What is Geothermal Energy?
Origin and relation with Earth dynamic

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6 November 2012
Strasbourg

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Plan

1 – Thermal process and Earth internal structures

2 – Heat flow and geothermal gradient

3 – Plate tectonic and geothermal resources

4 – Different types of geothermal energy

Thermal process and Earth internal structures

Earth temperature

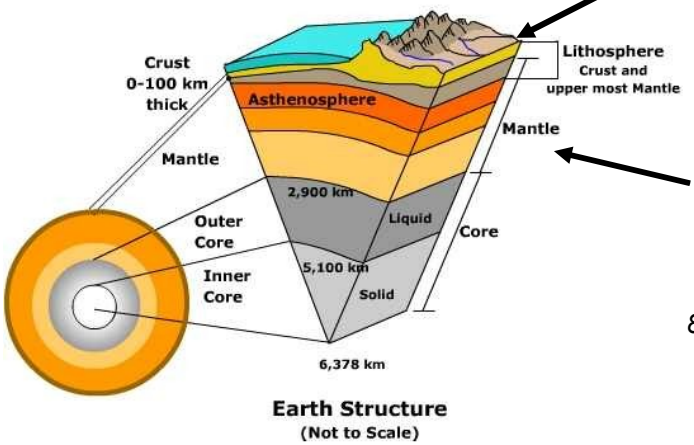
99% of Earth mass is above 1000°C

Crust:
Stable zones : 30°C/km
Active zones : 500°C/km

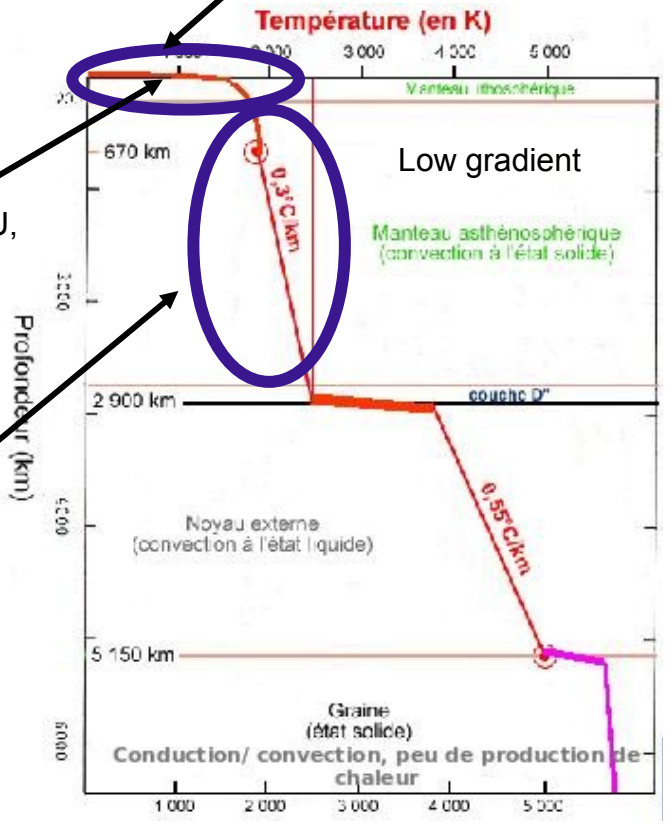
Disintegration of radioactive elements U, K, Th = up to 85% of heat production in continents

Evacuation of Mantle primitive heat

Mantle = ½ Earth radius - 85% volume



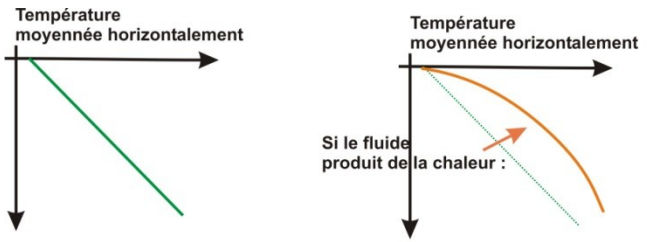
Earth Structure
(Not to Scale)



Heat Flow = Disintegration U, K, Th in crust + Evacuation primitive heat

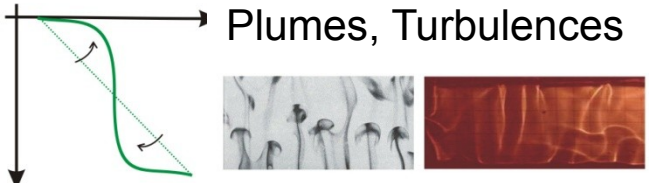
Thermal convection / conduction ?

