SUSTech Southern University of Science and Technology
南方科技大学
SOUTHERN UNIVERSITY OF SCIENCE AND TECHNOLOGY
地球与空间科学系
DEPARTMENT OF EARTH AND SPACE SCIENCES

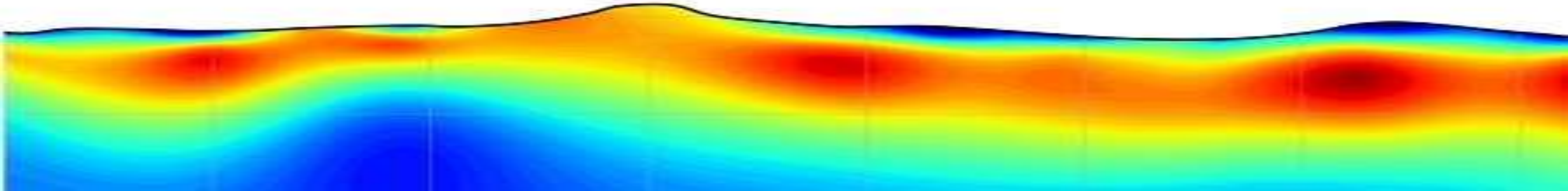
ESS302 Applied Geophysics II

Gravity, Magnetic, Electrical, Electromagnetic and Well Logging

Magnetic 1: Theory

Instructor: Dikun Yang

Feb – May, 2019



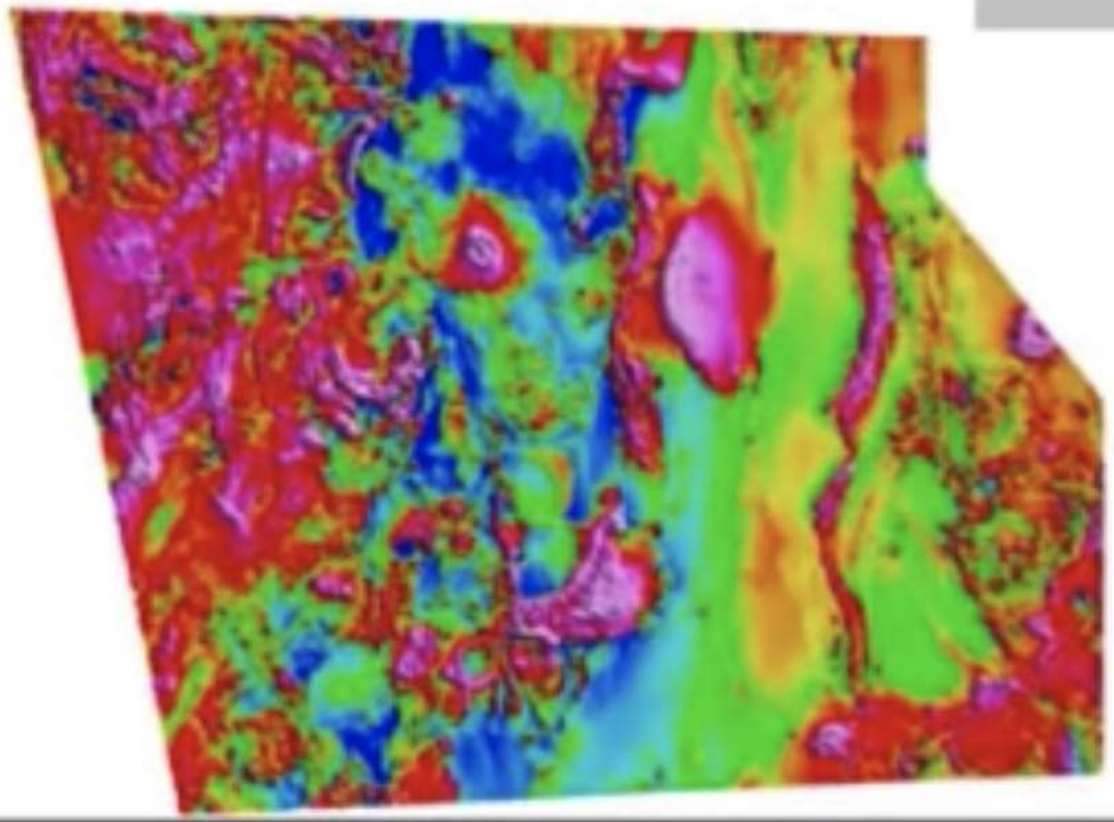
Quiz

- Name two techniques in the gravity method that can enhance boundary detection.
- In a sinkhole mapping project, the basement relief produces long-wavelength or short wavelength signals of gravity data?
- True or false and why: Gravity 3D inversion can resolve the exact structure of density in the subsurface.

Contents

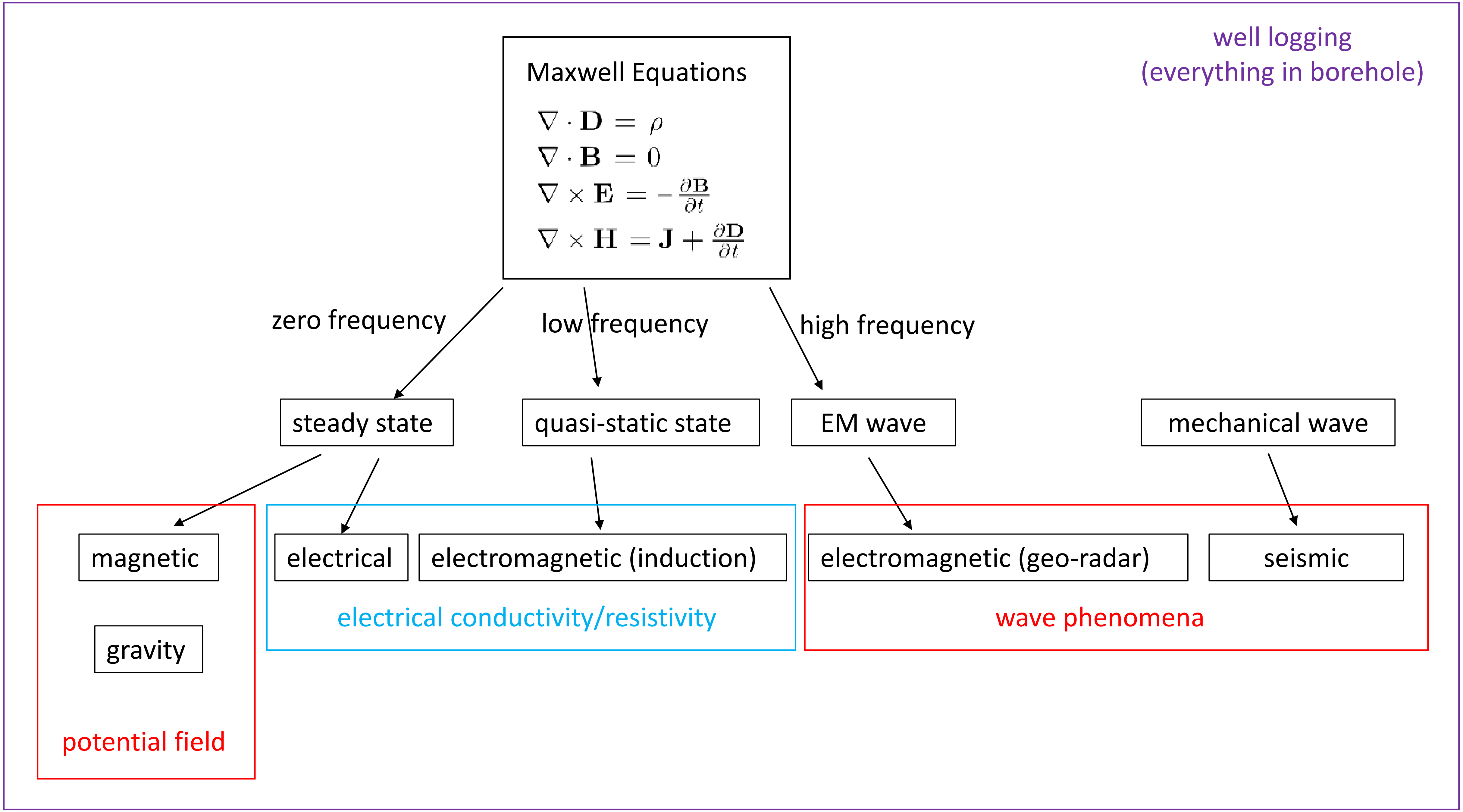
- Magnetic “charge” and dipole
- Earth’s magnetic field
- Magnetometer app demo
- Induced magnetization
  - Magnetic dipole response
  - Susceptibility

