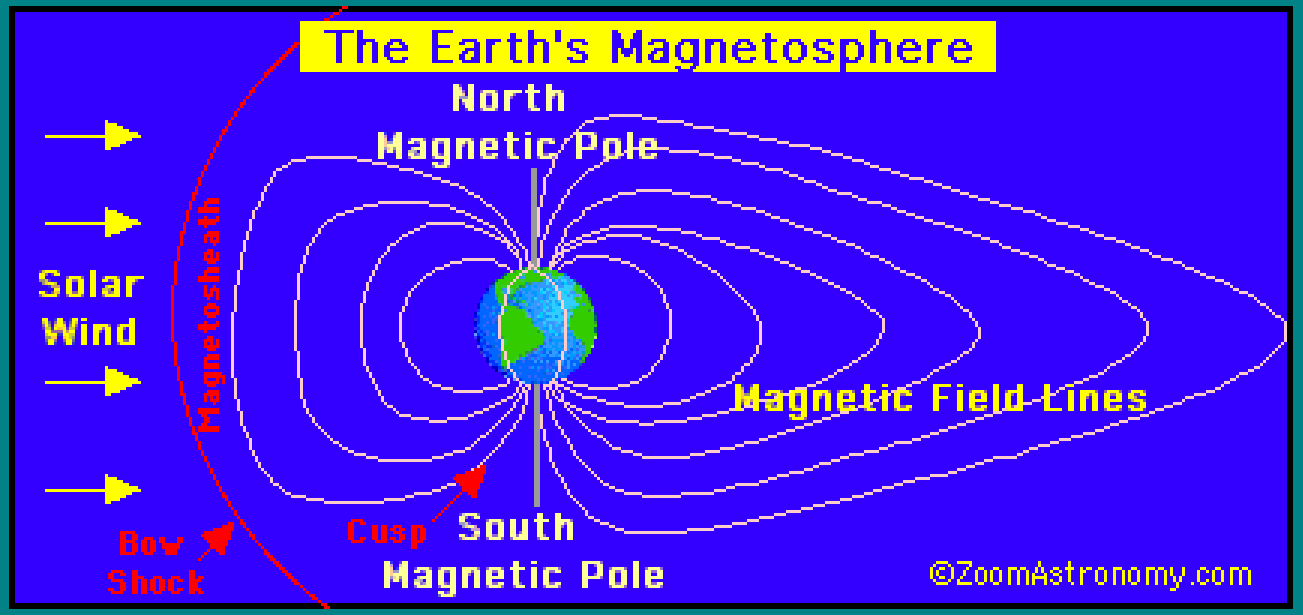
05_Electromagnetic principles

Electromagnetic principles

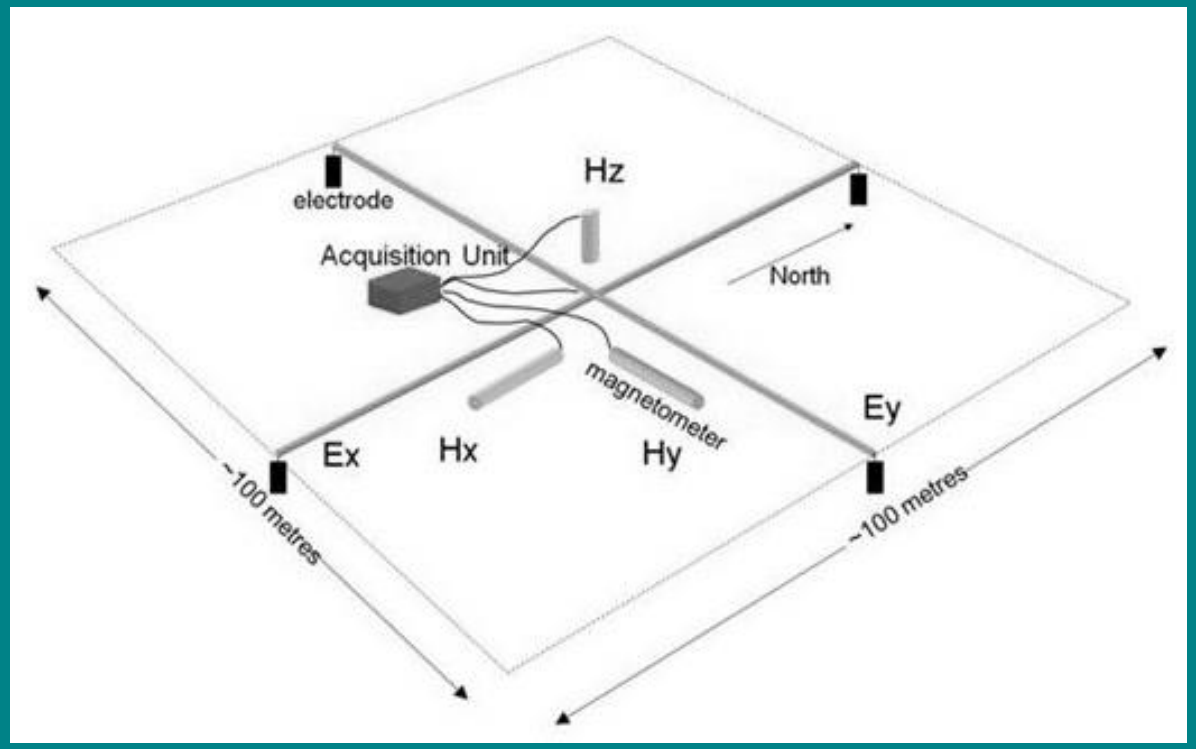
- During a MT experiment, we measure the **time-variations** in the **electromagnetic field** of the Earth
- Caused by magnetic storms (freq. < 1 Hz) and lightning activity (freq. > 1 Hz).