Pure conduction



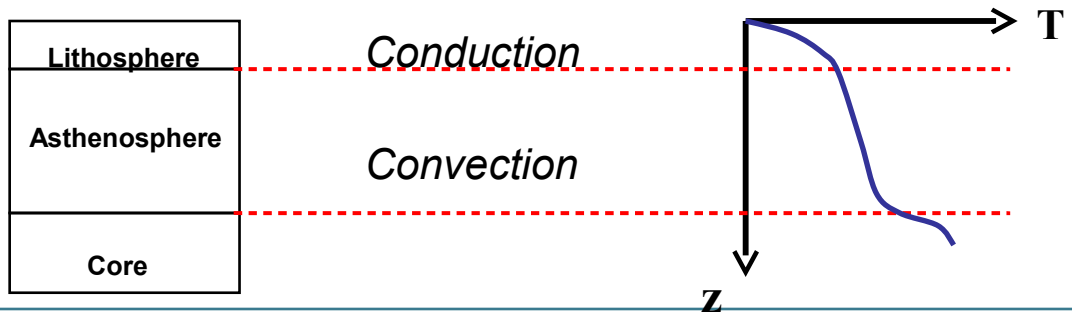
Convection

Intense convection



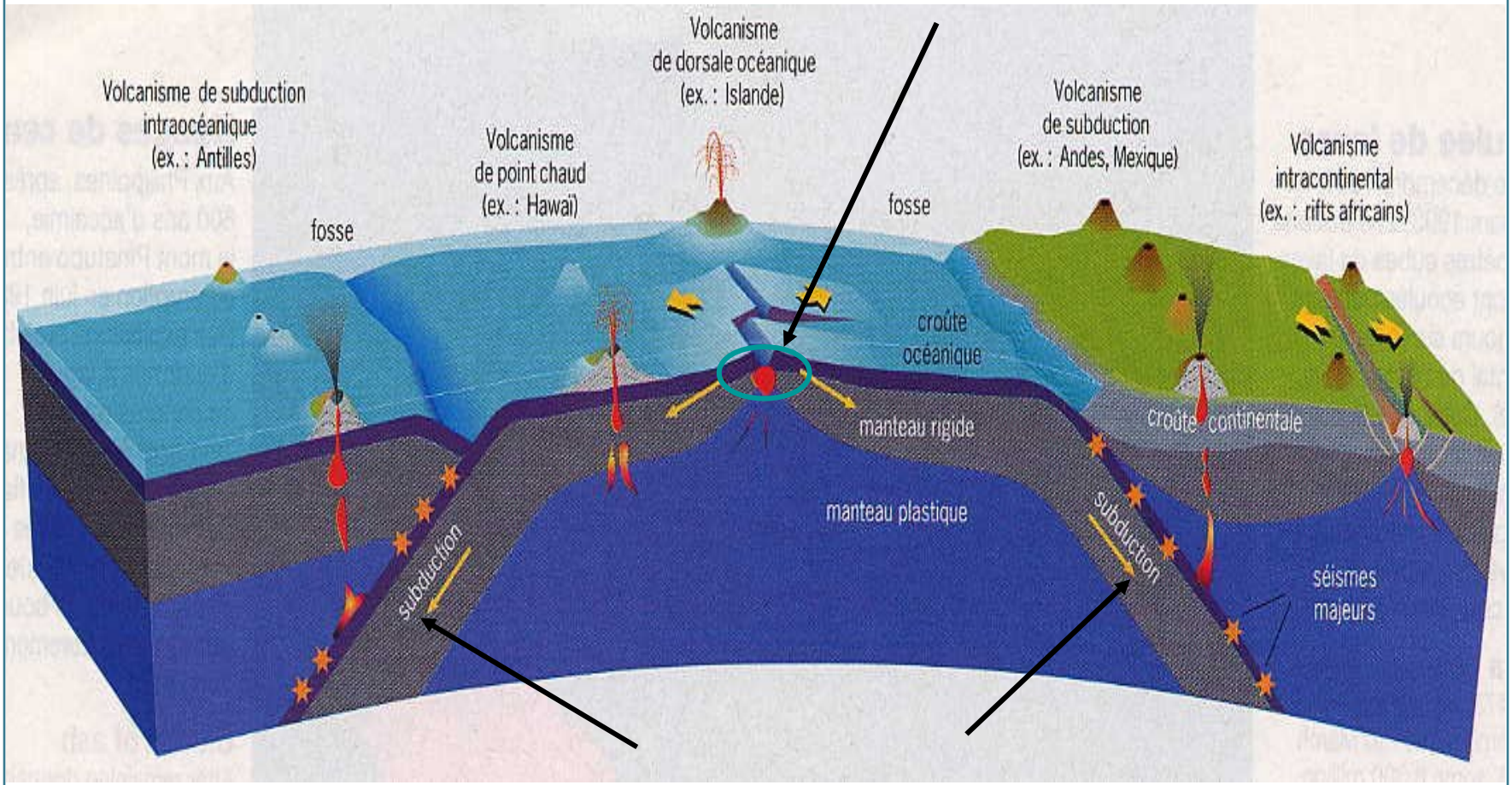
Thermal **Conduction** :
No movement

Thermal **Convection** :
