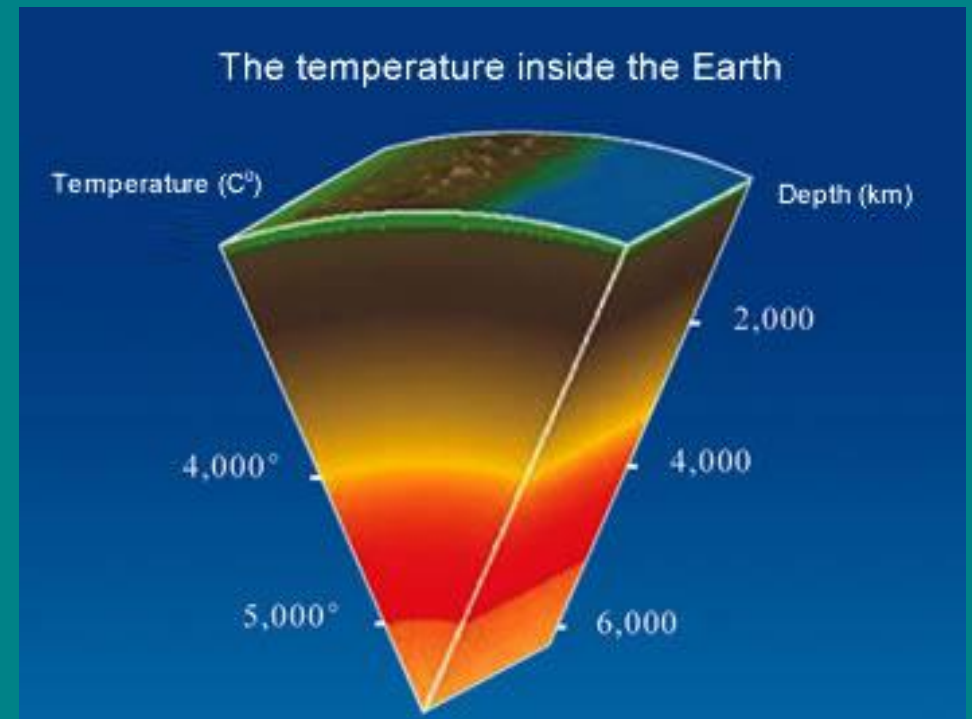


02_Geothermal energy

Definition of geothermal energy

- Definition according to *Dickson and Fanelli (2004)*: “that part of the Earth's heat that can, or could be, recovered and exploited by man”.
- Sources contributing to Earth's heat:
 - Radiogenic heat production in the mantle.
 - Core and mantle cooling.
- Heat present in liquid water or steam, trapped in the crust.

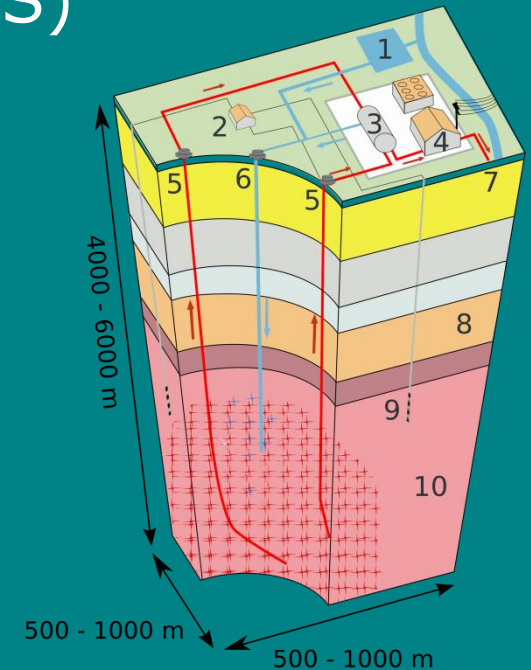
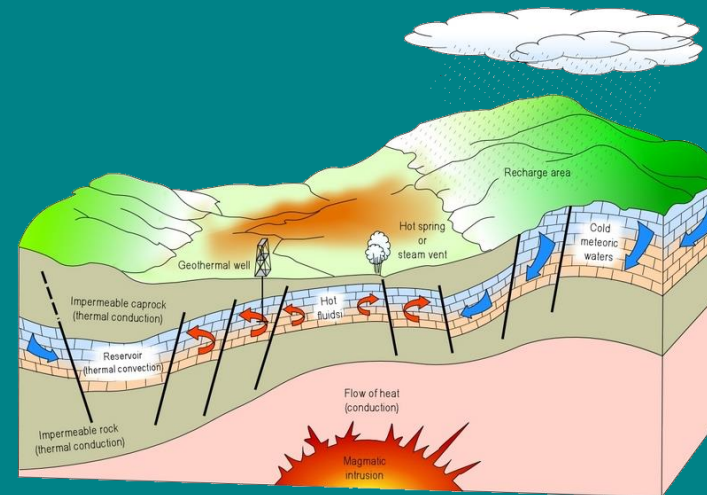


