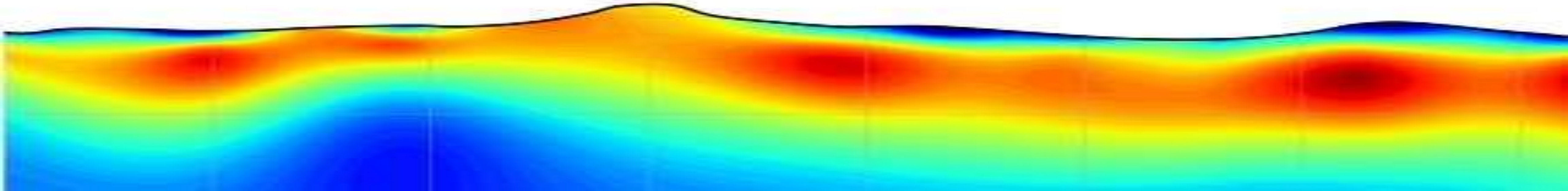
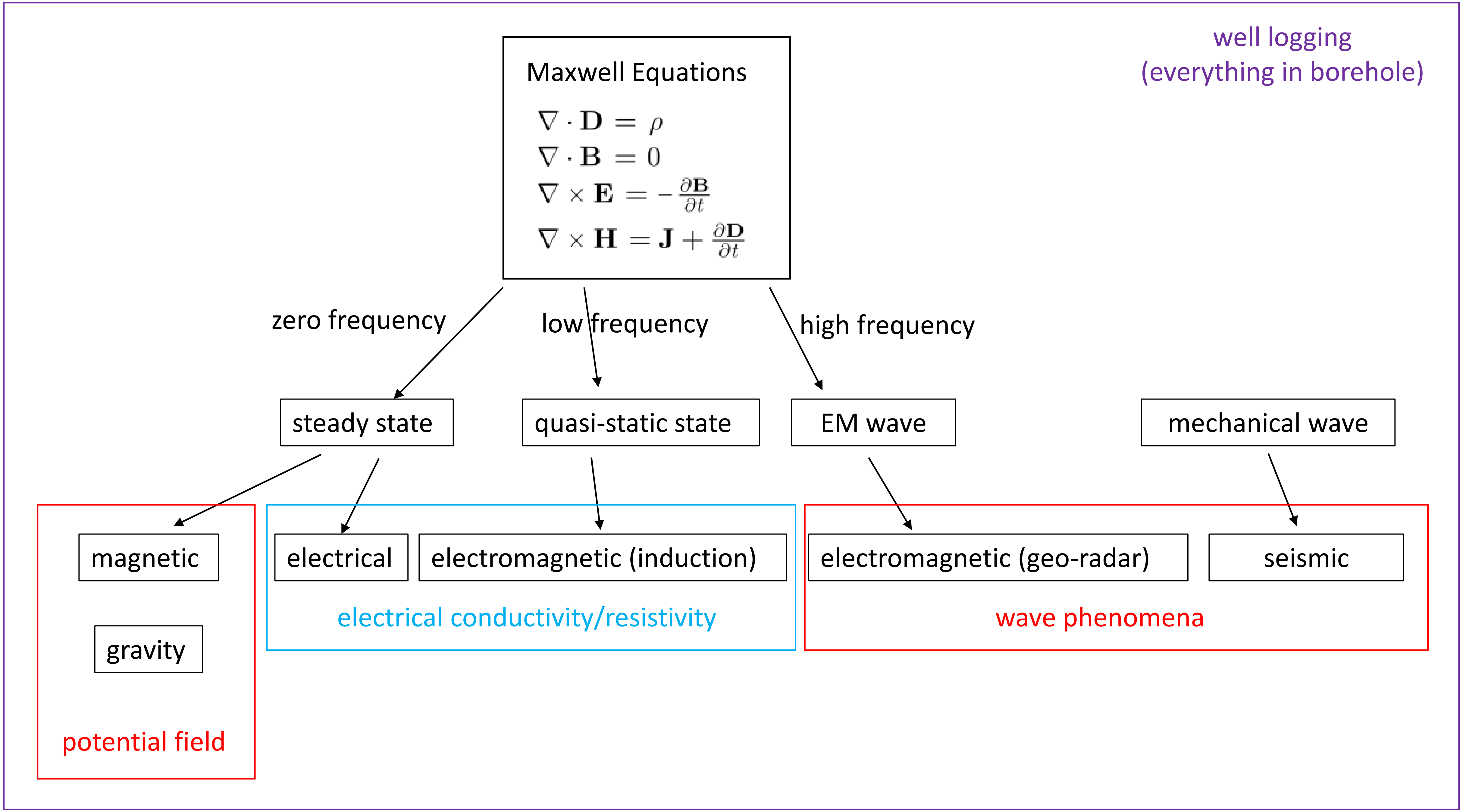
# ESS302 Applied Geophysics II

Gravity, Magnetic, Electrical, Electromagnetic and Well Logging

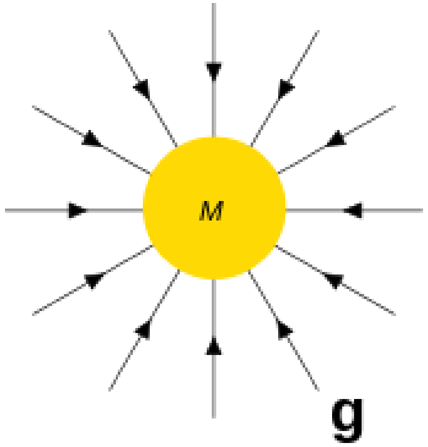
## Electrical 1: Theory

Instructor: Dikun Yang    Feb – May, 2019

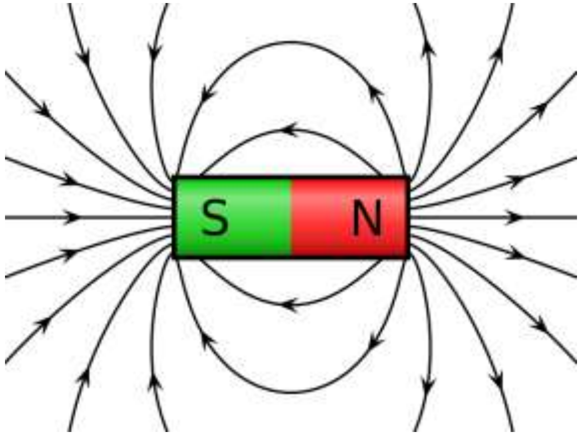



well logging
(everything in borehole)
Maxwell Equations
$\nabla \cdot \mathbf{D} = \rho$
$\nabla \cdot \mathbf{B} = 0$
$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$
$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}$
zero frequency
low frequency
high 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

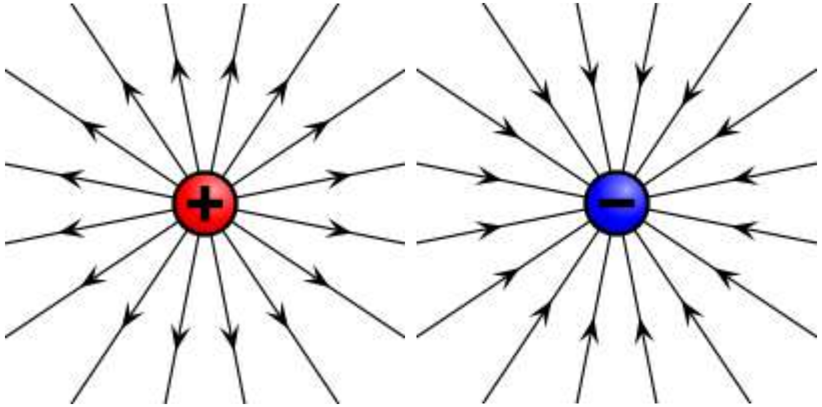
# Charge, Force, Field, Potential




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

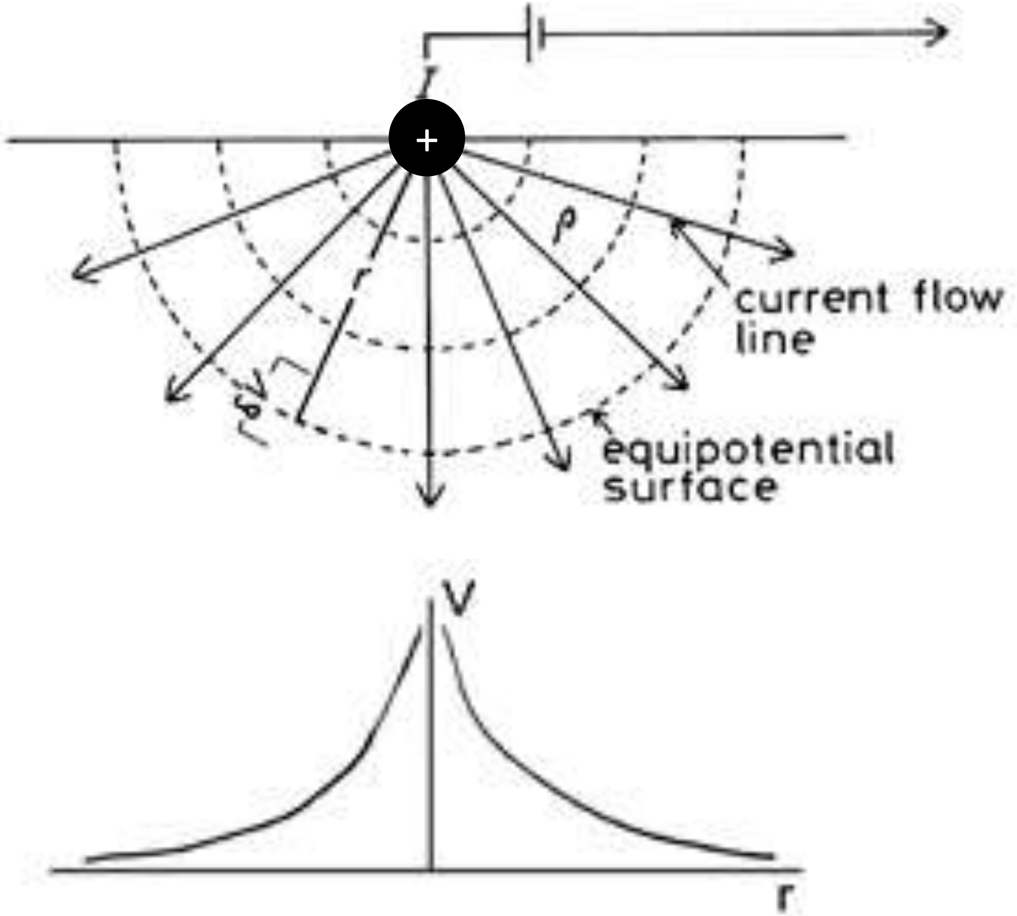



- Positive and negative charge but they have to be bounded as dipole (no monopole)
- Measure field to infer dipole distribution or susceptibility that gives rise to dipole distribution
- External excitation: geomagnetic field (passive)