Mater (fluid) movement



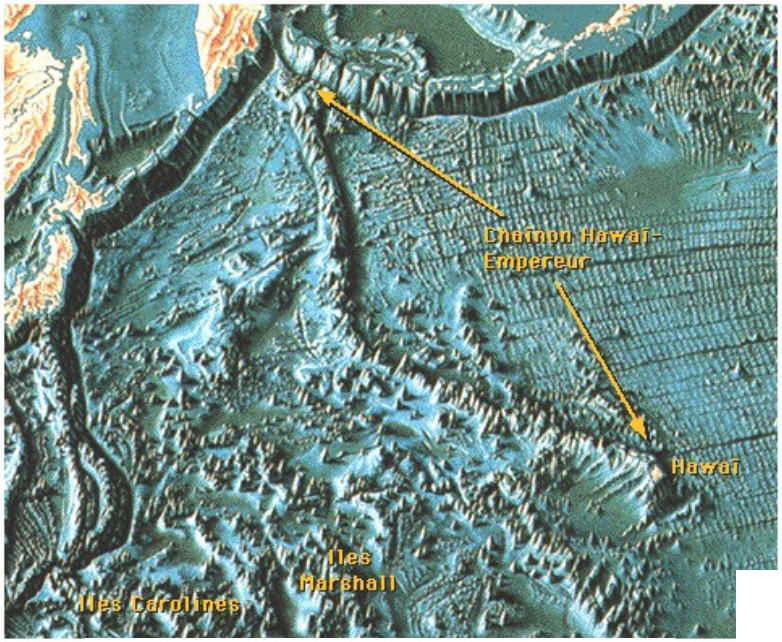
Geodynamics

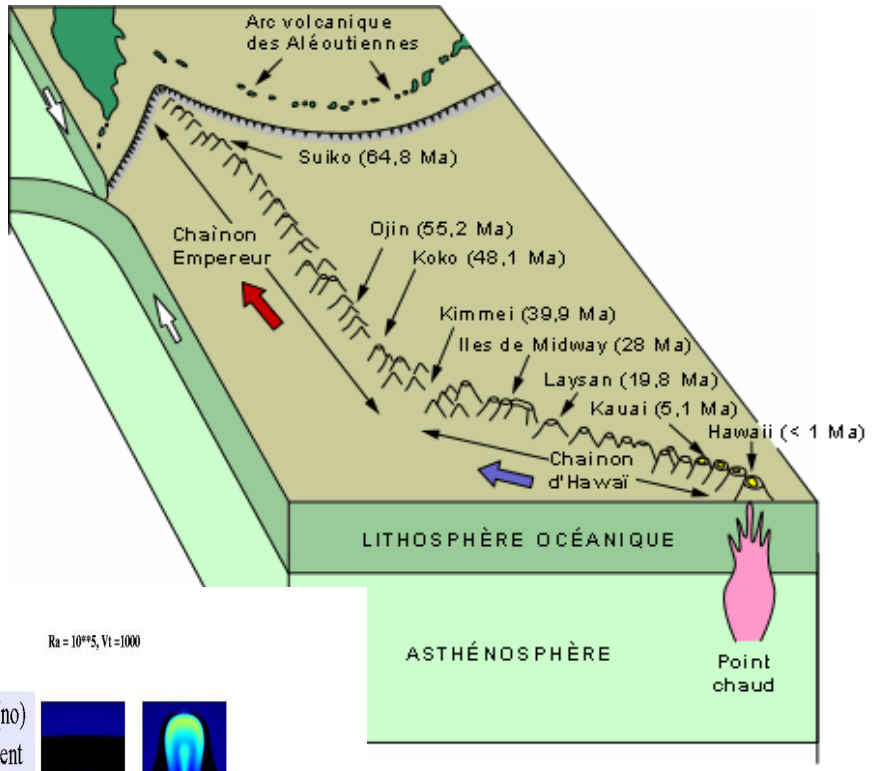
Intracrustal magmatic chamber: almost no volcanism
Oceanic expansion is a consequence of subduction

