Resistivity methods - MT

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Resistivity methods - Depth of penetration:

- **Schlumberger:** Depth: 0 – 1000 m
- **TEM (Transient-Electromagnetic):** Depth: 0 – 800 m
- **MT (Magnetotelluric):** Depth: 100 m – 10 km
- **AMT (Audio-magnetotelluric):** Depth: 0 – 800 m

These values are highly depend on the subsurface resistivity structure.
The fluctuating natural magnetic field induces electrical currents in the conductive ground – passive method

By measuring the fluctuating magnetic field and the electrical currents (i.e. the electrical field) in orthogonal directions on the surface of the earth, it is possible to infer the subsurface resistivity

Originated in the fifties by Japanese (Hirayama, Rikitake); later by Cagniard (1953) and Tikhonov (1950) – great improvements in recent years
The setup of a MT sounding: Electrodes for measuring the electric field, coils for the magnetic field; acquisition unit for digital recording and GPS for synchronizing data
Resistivity is calculated from the orthogonal elements of $E$ and $H$:

$$\rho_{xy} = 0.2T \left| \frac{E_x}{H_y} \right|^2; \rho_{yx} = 0.2T \left| \frac{E_y}{H_x} \right|^2$$

Depth of penetration depends on resistivity and period; The higher the period the deeper the sounding is detecting the resistivity:

Skin depth: $\delta = 500\sqrt{\rho T}$ in m
MT - Acquisition

• Normally, record five channels at each station
  • $E_x$, $E_y$, $H_x$, $H_y$ and $H_z$
  • $H_z$ is used only for strike information (interpretation) – it is not used in calculation of the resistivity.
  • Recording the time series; processing will convert data to frequency domain
• Best if $x$ and $y$ directions are orthogonal
• Orientation does not usually matter - $x$ and $y$ can be any direction as long as they are perpendicular
• Conventionally $x$ is in the magnetic north direction
Time series
Time series: $E_x$, $E_y$, $H_x$, $H_y$ and $H_z$ measured as a function of time. The times series contain many different frequencies or periods giving through processing resistivity as a function of period, using Fourier transformation.
Analogue representation of a sinusoidal function and a digital representation of the same function.

**Period** (s), $T$

**Frequency** = 1/period or $f = 1/T$ (s$^{-1}$ (1/s) or Herz (Hz))

What are timeseries and what do they describe? An example: The temperature outside is a function of time.

The MT signal is composed of many different frequencies. Phoenix records from 1.000 Hz (0.001 s) to 0.0001 Hz (10.000 s). Sampling frequency: 15, 150 and 2.400 Hz.

Timeseries analysis - Fourier analysis.
Frequency and period, and source

- MT refers to 100 Hz (0.01 s) to 1.000 s; 10.000 s
- AMT refers to >100 Hz to 10 kHz
- LMT refers to 1.000 s to 10.000 s or higher
- High frequency (> 1 Hz): Thunderstorms near equator
- Low frequency: Generated by ionospheric and magnetospheric currents caused by solar wind (plasma) interfering with the earth’s magnetic field.
- Solar wind is a continual stream of plasma, radiating mainly protons and electrons from the sun. Encountering the terrestrial magnetic field they are deflected, establishing electric field
Distortion of Magnetosphere
Aurora caused by same energy
Current Sunspot Cycle

Just coming out of a sunspot minimum

![Graph showing sunspot activity over time.](image-url)
AMT Source Fields

- High Frequencies: World-wide thunderstorm activity
  - Energy travels around Earth in waveguide
  - Bounded by Earth surface and Ionosphere
  - Frequencies > 8 Hz

Zhdanov and Keller
Lightning

- Source field almost always present (BUT weak in AMT deadband during daytime)
The natural magnetic field spectrum.

MT “deadband” ~ 0.5 – 5 Hz;

AMT “deadband” ~1 kHz – 5 kHz
MT measurements in Iceland in 1976

MT equipment in Iceland – 1984-1985
The magnetic variational field at the ocean bottom is attenuated by the conductance of the ocean as described in Section 10.4 (cf. discussion of Equation (3.2) in Section 3.1.1, also). Owing to the skin effect, the attenuation is stronger for shorter periods; the ocean behaves as a low-pass filter. Hence passive ocean-bottom experiments have generally been band-limited to periods longer than 1 minute, and crustal structures have rarely been resolved. A recent
Maxwell’s equations

From Maxwell equations:

\[ \nabla \times \mathbf{E} = -\mu \frac{\partial \mathbf{H}}{\partial t} \quad \text{Faraday’s law} \]

\[ \nabla \times \mathbf{H} = \mathbf{J} + \varepsilon \frac{\partial \mathbf{E}}{\partial t} \quad \text{Ampère’s law} \]

- \( \mathbf{E} \): Electrical field intensity (V/m)
- \( \mathbf{H} \): Magnetic field intensity (A/m)
- \( \mathbf{J} \): Electrical current density; \( \mathbf{J} = \sigma \mathbf{E} \)
- \( \sigma \): Conductivity (Simens/m); \( \rho = \frac{1}{\sigma} \) (\( \Omega \) m)
- \( \varepsilon \): Electrical permittivity
- \( \mu \): Magnetic permeability

Gauss’s law for the electric field (\( \text{div} \mathbf{D} = q \)) and the magnetic field (\( \text{div} \mathbf{B} = 0 \)), respectively.

Constitutive relations: \( j = \sigma E, D = \varepsilon E \) and \( B = \mu H \)
Homogeneous earth

\[ E_x = B_x e^{-kz} e^{i\omega t} \quad ; \quad E_y = B_y e^{-kz} e^{i\omega t} \]

\[ H_x = \frac{-k}{i\omega \mu} B_y e^{-kz} e^{i\omega t} = \frac{-k}{i\omega \mu} E_y \]

\[ H_y = \frac{k}{i\omega \mu} B_x e^{-kz} e^{i\omega t} = \frac{k}{i\omega \mu} E_x \]

and: \( k^2 \approx i\omega \mu \sigma \)
Remote reference station

- Measured signal is composed of signal and noise
- A part of the noise is cultural noise
- Task is to increase the signal to noise ratio (S/N)
- One method is using a remote reference station located sufficiently far from the measuring station that the cultural noise is uncorrelated (≈30 km)
- Through data processing this may increase the S/N ratio considerably
Modelled by Hjálmar Eysteinsson
Joint inversion of TEM and MT should always be done where the host rocks are volcanic.
\[ \mathbf{H}_z = T_x \mathbf{H}_x + T_y \mathbf{H}_y \]

The real induction arrows (blue colour) point away from a zone of low resistivity.
The dominant conductor is the well-conductive seawater (0.3 Ωm)!
Concluding remarks

• MT is a powerful method to probe deep resistivity structures

• Data collection is simple and the equipment is portable

• Sensitive to cultural noise (power lines etc.)

• Static shift corrections are essential and using remote reference station is a great advantage

• Probes a large volume of rocks and is therefore sensitive to 3D resistivity variations

• Consequently detailed interpretation is difficult