- 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

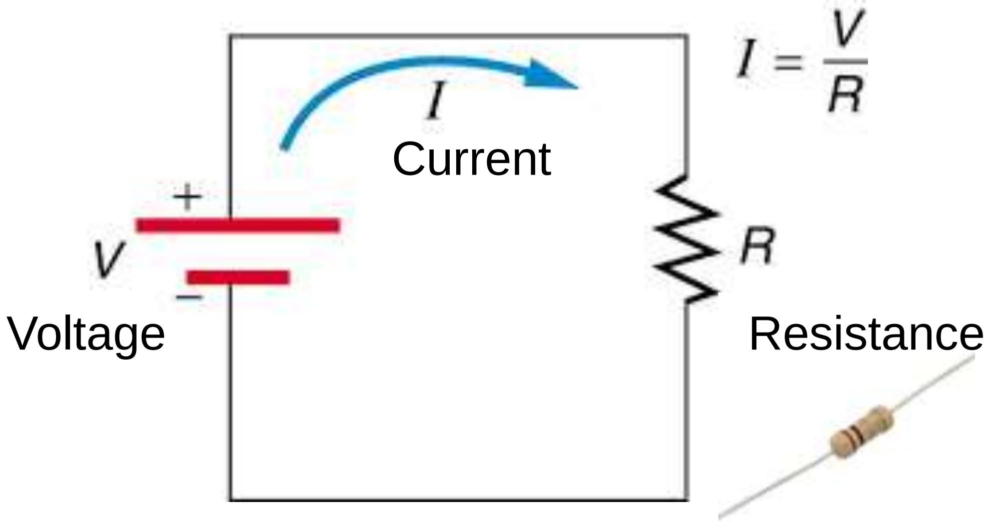


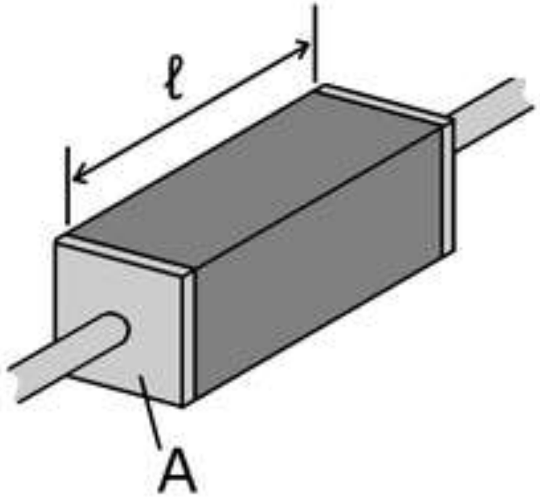

- Current flows radially outwards
- A positive charge at injection point
- Electrical potential decays as 1/r

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

# Electrical Resistivity or Conductivity

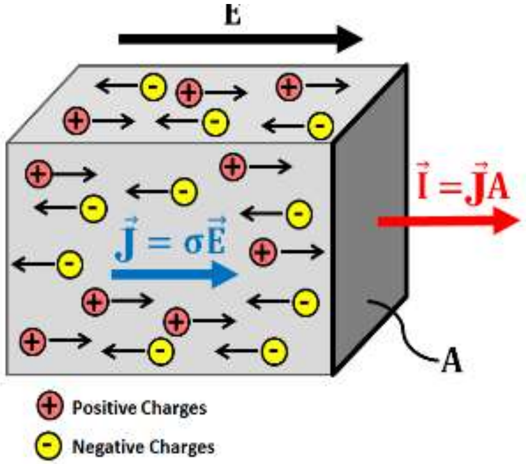
Ohm's law



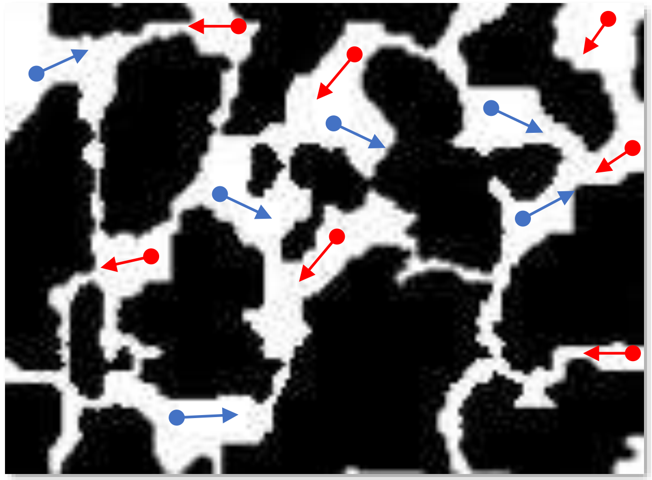

Resistivity (in Ωm) $\boldsymbol{\rho = R\frac{A}{\ell}}$,

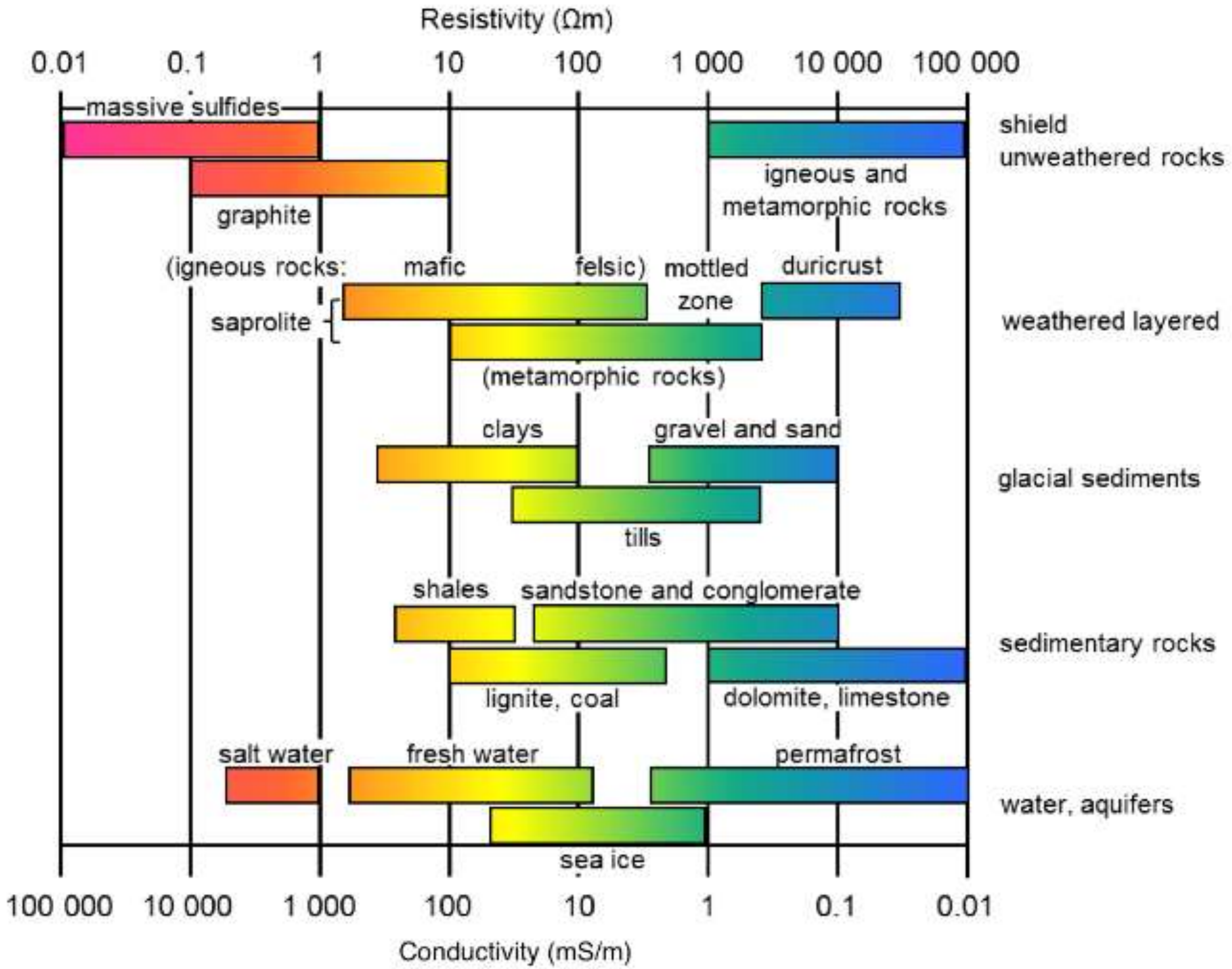
or conductivity (in S/m) $\boldsymbol{\sigma = \frac{1}{\rho}}$.