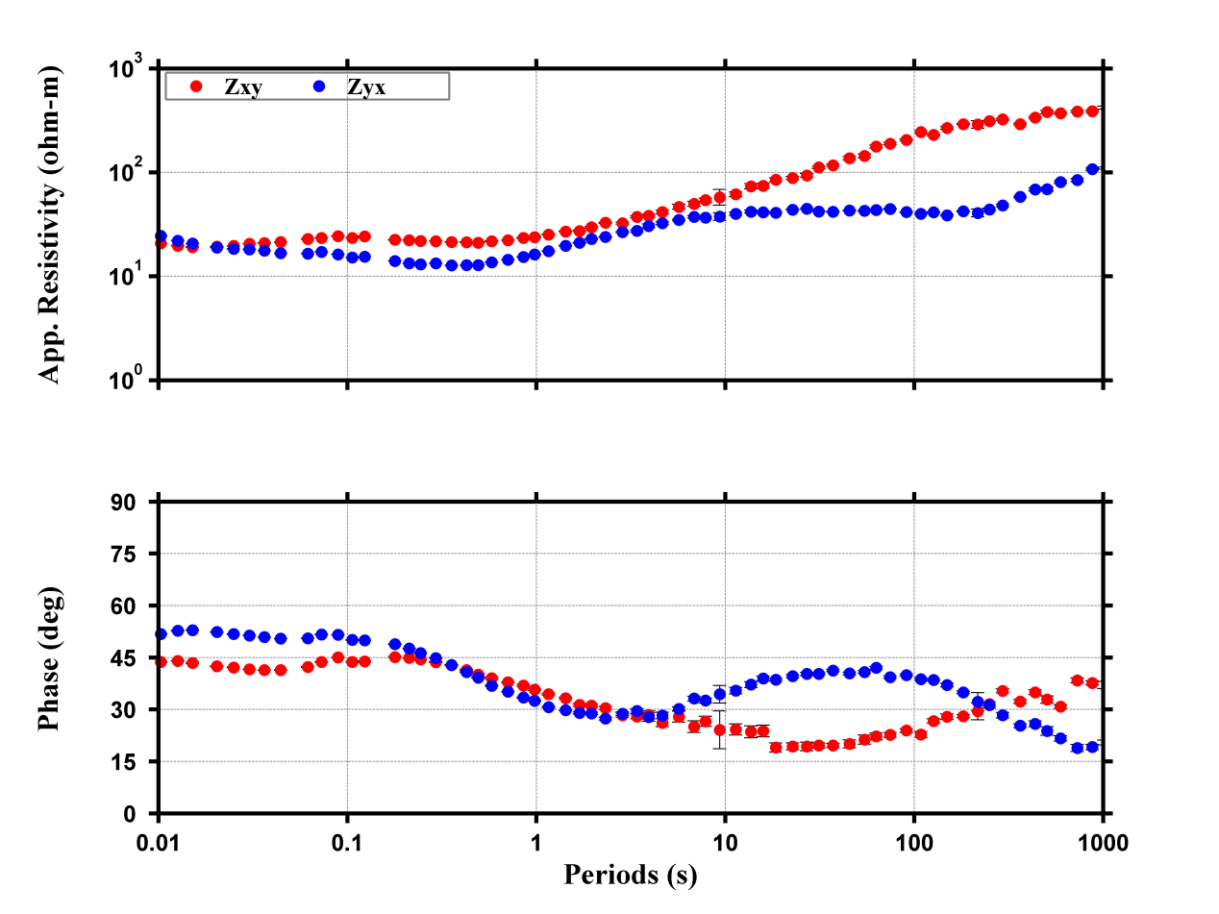
Magnetotelluric measurement

Measures the time-variations in the horizontal electric fields (E_x and E_y) as well as the the horizontal and vertical magnetic fields (B_x, B_y and B_z).

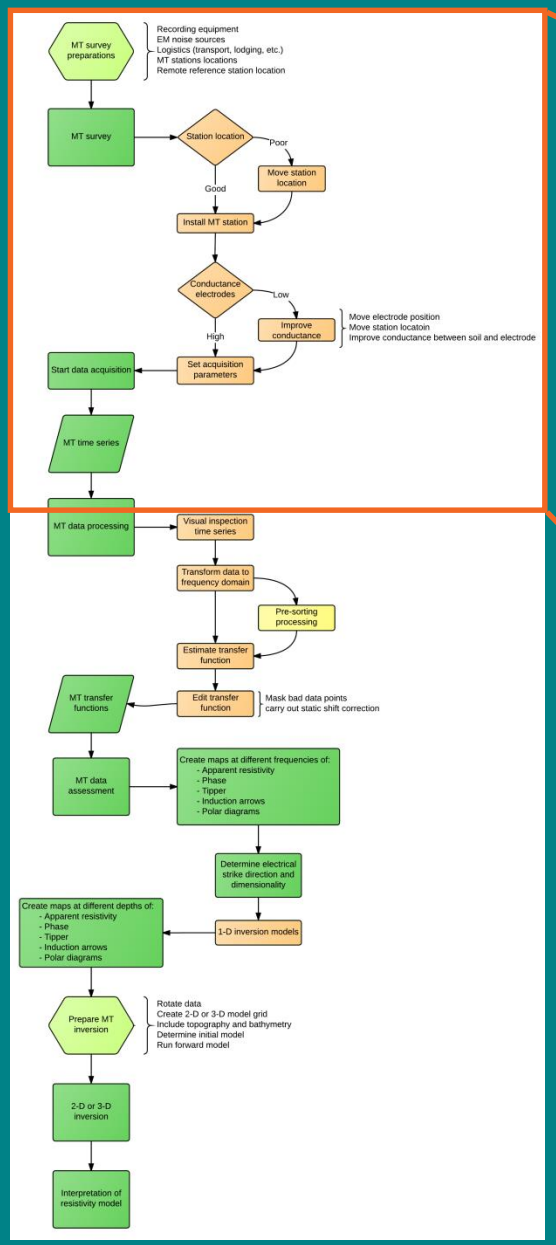
- E-fields are measured with (polarized) electrodes.
- B-fields are measured with magnetic coils.
- The 5 fields are recorded (in time) by a car battery powered data-logger.