MAGNETIC IMAGING



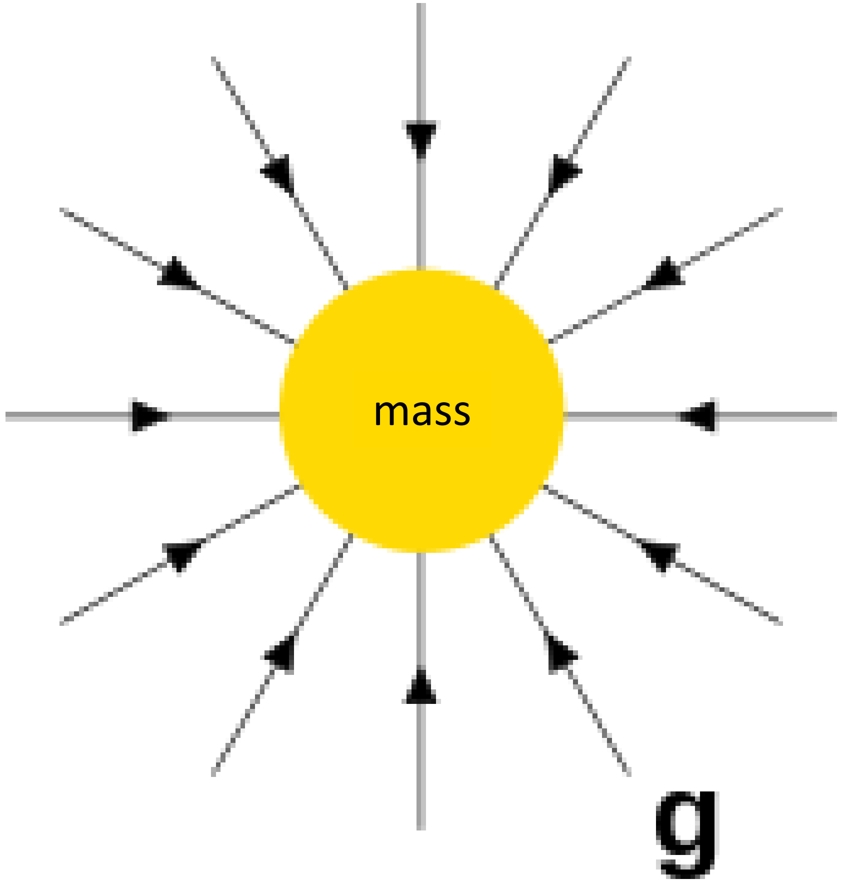
https://youtu.be/dUJib5s4B60

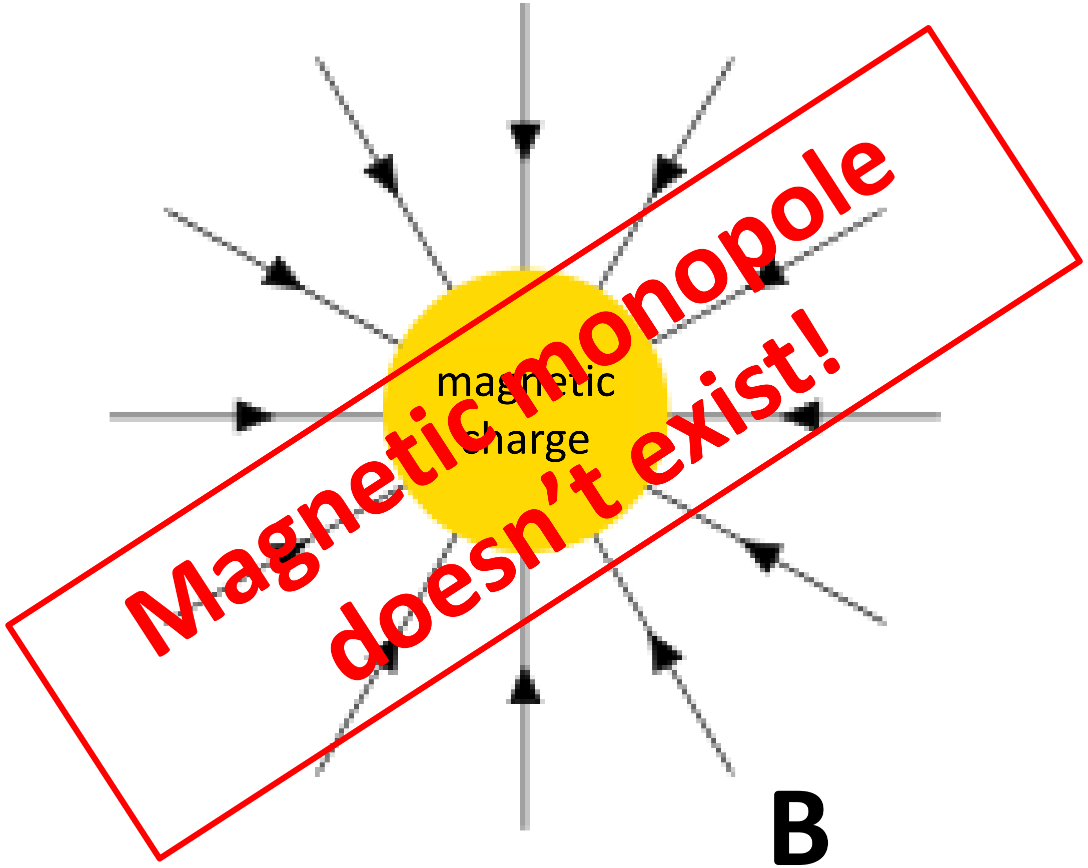
Magnetic surveying measures
local magnetic field characteristics of a surveyed region.



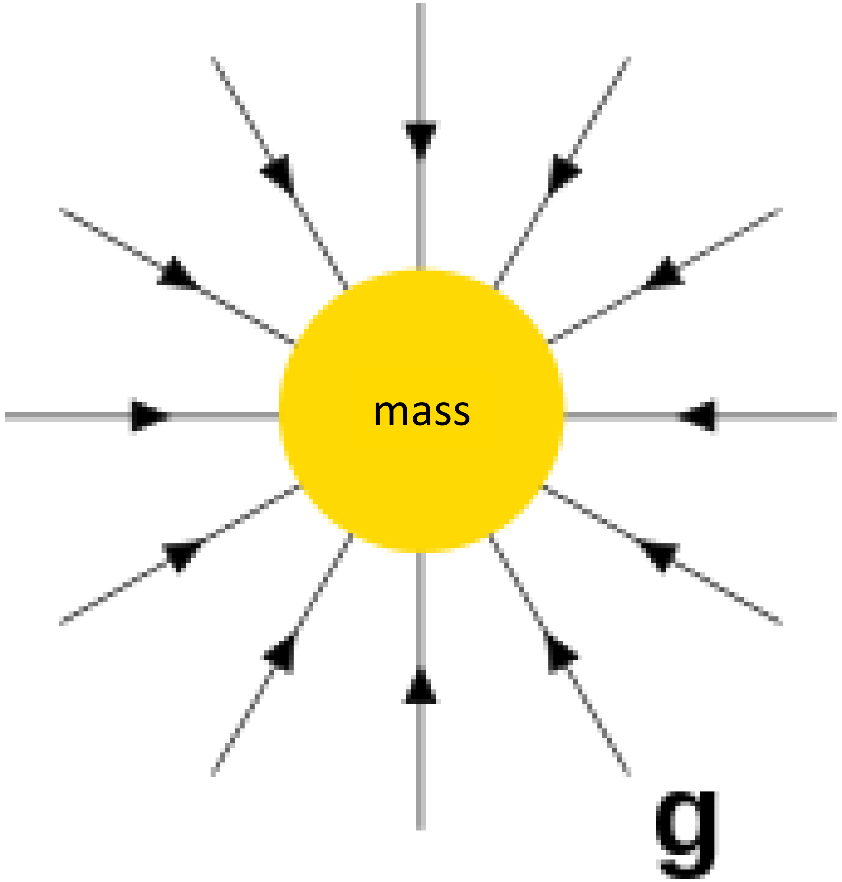
well logging
(everything in borehole)
Maxwell Equations
$\nabla \cdot \mathbf{D} = \rho$
$\nabla \cdot \mathbf{B} = 0$
$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$
$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}$
zero frequency
low frequency
high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