- Electrons
- Ions

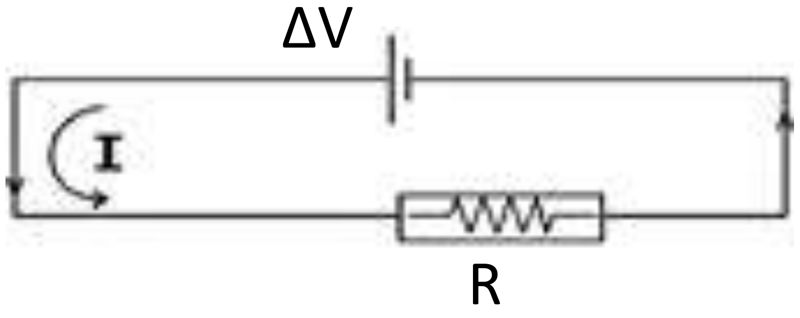
# Earth's Resistivity



# Measurement of Resistance or Resistivity

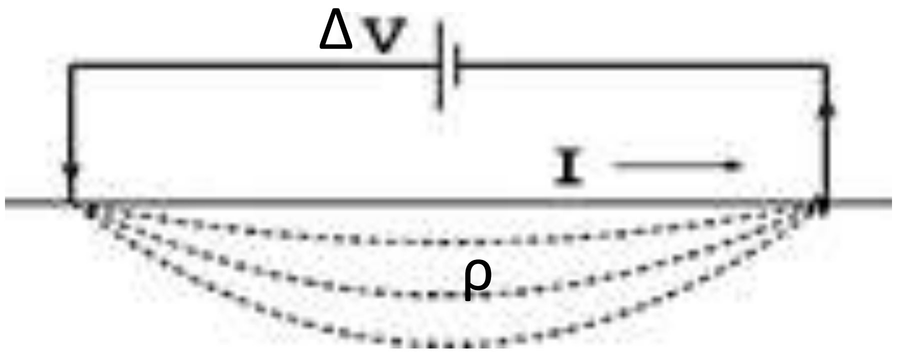
Electrical Circuit




Ohm's Law

$$\Delta V = IR$$

Earth Circuit




For the Earth:

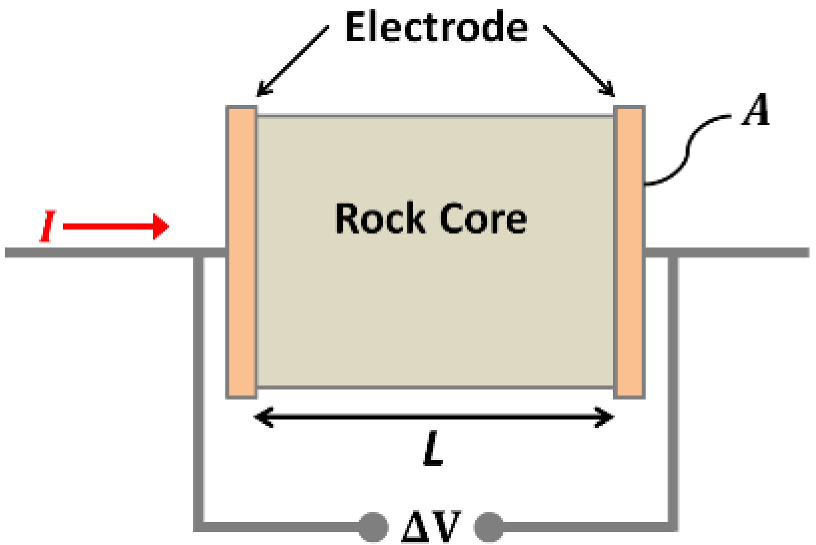
$$\Delta V = I\rho G$$

Depends on:

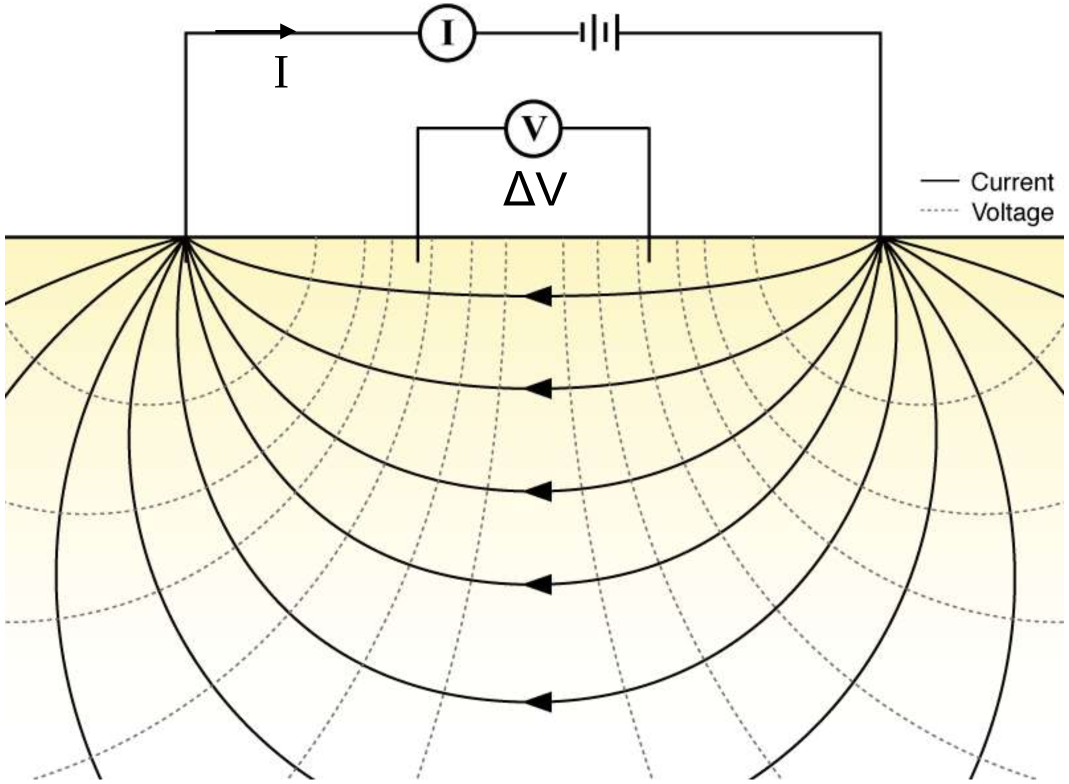
1) Earth's resistivity (ρ)
2) Geometry of electrodes (G)