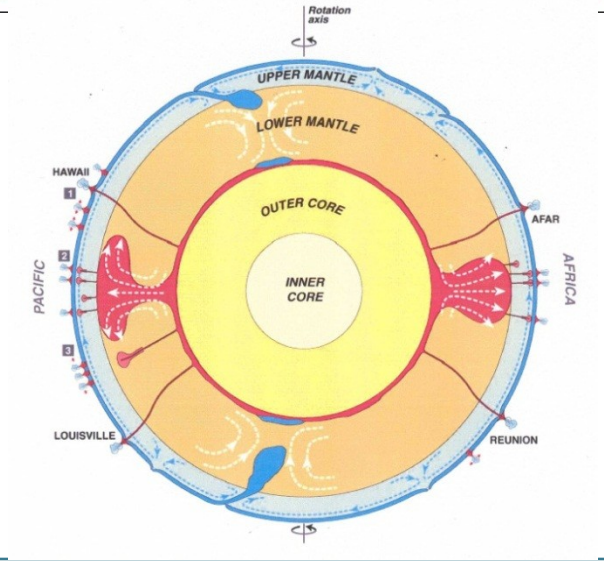


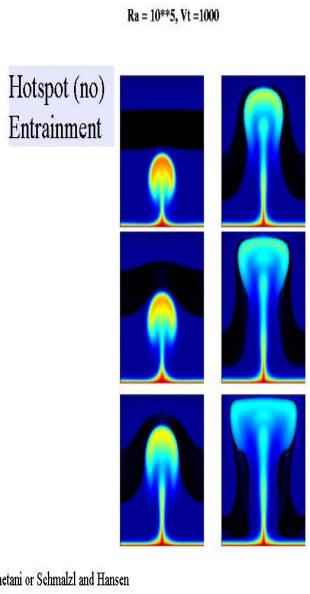
Cold lithosphere density >
warm asthenosphere density

