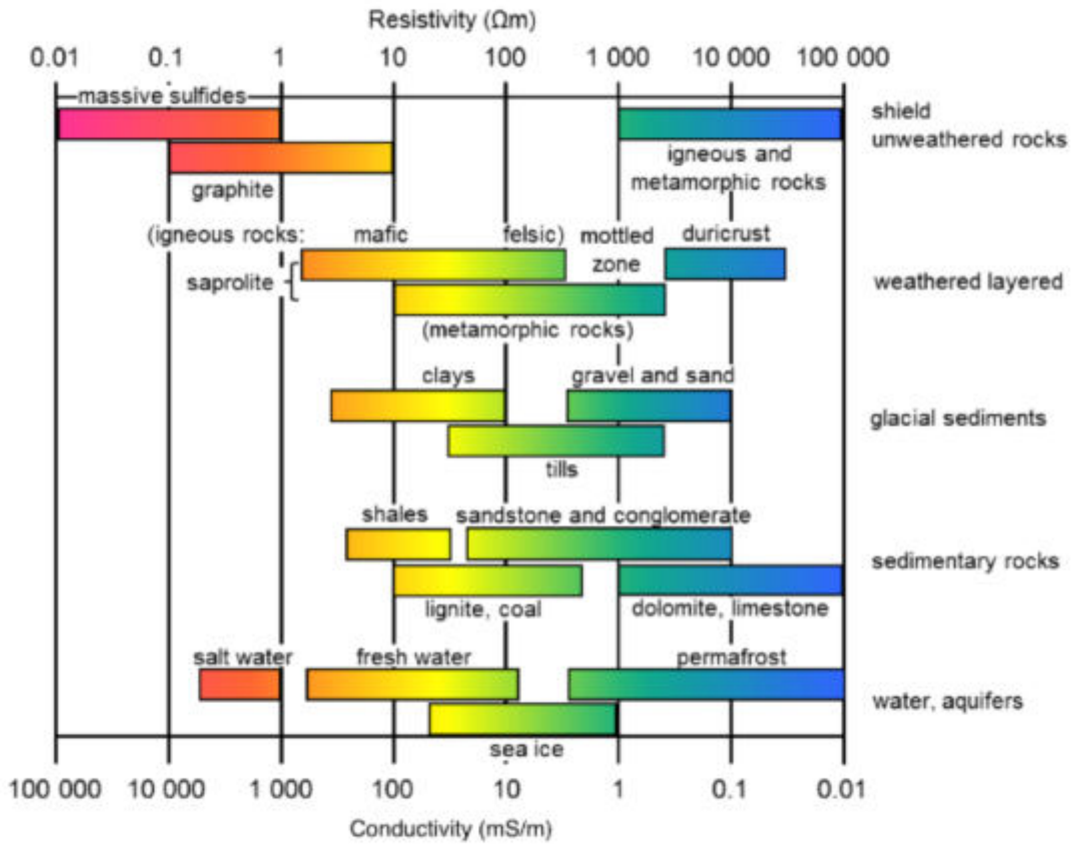
Pseudo-section

Inversion model



Characterization of the Earth Using Resistivity

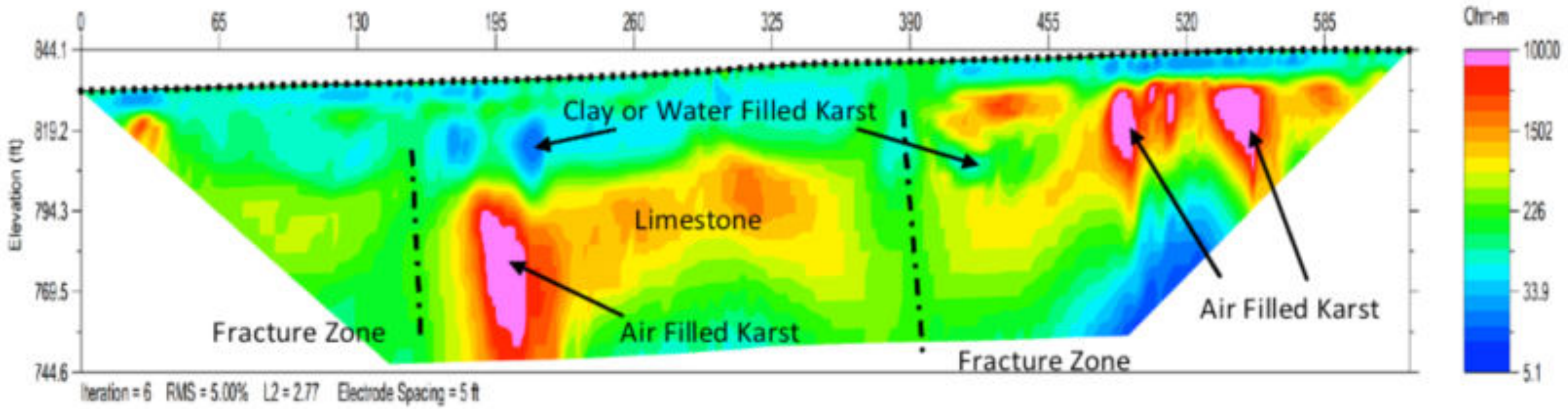




Environmental

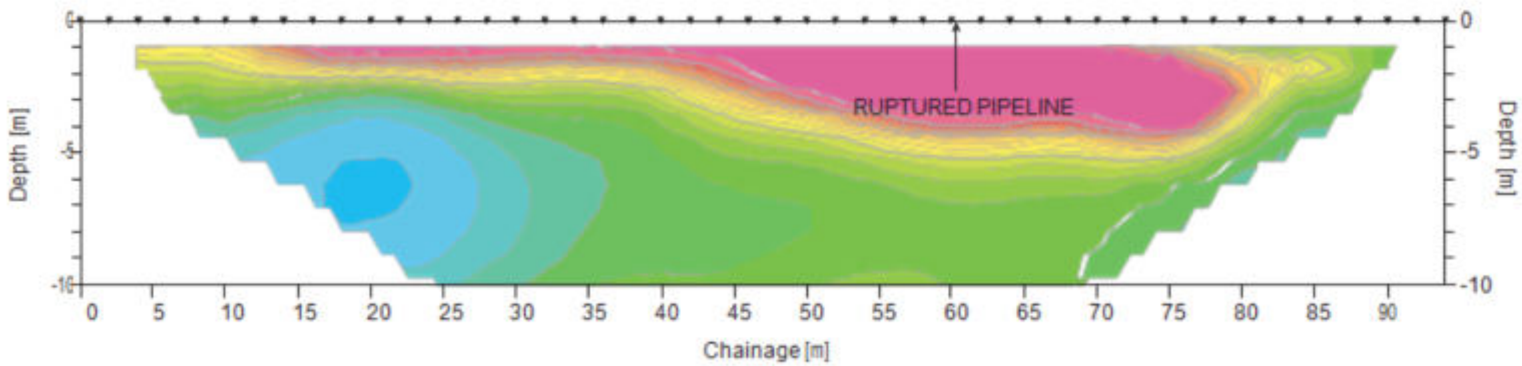
