What have we learned from the Case Histories

- Earth materials have a range of physical properties.

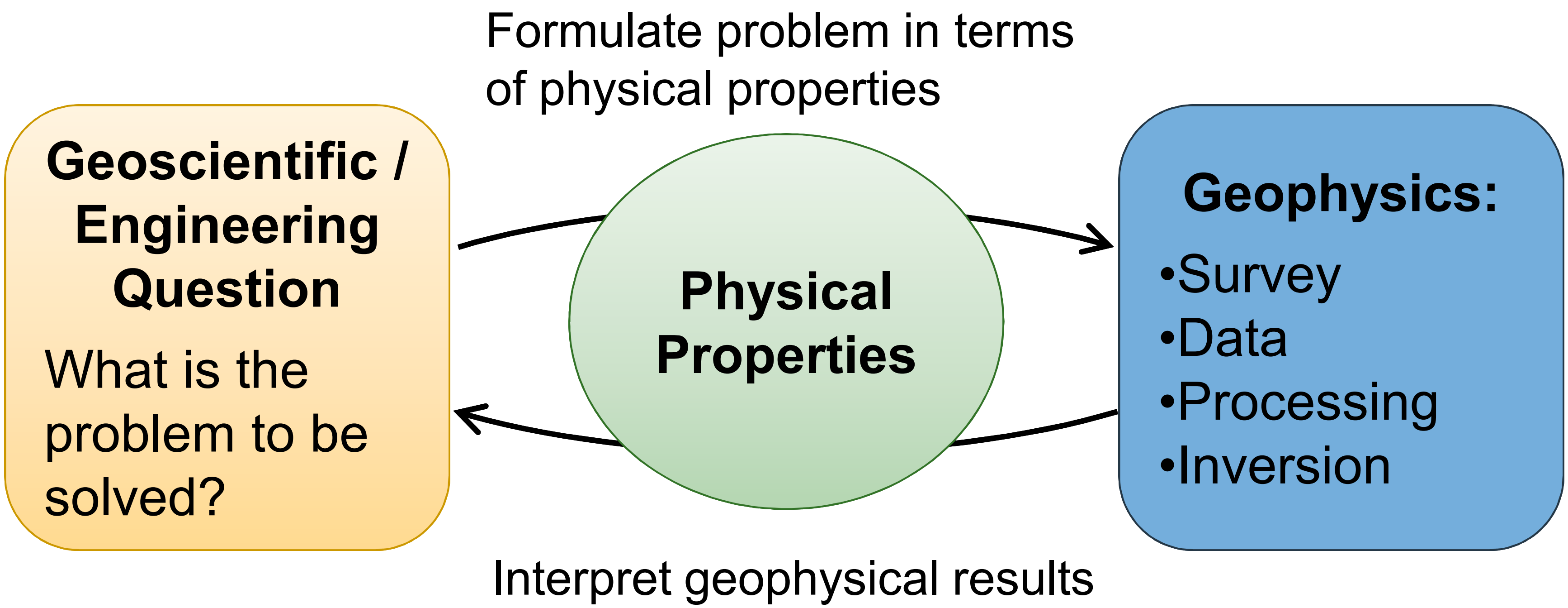
- Application of geophysics is carried out in a 7 Step process. Physical property of the target must be different from host material

- Knowledge of a single physical property does not uniquely identify a material. Interpretation was aided by using multiple surveys.

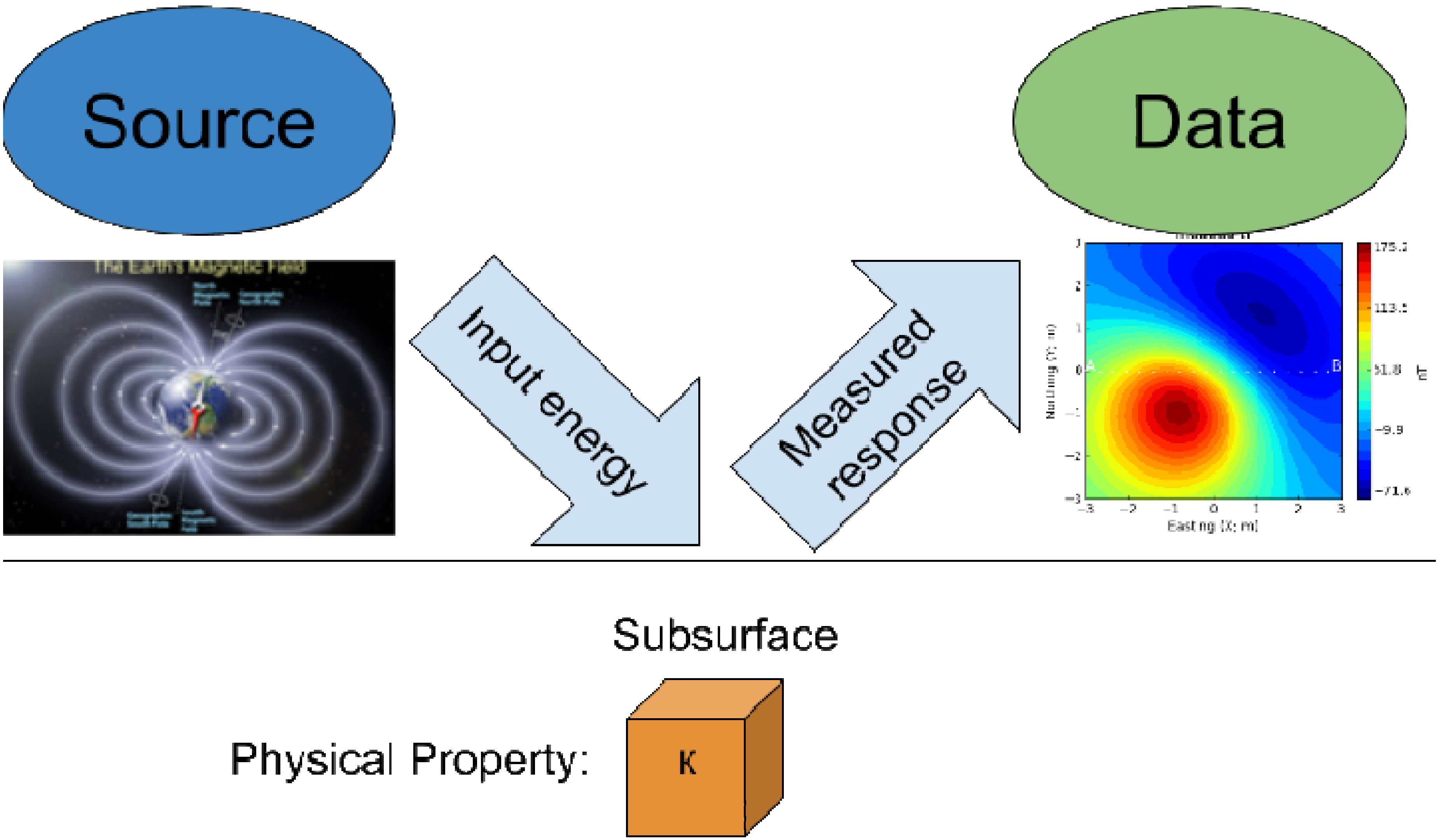
- Examples:
  - Gravel quaries: conductivity, elastic parameters
  - Karst investigations: density, conductivity
  - Mining: conductivity, chargeability