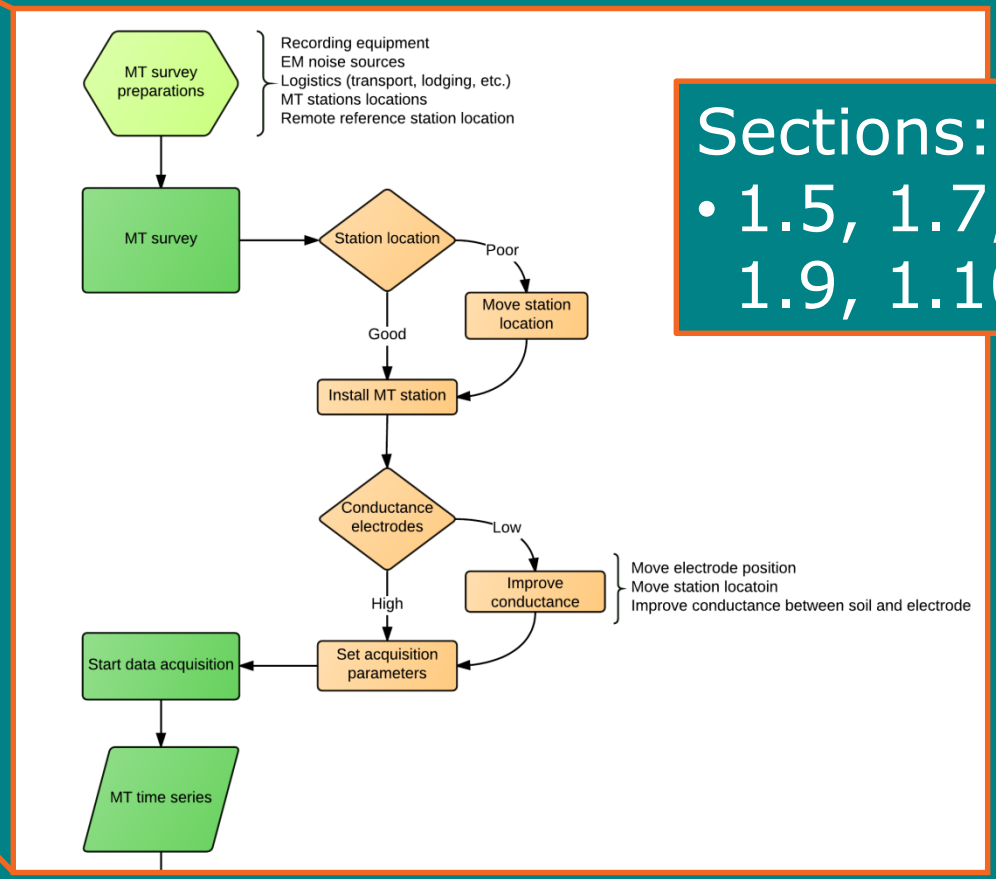


Magnetotelluric response



The MT process (1)