Geothermal system definition

- Definition according to *Williams et al. (2011)*:
“Any localized geological setting where portions of the Earth’s thermal energy may be extracted from natural or artificially induced circulating fluids transported to a point of use.”

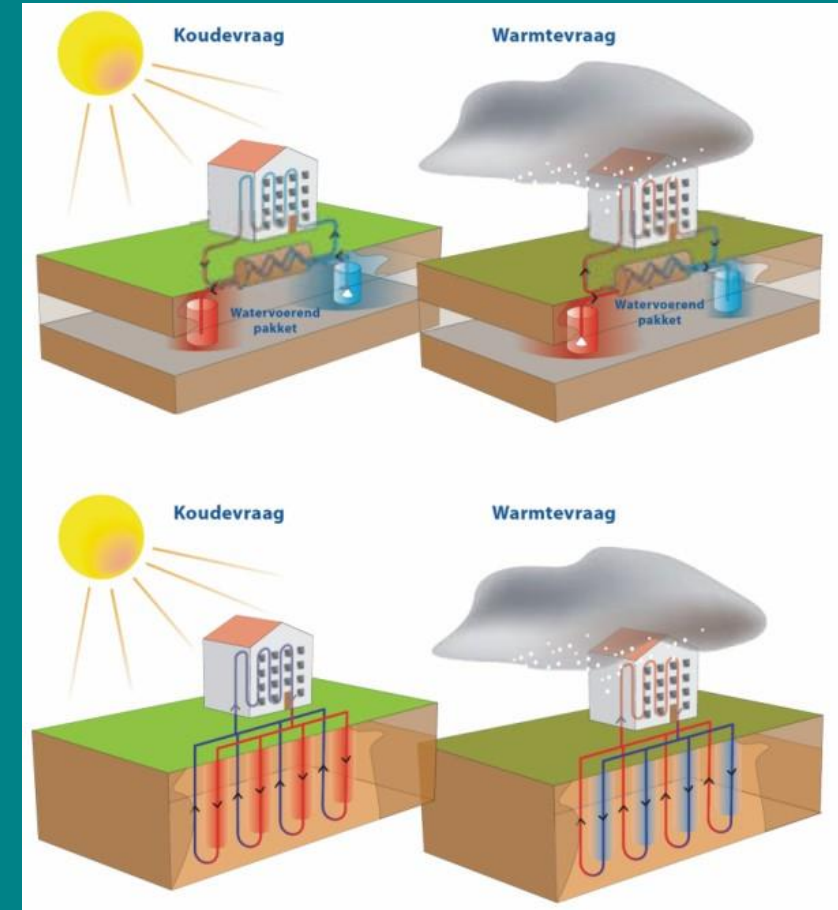
Geothermal system examples (1)