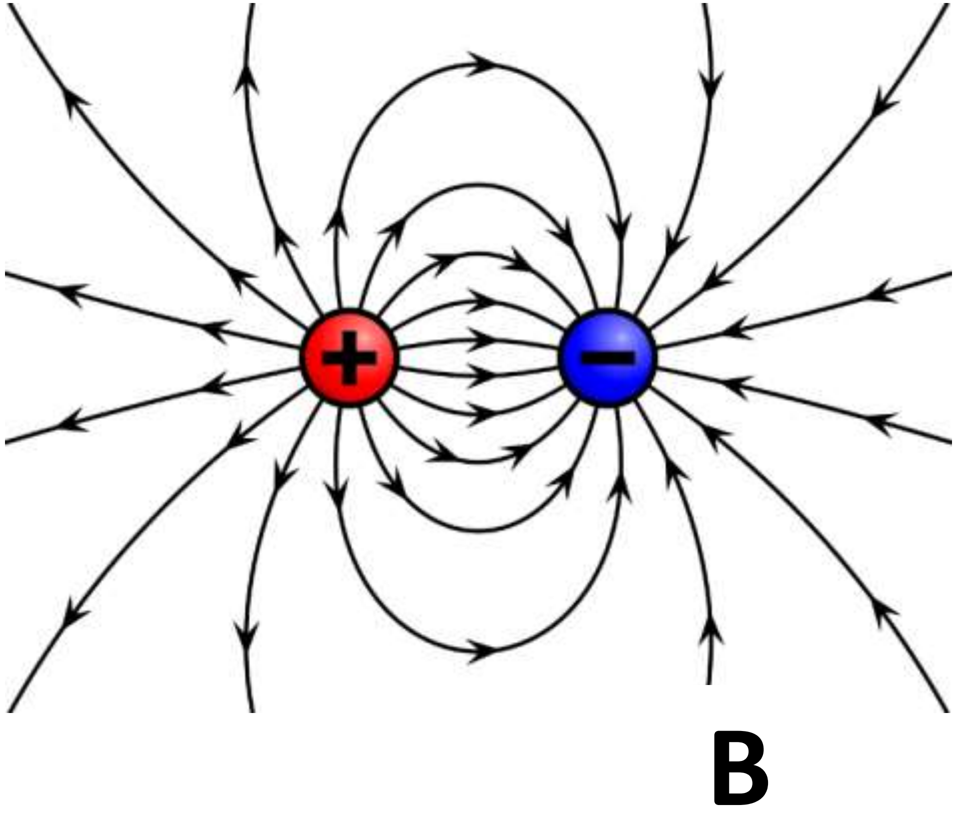




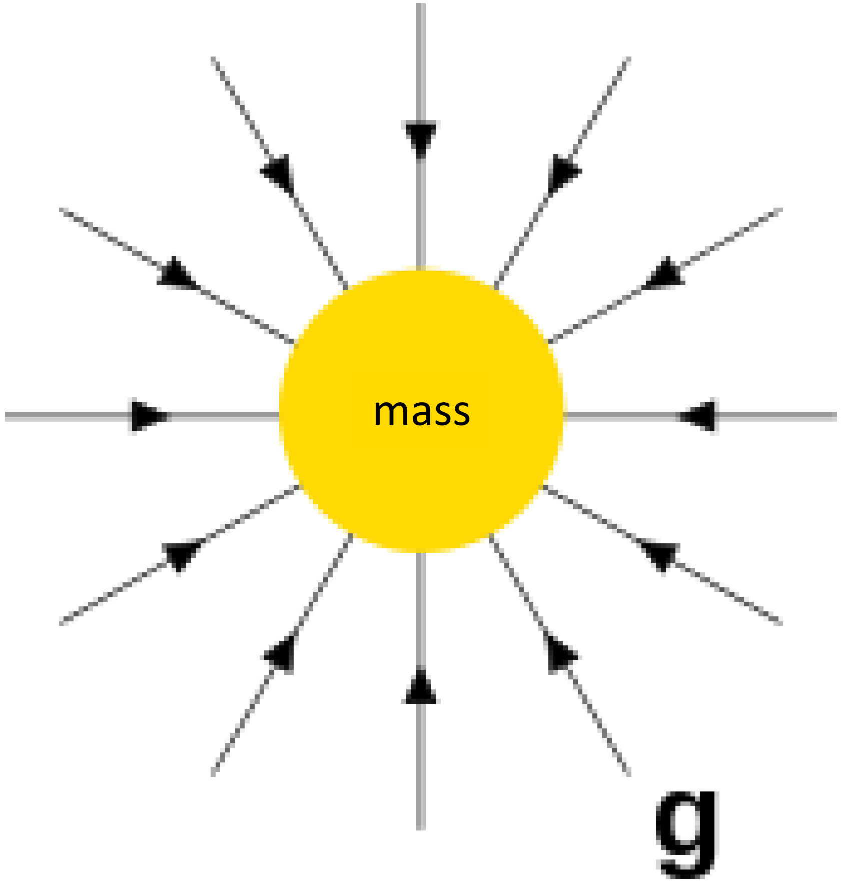
Charge and Field



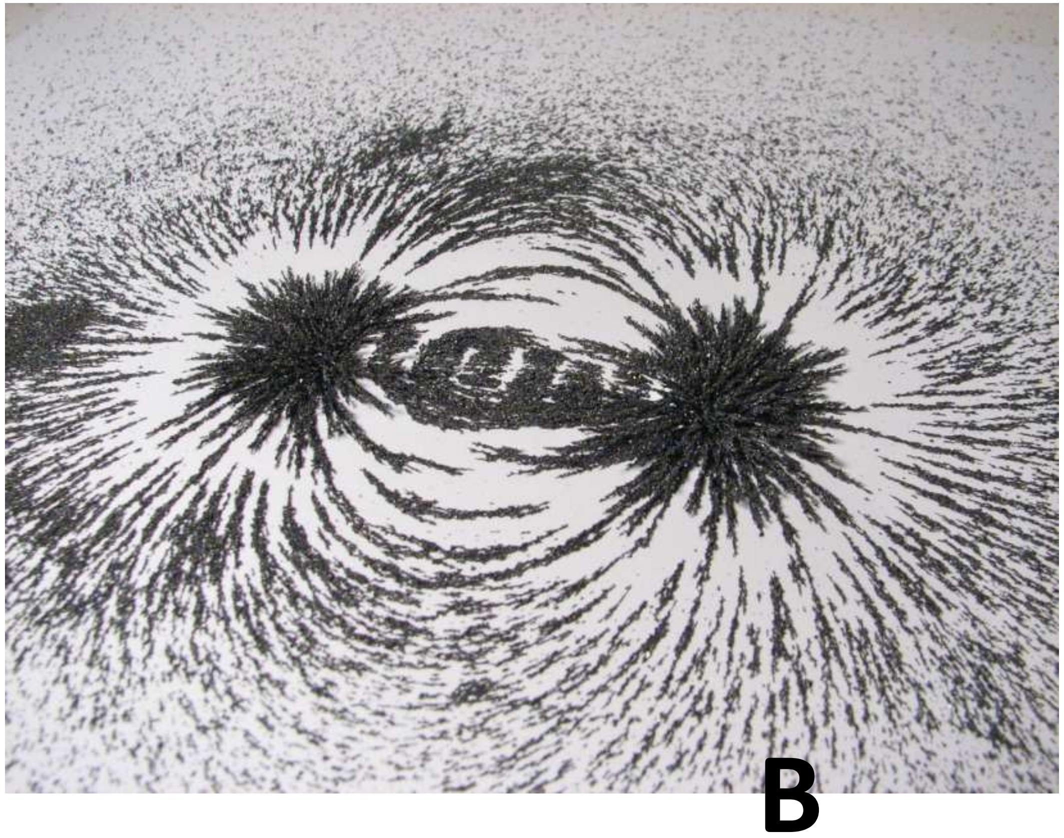
Magnetic dipole



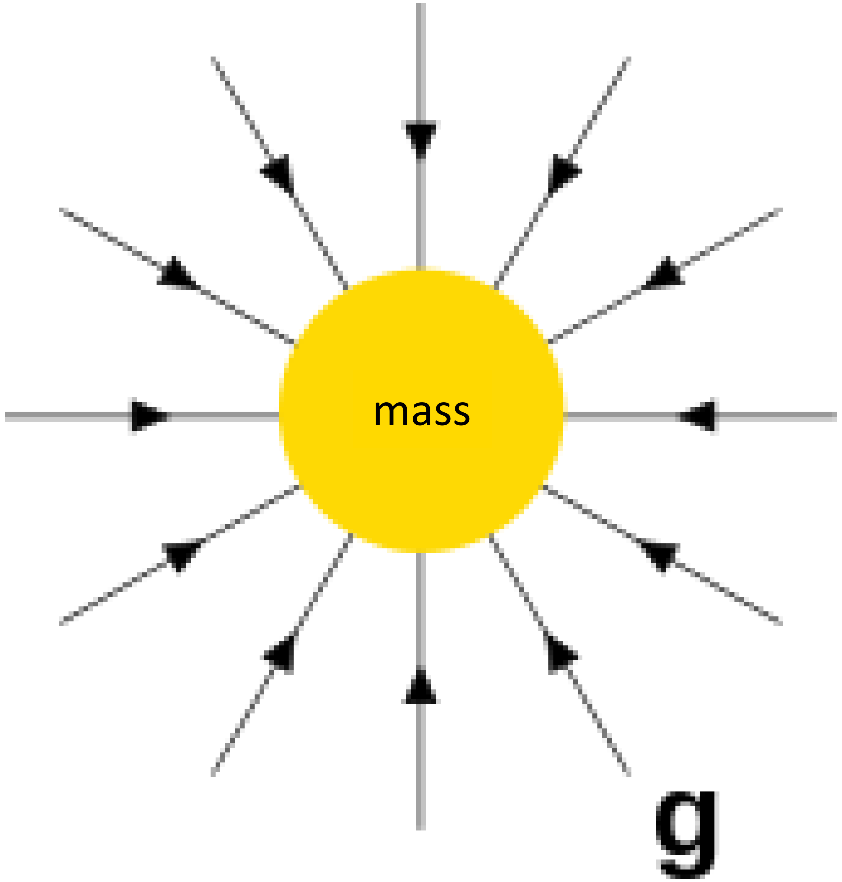
Charge and Field



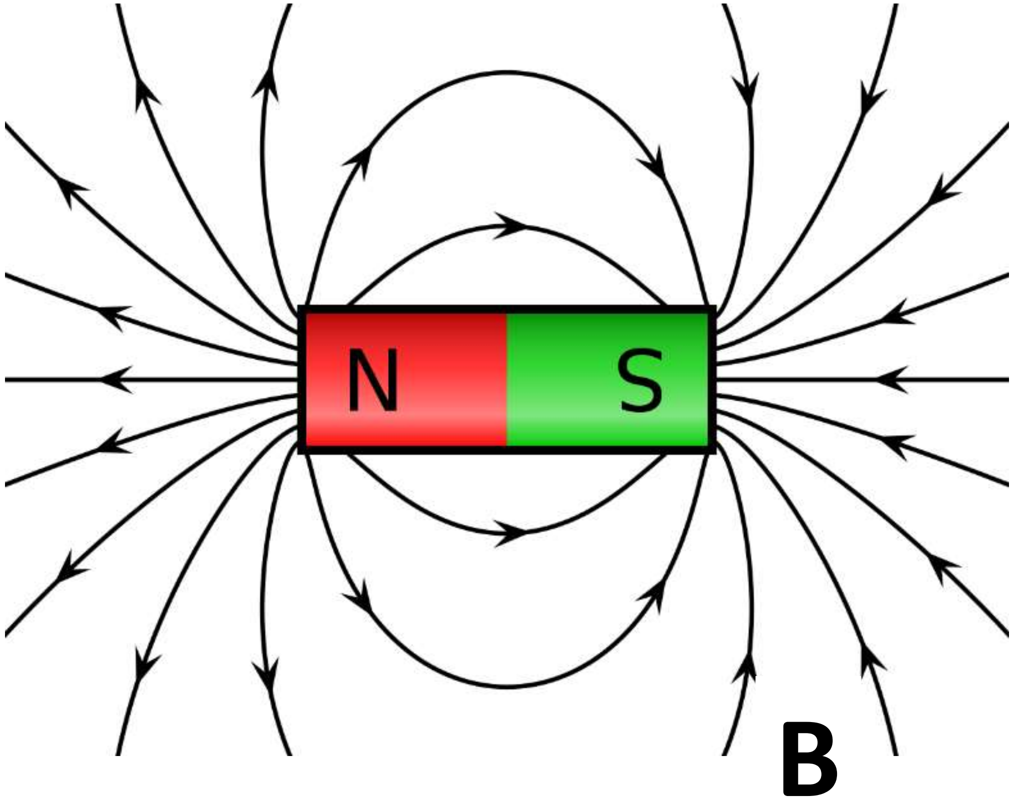
Magnetic field lines



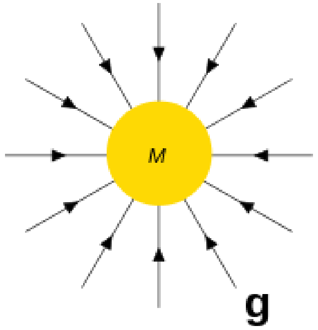
Charge and Field



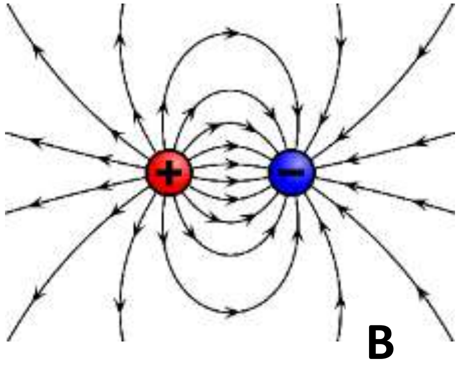
Bar magnet



Charge and Field



$$g = \frac{GM}{r^2}$$



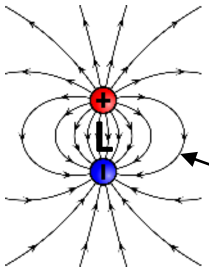
$$\mathbf{B} = \frac{\mu_0 Q}{4\pi r^2}$$

- Mass generates gravity potential and field
- Only positive mass*