Karst

- Air-filled
- Water-filled

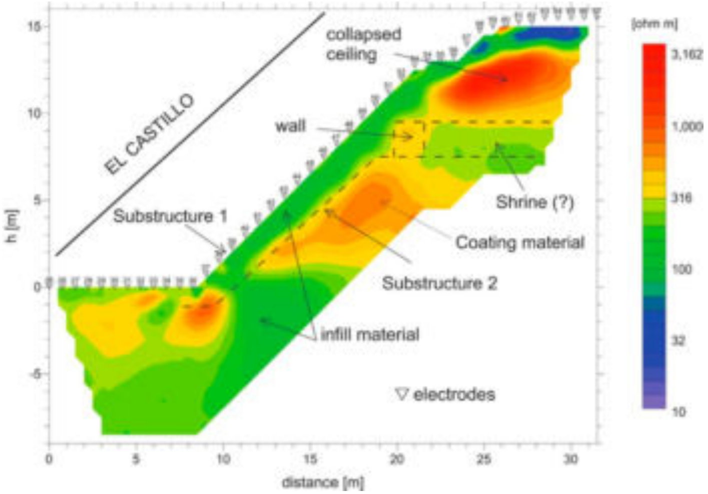


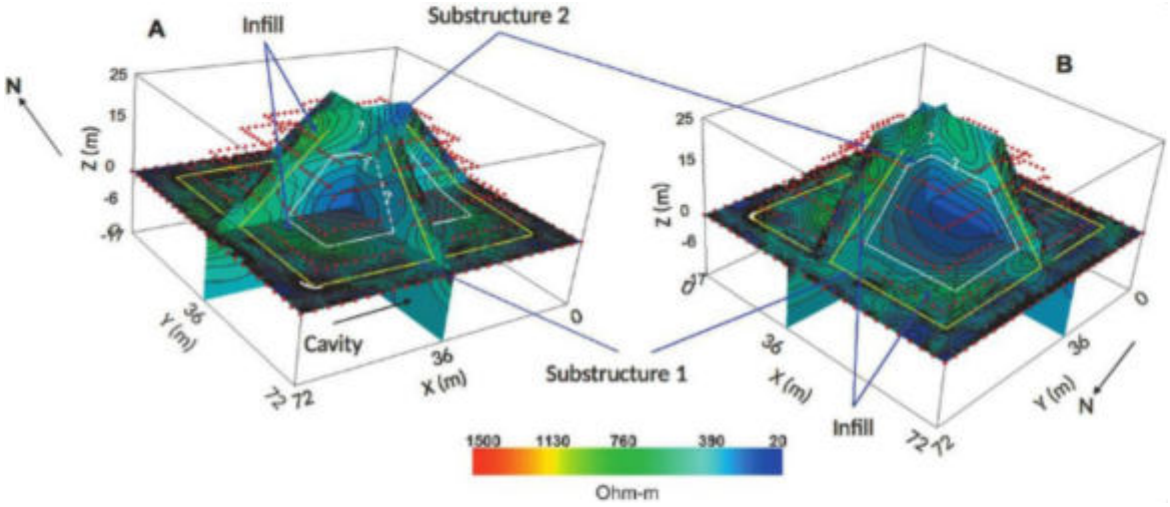
Oil spill

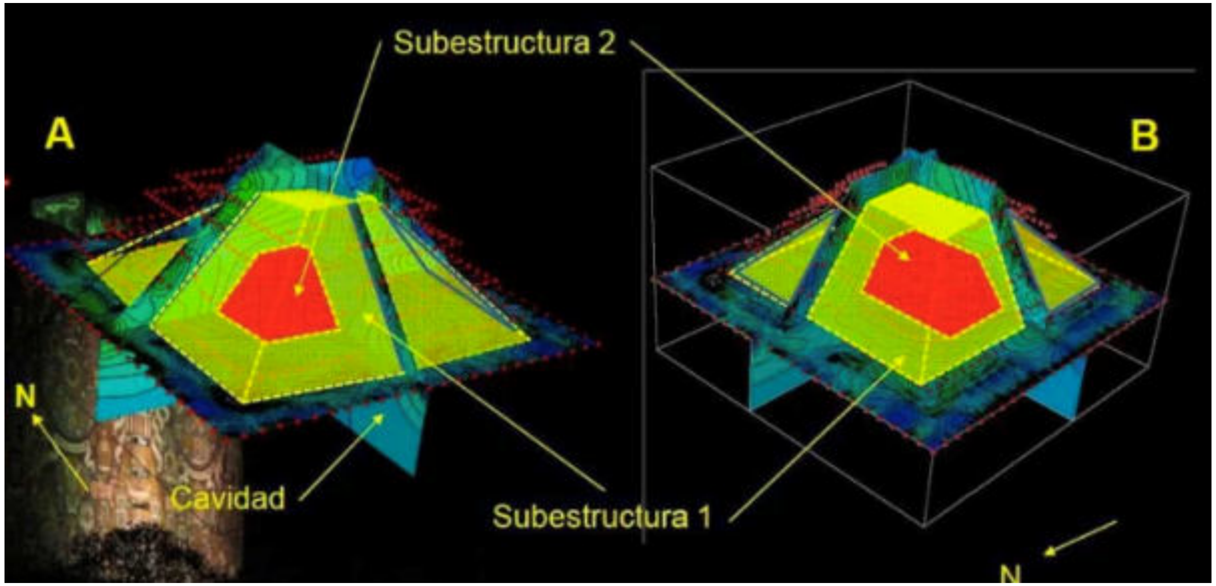
- Hydrocarbon: resistive



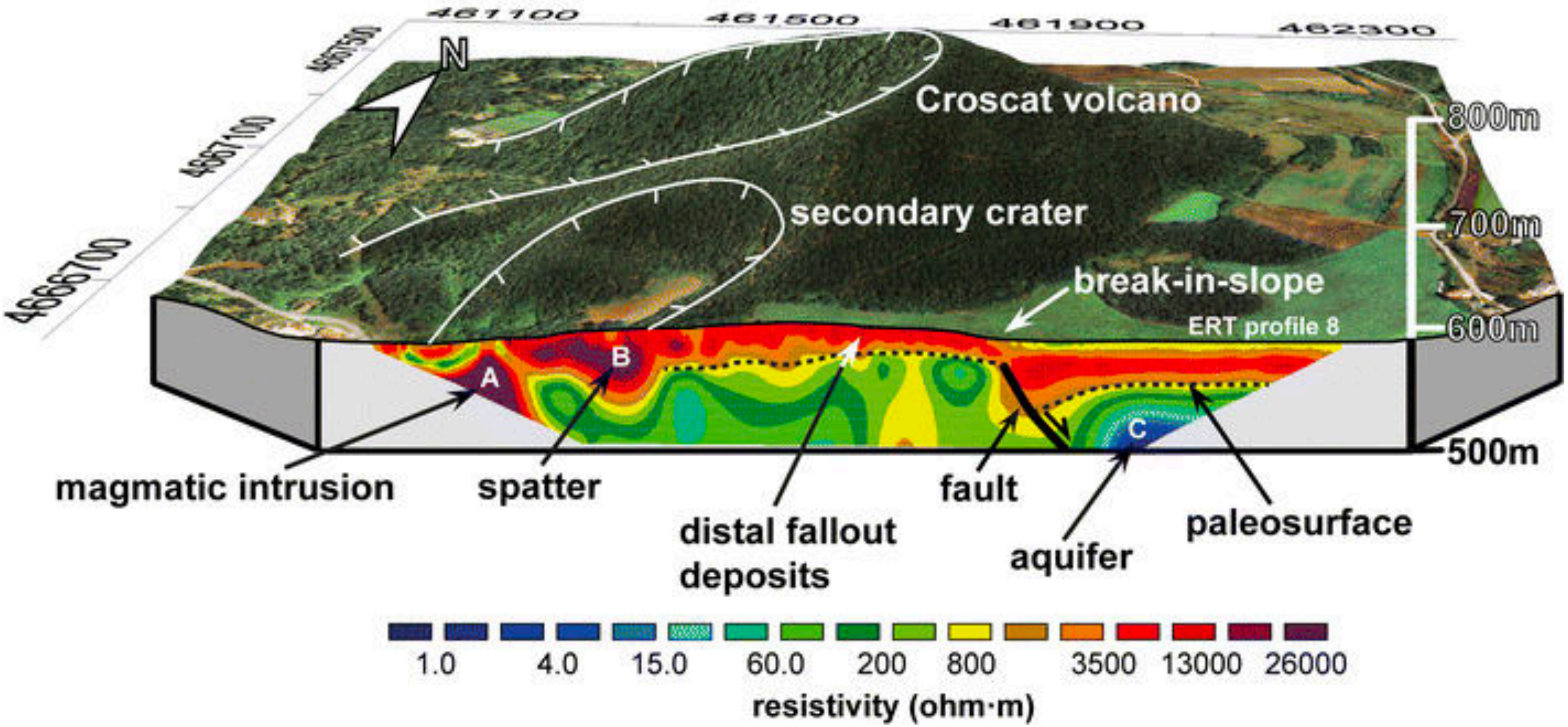