- Electrical power generation or direct heat:
 - Liquid or dry steam geothermal system
 - Engineered or enhanced geothermal systems (EGS)
 - Hot sedimentary aquifer geothermal system



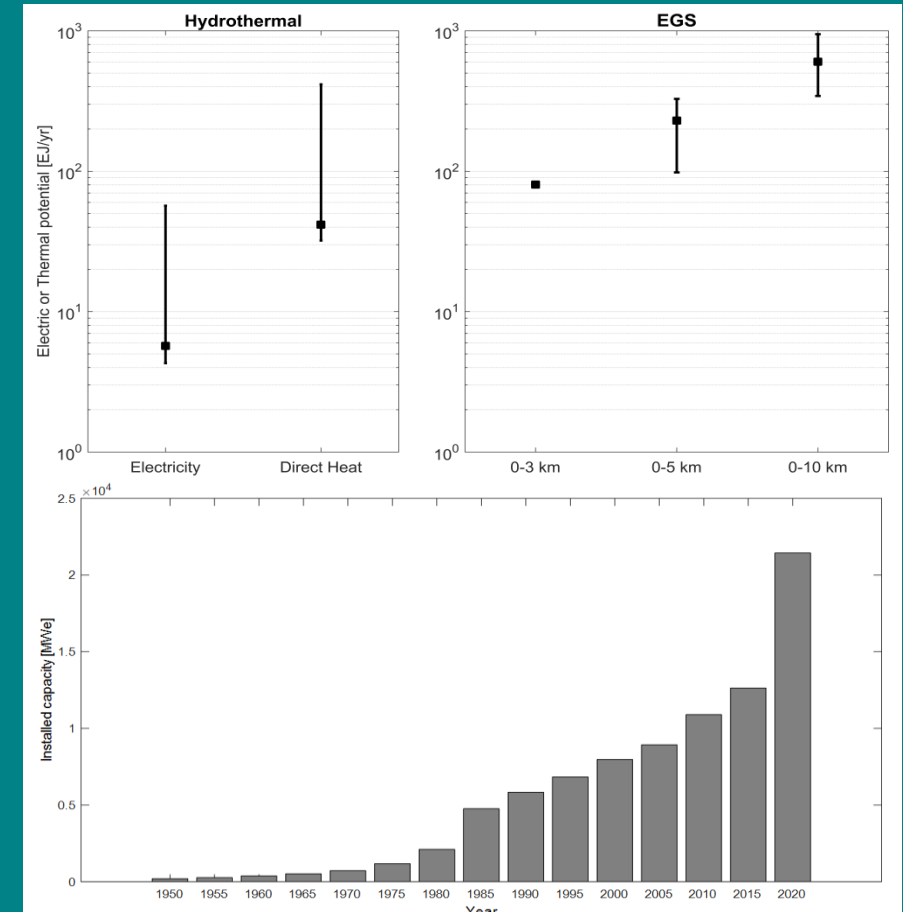
Geothermal system examples (2)