- Field lines from infinity to mass (open path)
- Unit of acceleration g: m/s^2

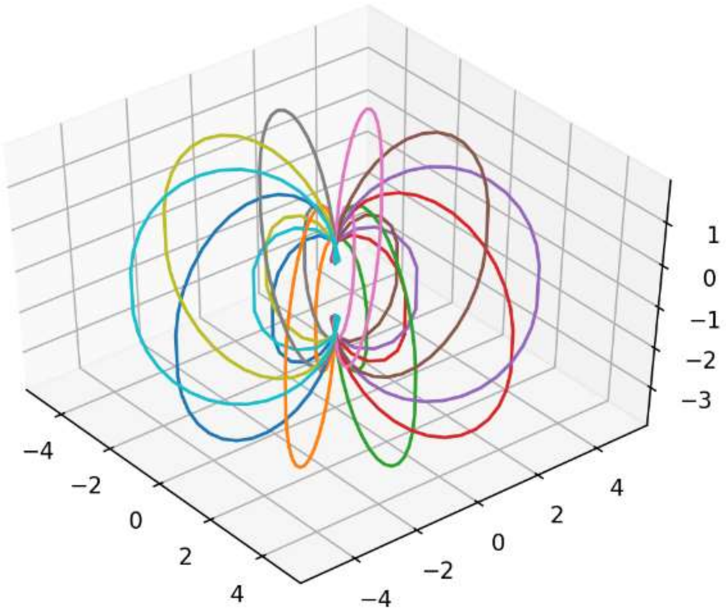
- Magnetic charges generate magnetic potential and field
- Positive charge and negative charge (stick together)
- Field lines from negative charge to positive charge (loop)
- Unit of B: Tesla

* Can be negative in relative sense

Magnetic Dipole



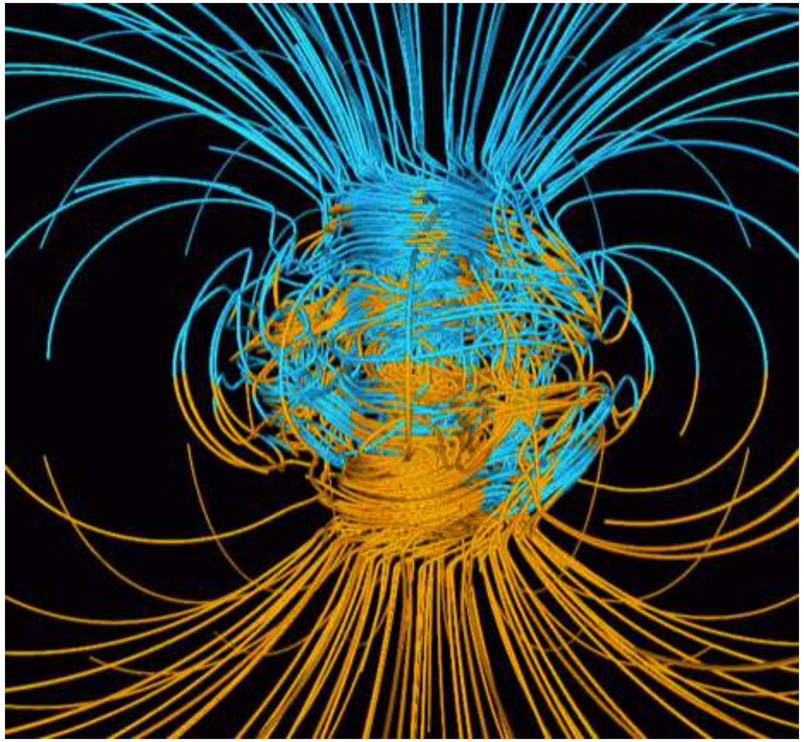
A vertical dipole and field lines



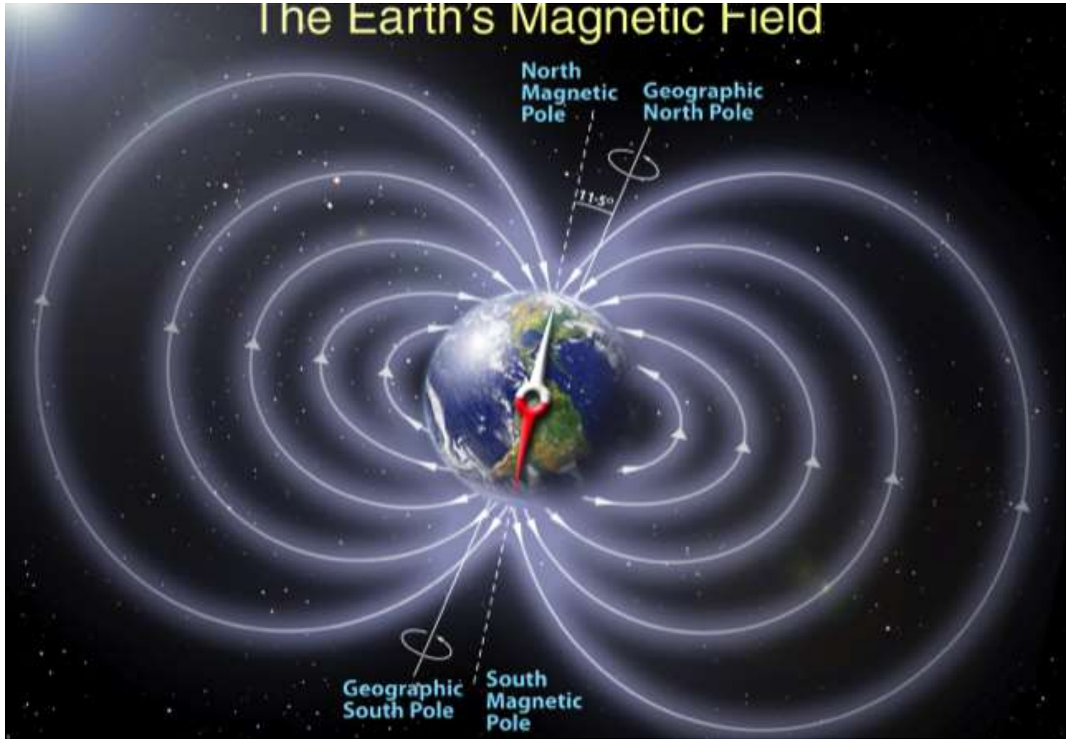
R

R >> L

Earth’s Magnetic Field



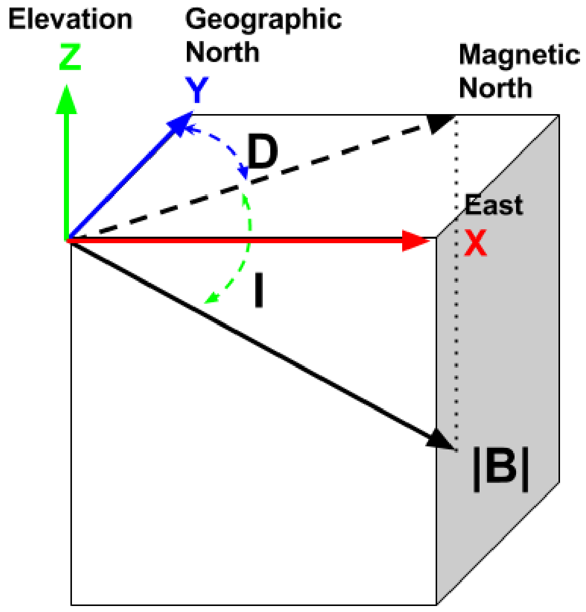
Complicated inside the earth near the core.

