03_Factors affecting resistivity

Conduction mechanisms in Earth materials

1. Electronic conduction

   Electronic conduction occurs in pure metals. The charge carriers are electrons that exist as a gas between ions and can move very easily through the metal. Typically very low (~1.6 x 10^{-8} Ωm)

2. Semiconductors

   Semi-conduction occurs in minerals such as sulphides. Here the charge carriers are electrons, ions or holes. The resistivity is usually in the order of 10^{-3} to 10^{-5} Ωm. This type of conduction occurs in igneous rocks and is usually temperature dependent.

3. Ionic conduction in liquids

   In liquids (aqueous fluids or molten materials), the ions can move freely. As the salinity of a brine increases, the resistivity decreases as more charge carriers become available.

Resistivity of the subsurface

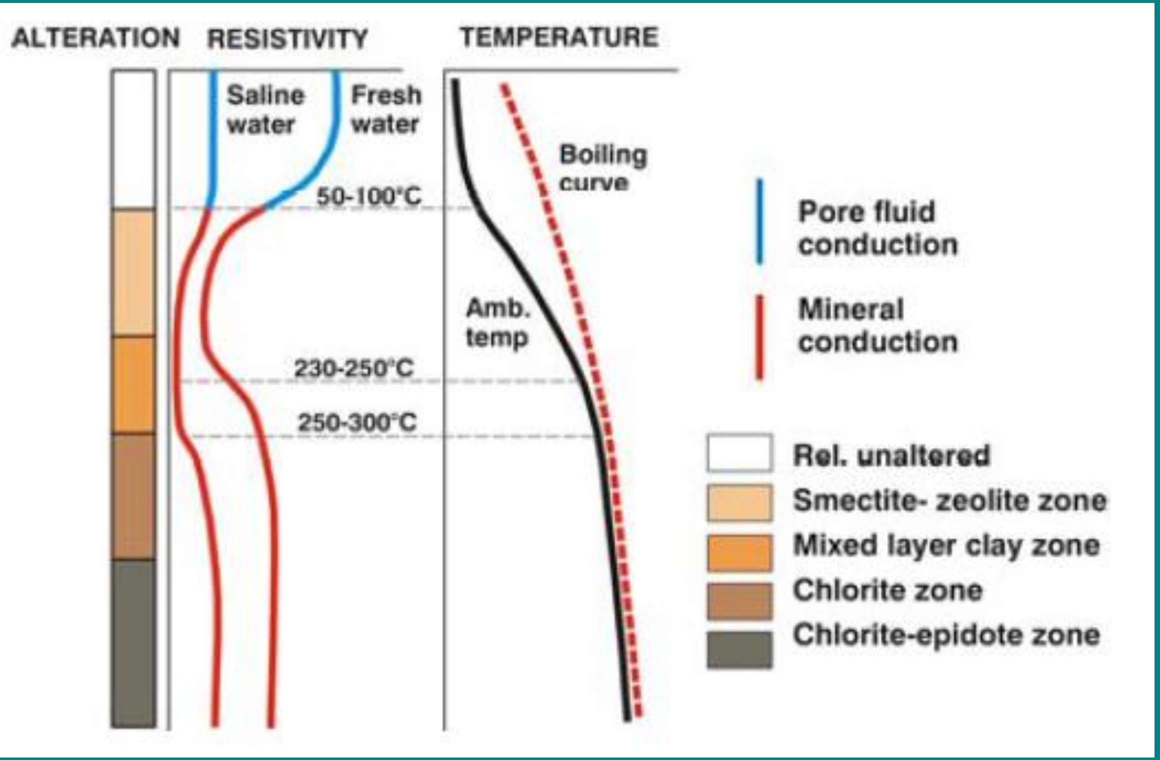
Electromagnetic methods measure the resistivity response of het subsurface.