- Ground source heat pumps:
 - Open systems
 - Closed systems



Potential and installed capacity

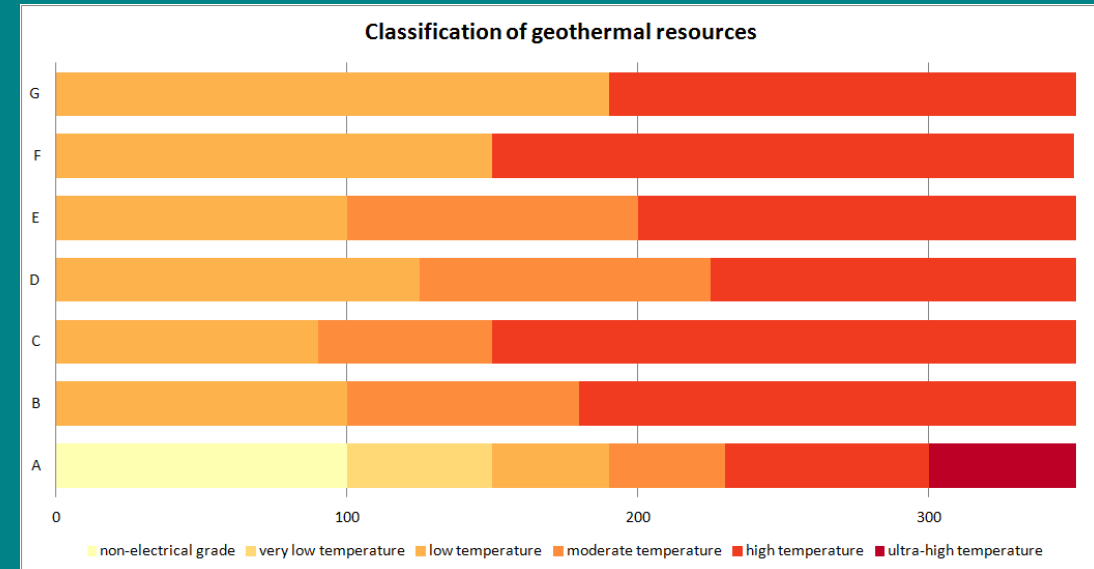
- Estimated **Geothermal technical potential** with upper and lower bounds for hydrothermal geothermal systems and engineered geothermal systems (EGS). Modified from *Goldstein et al. (2011)* and *Stefansson (2005)*.
- Worldwide **installed geothermal electricity power capacity** from 1950 up to end 2015 and short time forecasting until 2020. From *Bertani (2015)*.



Categorization of geothermal systems (1)

Temperature based

- Advantages:
 - Suited for users
 - Easy to understand
- Disadvantages:
 - Geology not included
 - Economics not included
 - No uniform categorization
 - Not suited to find analogue geothermal systems



Categorization of geothermal systems (2)

Heat-transfer mechanism (*conduction and convection*) based (*Moeck, 2014*).

- Advantages
 - Geology included
 - Possibility to assess economic viability
 - Analogue geothermal systems can be compared
 - Helps defining exploration strategy
 - Helps defining the conceptual model
- Disadvantages
 - Difficult to apply, sound geological understanding necessary

Categorization of geothermal systems (3)