Archaeology





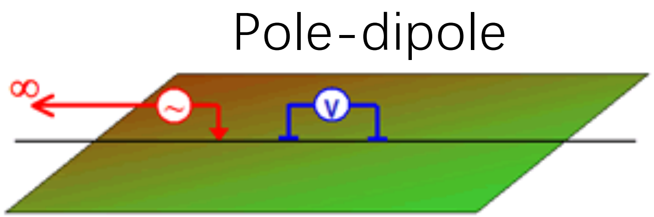


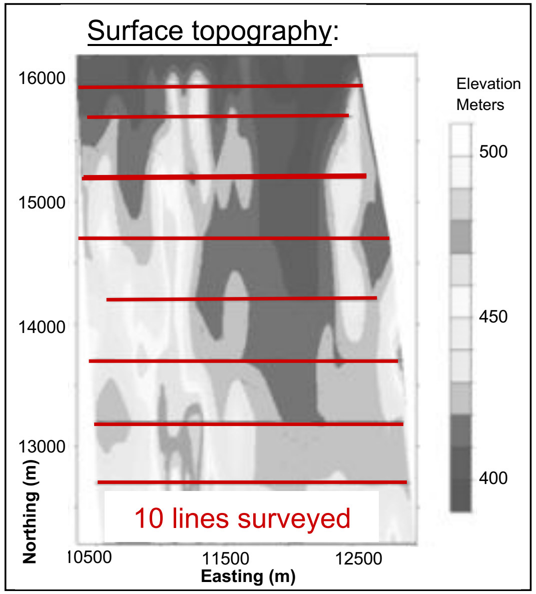
Volcano

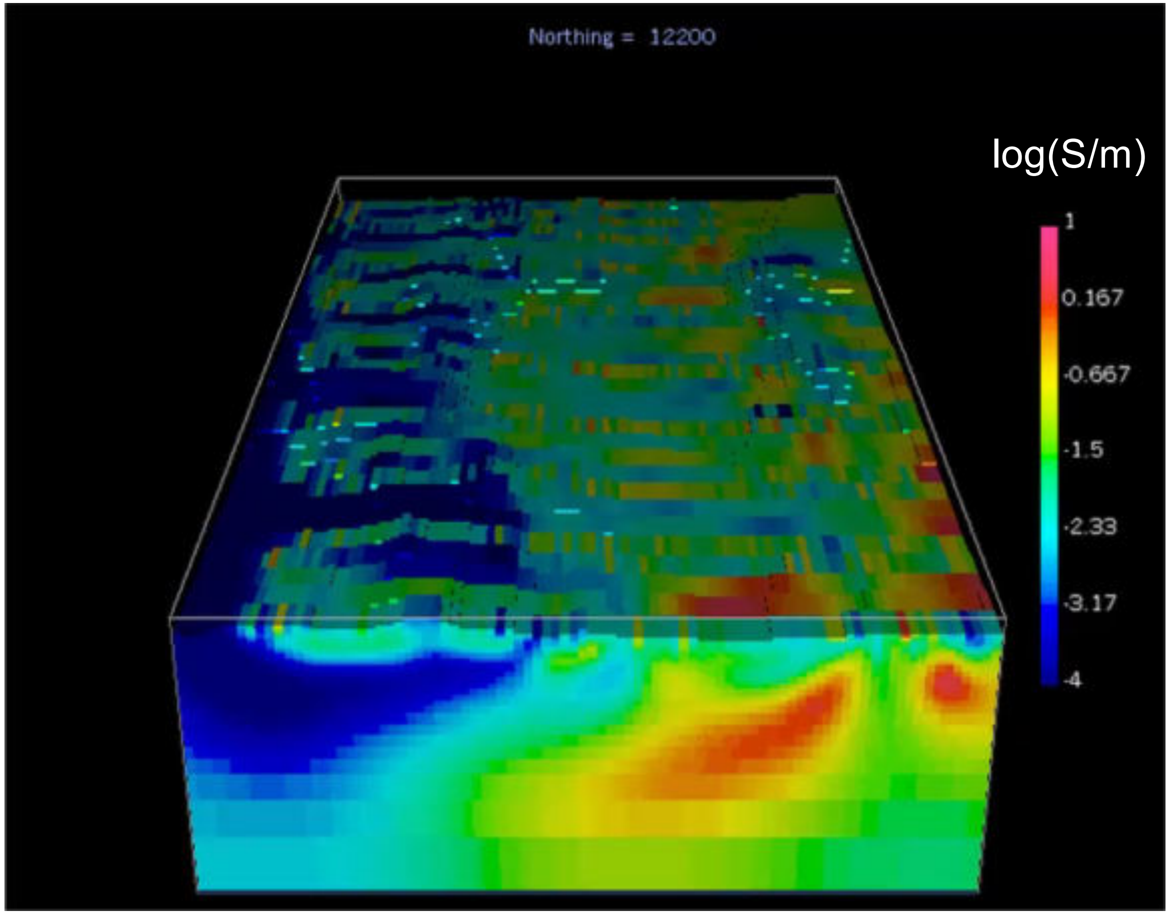


461100
461500
461900
462300
4667500
4667100
4666700
N