The resistivity response is mainly controlled by:

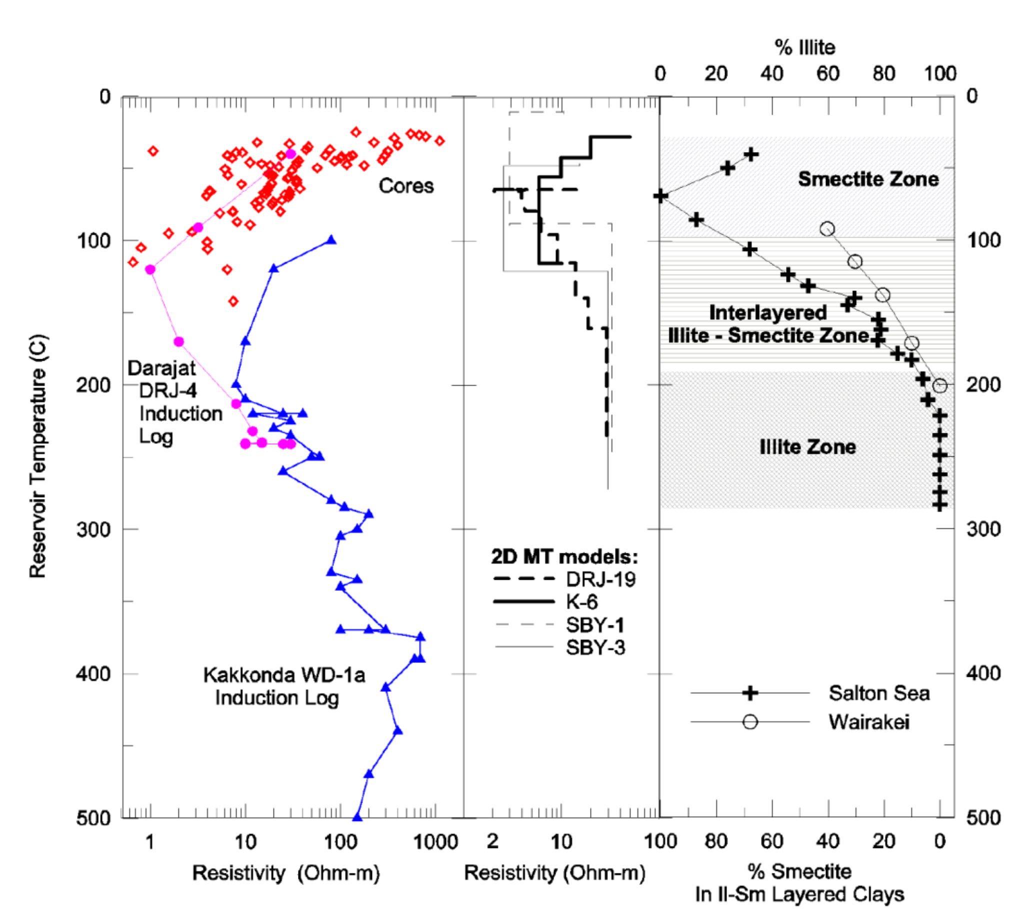
- **Melt**
- **Hydrothermal clay alteration**
- **Porosity and permeability**
- **Fluid composition**

Hydrothermal clay alteration

- Occurs when the fluid composition contains a volcanic component.
- Different minerals with different resistivities form at different temperatures.
- The clay minerals often form an impermeable conductive clay cap.
- **Alteration mineralogy is a reflection of the maximum temperature experienced by the rocks while the actual temperature might be lower.**



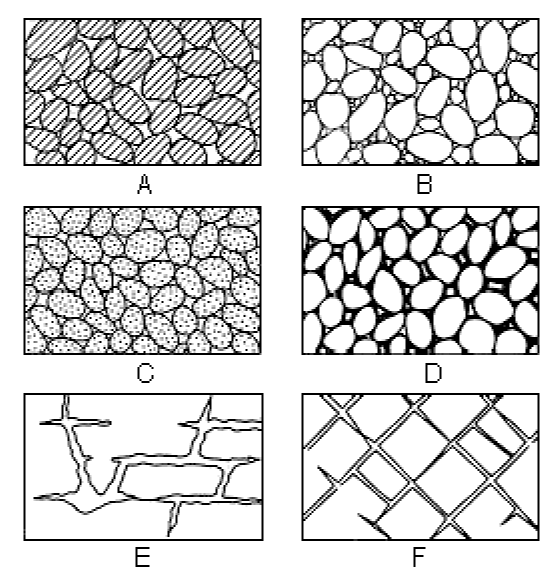
Temperature versus resistivity versus clay alteration mineralogy