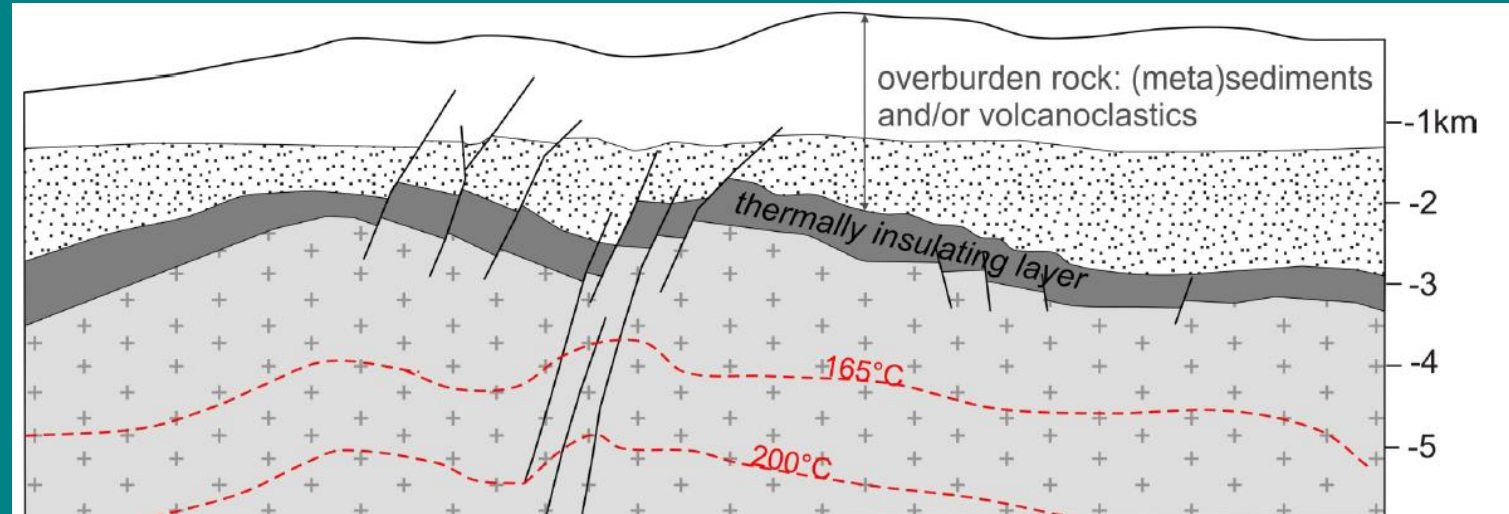
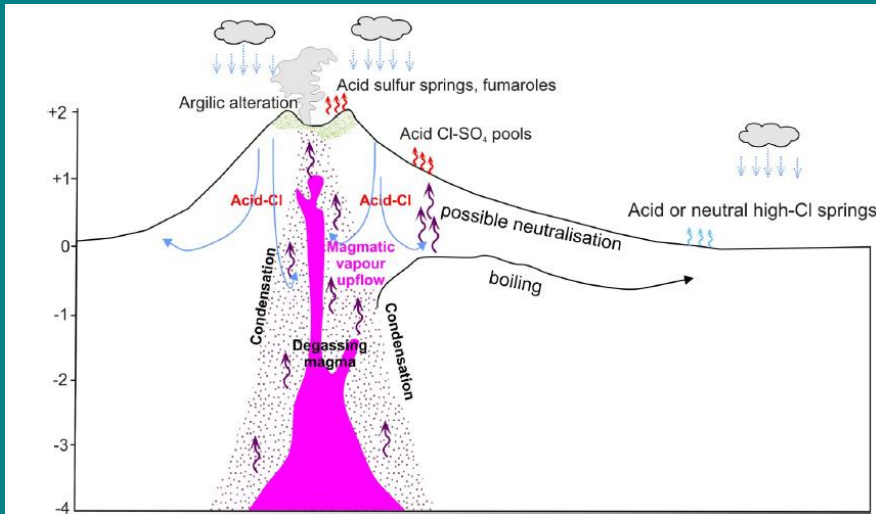
Convection-dominated and **conduction-dominated** type **geothermal plays**.

- The model which comprises the **geological factors** controlling a technically and economically recoverable geothermal resource. Providing:
 - **Heat source**
 - **Reservoir**
 - **Heat or fluid pathways**
 - **Seal**
 - **Storage capacity**
 - **Potential for economic recovery**

Categorization of geothermal systems (4)

Convection-dominated and conduction-dominated type geothermal plays.