MAGNETIC SURVEYING

Principles for using Geophysics



Magnetic Survey

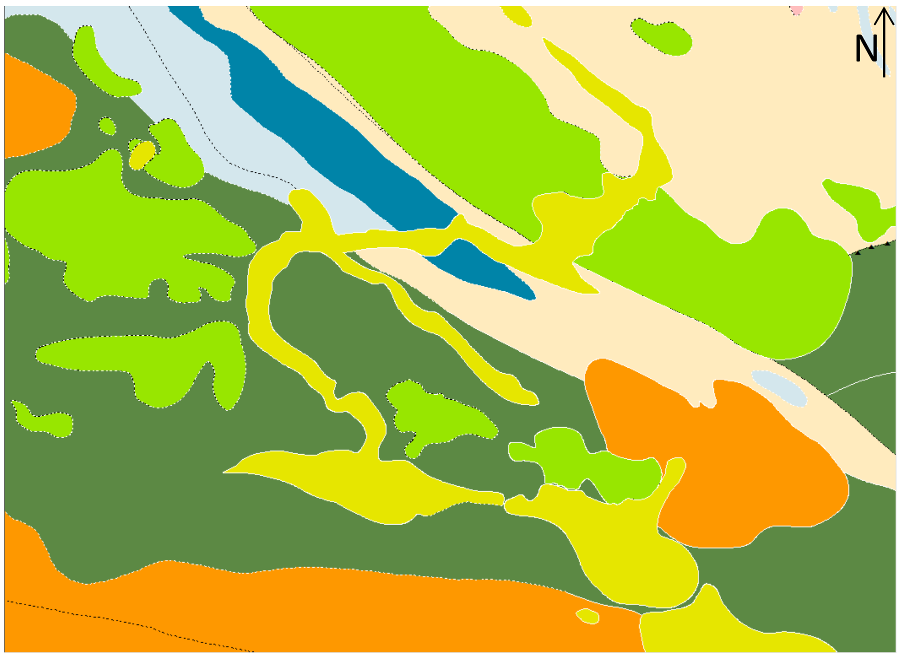


Some motivating examples for the use of magnetic susceptibility

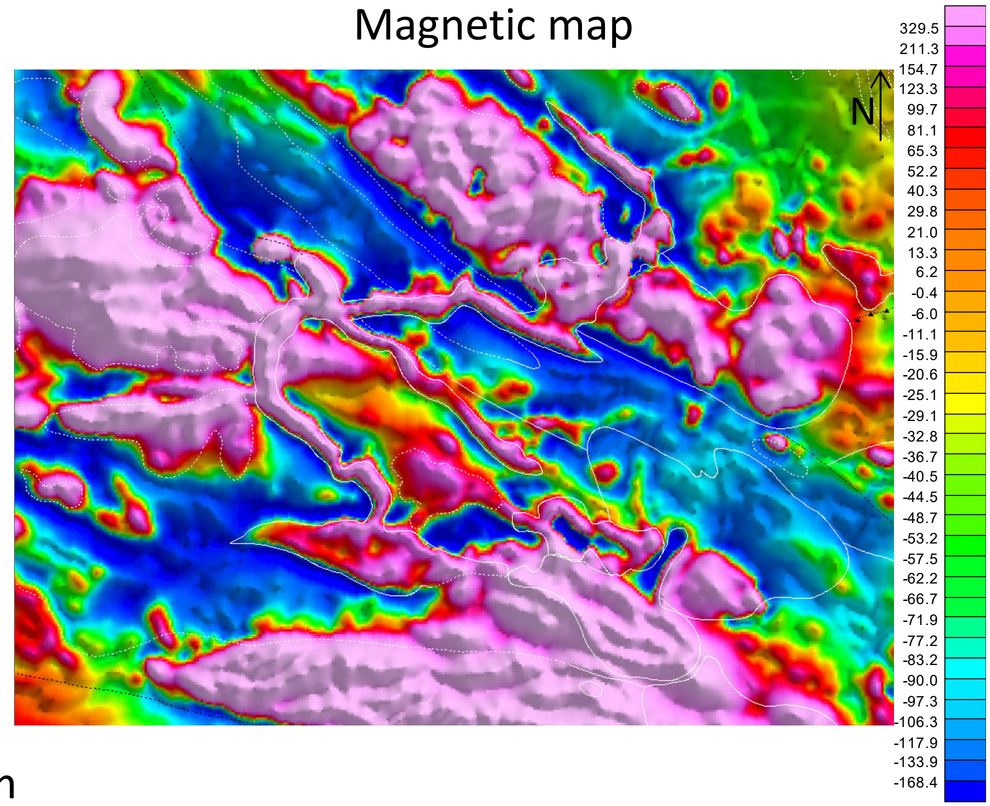
- Geologic mapping
- Ore deposits
- Geotechnical problems
- Unexploded ordnance
- Buried foundations
- Archeology

Need for Magnetics: Geologic mapping

Geology map



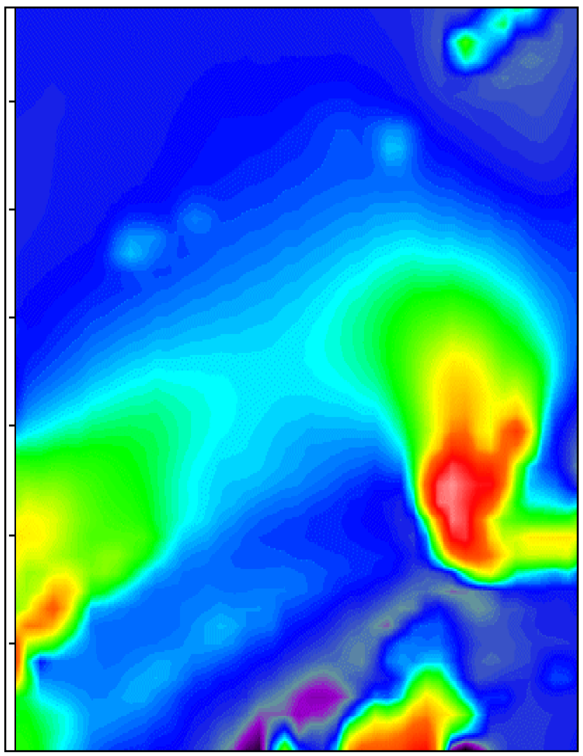
Magnetic map

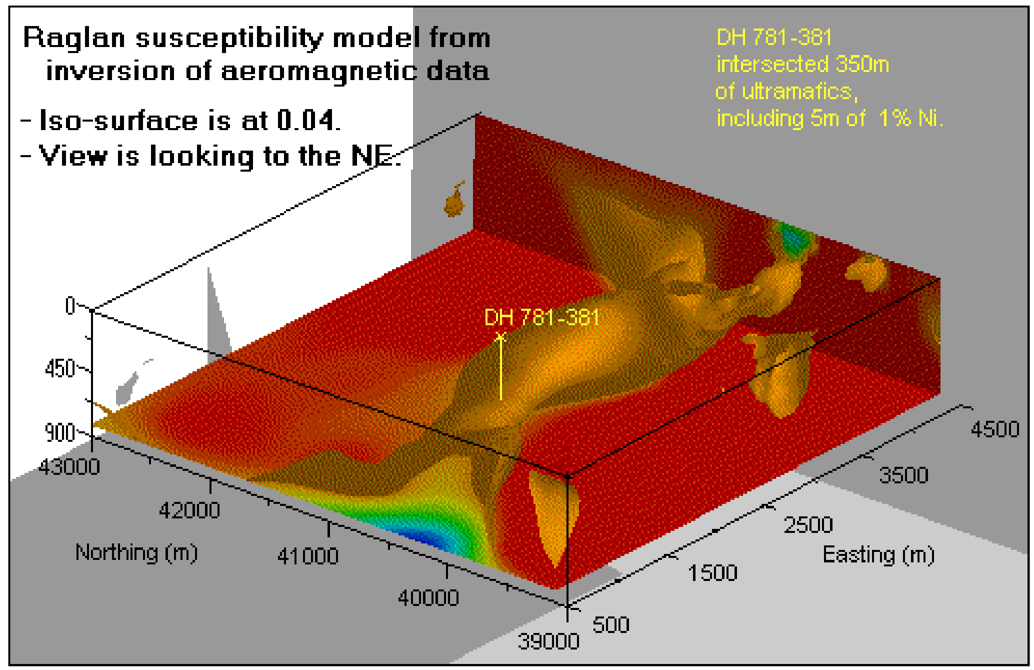


30 km

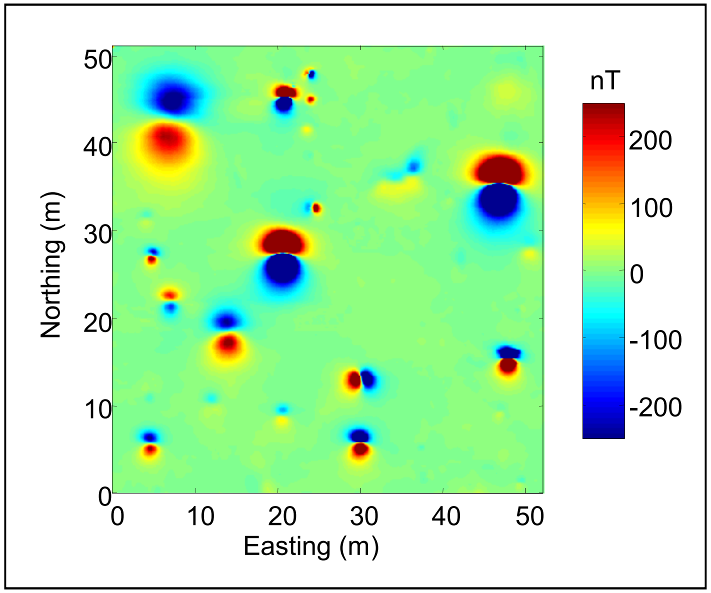
Geology contacts can be inferred from mag maps.

