Rock magnetization and translation

Reading: Fowler Ch 3 p51-93

Magnetizing rocks

**Curie temperature** - when the spontaneous, i.e. current, magnetic field is “frozen in”

**Blocking temperature** - temperature below which the orientation of the rock’s magnetization cannot change

- **Permanent residual magnetization**
- **Thermoremanent magnetization - TRM**
Magnetizing sedimentary rocks

**Depositional remnant magnetization – DRM**
- Magnetic crystals align while settling in calm waters

**Chemical remnant magnetization – CRM**
- Alignment of iron oxides during crystal growth
- Secondary magnetization

Strength of DRM and CRM fields typically 1-2 orders of magnitude smaller than TRM

Induced magnetic field

$$\mu_0 \mathbf{M}(r) = \chi \mathbf{B}(r)$$

- $\mathbf{M}(r)$: Induced magnetic field
- $\mathbf{B}(r)$: Earth’s magnetic field
- $\mu_0$: Magnetic permeability
- $\chi$: Magnetic susceptibility

Typically $10^{-4}$ to $10^{-1}$ for basalt

**Konigsberger ratio, $Q = \frac{\text{remnant mag}}{\text{induced mag}}$$$
Typically 1-160 for basalt

TRM is typically $\sim 1\%$ of the Earth’s field strength
Use of TMR

Calculating palaeomagnetic latitude

\[ \tan I = 2 \tan \lambda \]

where:
- \( I \) is the measured inclination
- \( \lambda \) is the palaeomagnetic latitude

**Example**

Palaeomag measurements on a basalt at 47°N 20°E

Inclination of remnant mag is 30°

\[ \lambda = \tan^{-1} \left( \frac{\tan 30°}{2} \right) = 16.1° \]

⇒ the site has moved 31° north to its current position at 47°N

Use of TMR

Locating the palaeomagnetic pole

- X - sample location
- N - current north pole
- P - Palaeomagnetic pole

We can see that

\[ b = 90 - \lambda_x \]
\[ c = 90 - \lambda_P \]

and

\[ A = \phi_P - \phi_x \]

also

\[ a = 90 - \lambda \] (palaeo lat)

\[ \tan I = 2 \tan \lambda \]

For spherical triangles:

\[ \cos c = \cos a \cos b + \sin a \sin b \cos C \]

\[ \frac{\sin a}{\sin A} = \frac{\sin b}{\sin B} = \frac{\sin c}{\sin C} \]
Use of TMR
Locating the palaeomagnetic pole

X - sample location
N - current north pole
P - Palaeomagnetic pole

Geographic latitude of palaeomagnetic pole:
\[
\sin \lambda_p = \sin \lambda_x \sin \lambda + \cos \lambda_x \cos \lambda \cos D
\]
where D is the remnant declination (C on diagram)

Difference between the longitudes of the palaeomagnetic pole and sample location (\(\phi_p - \phi_x\)):
\[
\sin(\phi_p - \phi_x) = \frac{\cos \lambda \sin D}{\cos \lambda_p}
\]
when \(\sin \lambda \geq \sin \lambda_p \sin \lambda_x\)
\[
\sin(180 + \phi_p - \phi_x) = \frac{\cos \lambda \sin D}{\cos \lambda_p}
\]
when \(\sin \lambda < \sin \lambda_p \sin \lambda_x\)

Polar wander paths
Europe and North America

North America - circles
Europe - squares
Correct for separation of the Atlantic and they fall along the same path
Polar wander paths for six continents and reconstructed plate motions

Dating the oceans
Magnetic stripes

Marine measurements
- Toe the magnetometer behind vessel during normal operations
- Measure the total field intensity
- Subtract regional value
- magnetic anomaly map
### Dating the oceans

**Magnetic stripes**

#### Raff and Mason, 1961
- First magnetic field map
- Off the western coast of North America

#### Magnetic anomaly map
- Take total magnetic field intensity and subtract regional average
- Black: positive intensity
- White: negative intensity
- Which is normal/ reversed polarity?

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### Dating the oceans

**Magnetic stripes**

#### Vine and Matthews, 1963
- First to understand the significance of the stripes
- Coupled the stripes with sea-floor spreading and magnetic pole reversals

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How does the amplitude of the field compare to the total Earth field?
Magnetic stripes

Vine and Matthews, 1963
- First to understand the significance of the stripes
- Coupled the stripes with sea-floor spreading and magnetic pole reversals

Real stripes are not quite so uniform

Stripes in the Pacific are more uniform than the Atlantic

- **Emplacement zones**
  - The region where new magma bodies are intruded
  - Centered around the mid-ocean ridge
  - ~10 km wide in the Atlantic
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**Dating the oceans**

**Magnetic stripes**

A record of past plate motions
- Ridges
- Transforms

Can we re-construct past plate motions?

**Reversal timescale**

**Evolution of the reversal timescale**

- K-Ar dating of volcanic deposits provided times for observed reversal history.
Reversal timescale

Black – normal polarity
White – reversed polarity
C1-C34 and M0-M38 – anomaly or “chron” numbers

Cretaceous Super-Chron
• aka Cretaceous Quite Zone
• Normal polarity 83-124 Ma
• Difficult to reconstruct plate motions during this time

Reconstructing past plate motions

• Date the ocean floor
• Estimate plate spreading rates
• Estimate orientation and latitude of ridge that created each section of ocean floor
• Reconstruction is complete only when ocean contains only ridges
Atlantic

History is almost complete
(South Sandwich and Puerto Rico Trenches)

Oldest ocean floor
Central Atlantic: M25 – 180 Ma

➤ deformation in Europe as Eurasia did not separate from North America until ~120-140 Ma

Atlantic

History is almost complete
(South Sandwich and Puerto Rico Trenches)

Baffin Bay
~60 to 35 Ma (C24-C13)

Labrador Sea
~60 to 43 Ma (C24-C19)

Reykjanes Ridge
started spreading
~55 Ma (C24)
Pacific

Juan de Fuca Ridge
- rotated 20° with respect to older anomalies

This is a response of the spreading center to a change in the rotation pole

Two models
a) Ridge rotation - asymmetrical spreading during adjustment
b) Propagating ridge - instantaneous rotation followed by outward propagation

- Surrounded by subduction zones - lost information
- Pre-dates super-chron
- Little information
- Post-dates super-chron
Pacific

N-S anomalies are product of Farallon Ridge which has now been subducted

Great Magnetic Bight
Means there was a third plate
RRR triple junction
Pacific plate history

In Super-Chron – little info

The importance of the Mendocino triple-junction

EXPLANATION

- Spreading center (divergent boundary)
- Subduction zone (convergent boundary)
- Transform fault; arrows show relative movement
- SAFZ, San Andreas fault zone
- Triple plate junction

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The importance of the Mendocino triple-junction

It is not stable
How is it accommodated?

Consequences
1. Rotation of North America
2. Extension of North America
3. Eastward stepping of San Andreas
The importance of the Mendocino triple-junction

Consequences
1. Rotation of North America — paleomag in Oregon
2. Extension of North America — Basin And Range
3. Eastward stepping of San Andreas — East CA shear zone