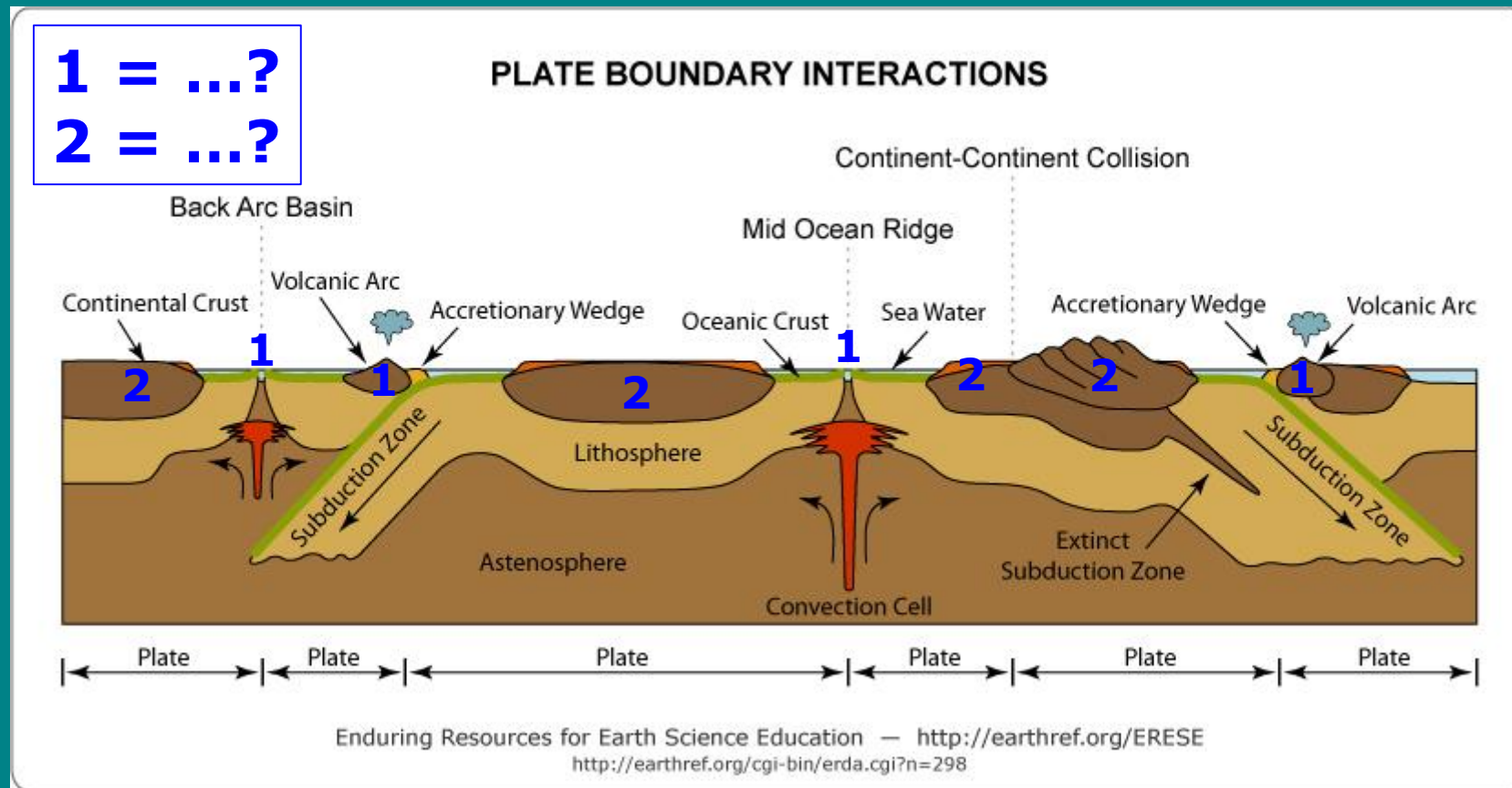
- **Convection-dominated:** e.g. volcanic, plutonic
- **Conduction-dominated:** e.g. basement, orogenic



Categorization of geothermal systems (5)

Convection dominated geothermal plays		
<i>Play type</i>	<i>Geological setting</i>	<i>Heat source</i>
Volcanic	Magmatic arcs, mid ocean ridges and hotspots	Magma chamber and intrusion
Plutonic	Young orogens, post-orogenic phase	Young intrusion and extension
Extensional domain	Metamorphic core complexes, back-arc extension, pull-apart basins and intracontinental rifts	Elevated heat flow due to thinned crust
Conduction dominated geothermal plays		
<i>Play type</i>	<i>Geological setting</i>	<i>Heat source</i>
Intracratonic basin	Rift basins and passive margin basins	Sedimentary aquifers and porosity/permeability with depth
Orogenic belt	Fold-and-thrust belts and foreland basins	Sedimentary aquifers, porosity/permeability with depth and fault and fracture zones
Basement	Intrusion in flat terrain and highly radiogenic rocks	Hot intrusive rock, low porosity/low permeability and fault and fracture zones