Need for magnetics: Mineral exploration



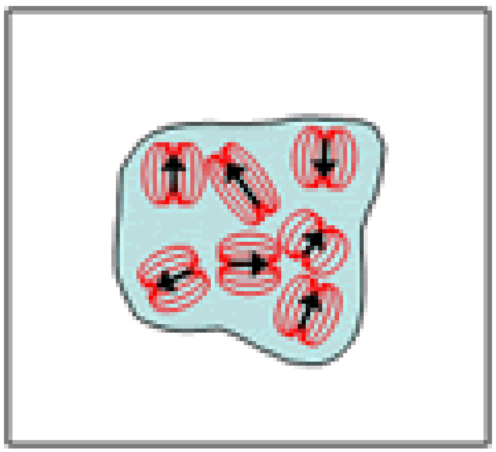


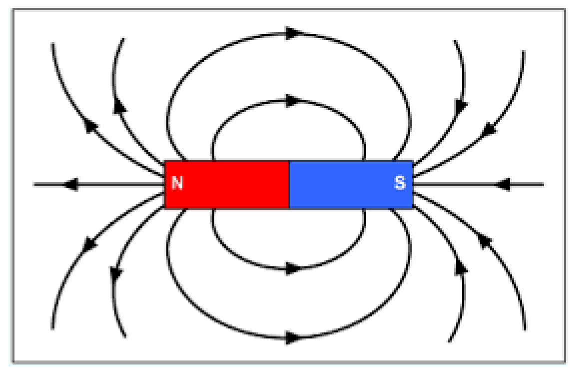
Need for Magnetics: UXO



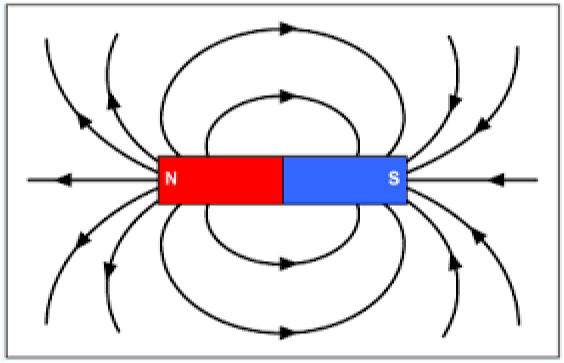
Magnetic materials and Magnetization

- Earth materials are built up of minerals that behave as small magnets



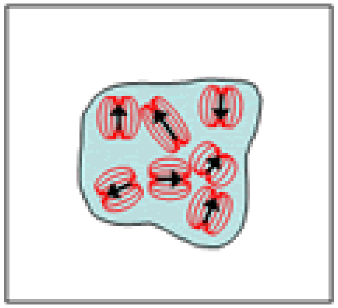


Bar Magnet



- North pole and South pole (dipole)
- Dipole moment m is related to the strength of the magnet
- Field lines extend from the north pole to the south poles

Magnetic materials and Magnetization



- Earth materials are built up of minerals that behave as small magnets
- Strength of each magnet is given by the magnetic moment

  $m_i \;\; A\text{-}m^2$

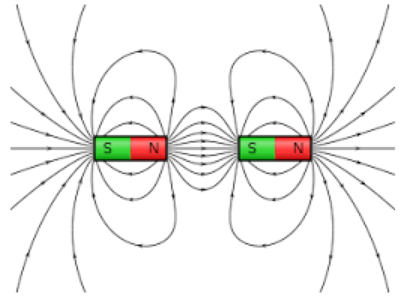
- Magnetization $$M = \frac{\Sigma m_i}{Volume}$$

  Units: A/m dipole moment per unit volume

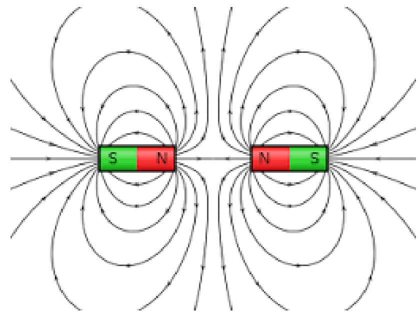
- When the particles are randomly distributed M can be zero

Small magnets in presence of large ones

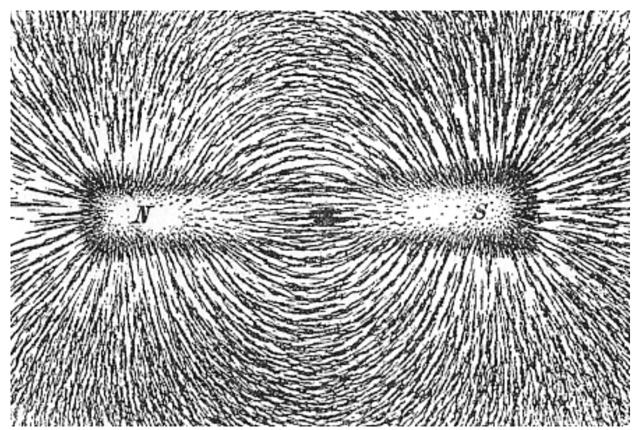
- Opposite poles attract



- Like poles repel

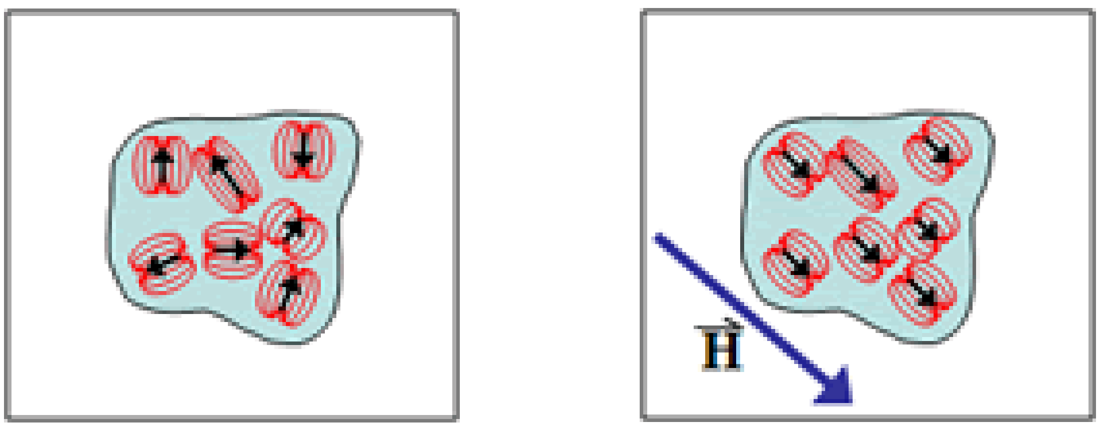


- Small magnets align with fields of a larger magnet



Magnetic Susceptibility: κ

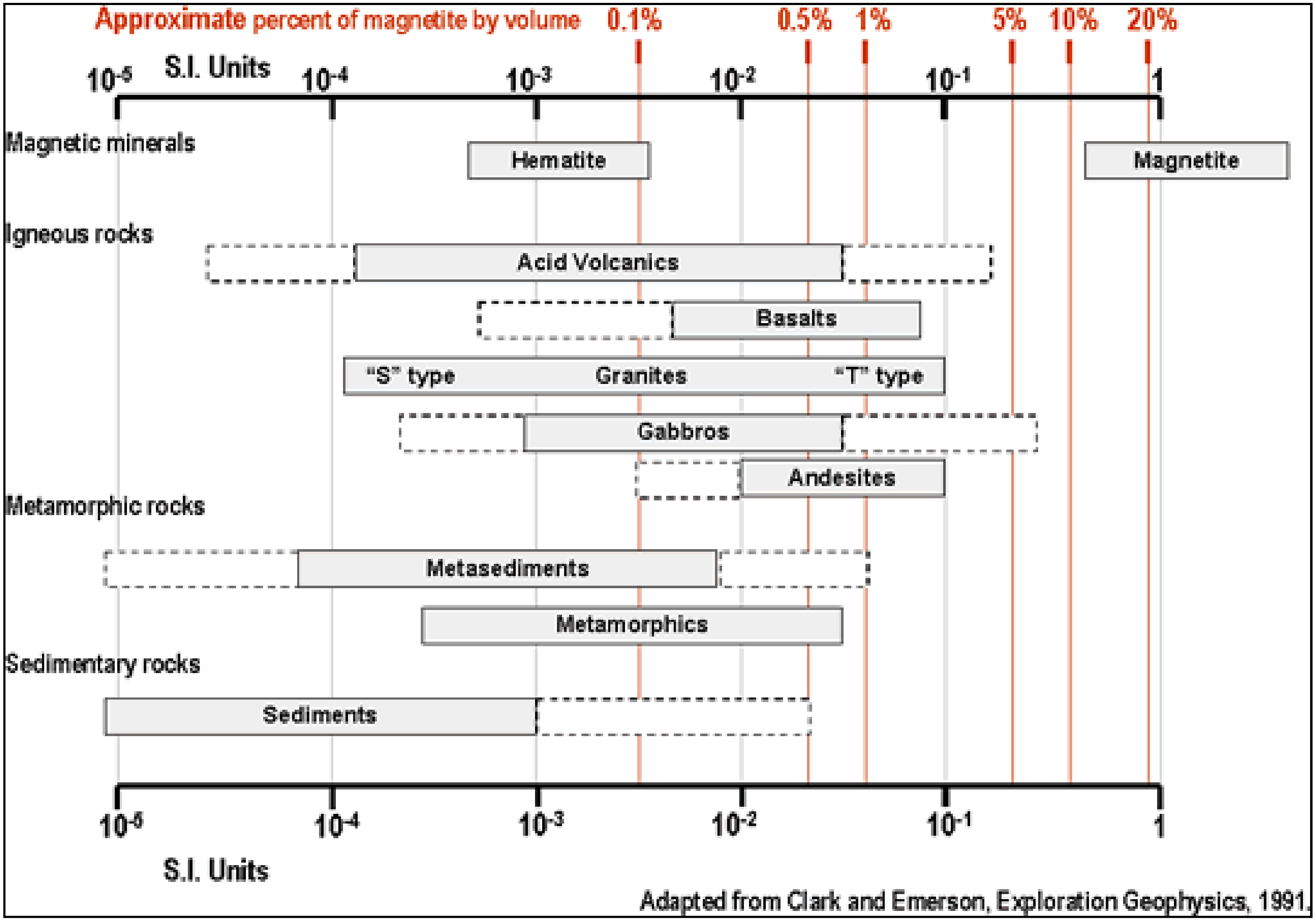
- Ability for a rock to become "magnetized" when an external magnetic field is applied.
- Units: dimensionless