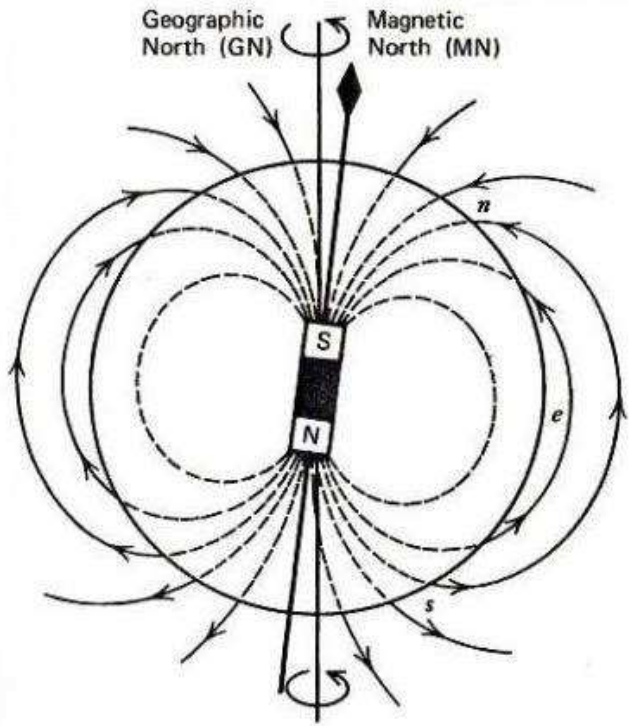


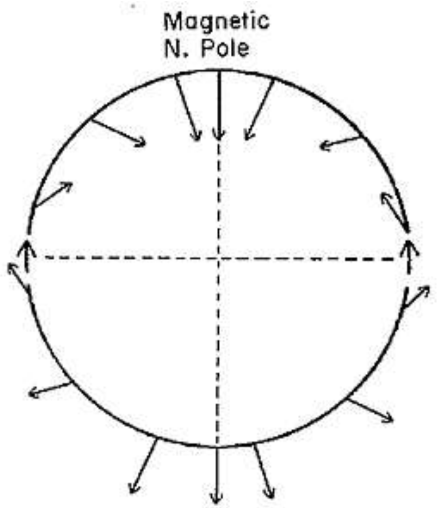
Outside the earth it looks like a magnetic field due to a dipole (bar magnet).

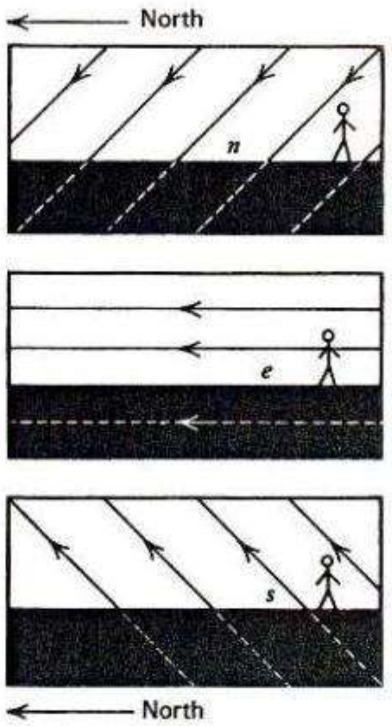
Earth’s Magnetic Field

- A vector field
- How is the field described anywhere?
  - Orthogonal decomposition: X, Y, Z
  - Inclination, Declination, Magnitude