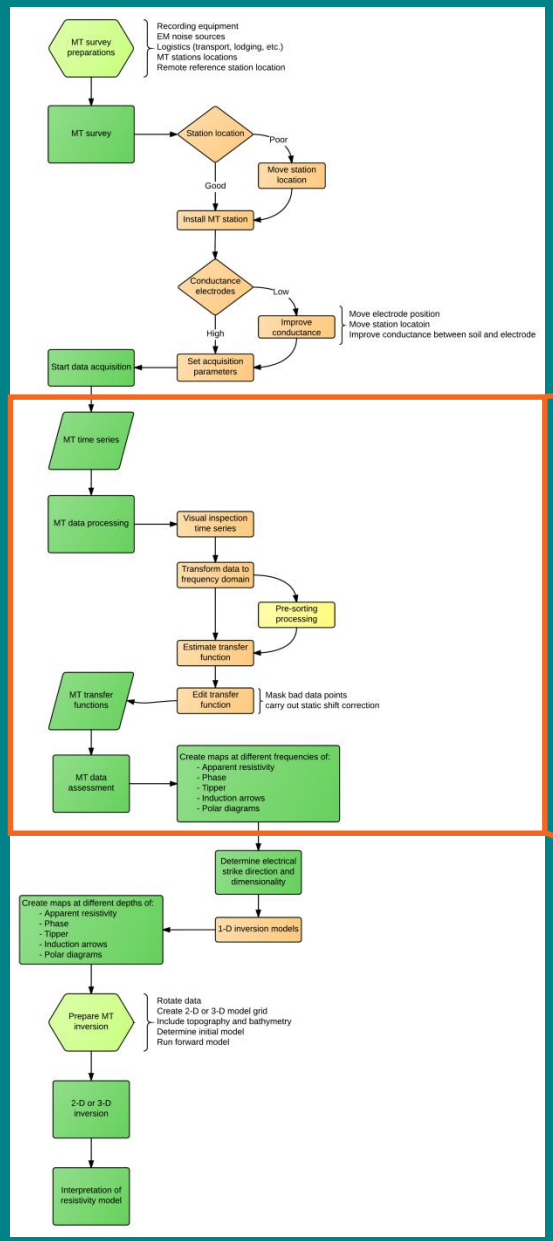


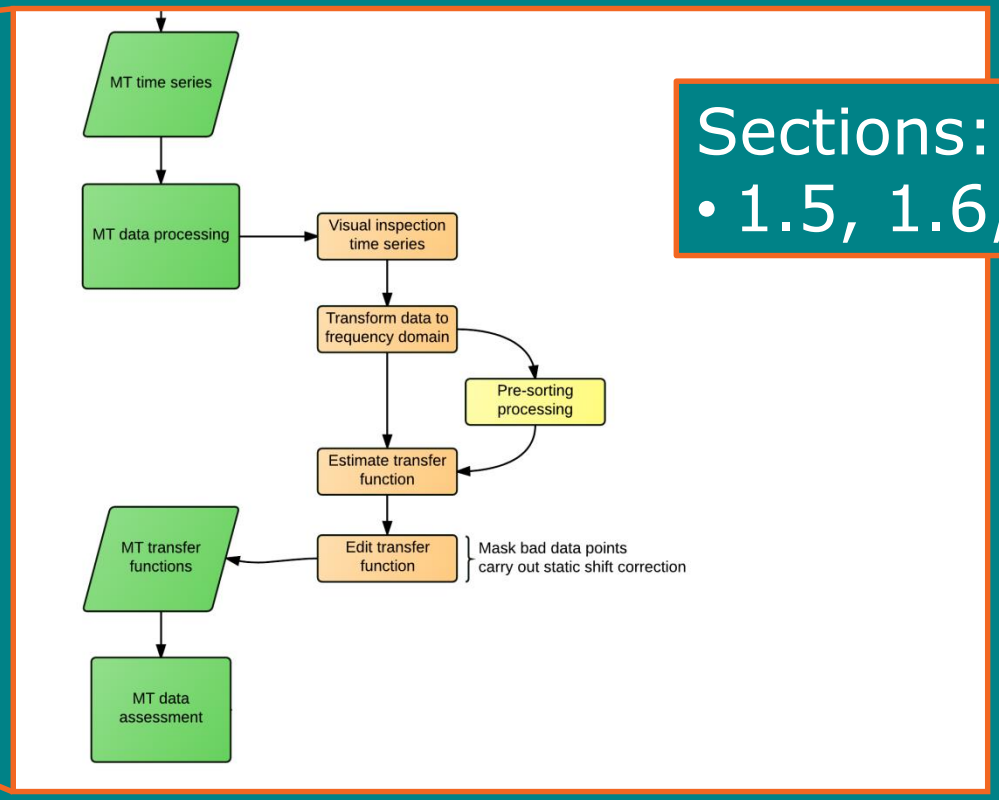


Sections:

- 1.5, 1.7, 1.8, 1.9, 1.10, 1.11

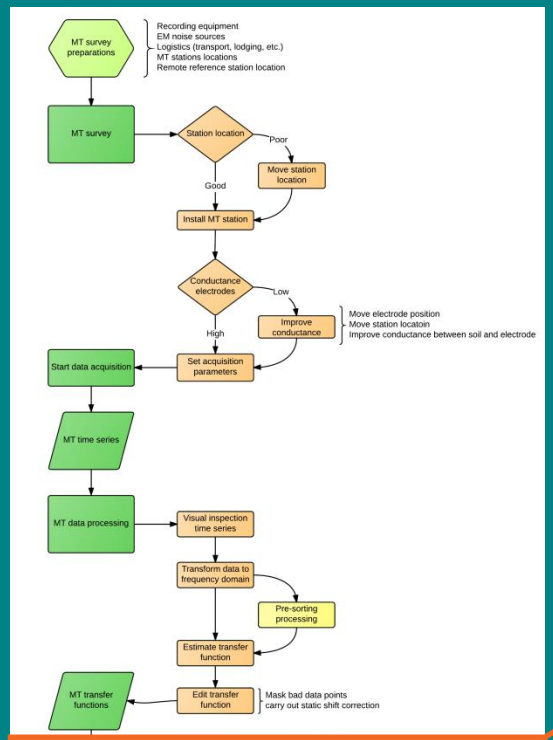
The MT process (2)