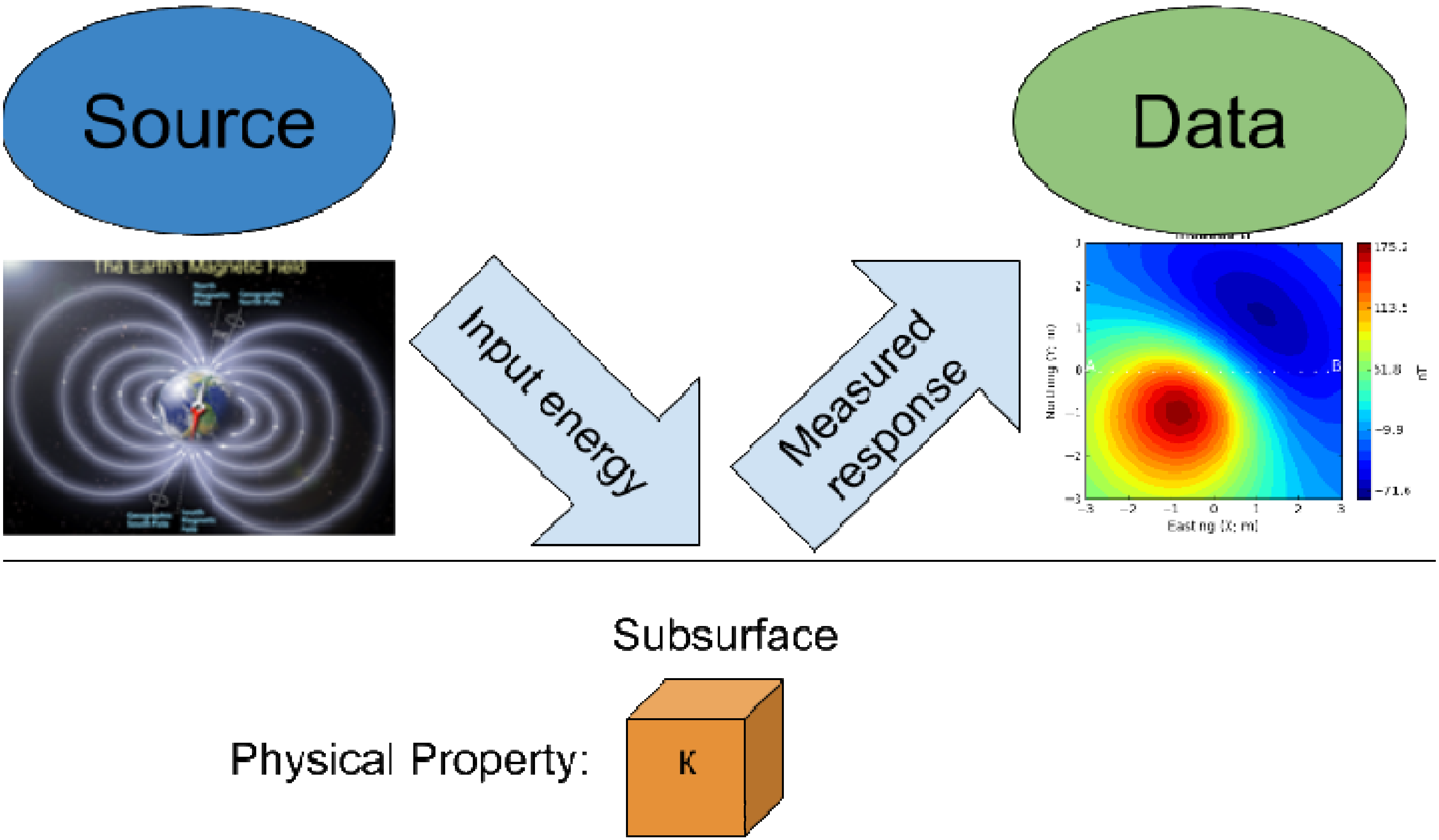
- Magnetization: $M = \frac{\Sigma m_i}{Volume}$

