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12.002 Physics and Chemistry of the Earth and Terrestrial Planets
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Geomagnetism and Paleomagnetism

Lodestone – magnetite (Fe_3O_4 , most common crustal ferromagnetic mineral)-bearing rock which was hit by lightning, meaning that it becomes magnetized.
lode = way (Old English)

History:

700 BC - lodestones known to Thales (Greek philosopher) - found lodestone deposits near city of Magnesia (origin of word "magnet")

2nd century BC - Chinese - first compass

13th century AD - Petrus Peregrinus (French scholar)

1269 - wrote *Epoistola de Magnete*

First scientific treatise of any kind

Showed that: Magnets attract and repel

Dipolar geometry of a magnet field

Magnets have two poles poles

Aside: Field of a dipole equation

1600 - William Gilbert wrote *De Magnete*

Nut hypothesis: Earth is a magnet (nut paper) (generates a dipole field)

Apart from roundness, magnetism was first large scale property ascribed to the body of the Earth (Newton's Principia, on gravity, was published 87 years later)

1701 - Edmund Halley (of comet fame)

Made first map of Earth's magnetic field declination: *Tabula Nautica Variationum Magneticarum*

Inclination = dip of magnetic field with respect to Earth's surface

Declination = angular deviation from geographic north (defined at zero when directly north)

First contour plot

Discovered two things

i. declination is not zero everywhere but varies with locations

ii. declination is also time dependent (his map became useless very soon)

This time variability is chief argument against the hypothesis that Earth's field is generated by remanent magnetization (bar magnet)

Instead, he concluded, wrongly, that the Earth is hollow and composed of rotating magnetic nested spheres

However, Earth's interior is too hot for remanent magnetization...

1797 - Alexander Von Humboldt

Discovered paleomagnetism (study of past magnetism)

He was walking in the Alps with this compass, and it kept deflecting from true north.

He then realized he was walking over rocks that had been hit by lightning in the past and had recorded the intense lightning magnetic field

1849 to 1853 - Delesse and Melloni

When rocks cool in a field, they acquire a thermoremanent magnetization. Points in direction of ambient field. Therefore, remanent magnetization gives direction of paleofield relative rock

The study of the records constitutes the field of *paleomagnetism*

1906 - Brunhes

From paleomagnetic studies of rocks older than 780,000 years, showed that the Earth's field had *reversed*

North pole - south pole switched. Found that past magnetic inclination had opposite sign of field today and had declination 180 degrees away from field today

Note: inclination is defined downward as positive, so in the southern hemisphere today, inclination is negative.

1906 Oldham / 1912 Gutenberg argued that Earth had liquid outer core from seismic studies (S waves do not go pass through liquids)

1940s - Larmor argued that motion of conducting fluid in outer liquid core generates field

1950s - Bullard - geodynamo - self-sustaining field driven by liquid motion

Moving charge (currents) generates all magnetic fields in the universe.

How can this explain ferromagnetism? Electron spins = current loops: generate fields.

Dipole moment (units: Am^2) – characterizes field geometry and field intensity generating-capacity of a current loop

Stronger field if loop is bigger, or stronger field if current is increased. Dipole moment units express dependence on these two features.

Earth's field has two main components

- a. Core Field
- b. Crustal Field

Crustal Field

Produced by remnant magnetization, two components:

- i. Induced (from paramagnetic minerals aligned in direction of Earth's field)
- ii. Remanent ferromagnetic minerals not aligned with the Earth's field

Reason crustal field is weak is that crust is slow moving (several cm/y) and has low conductivity (0.01 Siemens per meter; 1 siemen = $1/\text{ohm}$)