# Measuring Earth's Materials

Resistivity measurement in the lab

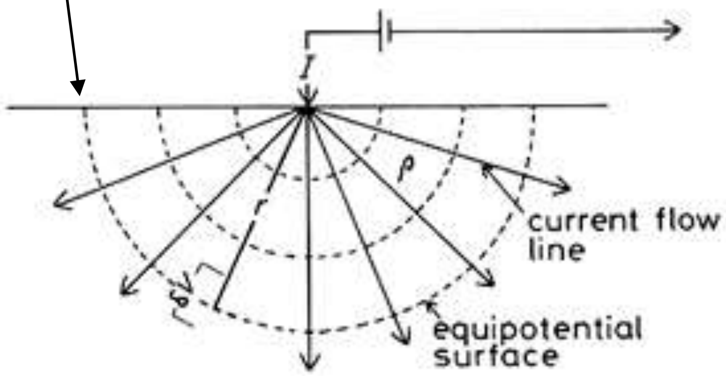


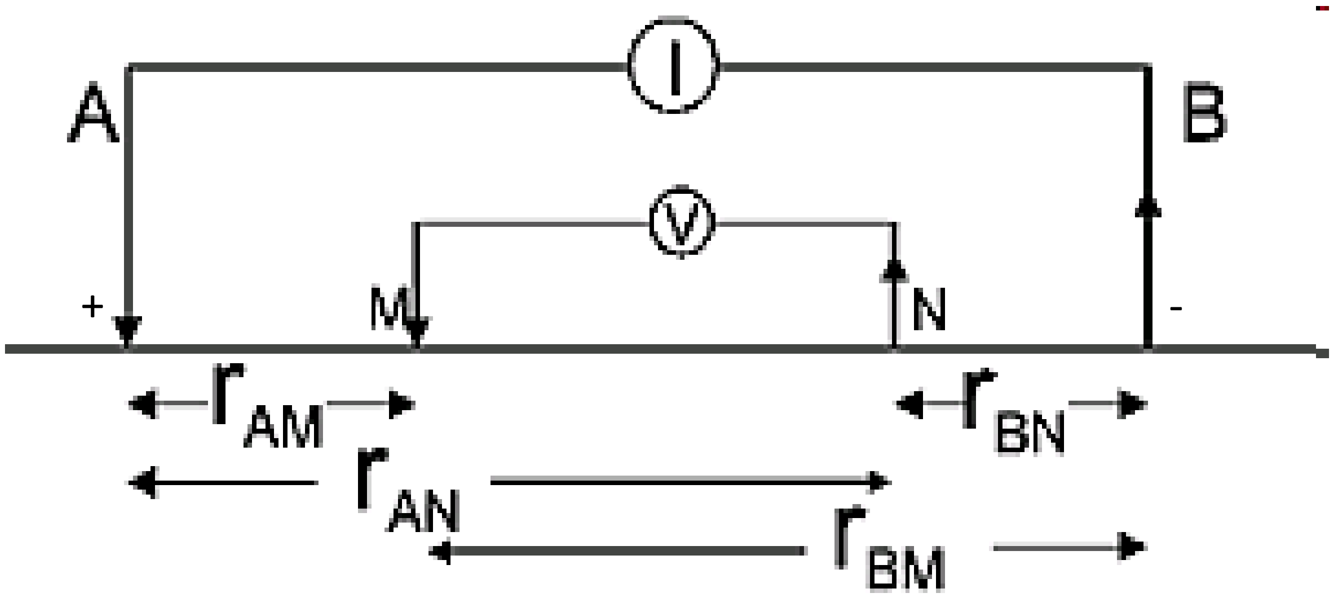

Resistivity survey in the field



# Four-electrode Array

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



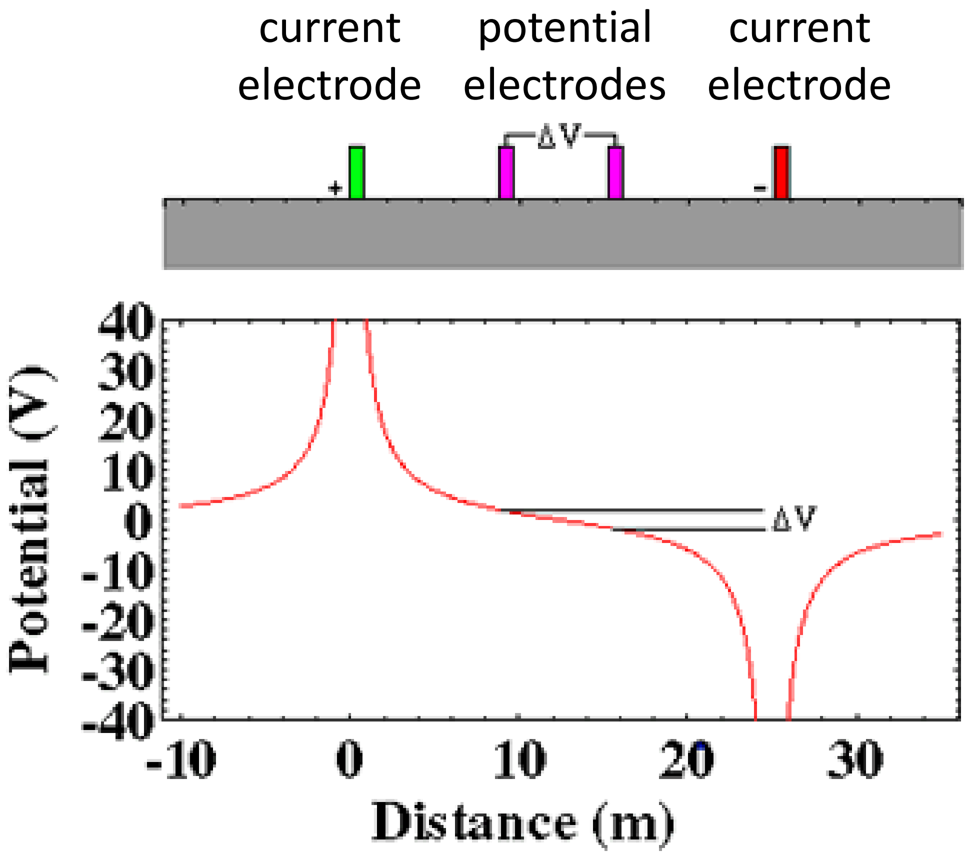



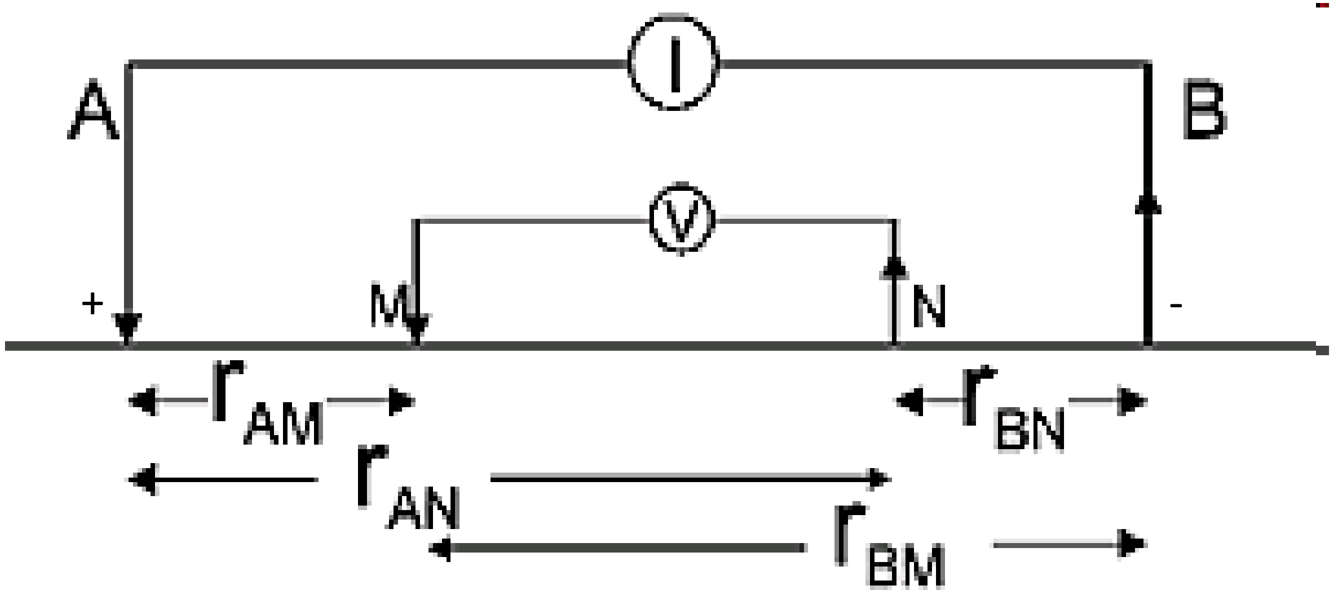

$$\Delta V = I\rho G = \frac{I\rho}{2\pi}\left\{\frac{1}{r_{AM}} - \frac{1}{r_{BM}} - \frac{1}{r_{AN}} + \frac{1}{r_{BN}}\right\}$$

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

Calculated earth's resistivity

# Four-electrode Array

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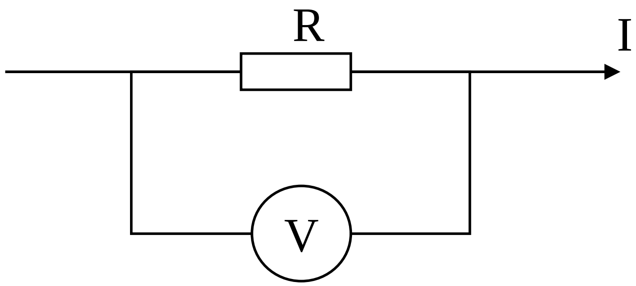
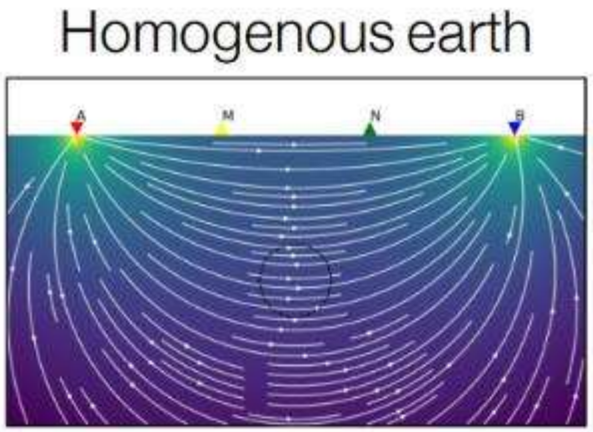
$$\rho = \frac{\Delta V}{IG}$$