Categorization of geothermal systems (6)

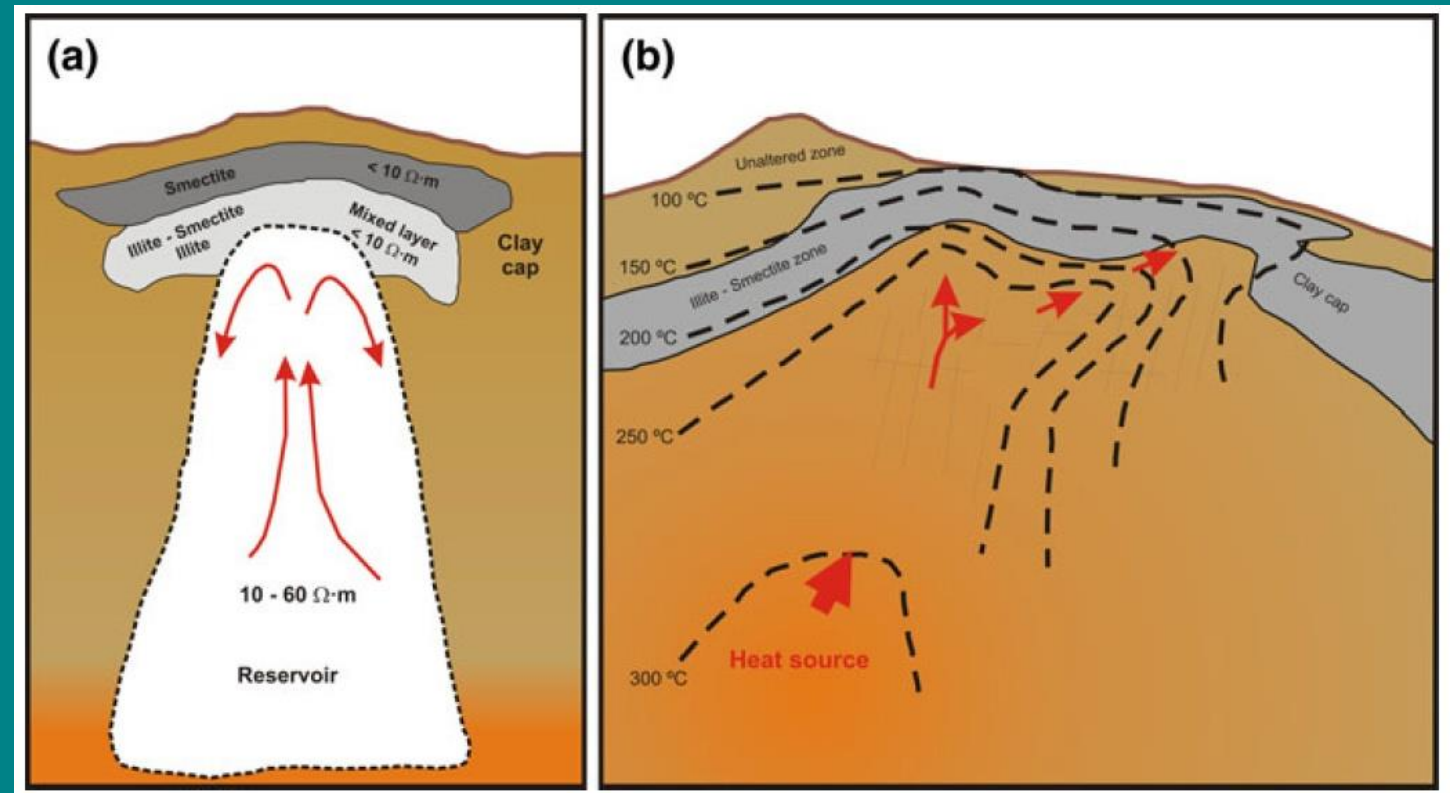


Conceptual model (1)