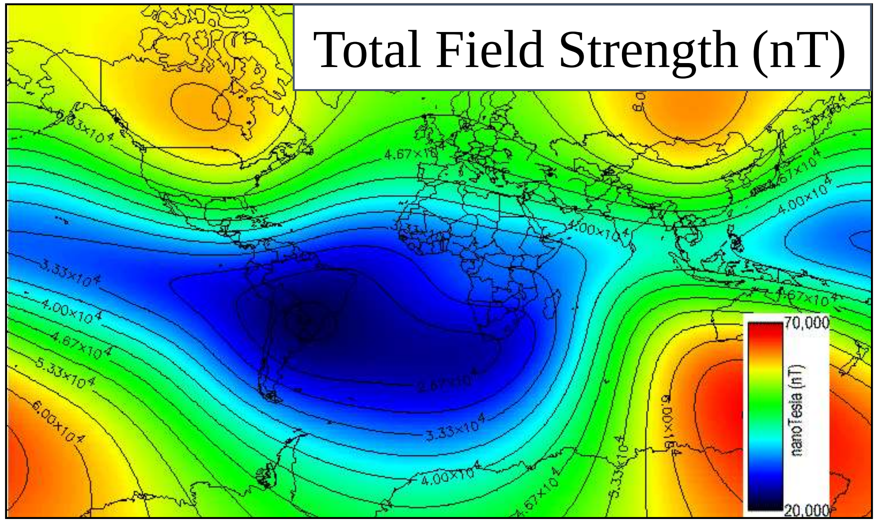


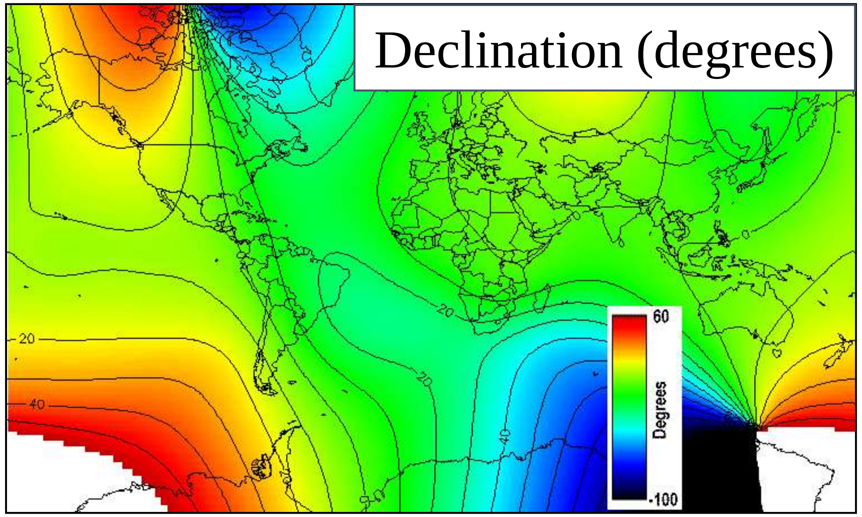


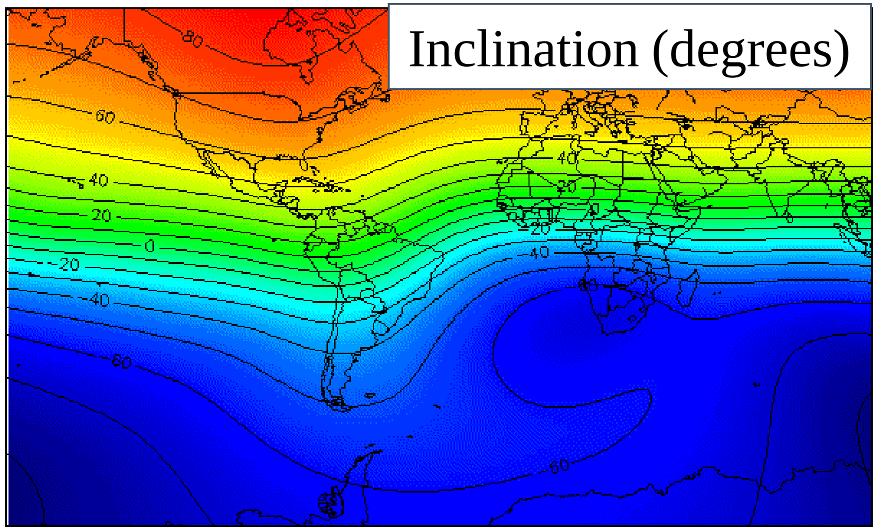




IGRF: TMI, Dec, Inc







https://www.ngdc.noaa.gov/geomag/calculators/magcalc.shtml?model=igrf#igrfwmm

Shenzhen

Latitude: 22.5936° N

Longitude: 113.9845° E

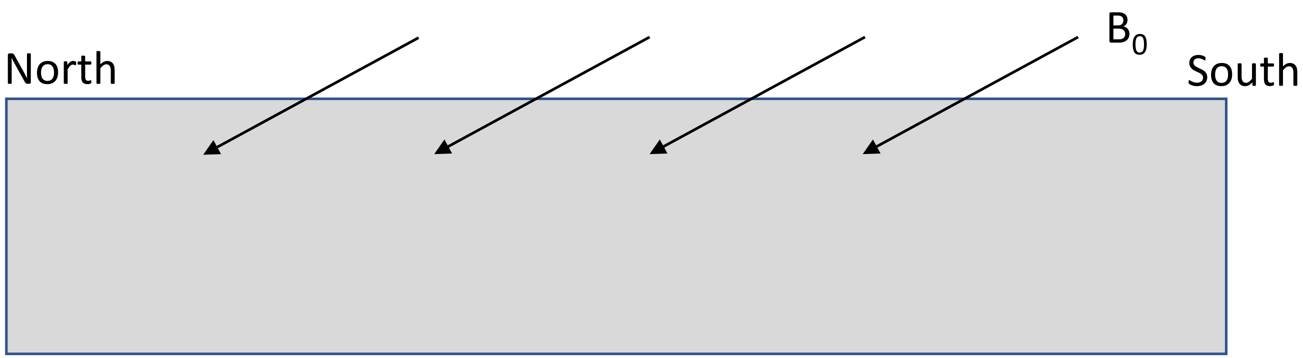
Declination: -2.9765°

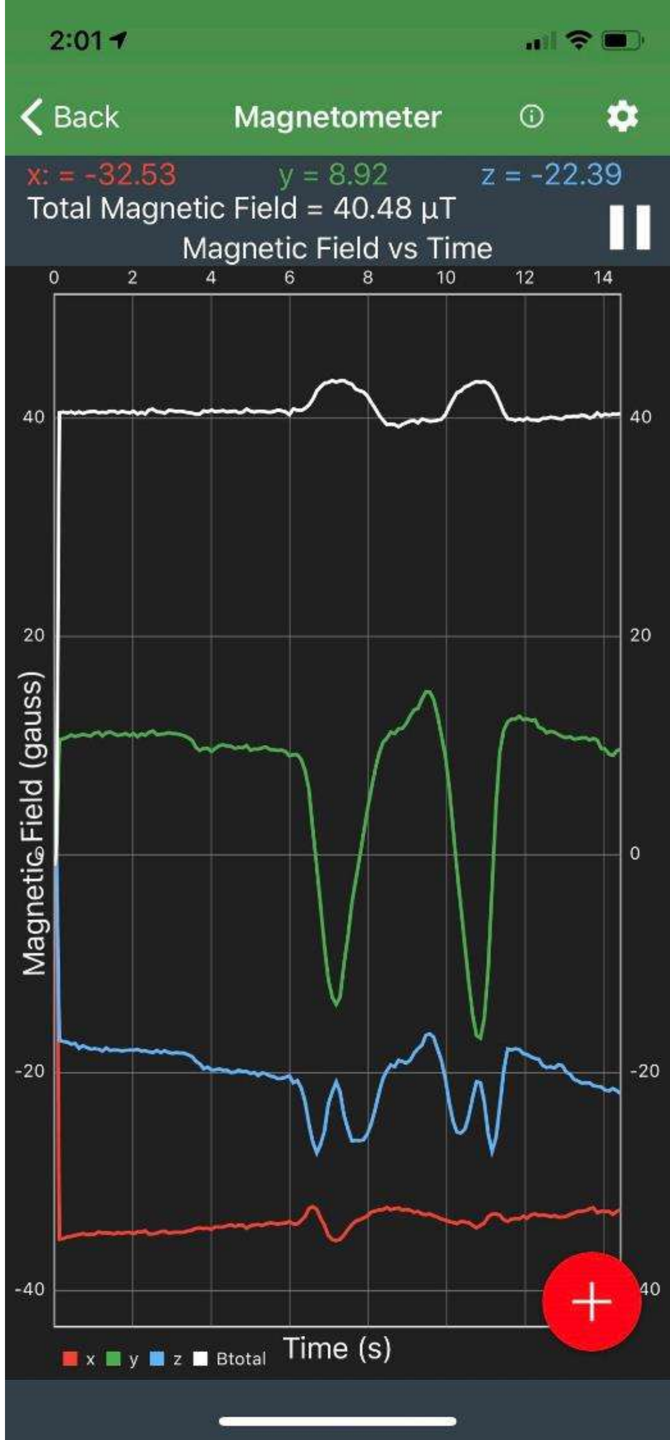
Inclination: 33.9377°

Magnetic field strength: 45,461.6 nT

Magnetometer on Cell Phones

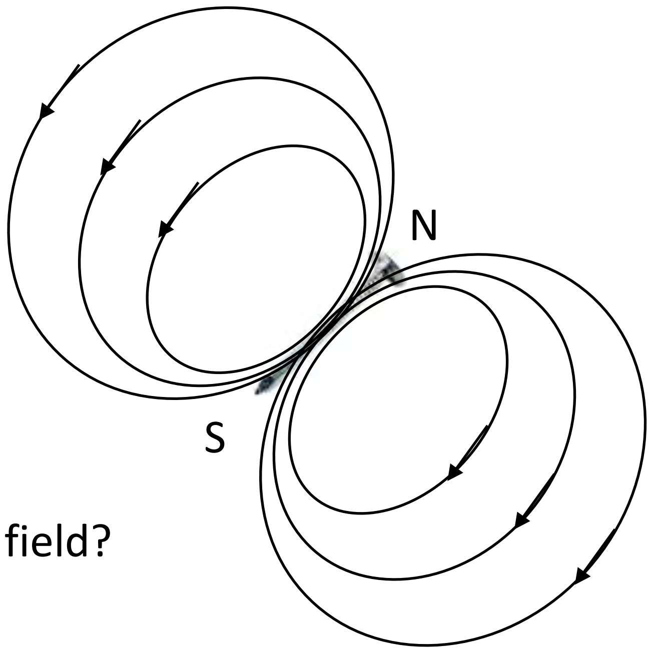
- Physics Toolbox Suite
  - 3-axis magnetometer:
    - Bx: along the short edge
    - By: along the long edge
    - Bz: normal to the face
  - Verify the total field, dec and inc in Shenzhen
    - Adjust your phone so that Bx = 0, By = Total, Bz = 0
    - Draw a N-S cross section of the earth and draw B_0 field lines



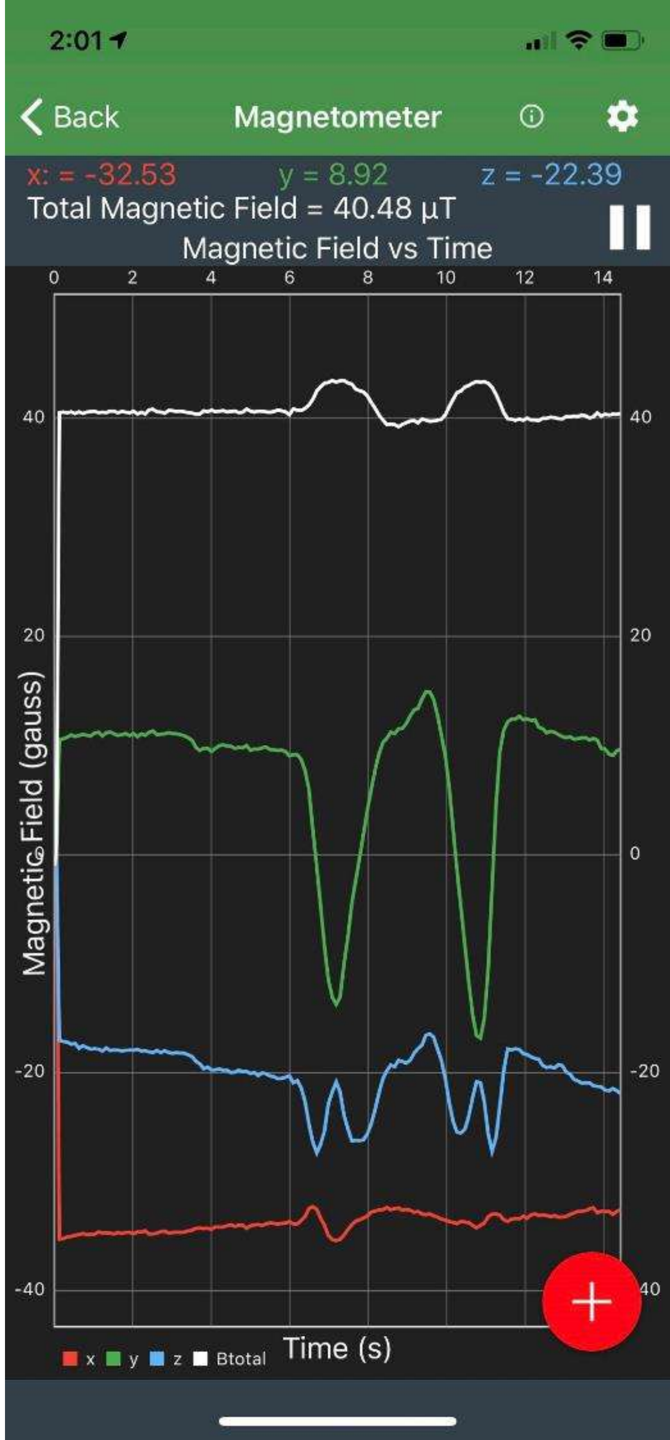


Magnetometer on Cell Phones

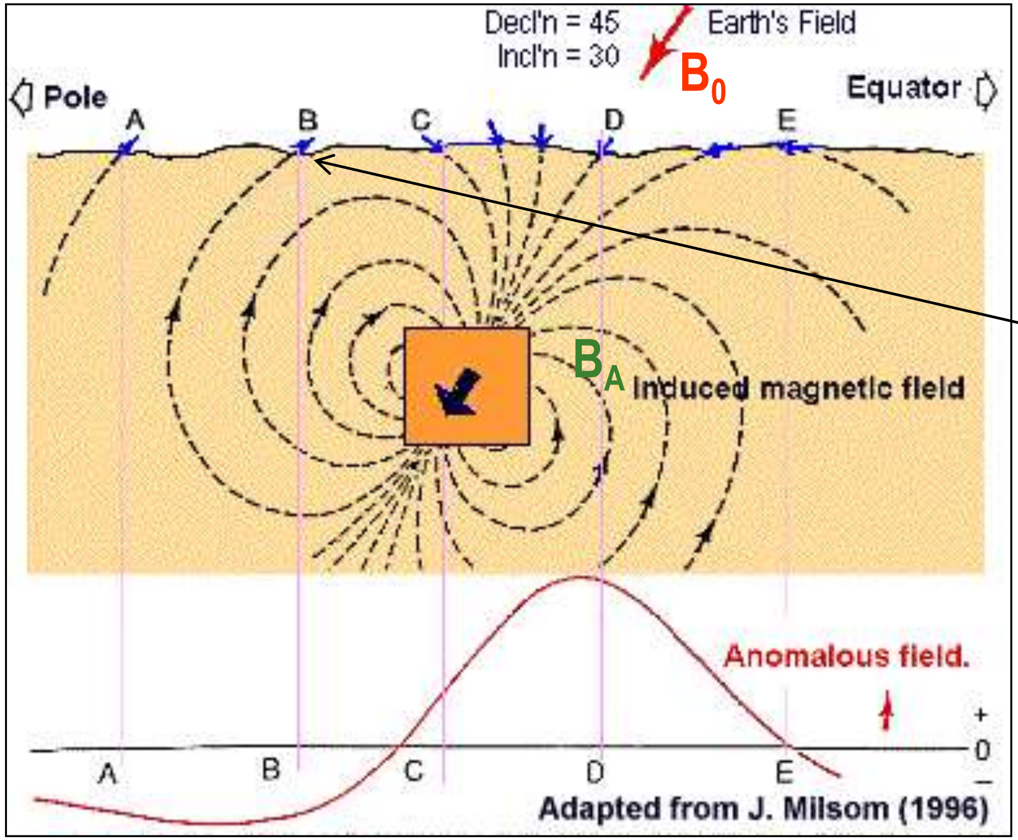
- Physics Toolbox Suite
  - Detect the polarity of a nail (dipole)
  - Assign N and S
  - Draw field lines