Calculated earth's resistivity

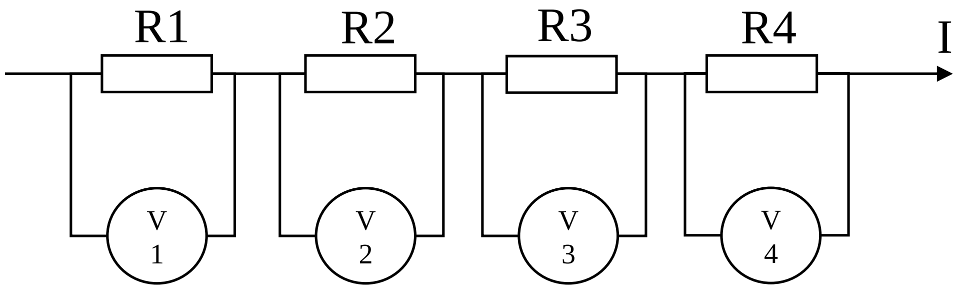
# Inhomogeneous Earth

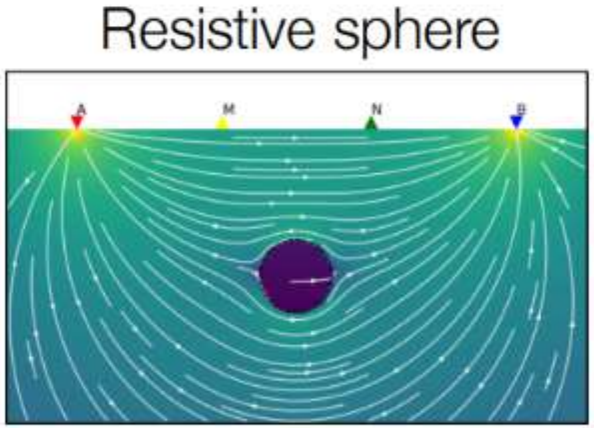
Uniform sample




Non-uniform sample

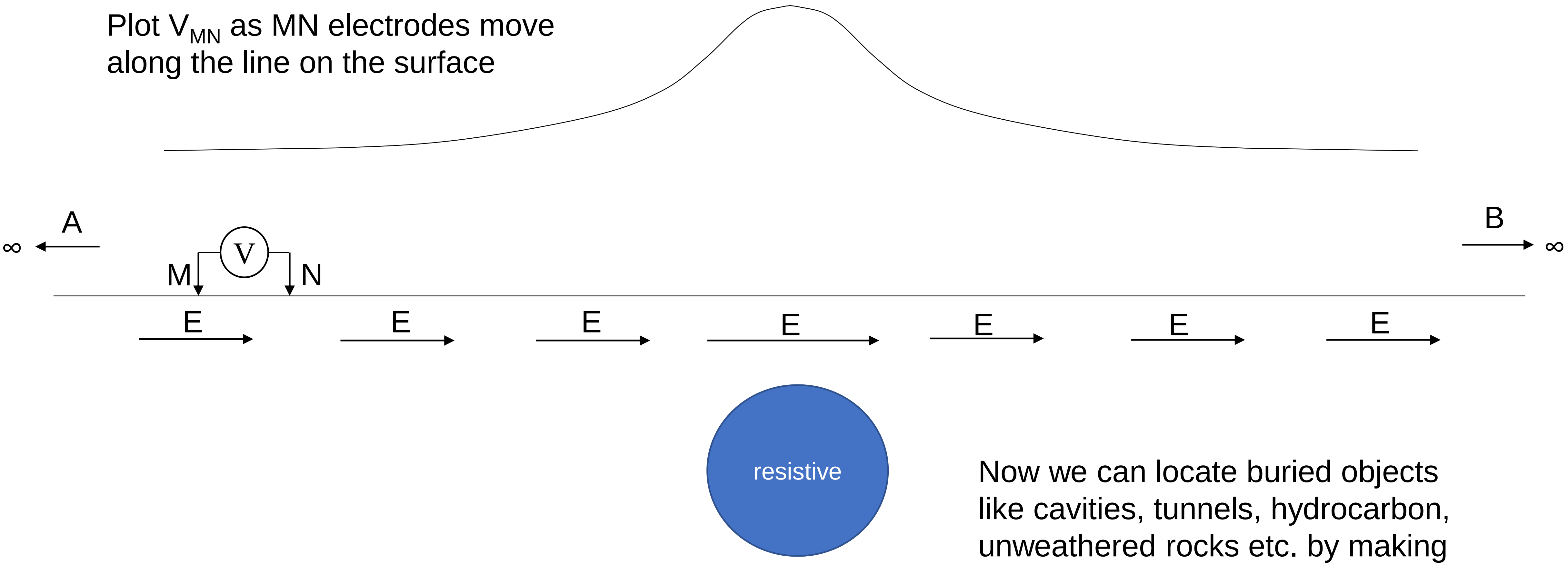



How would $V_{MN}$ change if a resistor exists?

# Finding a Sphere

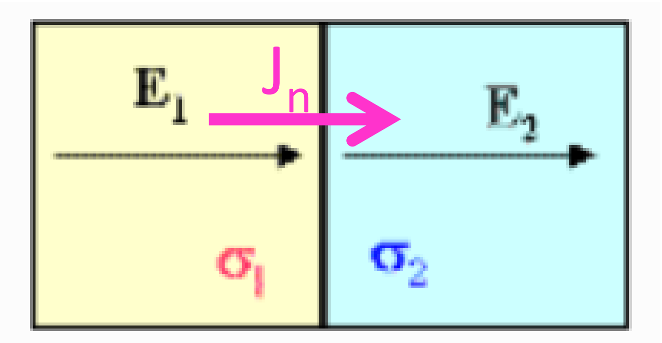
Plot $V_{MN}$ as MN electrodes move along the line on the surface

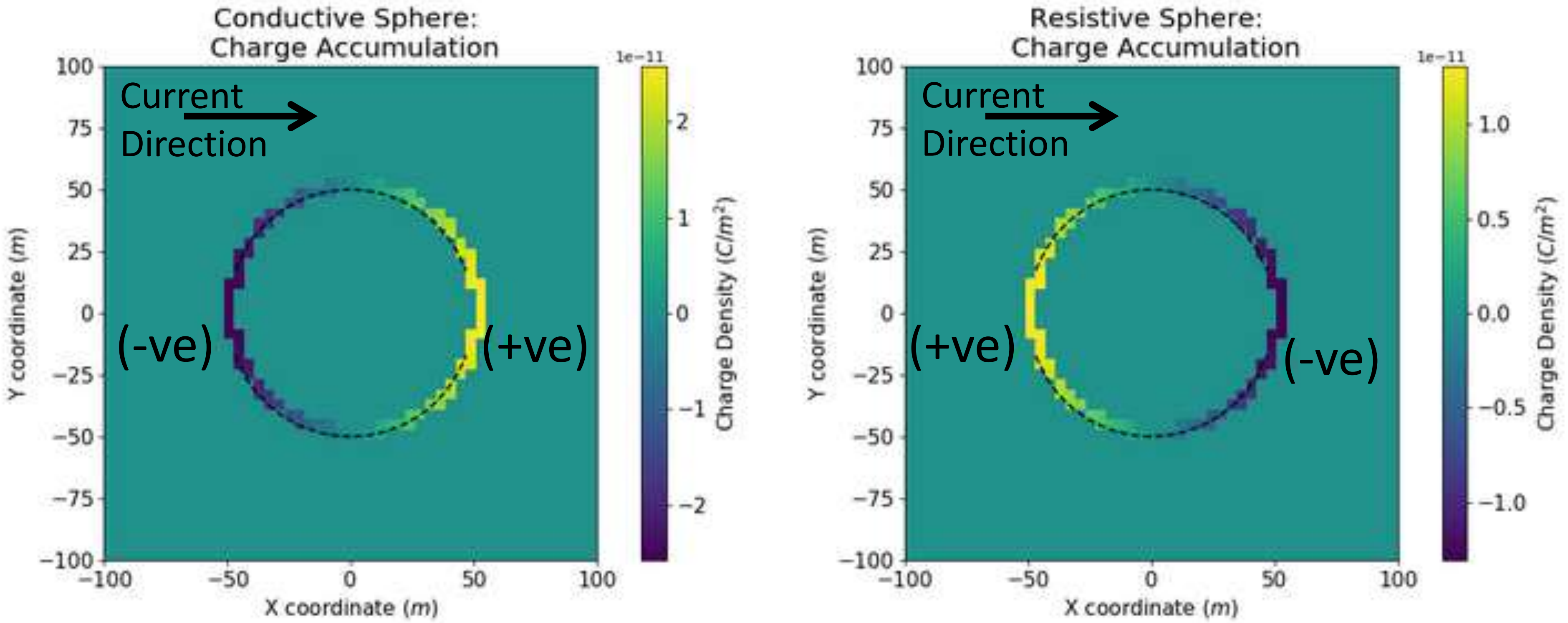



Now we can locate buried objects like cavities, tunnels, hydrocarbon, unweathered rocks etc. by making measurements on the surface!

# In Terms of Charges

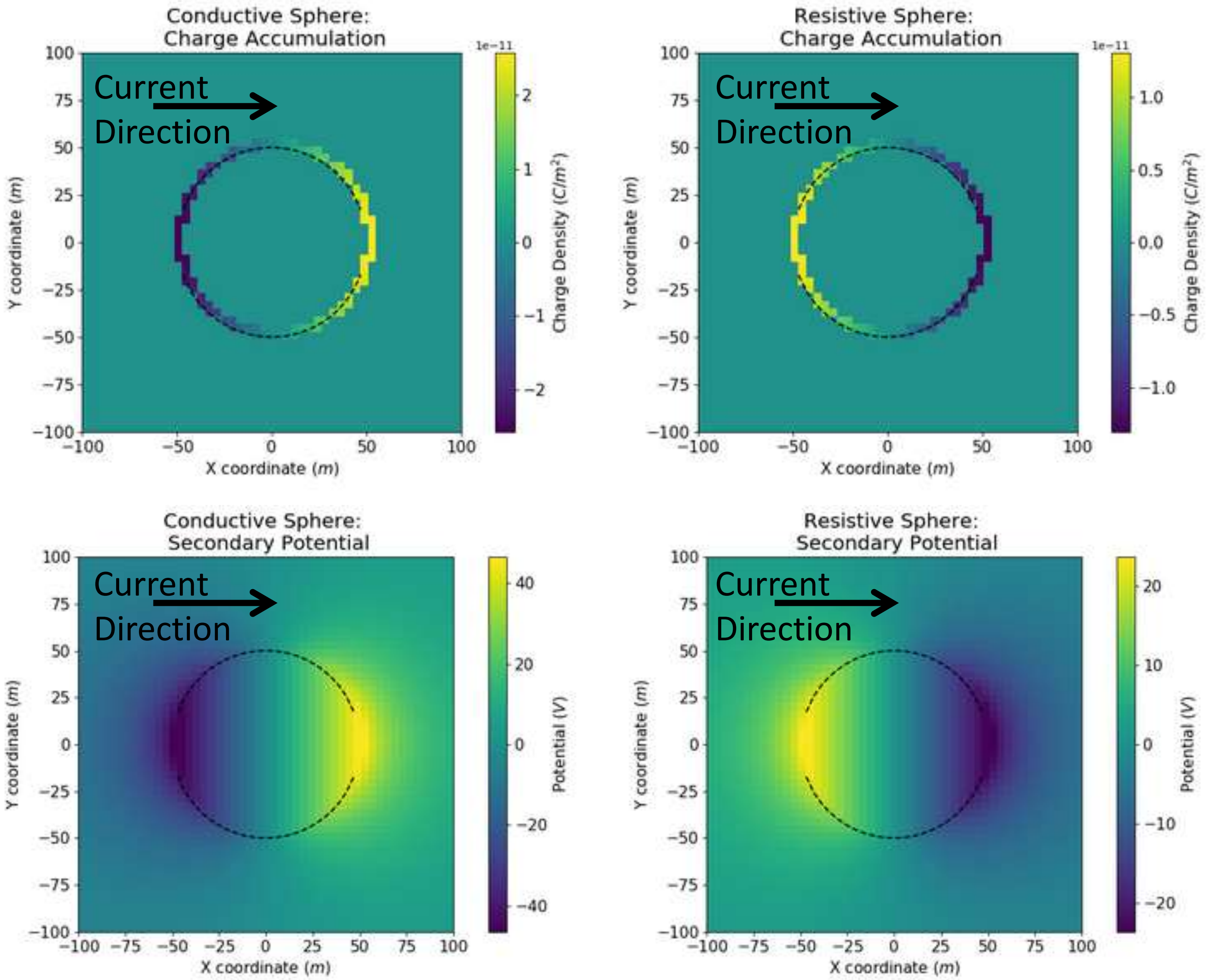
- Charges build-up on boundaries
  From resistor into conductor → negative charges build-up
  From conductor into a resistor → positive charges build-up