  Units: Dipole moment per unit volume

Magnetic Susceptibility of Rocks

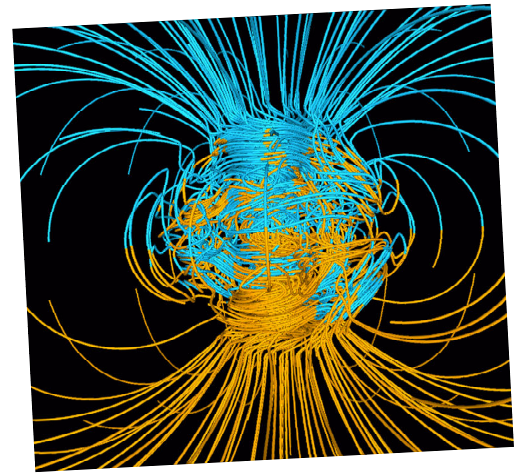


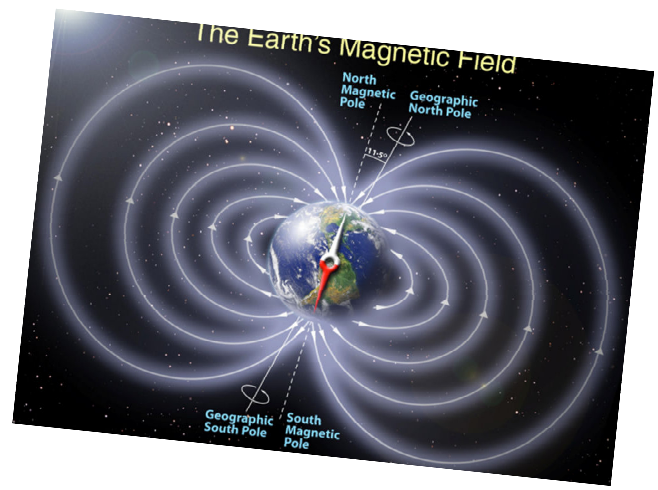
Magnetic Survey



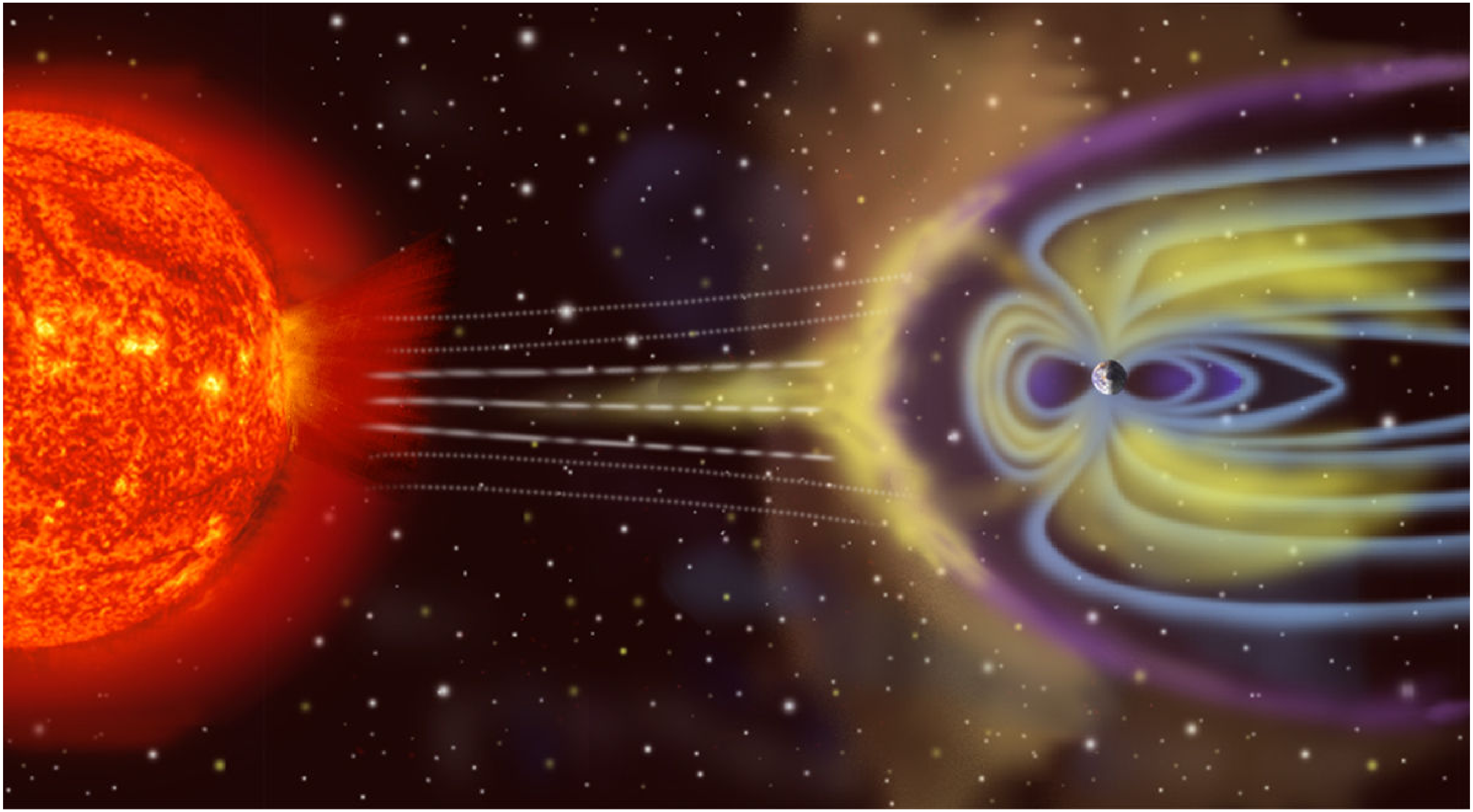
Earth's Magnetic field

- Geomagnetic dynamo.
- Complicated inside the earth near the core.
- Outside the earth it looks like a magnetic field due to a dipole.



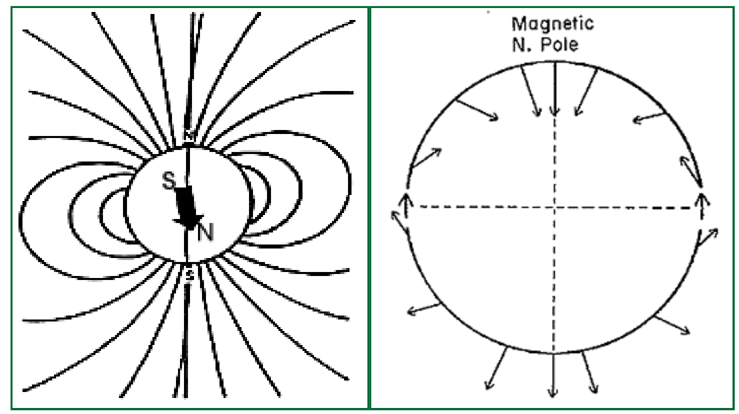


Magnetics – Earth's field



Magnetic fields and definitions

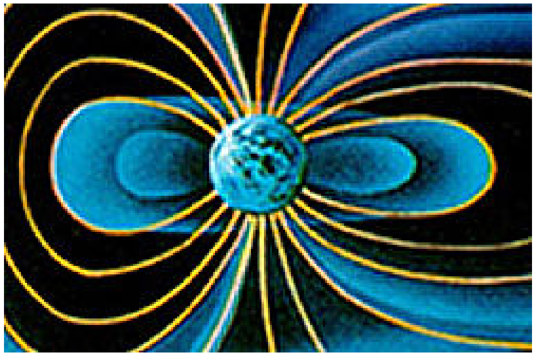
$\vec{B}$: Magnetic Flux Density $(Wb/m^2 = \text{Tesla})$
$\vec{H}$: Magnetic Field (A/m)
$\vec{B} = \mu \vec{H}$



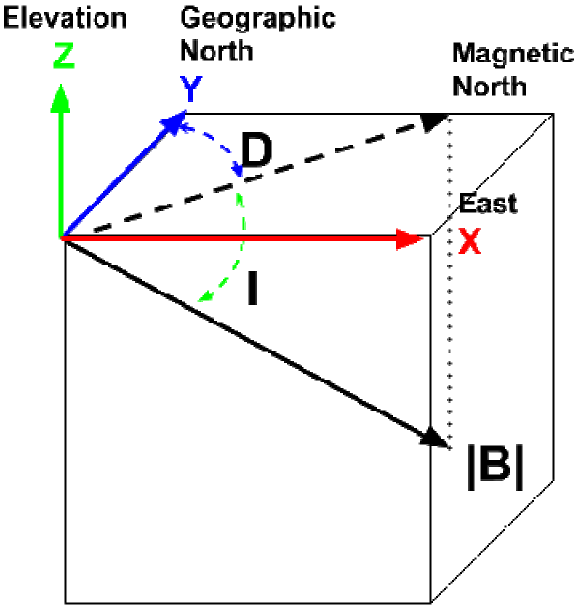
μ = magnetic permeability
$\mu = \mu_0(1 + \kappa)$

Magnetic permeability of free space:
$\mu_0 = 4\pi \times 10^{-7}$

Magnetics – Earth's field

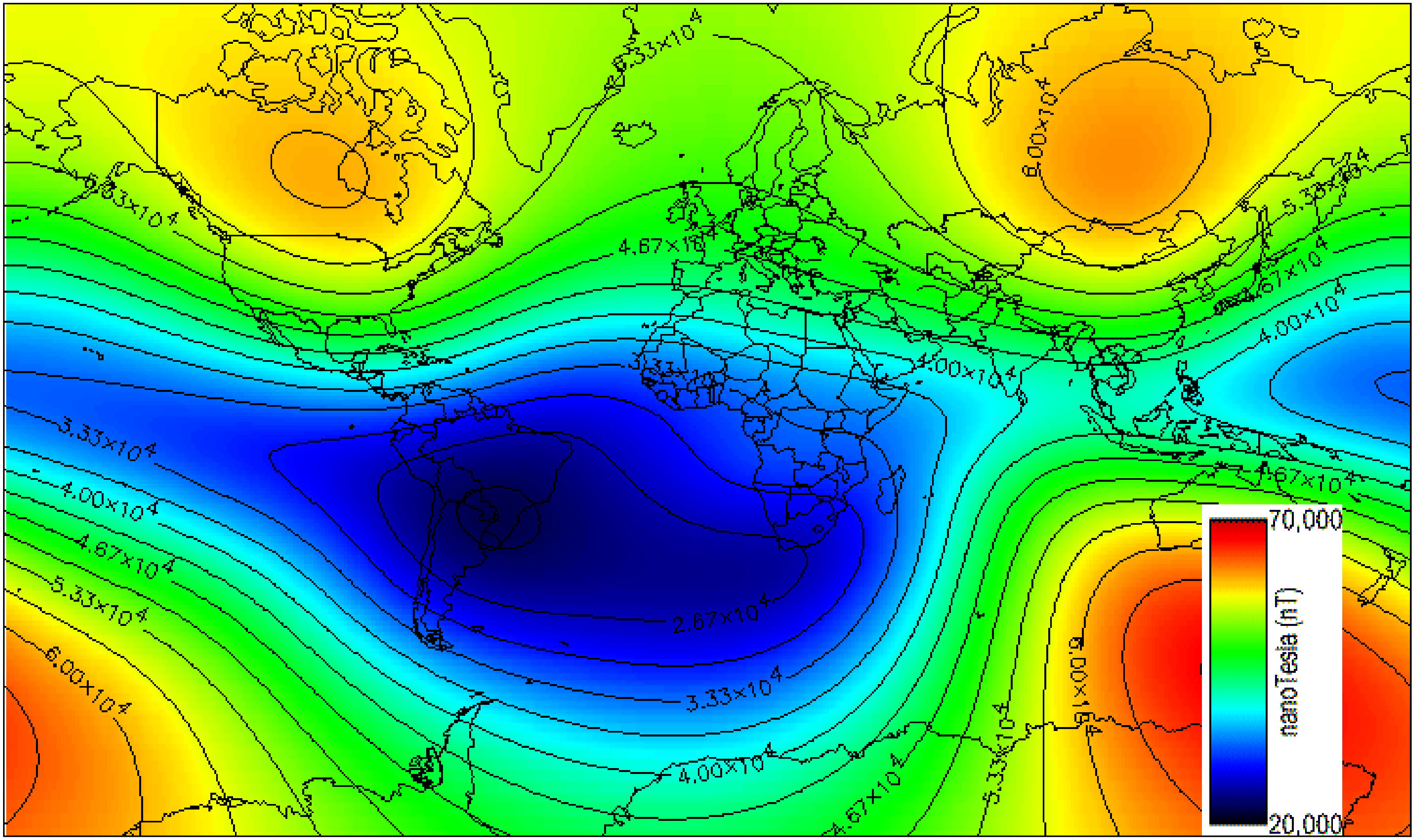


- Link to GPG
- How is the field described anywhere?
  - X, Y, Z
  - Inclination, Declination, Magnitude