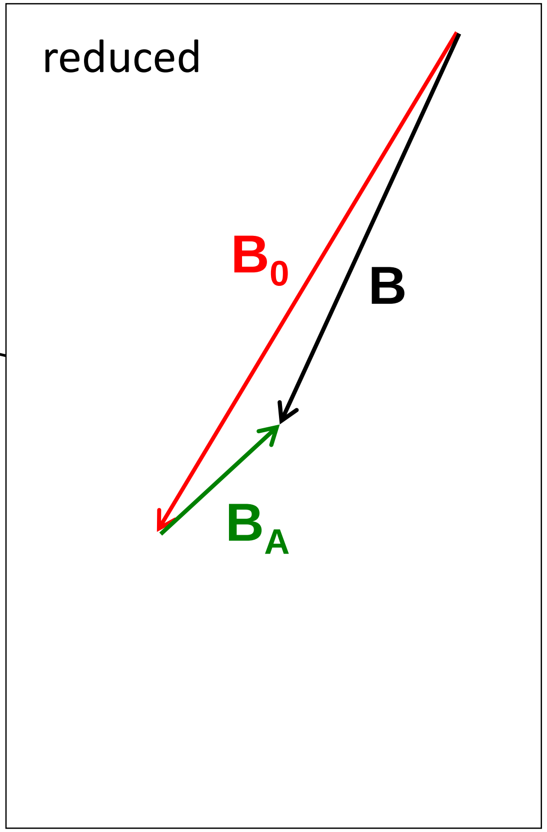


Enhancing or reducing the earth's field?



A Buried Dipole





Composite field:

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

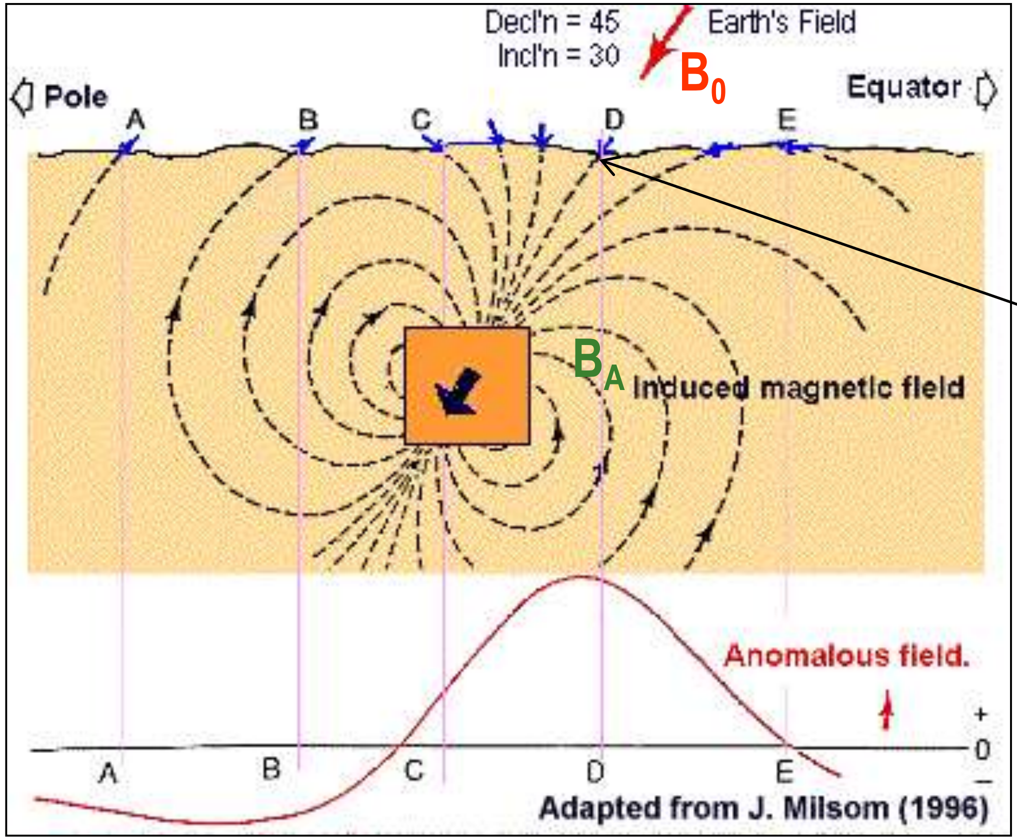
B is a vector:

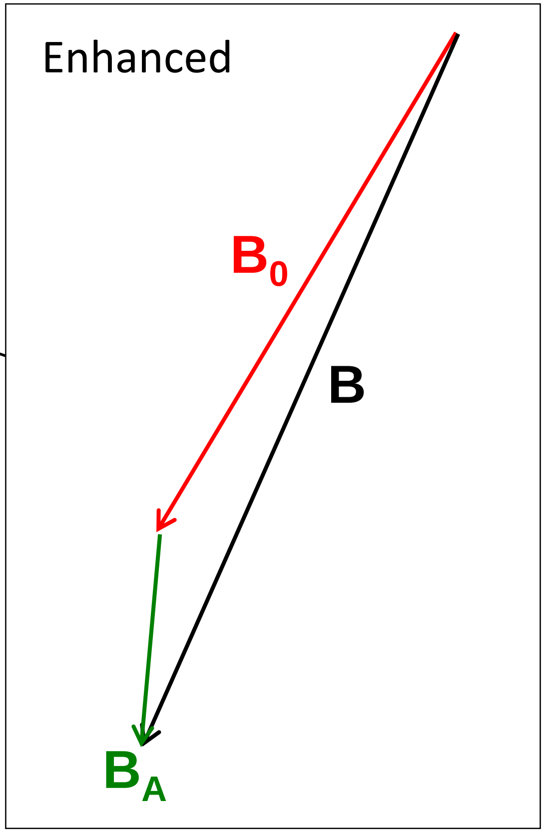
$$\mathbf{B} = \{B_x, B_y, B_z\}$$

Total field:

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

A Buried Dipole





Composite field:

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

B is a vector:

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

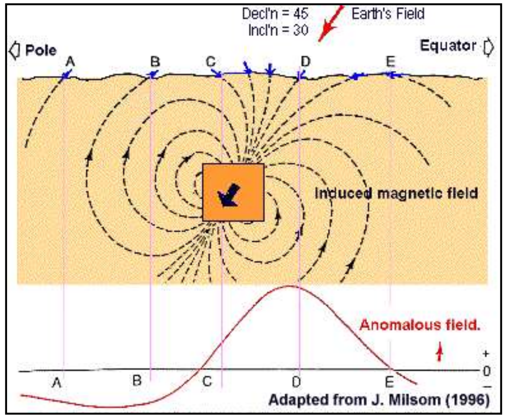
Total field:

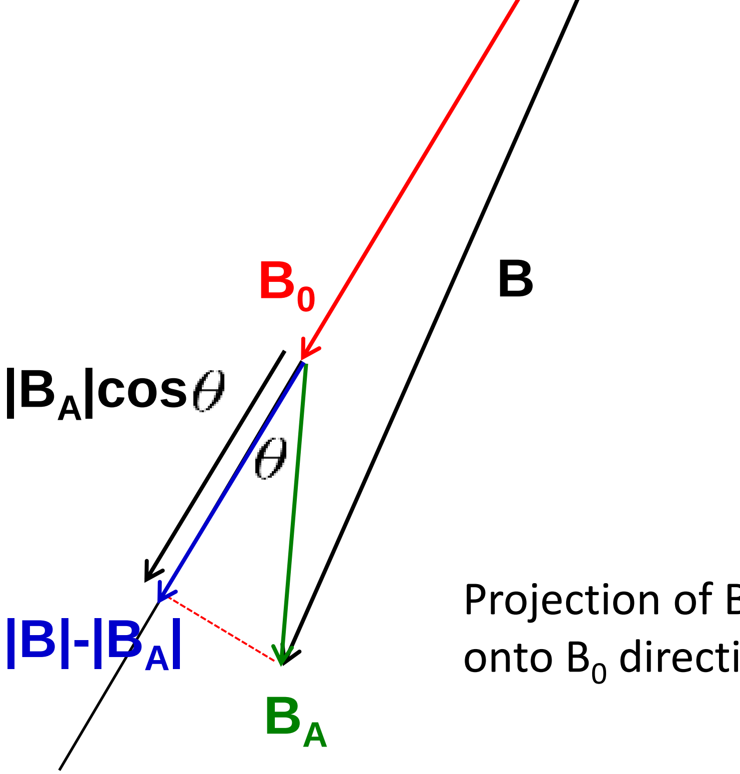
$|\mathbf{B}| = |\mathbf{B_0} + \mathbf{B_A}|$

Anomalous Field

- Measured data **|B|** = | **B_0** + **B_A** **|**
- Remove the influence of **B_0**
- The *total* field *anomaly*:
- **$|\Delta B| = |B| - |B_0|$**
- If **$|B_A|$ << $|B_0|$** then