Croscat volcano
secondary crater
break-in-slope
ERT profile 8
800m
700m
600m
500m
A
B
C
magmatic intrusion
spatter
distal fallout deposits
fault
aquifer
paleosurface
1.0
4.0
15.0
60.0
200
800
3500
13000
26000
resistivity (ohm·m)

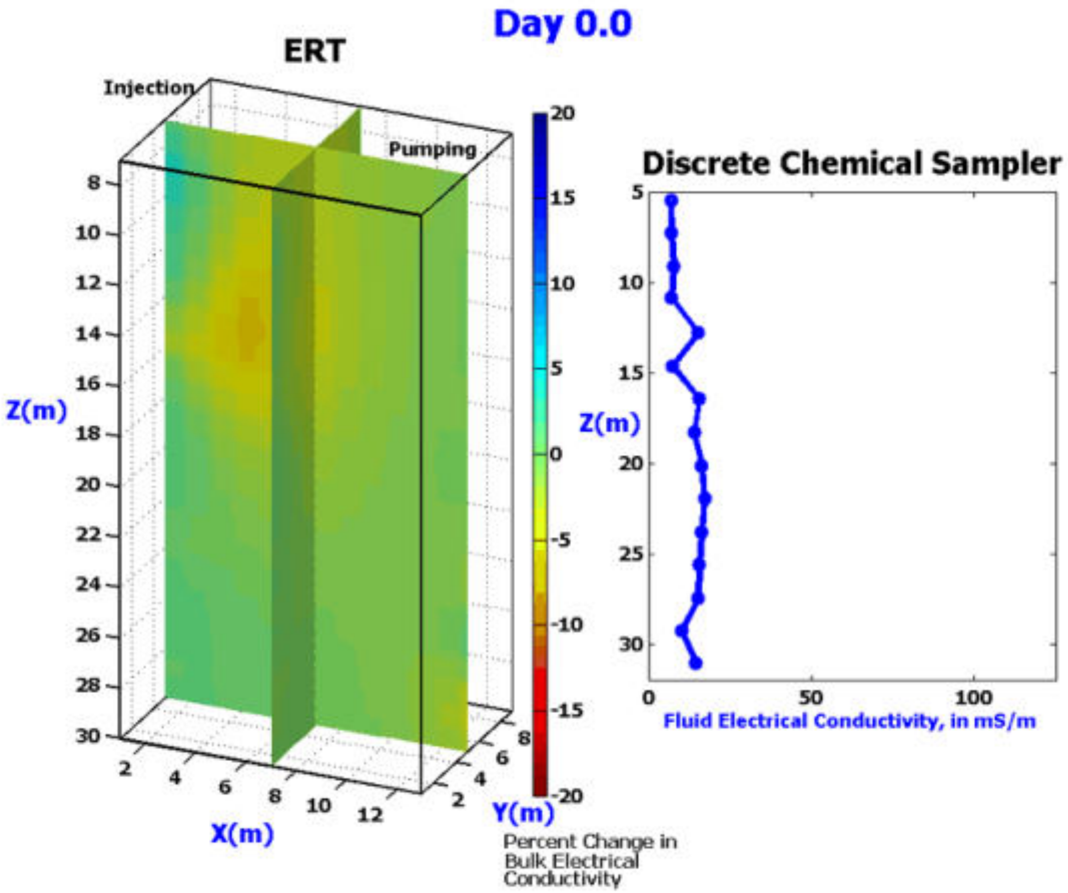
3D Electrical Imaging for Mining Exploration







4D ERT for Hydrological Monitoring



Summary of Electrical (ERT or dc resistivity)

- Electrical resistivity or conductivity
- Four-electrode arrays: dipole-dipole, pole-pole, Wenner, etc.
- Electrode spacing – depth
- Apparent resistivity and pseudo-section
- Electrical data inversion
- Applications: environmental, archaeology, resource, engineering