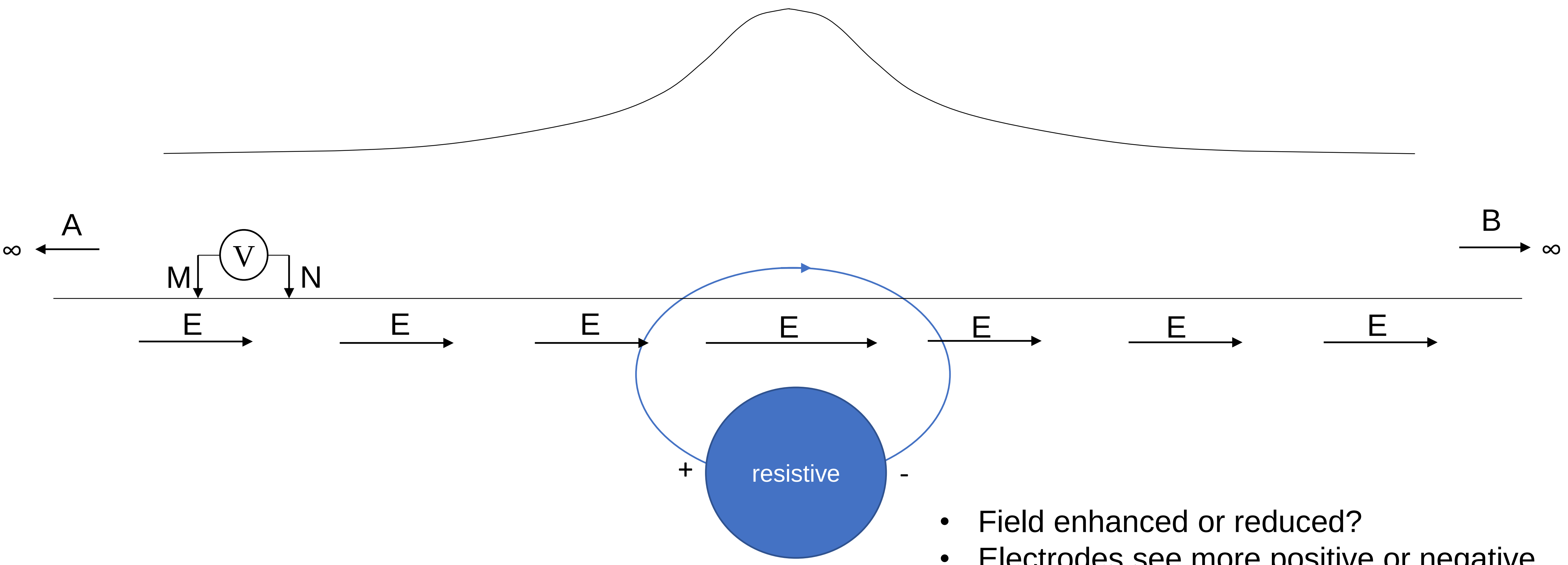



- Charges

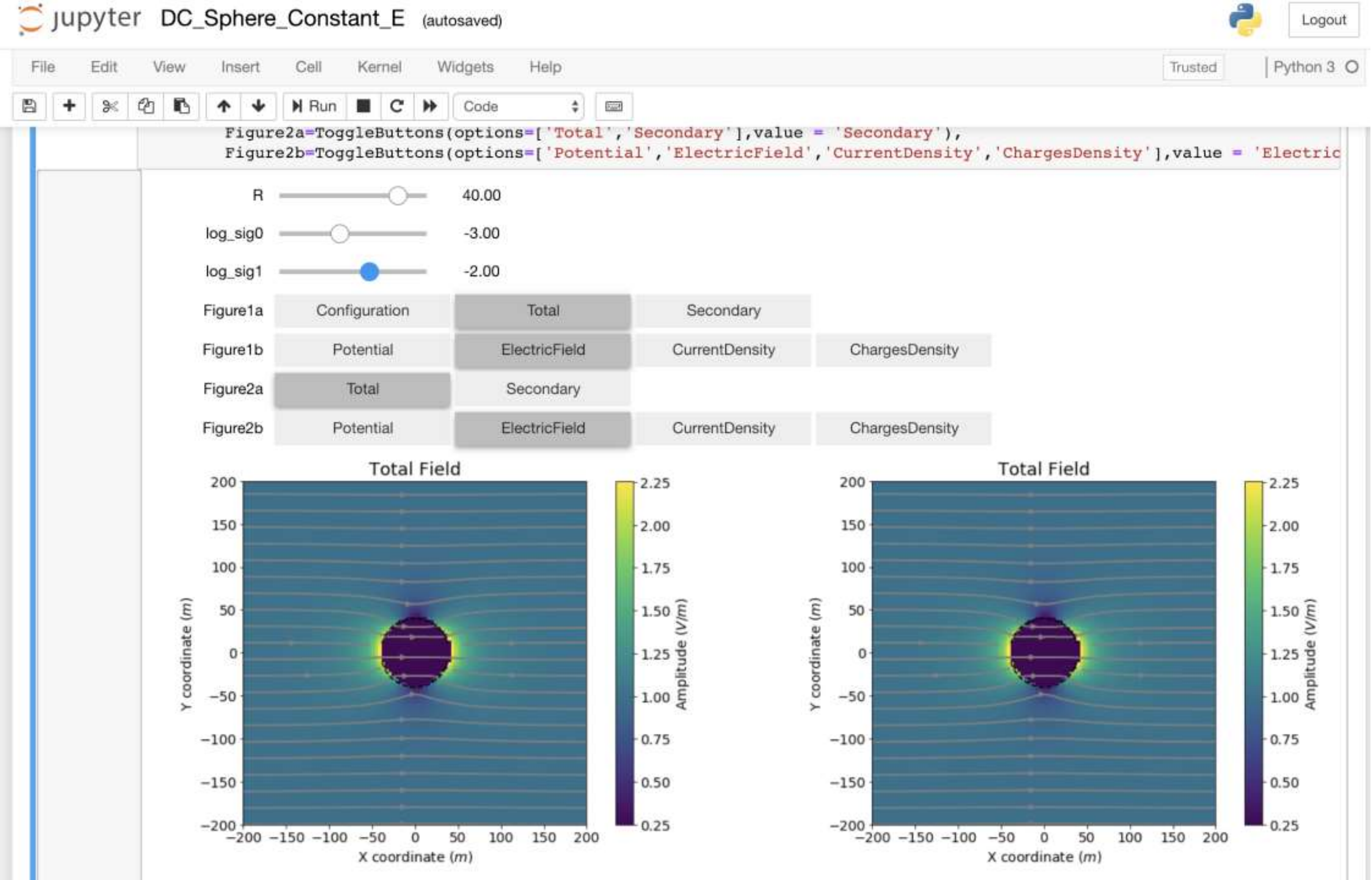
- Secondary Potential

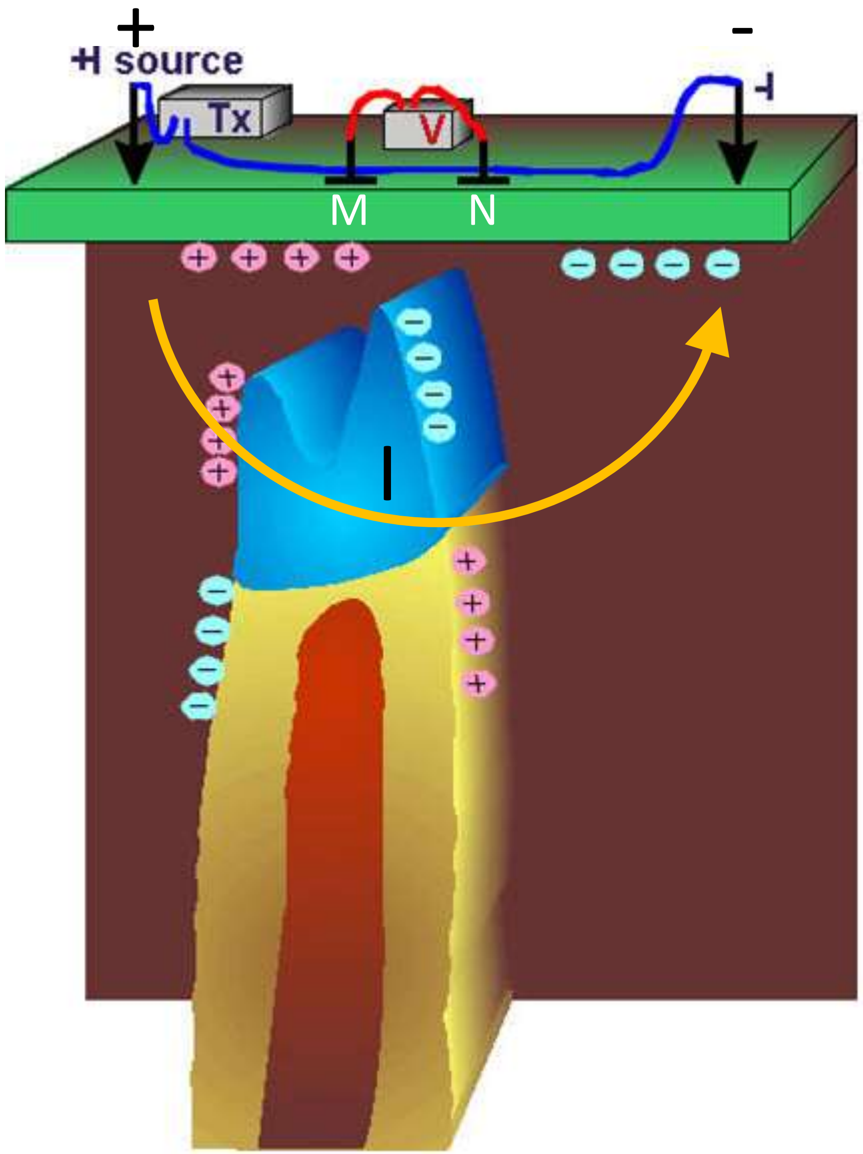


# Finding a Sphere




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


jupyter DC_Sphere_Constant_E (autosaved)
Logout
File Edit View Insert Cell Kernel Widgets Help
Trusted
Python 3
Run
Code
Figure2a=ToggleButtons(options=['Total','Secondary'],value = 'Secondary'),
Figure2b=ToggleButtons(options=['Potential','ElectricField','CurrentDensity','ChargesDensity'],value = 'Electric
R 40.00
log_sig0 -3.00