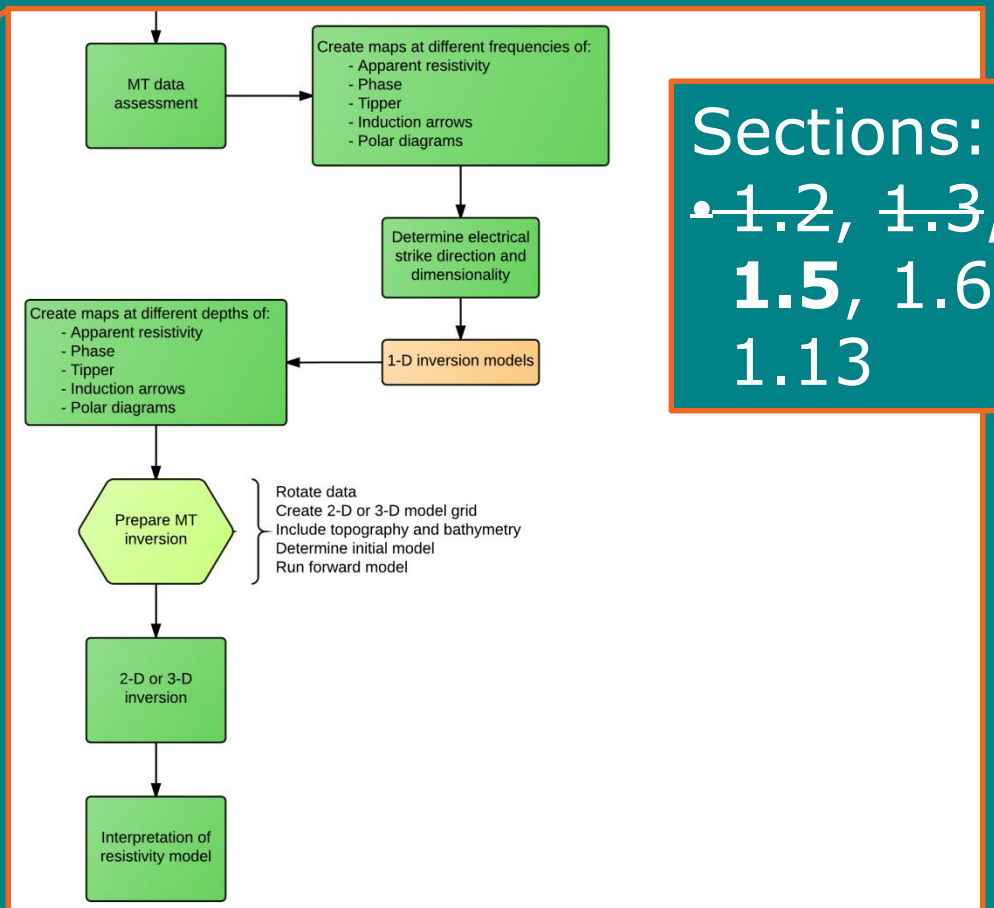




Sections:
- 1.5, 1.6, 1.11

The MT process (3)





Sections:

- ~~1.2~~, ~~1.3~~, ~~1.4~~
  1.5, 1.6, 1.12, 1.13

Very short history of electromagnetics

- Electric response of the *deep* Earth retrieved by measuring *longer* (Rikitake, 1948; Tikhonov, 1950; Cagnaird, 1953).
  - **Magnetotellurics (MT)**; low frequency (0.001 Hz – 300 Hz).
  - **Audio-magnetotellurics (AMT)**; mid frequency (10 Hz – 10 kHz), 1960's.
  - **Controlled-source audio-magnetotellurics (CSAMT)**; high frequency (1 Hz – 2 kHz), 1970's (e.g. Goldstein; 1971, Strangway; 1975), Zonge; 1980).