Uprising structures: Hot Spots



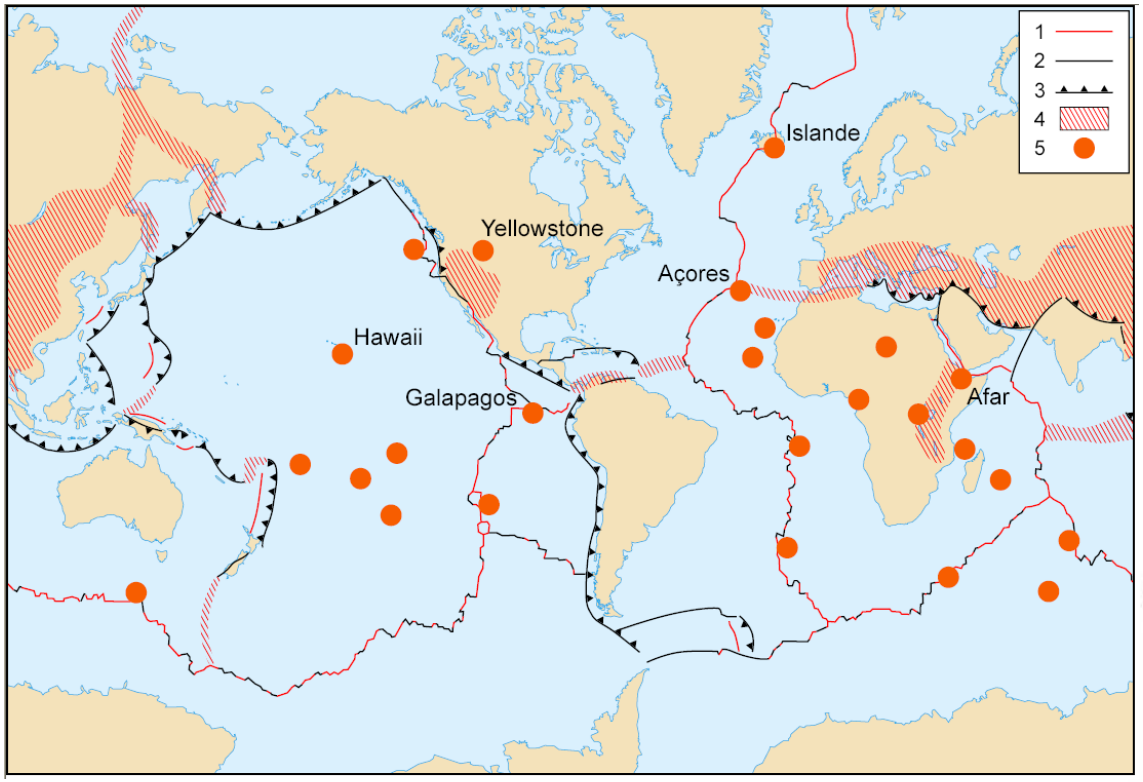




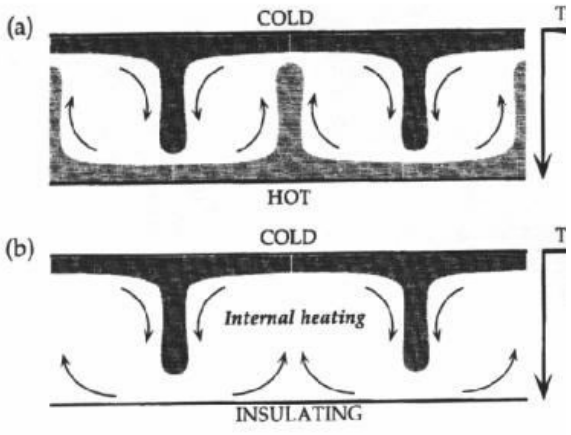


Farnetani or Schmalzl and Hansen

Motor of earth dynamic



Hot Spots : 55t/an
Subduction : 650t/an

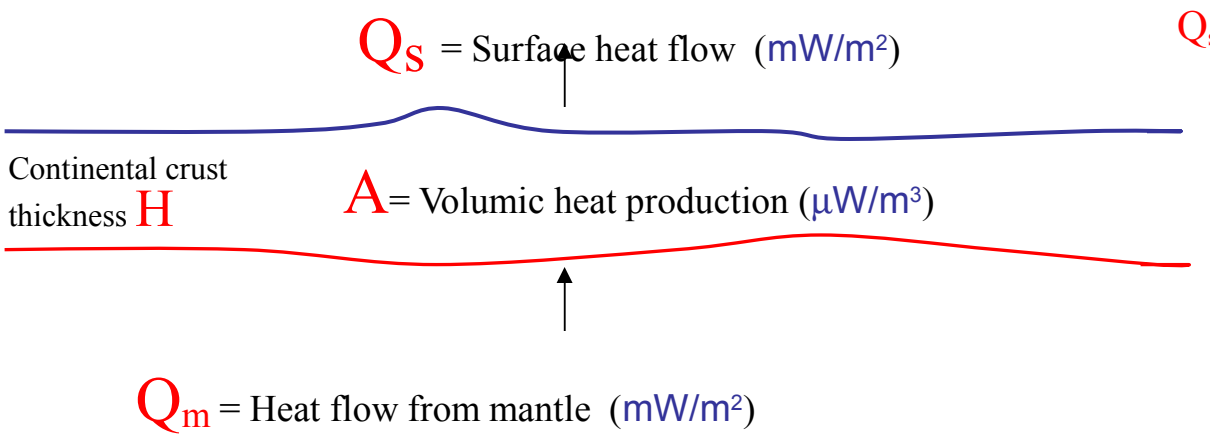


- **Few uprising hot structures located**
- **Lots of descending cold zones**
  > Earth is heated in volume, not from below

-> Dissipation of primitive heat

Internal heat production

Average heat production by radioactive disintegration		
	in continental crust	~ 1.0 μW/m³
	in oceanic crust	~ 0.5 μW/m³
	in mantle	~ 0.02 μW/m³