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

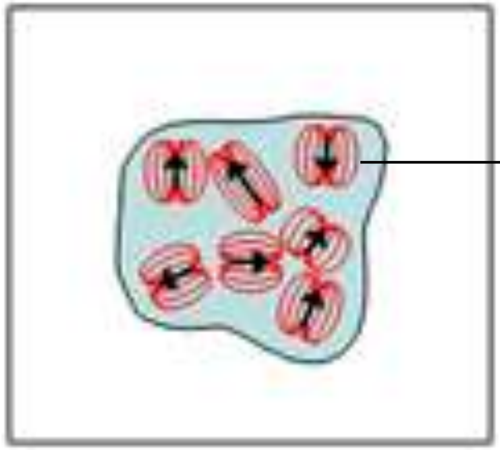


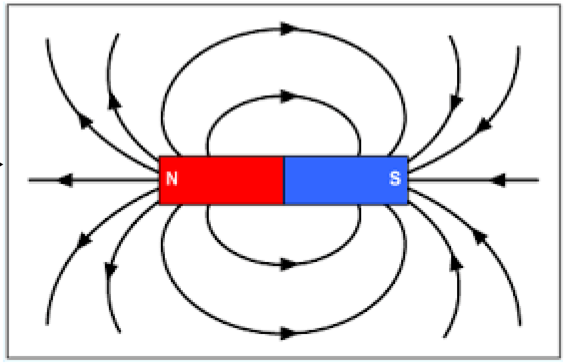


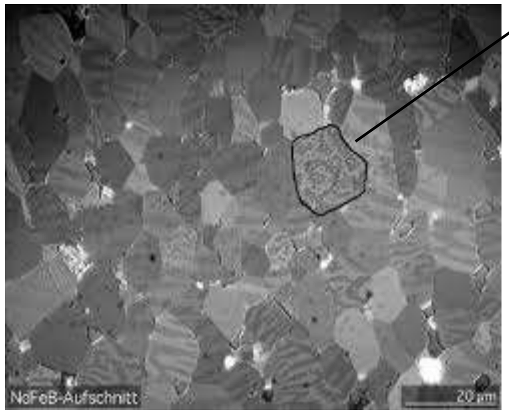
Projection of B_A onto B_0 direction

Induced Magnetization

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





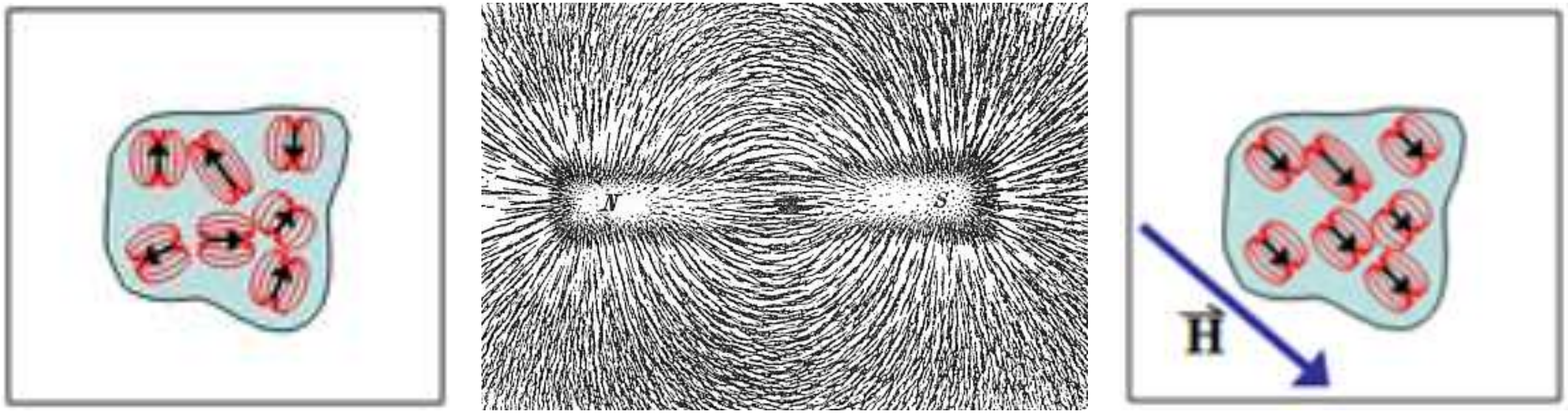


- Dipole: North pole and South pole (dipole)
- Dipole moment **m** is related to the strength of the magnet
- Magnetic field lines extend from N to S

Induced Magnetization

- Strength of each magnet: the magnetic dipole moment m_i
- Magnetization: net “density” of small bar magnets
- Note: every m_i has its own direction, so M can be zero when the magnets are randomly oriented

$$\vec{M} = \frac{\Sigma \vec{m}_i}{Volume}$$



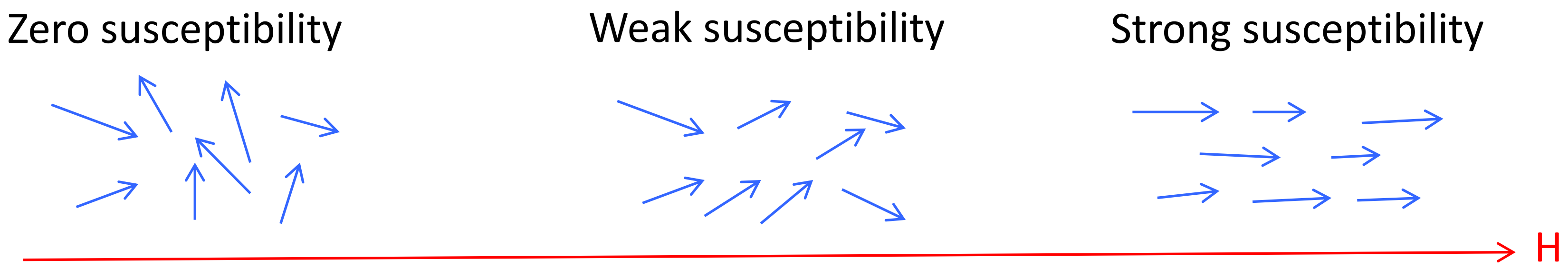
Small magnets align with fields of a larger magnet to have a non-zero total magnetic moment.

Susceptibility

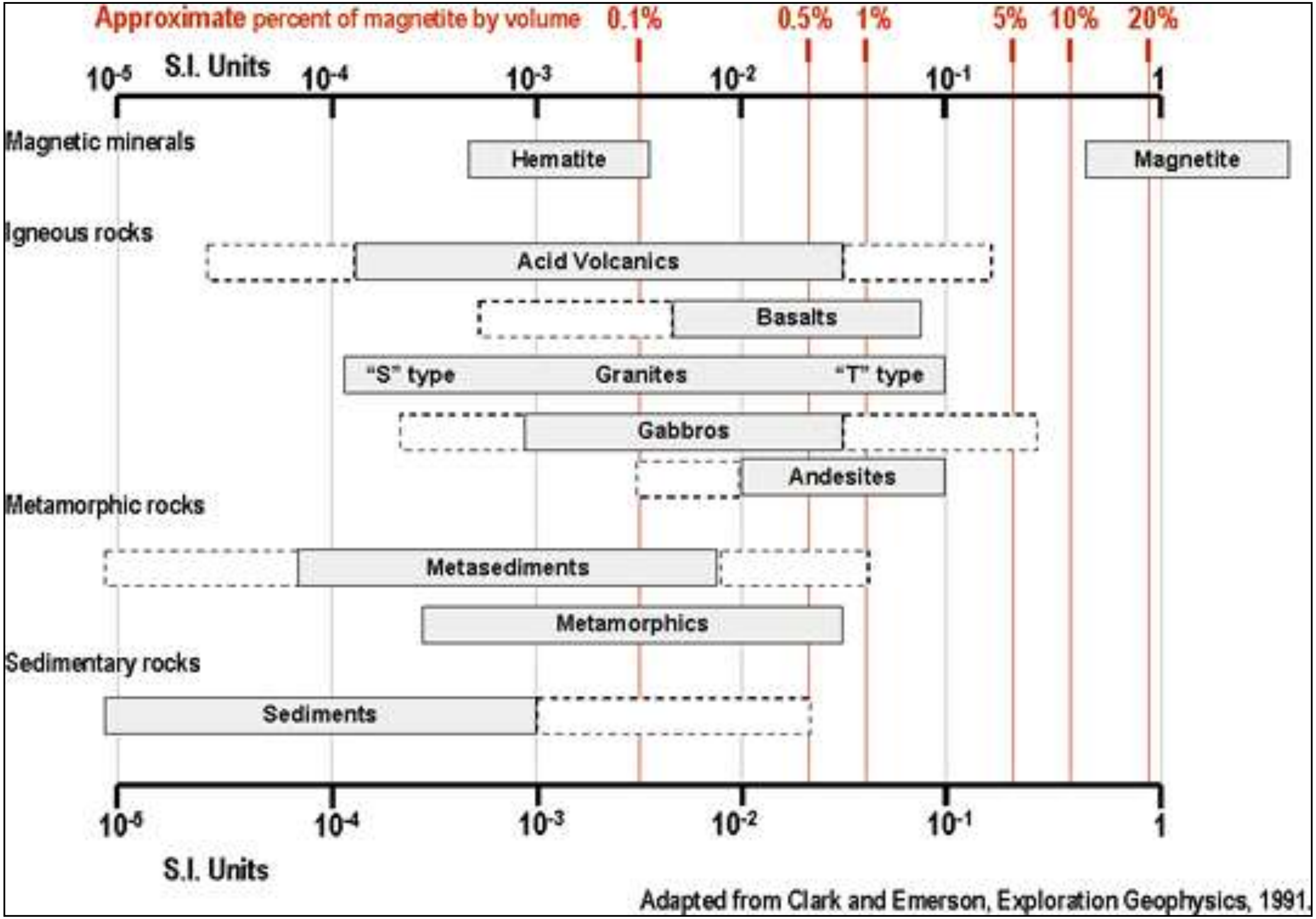
- Physical understanding
  - Microscopic: ability for the small bar magnets in a rock to re-orient to form a large magnet when an external magnetic field is applied.
  - Macroscopic: how much additional magnetic field can be excited (a dimensionless factor)?

$$\vec{M} = \frac{\Sigma \vec{m}_i}{Volume}$$

$$\vec{M} = \kappa \vec{H}$$



Magnetic Susceptibility



Summary

- Source of magnetic field
- Earth's field B_0
  - Dipole field
  - Total, inc, dec
- Magnetic dipole anomaly
  - Enhancing or reducing B_0
  - Draw magnetic anomaly on surface due to a buried dipole
- Susceptibility
  - Influence of the inducing fields