log_sig1 -2.00
Figure1a Configuration Total Secondary
Figure1b Potential ElectricField CurrentDensity ChargesDensity
Figure2a Total Secondary
Figure2b Potential ElectricField CurrentDensity ChargesDensity
Total Field
Y coordinate (m)
X coordinate (m)
Amplitude (V/m)
Total Field
Y coordinate (m)
X coordinate (m)
Amplitude (V/m)

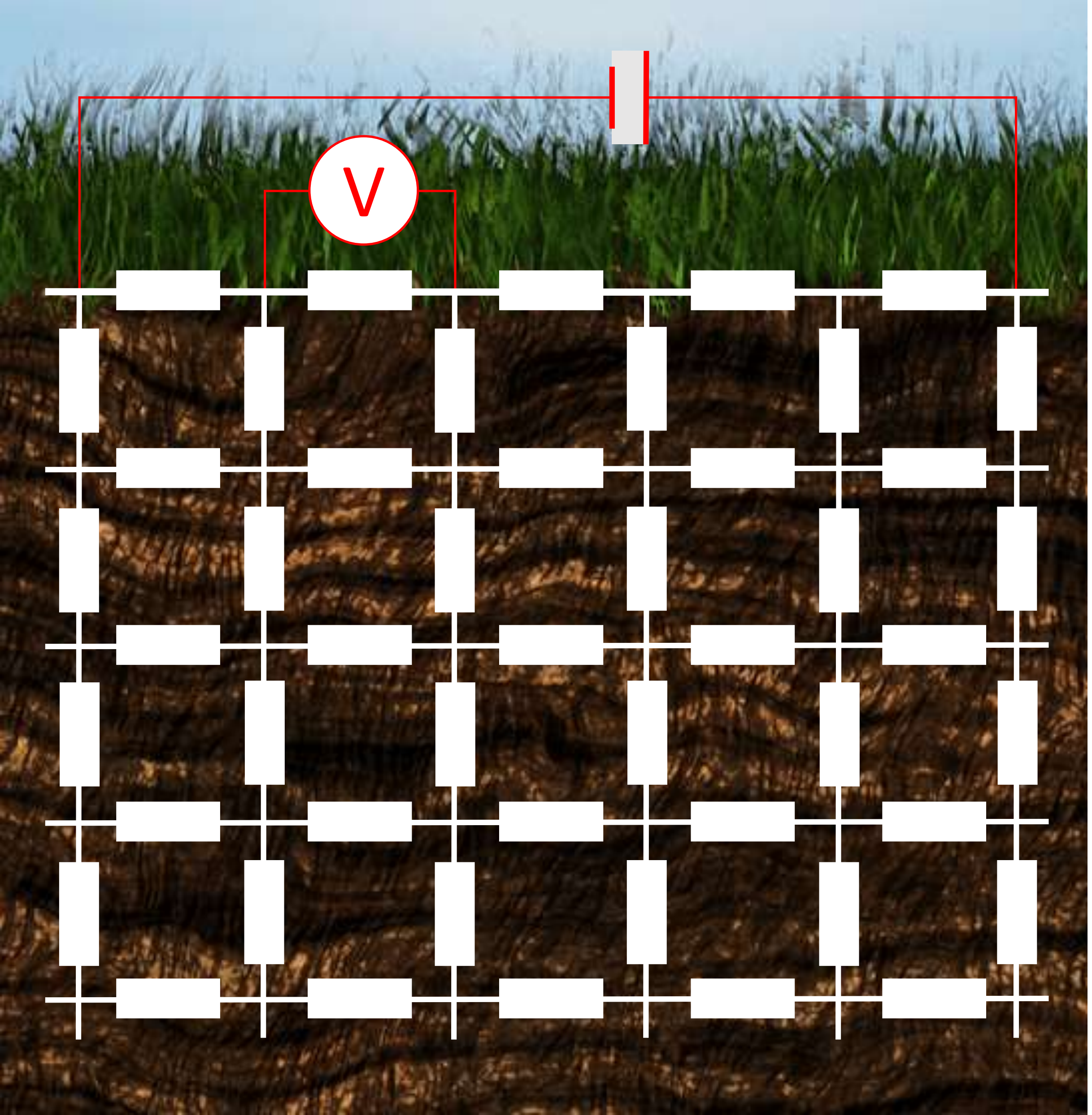


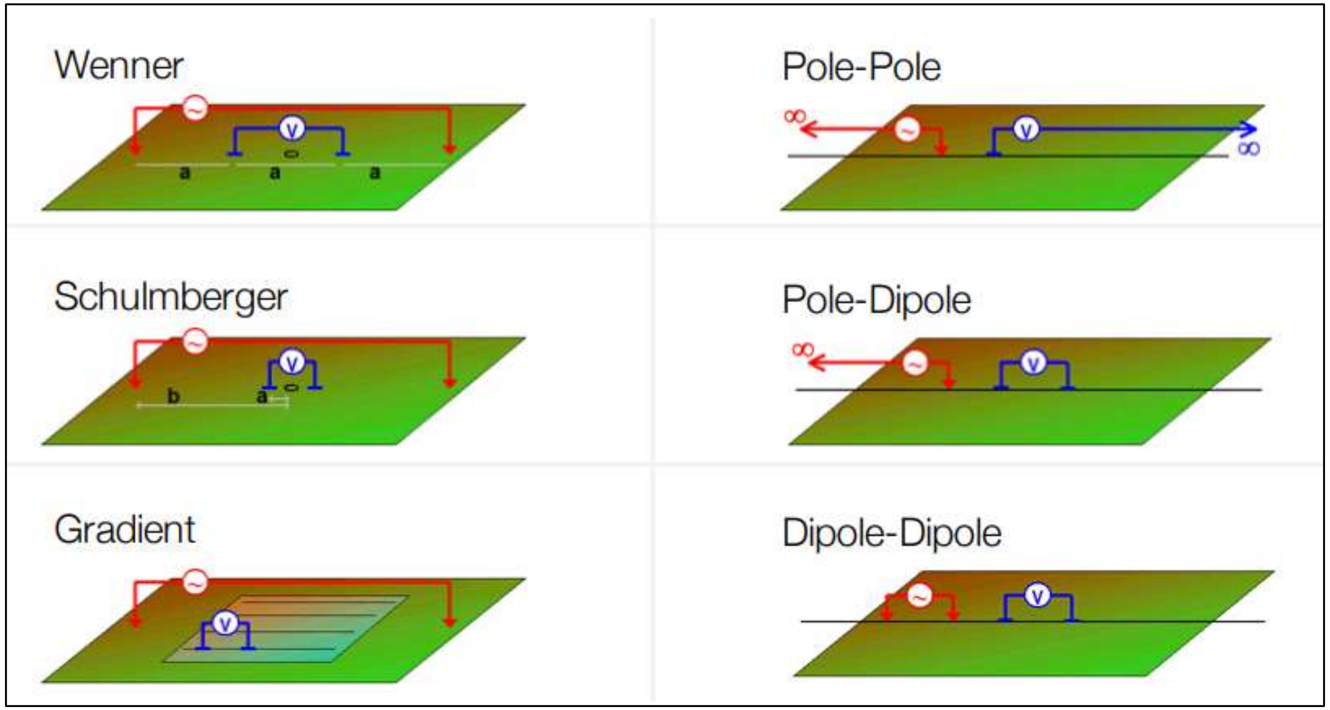

Physical Properties

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

- Is anomalous potential +ve or –ve at location N?
- Is $\Delta V = V_N - V_M$ +ve or –ve?