Heat production : 20 TW

Measured heat flow Q_S = 44 TW

> Earth colds down 2x quickly than heat production

-> evacuation of primitive heat

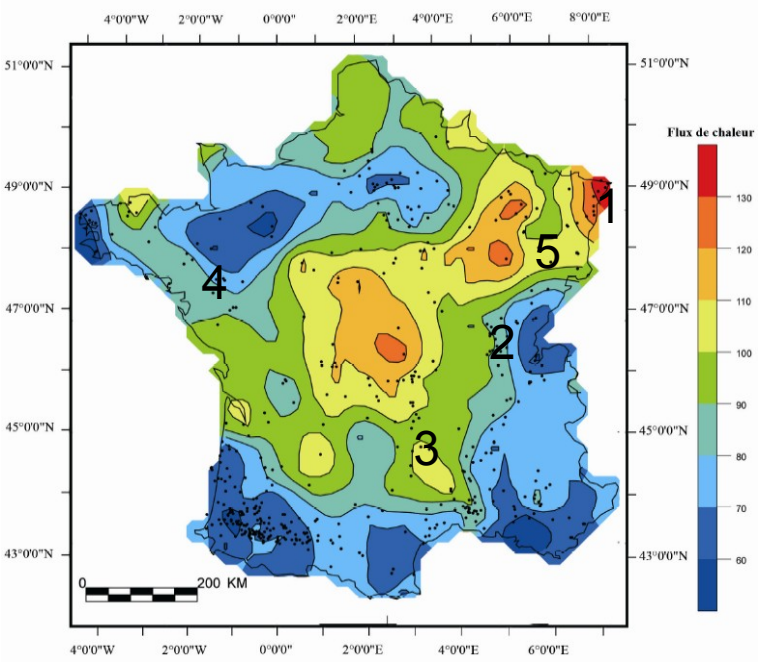
Heat flow
and
Geothermal gradient

Heat flow

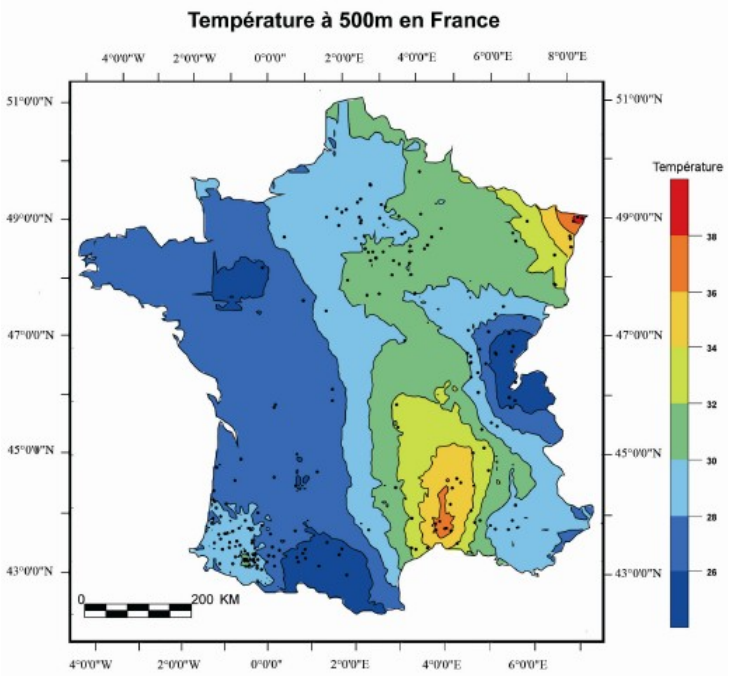
Heat flow (mW/m²) =
thermal conductivity (W/m/K) × geothermal gradient (°C/km).