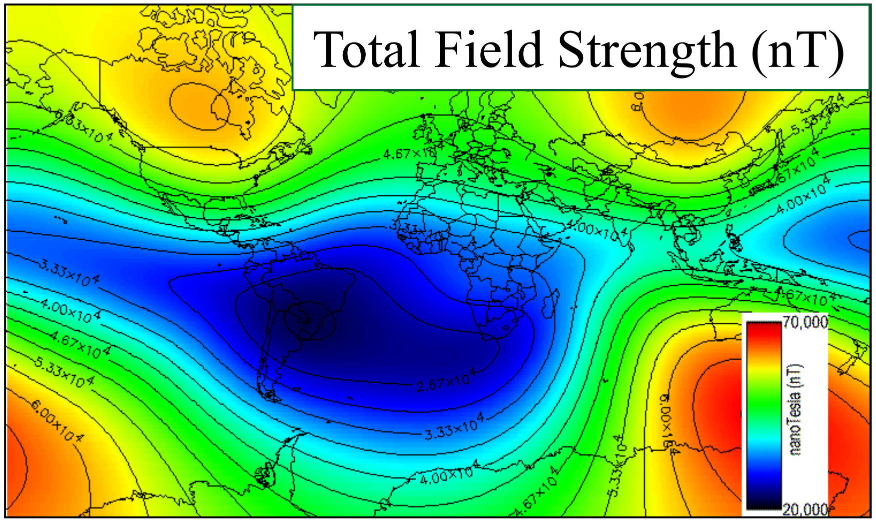


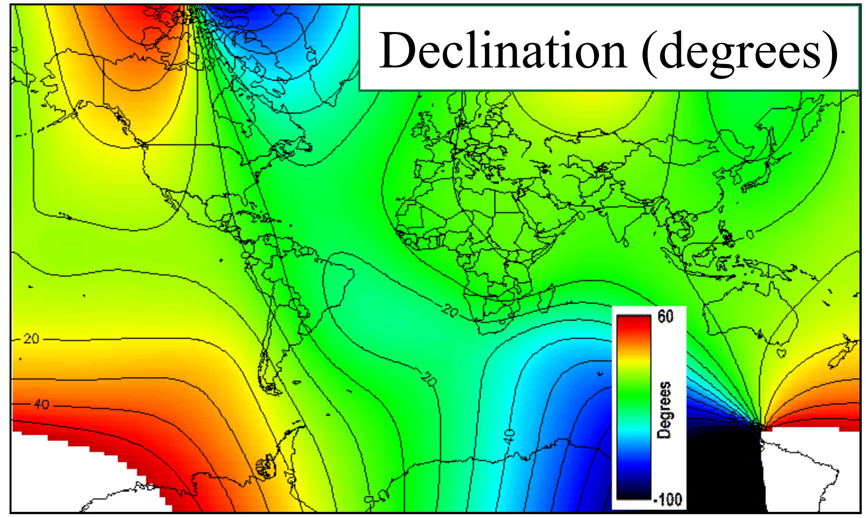
- Compass? Inclination?
- Declination?
- Earth's field strength vs. anomalies.

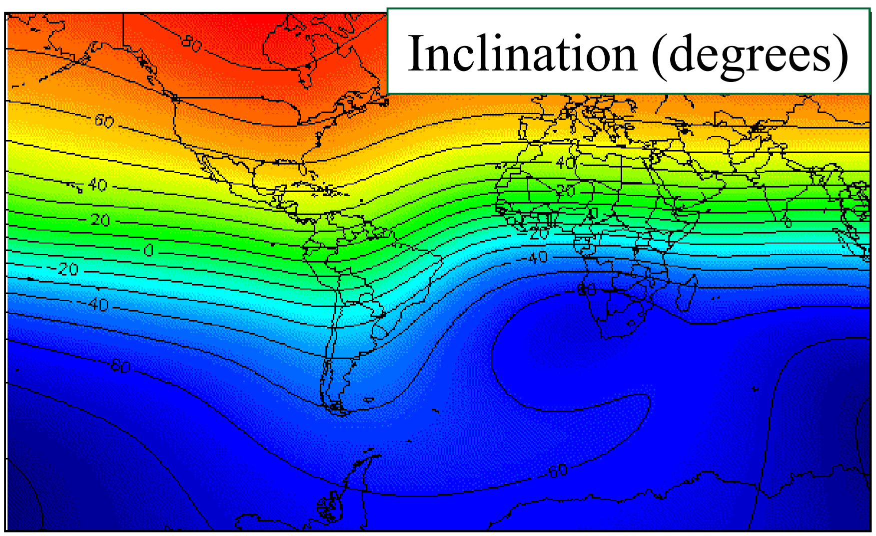
Earth's Magnetic Field



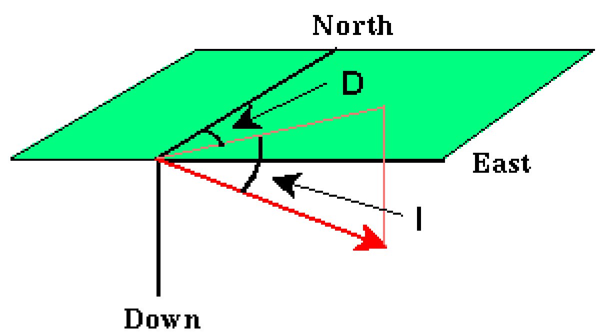
Earth's magnetic field: Strength |B| Inclination I   Declination D

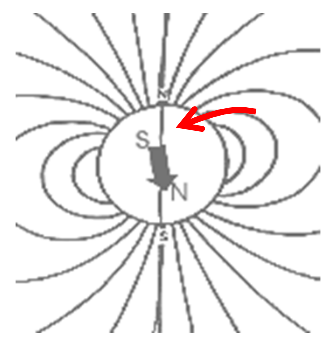






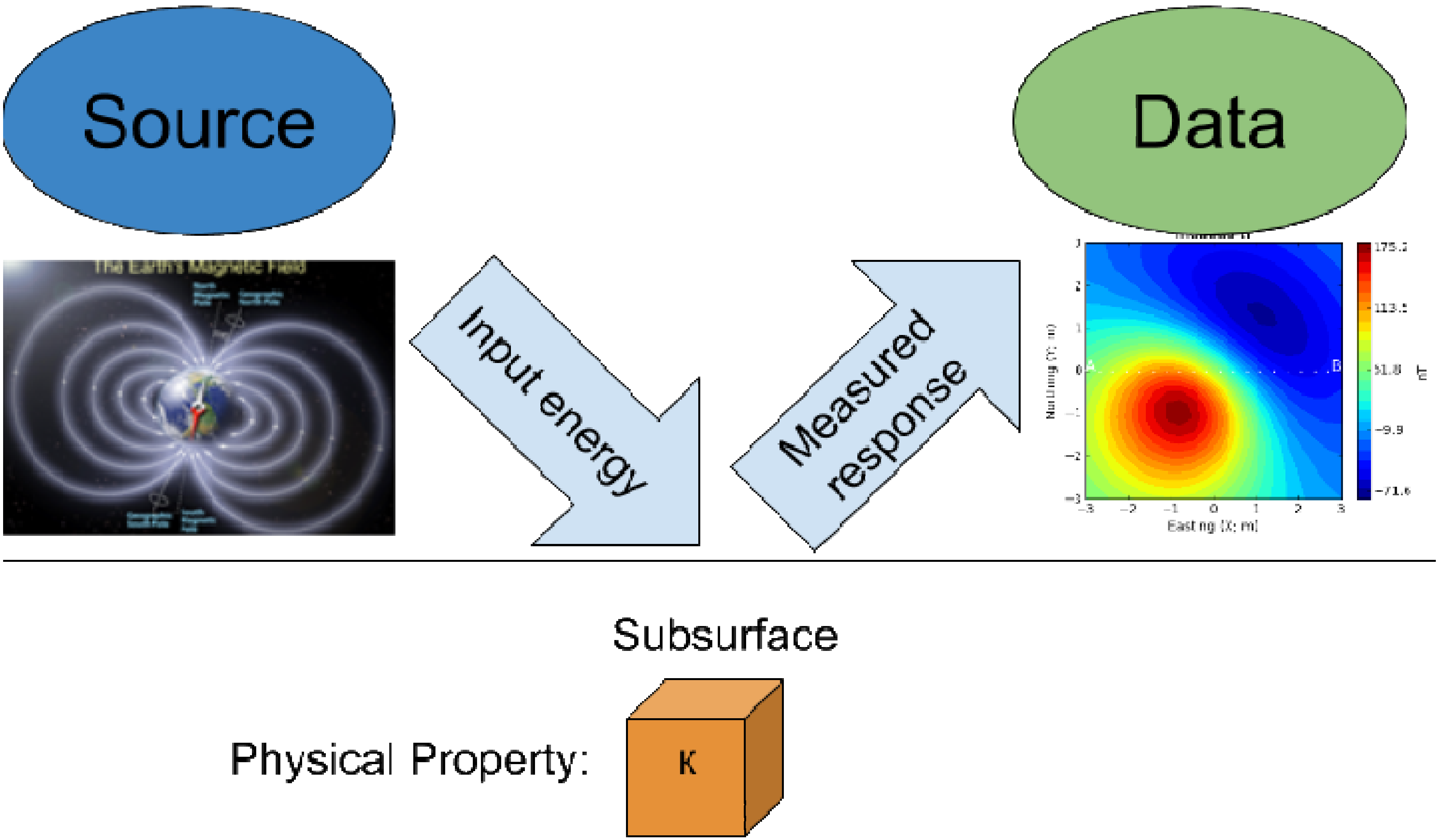
$\mathbf{B}_{max}$ = 70,000 nT $\mathbf{H}_{max}$ = 55.7A/m
$\mathbf{B}_{min}$ = 20,000 nT $\mathbf{H}_{min}$ = 15.9A/m