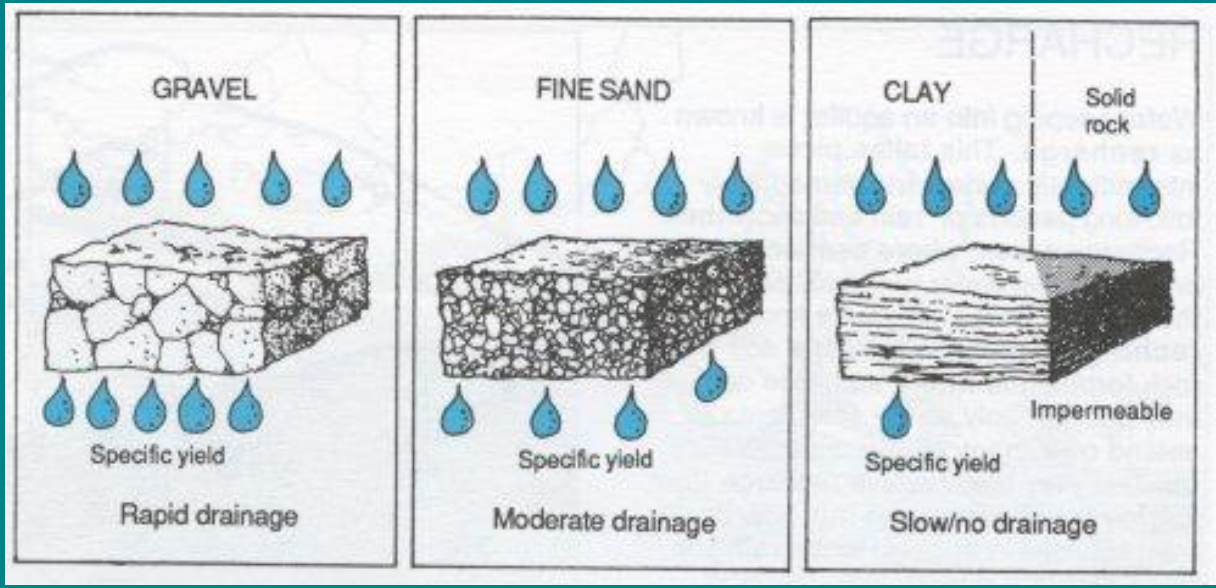


From Ussher et al. (*2001*)

Porosity and permeability (1)

- Porosity is the fraction of rock occupied by the fluid.
- Permeability is the ability of a porous rock to transmit fluids.





Porosity and permeability (2)

- Resistivity and porosity are not only dependent on temperature and pressure, but also on the geological history of the formations.
- Empirical relation like *Archie* (1942) describe the relationship between porosity and resistivity.
  - Porosity from resistivity can be derived using, e.g., Archie's second law

$$F = a\phi^{-m} S_w^{-n}$$

where a is the tortuosity factor, φ is the porosity, m is the cementation factor, S_w is the water saturation, and n is the saturation exponent.

Porosity and permeability (3)

- Rocks with clean matrix conductance do not exist. Caldwell et al. (*1986*) their modification of Archie's law, which include a component for conduction by clay minerals within the matrix, is more useful:

$$\rho = a\rho_w \phi^{-n} S_w^{\;-m} \left(1 + KC\rho_w\right)^{-1}$$

where C is the proportion of the clay minerals in the matrix, and K is a constant according to the type of clay minerals present.

Porosity and permeability (4)

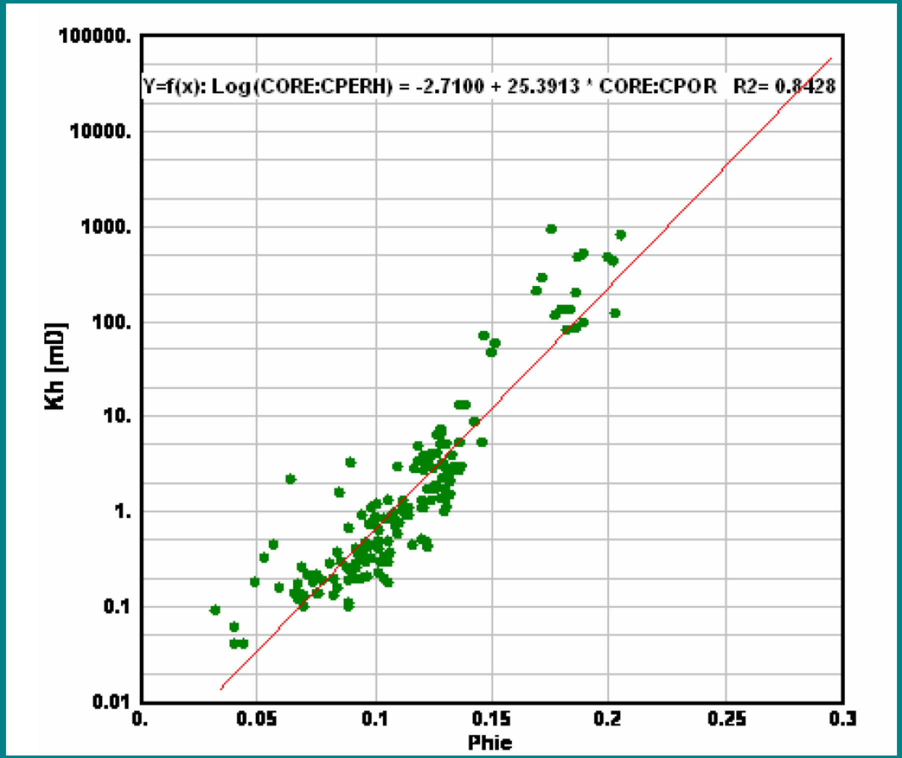
- Permeability can be derived from porosity using, e.g.:

1. The RGPZ model (*Glover, 2006*)

$$k = \frac{d^2 \phi^{3m}}{4pm^2}$$

   where *k* is the permeability, *d* is the effective grain diameter, and *p* is the packing parameter.

2. By construction a porosity-permeability relationship from borehole information.
3. …



Melt

- The resistivity of the melt is greatly dependent on its composition, the fraction of partial melt and the presence of water.
- At temperatures above 800°C magma has a very low resistivity.

Fluid temperature

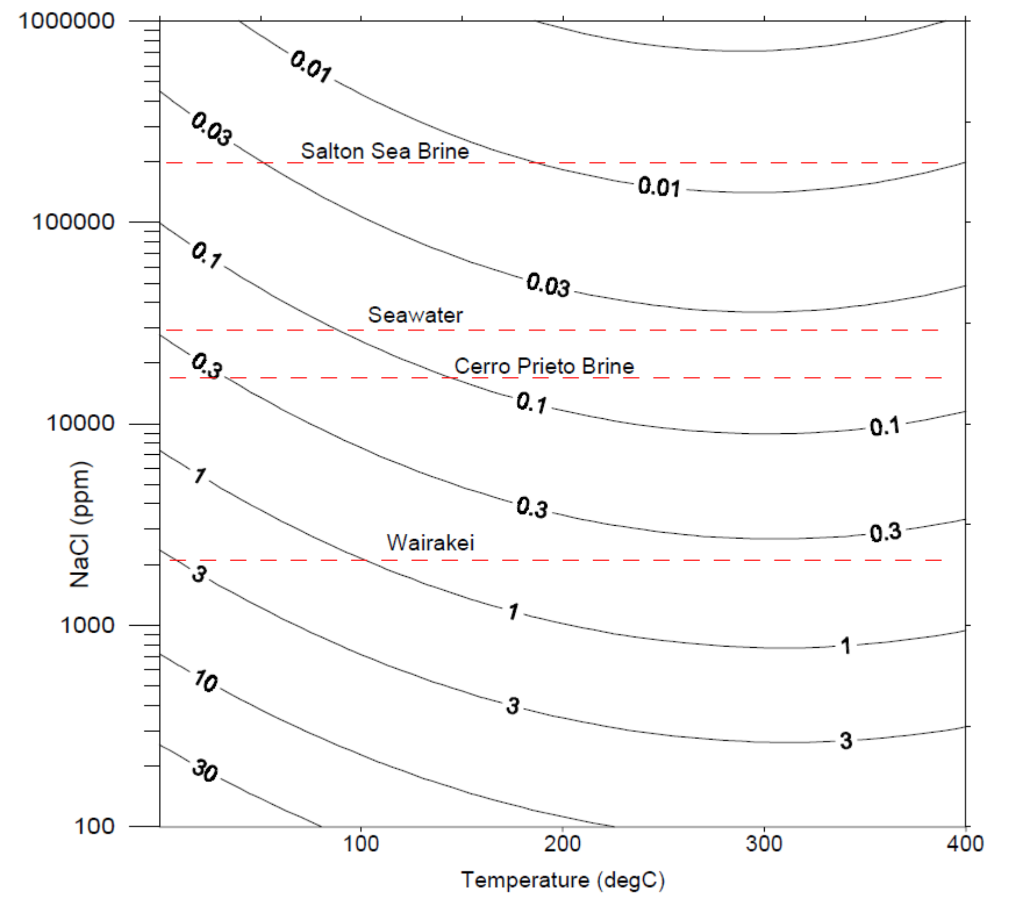
- Conduction by ionic processes in clay and porous sandstones:
  - Clay contains electrolytes in its pores
  - Sandstone contains brines in its pores
- Electrolyte resistivity is directly related to the viscosity of the fluid, which decreases with temperature.