- The **conceptual model** of a geothermal system is the “geological description of a geothermal system, containing the relevant structures and processes characterizing the geothermal reservoir and its response to exploitation”.
- Conceptual models of **all** play types comprise history, relation and properties of three elements:
 - **Heat source**
 - **Geothermal reservoir**
 - **Seal or cap rock**

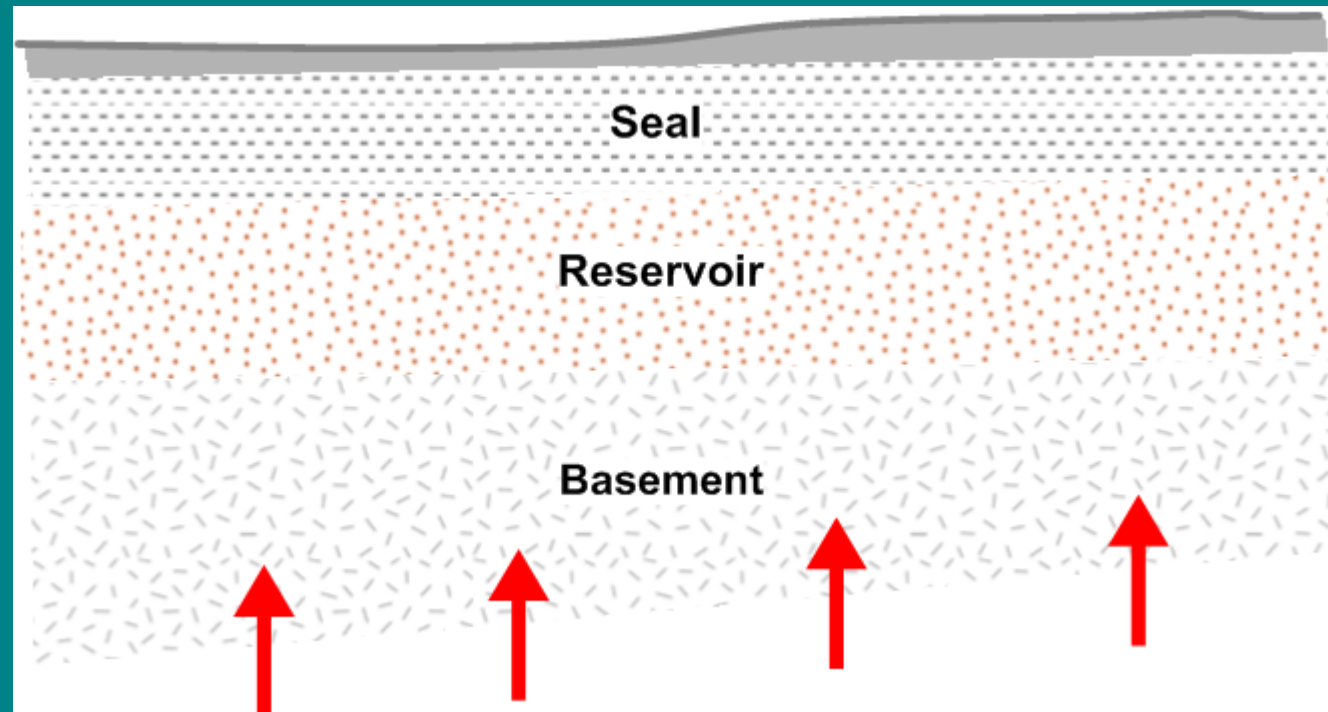
Conceptual model (2)

- Volcanic conceptual model



Conceptual model (3)

- Sedimentary conceptual model



Conceptual model (3)

- A conceptual model is quantitative (whereas a geothermal play type is qualitative)
- A conceptual model is defined after (surface) exploration is carried out
- A conceptual model is continuously updated (a geothermal play type is static)