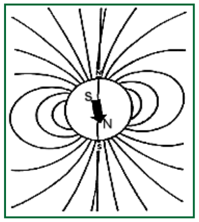
http://www.ngdc.noaa.gov/cgi-bin/seg/gmag/igrfpg.pl

Magnetic Survey

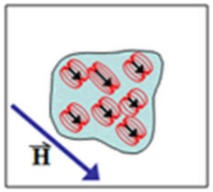


Basics of Magnetics Surveying

- Earth's magnetic field is the source:



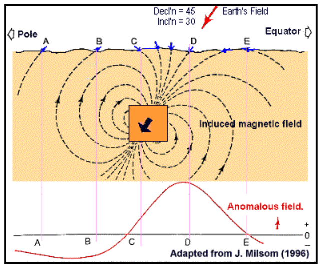
- Materials in the earth become magnetized



$$\vec{M} = \kappa \vec{H}$$ (dipole moment per unit volume)

- Magnetized rocks create anomalous

(compact object looks like a magnetic dipole)



- The anomalous field is a vector. To view we project it onto specific directions (x, y, z)

Magnetic Applet

Simulating the field due to prisms

Define a 3D prism

Our model is a rectangular prism. Parameters to define this prism are given below:

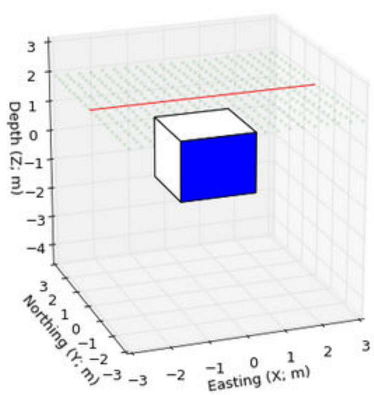
- dx: length in Easting (x) direction (meter)
- dy: length in Northing (y) direction (meter)
- dz: length in Depth (z) direction (meter) below the receiver
- depth: top boundary of the prism (meter)
- pinc: inclination of the prism (reference is a unit northing vector; degree)
- pdec: declination of the prism (reference is a unit northing vector; degree)

You can also change the height of the survey grid above the ground

- rx_h: height of the grid (meter)

Green dots show a plane where we measure data.

dx 2
dy 2
dz 2
depth 0
pinc 0
pdec 0
npts2D 20
xylim 3
rx_h 1.9
View_elev 20
View_azim 250



Magnetic applet

Based on the prism that you made above, below Magnetic applet computes magnetic field at receiver locations, and provide both 2D map (left) and profile line (right).

For the prism, you can alter:

- sus: susceptibility of the prism

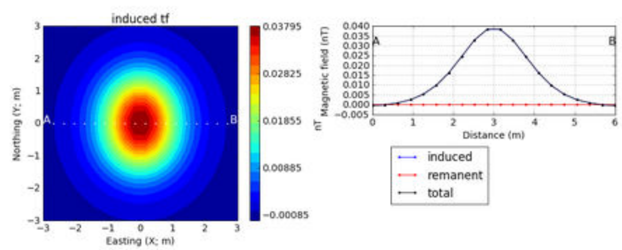
Parameters for the earth field are:

- Einc: inclination of the earth field (degree)
- Edec: declination of the earth field (degree)
- Bigrf: intensity of the earth field (nT)

For data, you can view:

susc 0.1
Einc 90
Edec 0
Bigrf 54500
comp tf bx by bz
irt induced remanent total
Q 0
rinc 0
rdec 0

```
Computing G
Computing G
```




```
True
```

- [Interactive and live … click here]

Learning from the applet

- Locating the prism at the pole and equator
  - Plotting Bx,By,Bz fields (sign convention)
  - Map data
  - Profile
  - Profile over a magnetic dipole.

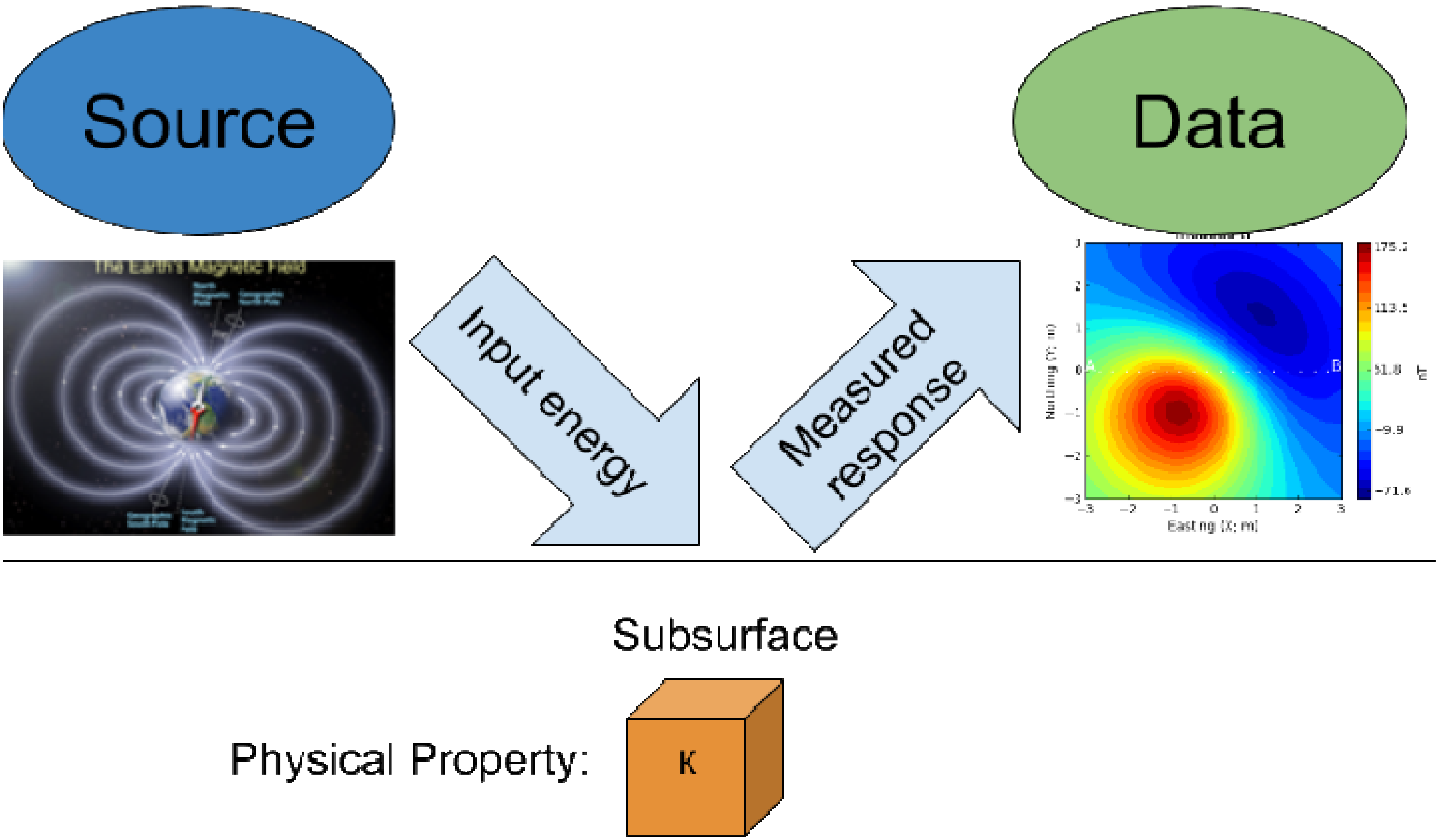
- Effects of depth of burial (half width)

- Data sampling

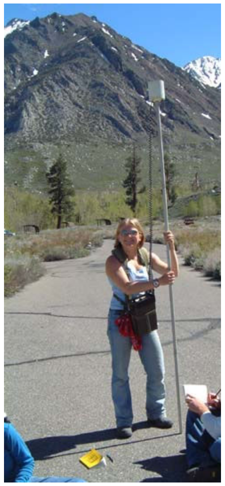
Survey Acquisition (with applet)

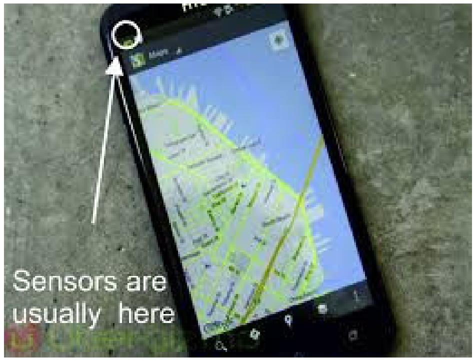
- Must sample data sufficiently often to capture the anomaly.
- Want 3-5 points in a halfwidth
- Width of the signal increases with depth of burial.
- Ground surveys generally choose line spacing and station spacing to be equal.