Electromagnetic methods

no.	EM method	Signal source		Frequency	Depth	Application
1	MT	Solar wind Ligthning	➢Passive	Low	100 m – 100 km	Geothermal Hydrocarbon Mineral Crust and mantle studies
2	AMT		➢Active	Mid	< 3 km	Geothermal Mineral
3	CSAMT/CSEM	Grounded dipole	➢Active	High	< 3 km	Geothermal Hydrocarbon Mineral
4	TDEM[1]	Transmitting loop	➢Active	High	< 500 m	MT static shift correction
5	VES, GPR, …		➢ Active	High	< 500 m	e.g. infrastructure Archeology

[1]Time-domain electromagnetics

Electromagnetic skin depth (1)

- **Electromagnetic skin depth relation:**

$$p(T) \approx 500\sqrt{T\rho_a}$$

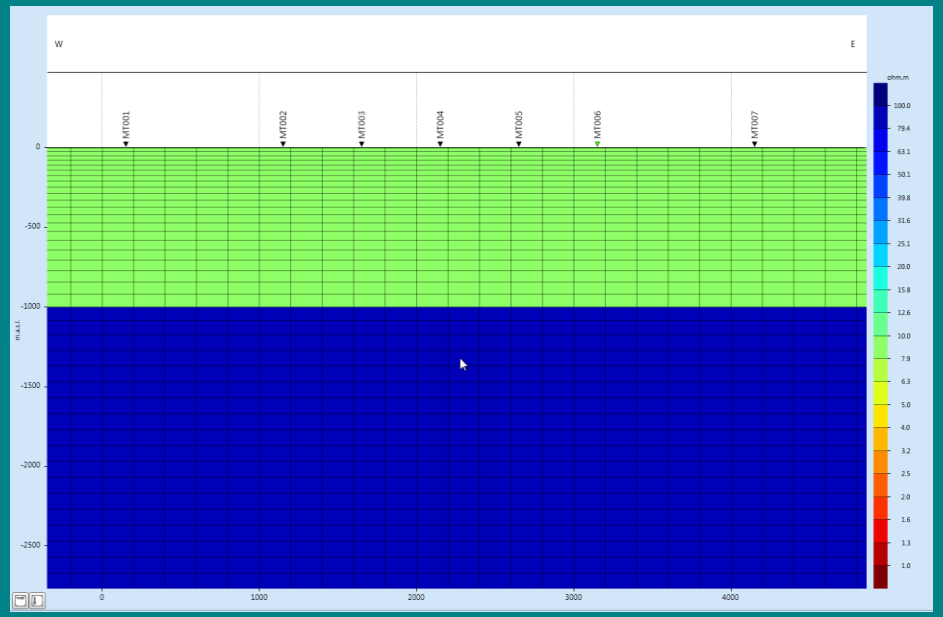
where ***p(T)*** is the EM skin depth in metres (m), ***T*** is the sounding period in seconds (s), $\boldsymbol{\rho_a}$ is apparent bulk resistyivity in Ohm-metre (Ωm).

Electromagnetic skin depth (2)

$$p(T) \approx 500\sqrt{T\rho_a}$$ or $$T = \mu_0 \sigma \pi p^2$$

- Consider a layered Earth:

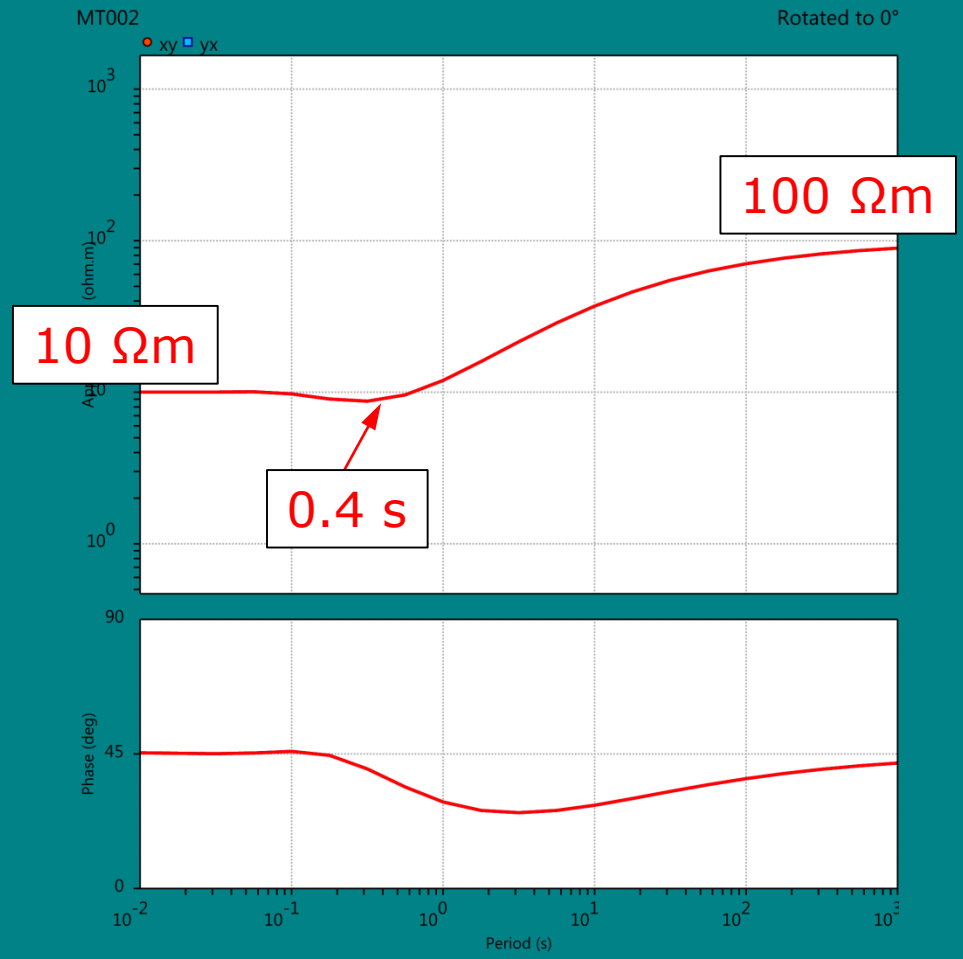
Layer	Thickness	Resistivity
Top layer	1,000 m	10 Ωm
Basement	∞	100 Ωm



Electromagnetic skin depth (3)

- Base of layer visible in apparent resistivity at ~0.4 s.

- Bulk electrical resistivity of the Earth ranges from 10^{-1} to 10^{5} Ωm.
- Target depths range from 500 m to 100 km
- Frequency range utilized in MT: 10^{-4} to 10^{5} s
- For geothermal exploration: 10^{-4} to 1,000 s



Assumptions of the MT method

- Maxwell's equations are obeyed
- The Earth does not generate EM energy
- Normally incident EM waves on the Earth's surface are uniform and planar **(plane-wave assumption)**
- …
- and more, see e.g. Simpson and Bahr (2005)

Plane wave assumption

- A plane wave propagates normal to a plane in which the fields are constant.
- The *impedance tensor* at a specific location is always the same, independent of when the fields are recorded.
  - Very shallow surface conditions change (geology)

Maxwell equations (1)

- Gauss' law for electric fields:
  - Opposite charges attract and negative charges repel
- Gauss' law for magnetic fields:
  - Magnetic monopoles do not exist
- Faraday's law
- Ampere's law

Maxwell equations (2)

- **Faraday's law**:
  - Electric current gives rise to magnetic fields. Magnetic fields around a circuit gives rise to electric current.
  - A time-varying magnetic field gives rise to an electric field circulating around it.
  - A circulating electric field in time gives rise to a time-varying magnetic field.

Maxwell equations (3)

- **Ampere's law:**
  - A flowing electric current gives rise to a magnetic field that circles around it
  - A time-varying electric flux density gives rise to a magnetic field that circles around it.
- In combination with Faraday's law:
  - A time-varying magnetic field gives rise to a (perpendicular flowing) time-varying electric field. And a time-varying electric field gives rise to a (perpendicular flowing) time-varying magnetic field – which will produce a time-varying (perpendicular flowing) electric field, etc.