Fluid composition (1)

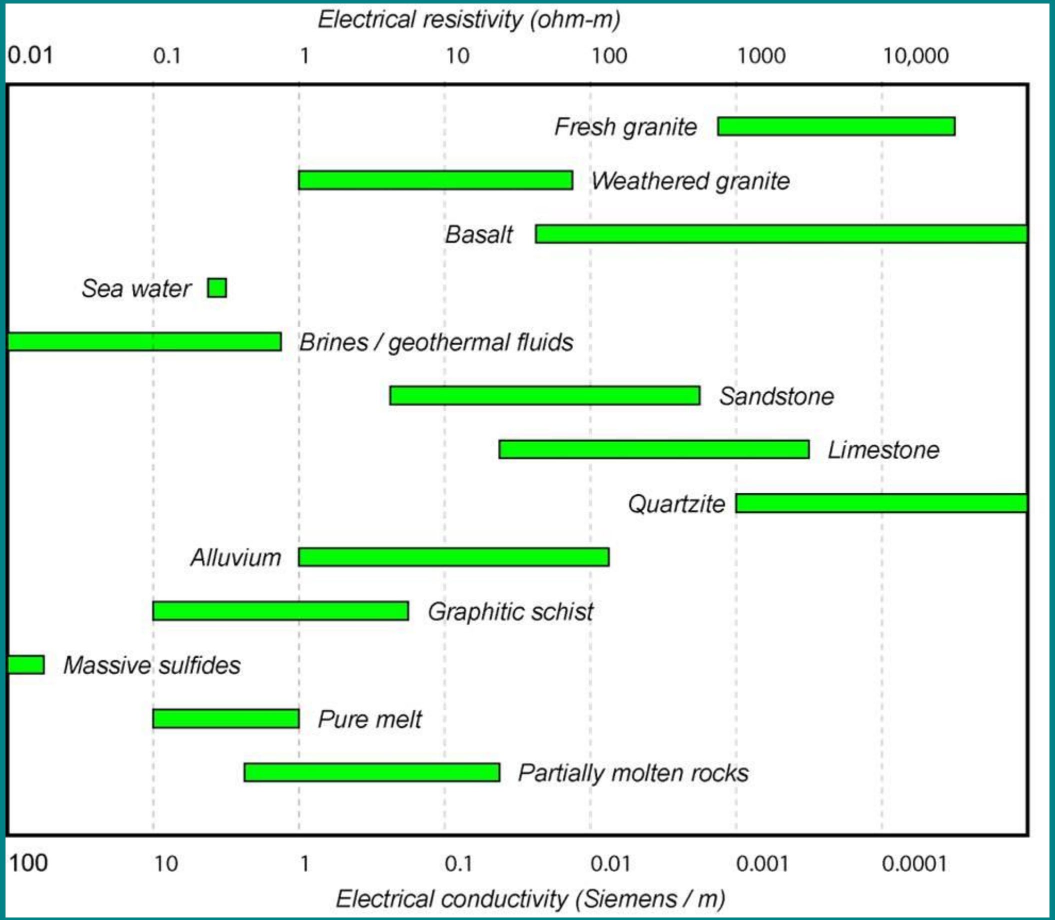
- Fluids with a higher concentration of dissolved salts (TDS) generally have a higher conductivity.
- Conductivity with constant salinity is dependent on temperature and pressure.
- Several empirical relations between resistivity and salinity available, e.g.:
  - Block (2001),
  - Meju (2000);

Fluid composition (2)

- The variation of resistivity in Ωm of NaCl solutions from measurements of Ucok et al. (*1980*).
- The salinity of several well known geothermal fields are shown for reference (*Ussher et al., 2000*).



Resistivity of Earth materials (1)



- Huge variation in the resistivity of Earth materials (10^{-2} – 10^{5} Ωm)

Resistivity of Earth materials (2)

Factor	DECREASE of resistivity	INCREASE of resistivity
Pore fluid volume	Increase	Decrease
Pore fluid salinity	Increase	Decrease
Electrical current flow pathways	Increase (fracture the rock)	Decrease (compaction)
Clay alteration mineral content	Increase	Decrease
Rock formation permeability	Increase	Decrease
Temperature	Increase	Decrease