Lab measure ↙ ↘ *Well measure*

Heat flow



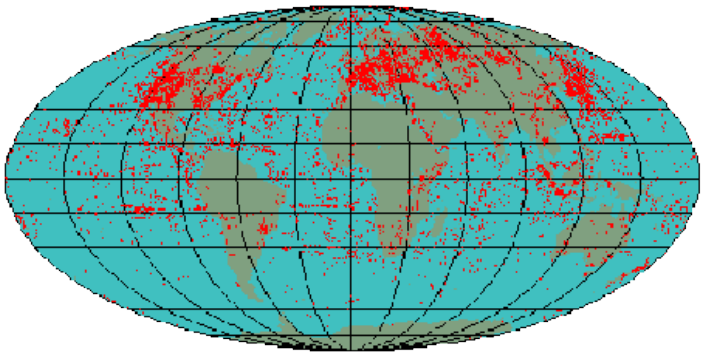
Temperature at 500m depth

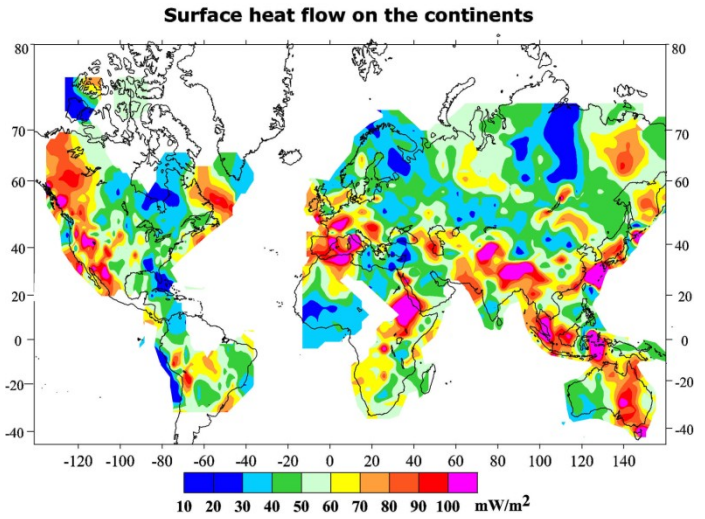


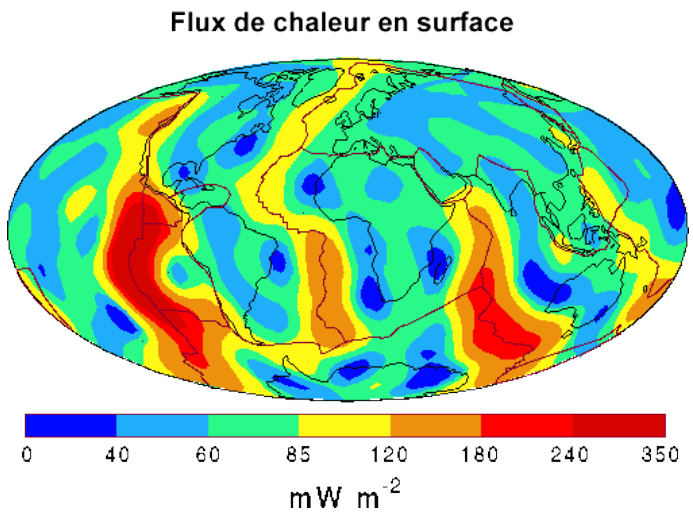
Site	Flux	=	Cond	×	Grad
1- Soultz	109 mW/m²	=	2,8 (W/m/K)	×	39,0 (°C/km)
2- Bresse 1	108 mW/m²	=	2,1 (W/m/K)	×	51,5 (°C/km)
3- Puy Mary	134 mW/m²	=	1,9 (W/m/K)	×	70,5 (°C/km)
4- Fougères	66 mW/m²	=	3,1 (W/m/K)	×	21,3 (°C/km)
5- Nancy	72 mW/m²	=	2,5 (W/m/K)	×	28,8 (°C/km)

World wide heat flow

Surface measure points



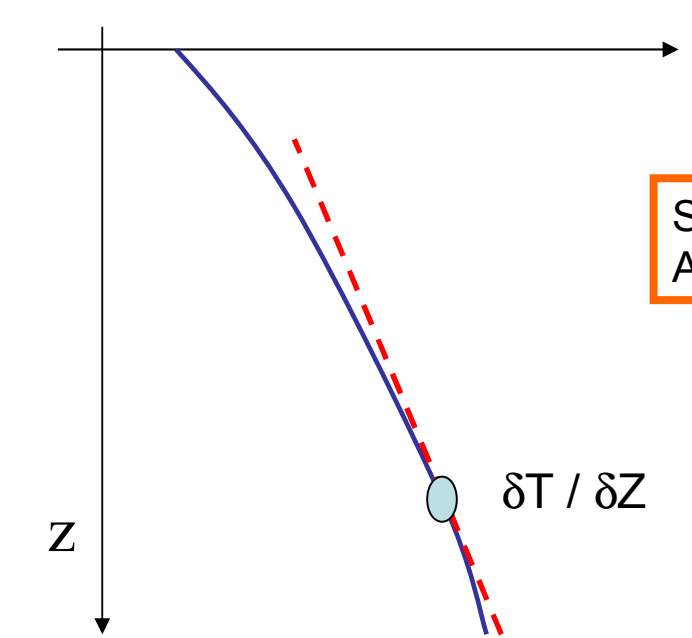




* **60 à 100 mW/m2 in stable zone**
* **at least 10 times more in active zones**

Geothermal gradient

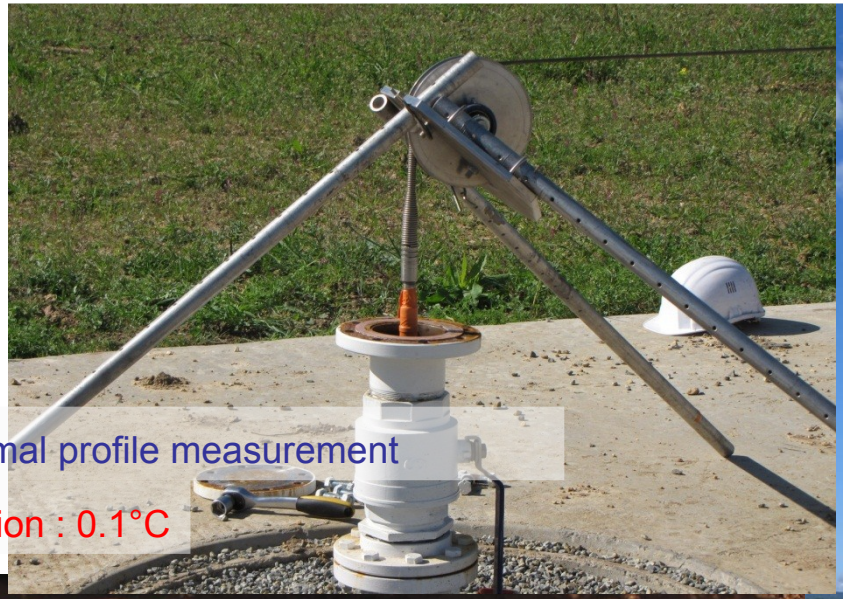
-> what will interest geothermal exploration