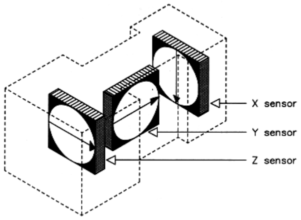
Magnetic Survey



Magnetic Sensors to acquire data







In-class magnetic surveying: Detection

- Magnetic material underneath the table tops.
- NO PEEKING!!!!
- Use magnetic compass on smartphones (download apps if not already done)
- Carry out a survey to detect the magnetic bodies.
- Flag them with tape.

If the magnet was a UXO

- Magnet:
- diameter: 6mm;

- UXO
- 20cm in diameter…

- If our table: ~ 1m X 3m

how large would a survey area equivalent to the table be?

- Length scale ratio ~1:33
- Survey area ~ 10m x 30m

If the magnet was a UXO

If the magnet was a UXO

Team Exercise: Searching for $1B Cu deposit

- Magnet: diameter: 6mm; height=2mm vol 5.65e-8 m^3
- For table size: ~ 1m X 3m

- Price: $310 USD/lb; $684 /kg
- $1 billion. I need: ??? Kg
- Density of copper 8960 kg/m^3
- Need ??? m^3 of copper
- Assume 0.3% Cu by volume: ??? m^3
- Scale length of deposit: 1 ~ ????
- Survey area: ?? km x ?? km

Student exercise

- Magnet: diameter: 6mm; height=2mm vol 5.65e-8 m^3
- Table: 1m x 3m

- Find a copper resource worth $1B
- Price: $3.10 USD/lb; $6.84 /kg (Note decimal)
- $1 billion 1,461,305 kg
- Density of copper 8960 kg/m^3
- Need 163 m^3 of copper
- Assume 0.3% Cu by volume: 54,330 m^3 (cube: 38 m on side)

- Scale length: $$\left(\frac{V_c}{V_m}\right)^{\frac{1}{3}} \simeq 10000 \tag{1}$$

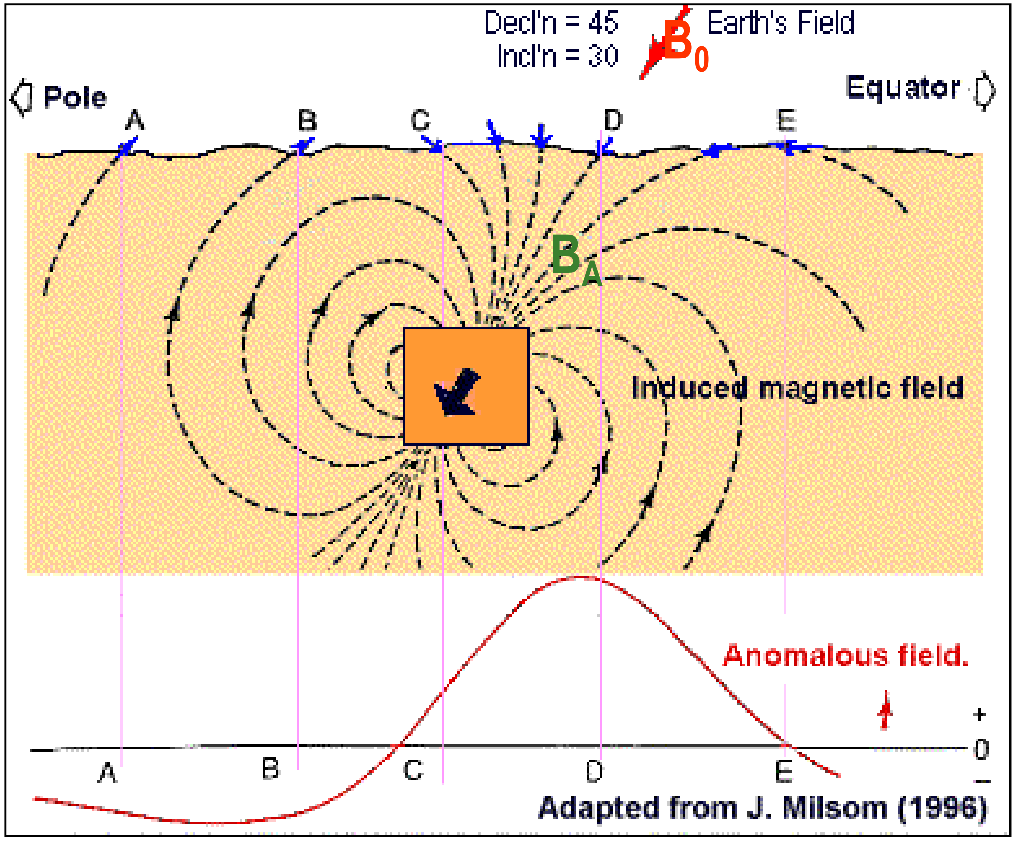
- Survey area: 10 km x 30 km

If the magnet was a billion dollar copper deposit

Readings

- GPG Magnetics
- Lab #2 (see course website)

The composite field



Composite field:

$$\mathbf{B} = \mathbf{B_0} + \mathbf{B_A}$$

B is a vector:

$$\mathbf{B} = \{B_x, B_y, B_z\}$$

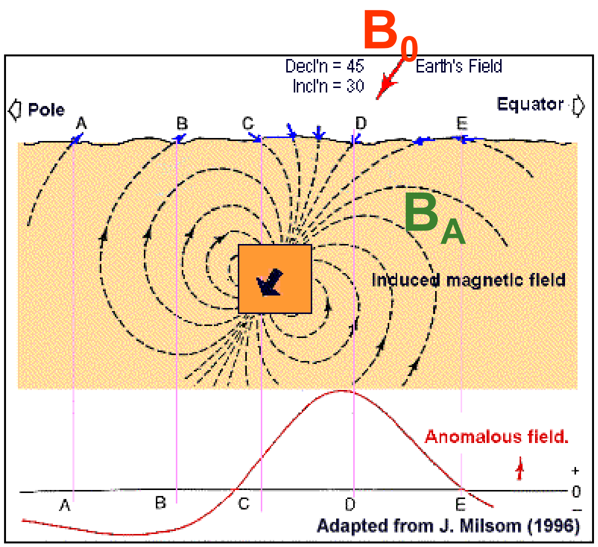
Total field:

$$|\mathbf{B}| = |\mathbf{B_0} + \mathbf{B_A}|$$

The Anomalous field

Measured field B = B_0 + B_A

[Link to GPG](#)

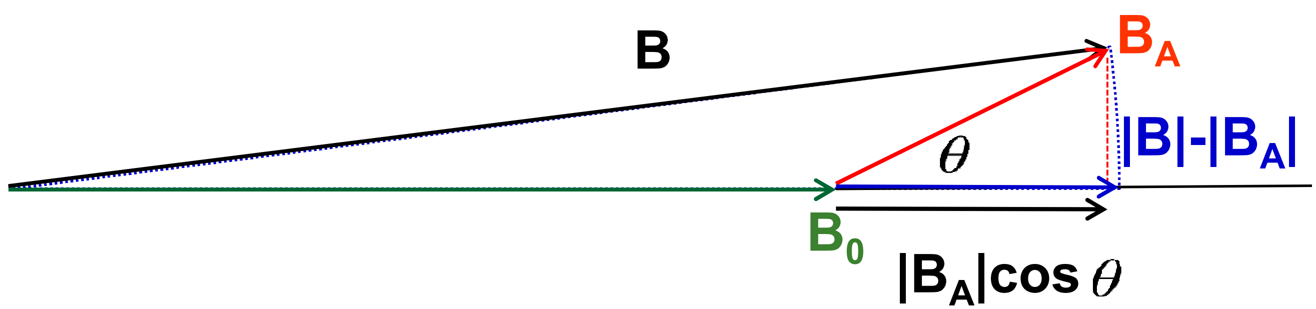


- The *total* field *anomaly*: **$\Delta B = |B| - |B_0|$**
- If $|B_A| \ll |B_0|$ then
- That is, total field anomaly **ΔB** is the projection of the anomalous field onto the *direction* of the inducing field.

$$\Delta\vec{B} \simeq \vec{B}_A \cdot \hat{B}_0$$

Why is the total field anomaly: $\triangle\vec{B} \simeq \vec{B}_A \cdot \hat{B}_0$

- Vector Diagram



$$
\begin{aligned}
|\triangle\vec{B}| &= |\vec{B}_0 + \vec{B}_A| - |\vec{B}_0| \\
&\simeq \vec{B}_A \cdot \hat{B}_0 \\
&= |\vec{B}_A| cos\theta
\end{aligned}
$$

Data Processing

- Removing time variations of the Earth's field (necessity for a base station)

- Removing a regional trend

Magnetics – Earth's field