# Electrode Arrays: A Circuit Perspective

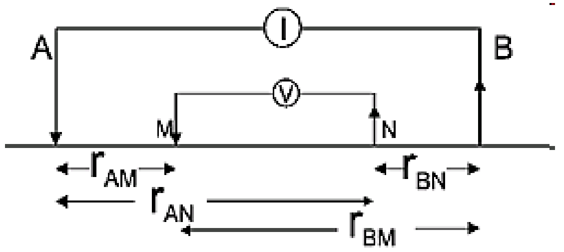



How to gain:

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

# Apparent Resistivity on Pseudo-section

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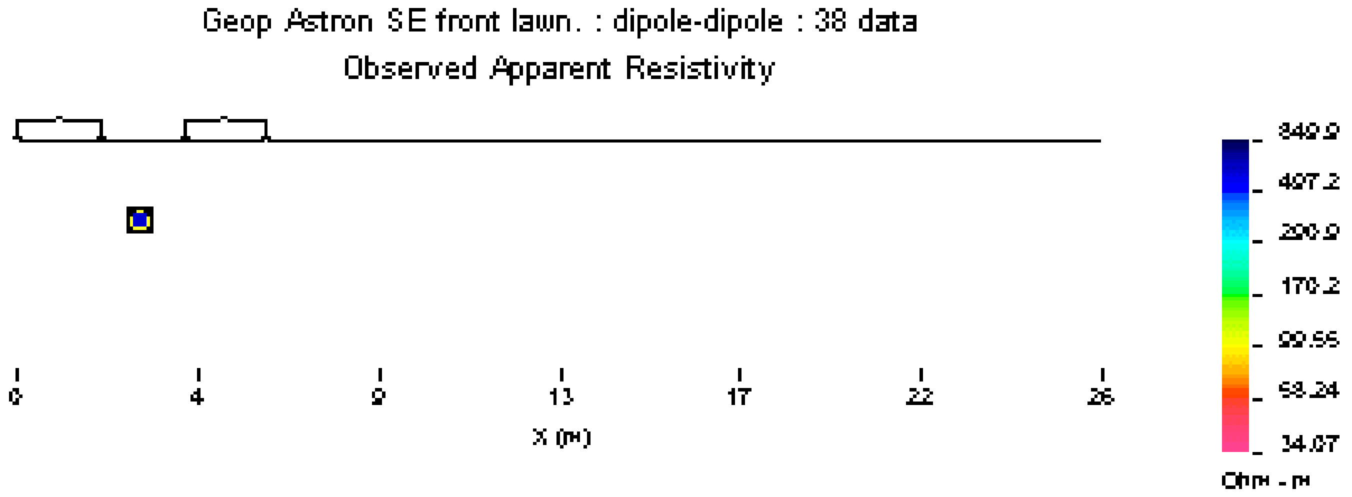
$$\rho = \frac{\Delta V}{IG}$$




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

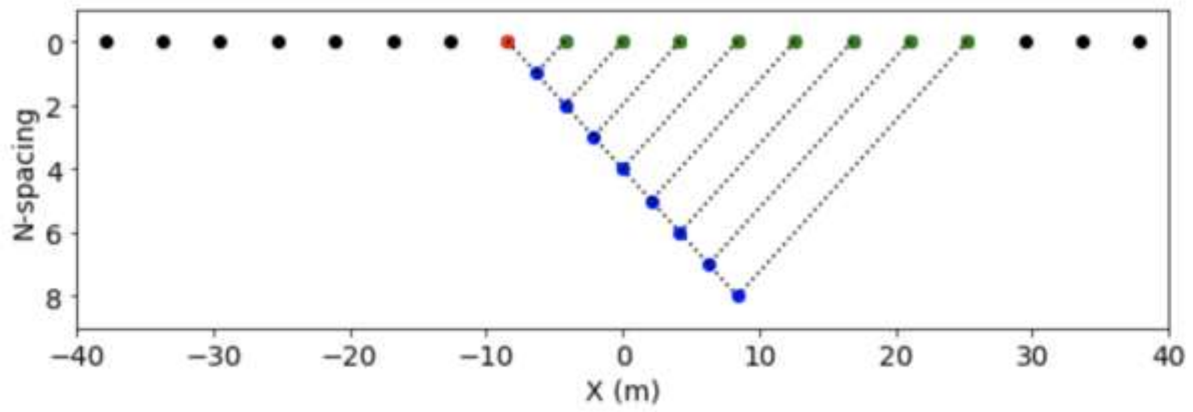
File Edit View Insert Cell Kernel Widgets Help

Trusted | Python 3

Run Code

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

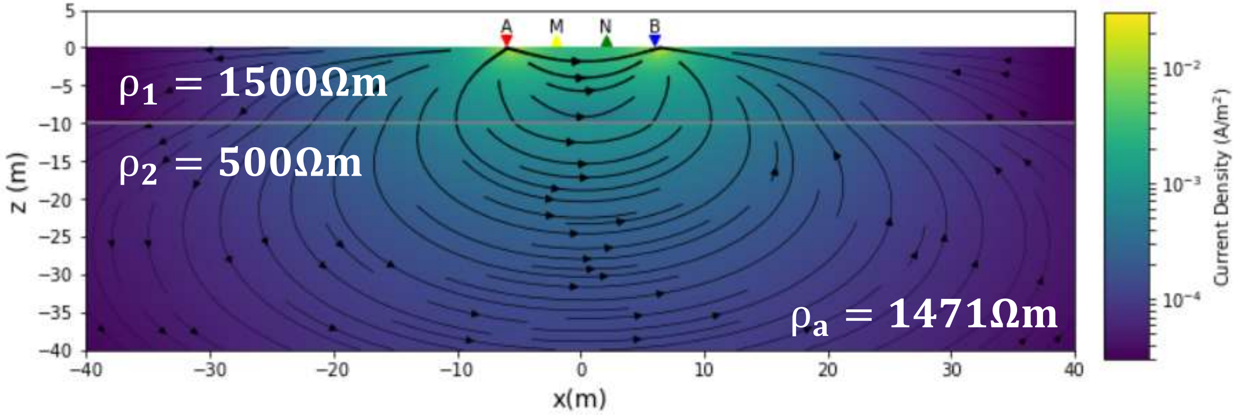
i 7



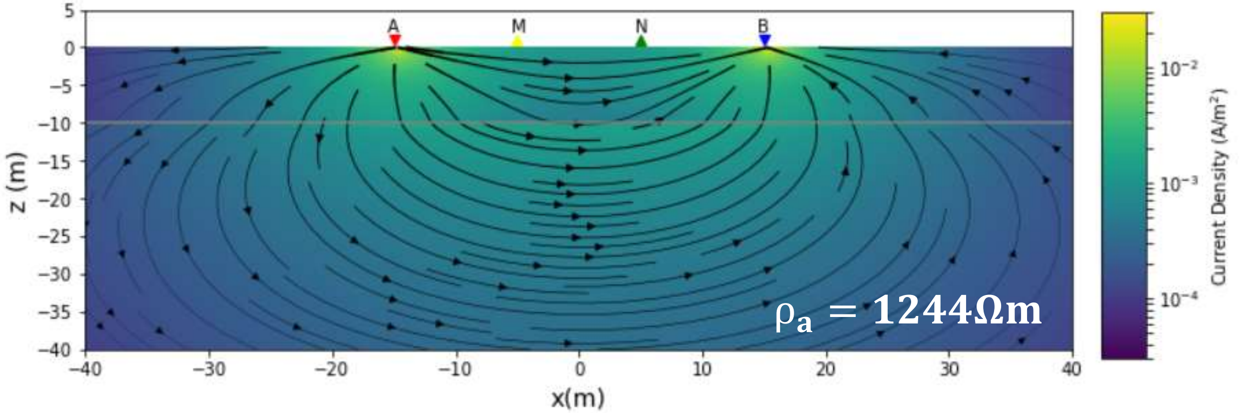

- $\rho_1$ : Resistivity of the halfspace
- $\rho_2$ : Resistivity of the cylinder
- **xc**: x location of cylinder center
- **zc**: z location of cylinder center
- **r**: radius of cylinder
- **surveyType**: Type of survey
- **Run Interact**: Use this button to update your plot

**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.

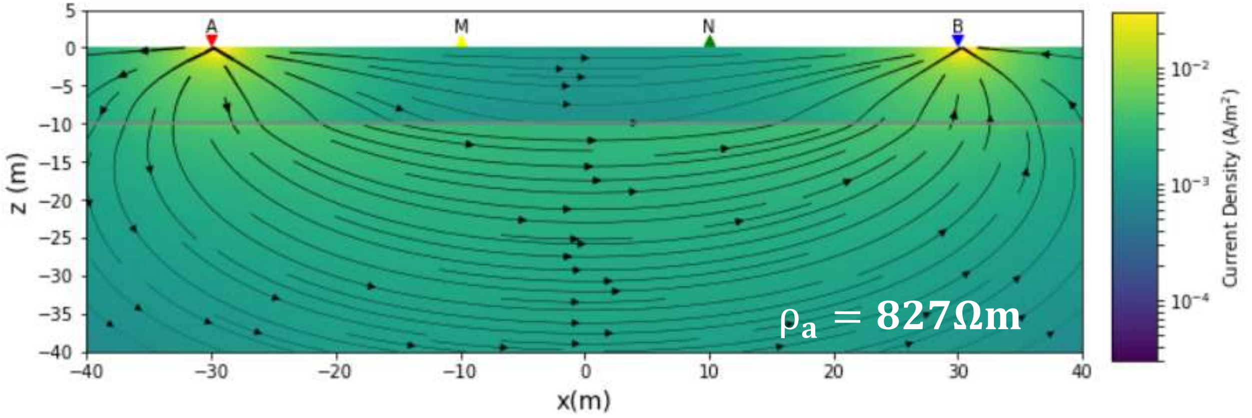
In [6]:
```
out = DC2DPseudoWidget()
display(out)
```




- Most currents near electrodes
- Only sees top layer




- Currents in lower layer
- Lower apparent resistivity




- Apparent resistivity sensitive to lower layer

# Summary

- Electrical: Charge, field, force, potential
- Electrical resistivity/conductivity
- Ohm’s law applied to the Earth: Four-electrode array (ABMN)
- Understanding DC resistivity data
  - Charges build-up
  - Circuit
- Electrode arrays and sensitivity
- Apparent resistivity