Stable zones: 30°C/km
Active zones: 500°C/km

The slope of the thermal profile represents the geothermal gradient

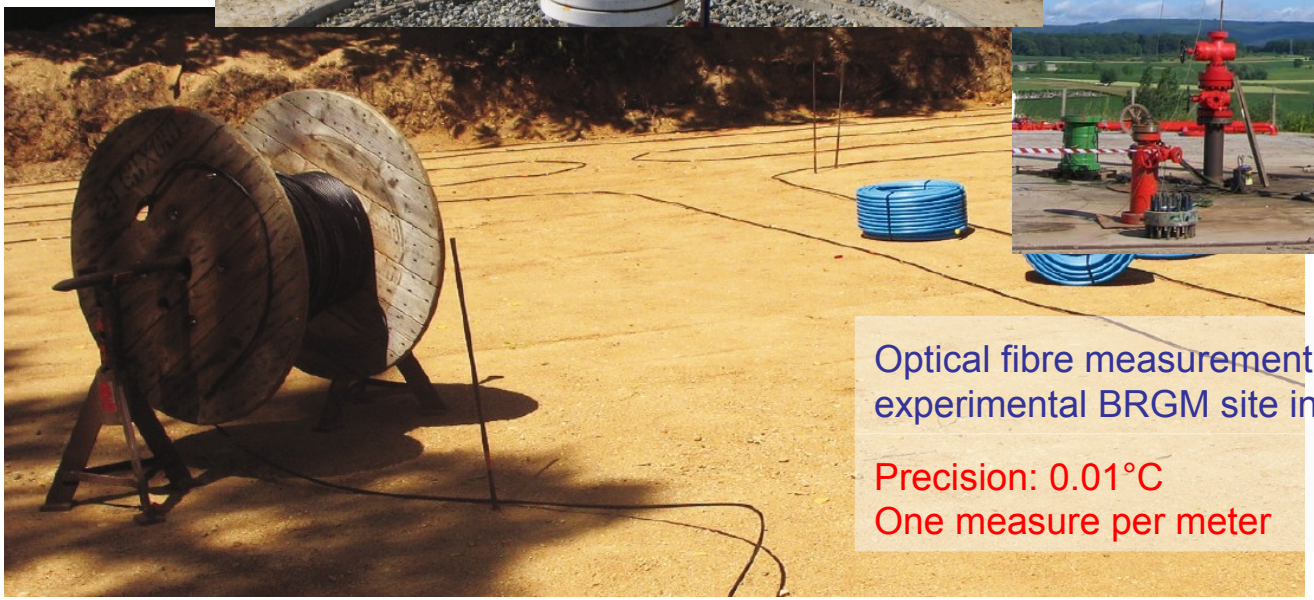
Thermal gradient measurement



Field thermal profile measurement

Precision : 0.1°C

Probe at Soultz (5000m)

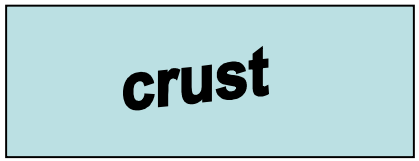


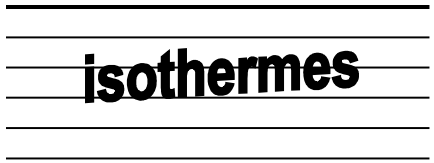
Optical fibre measurement on an experimental BRGM site in Orléans

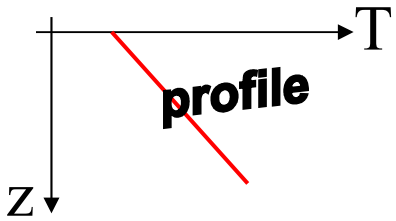
Precision: 0.01°C
One measure per meter

Type of geothermal profile

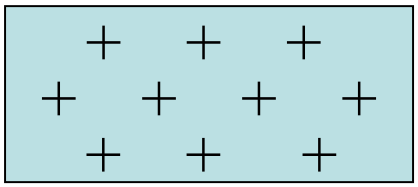
1) Homogeneous crust, no heat production

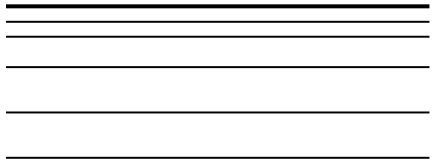


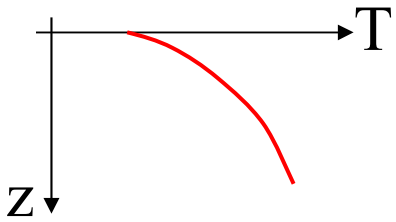




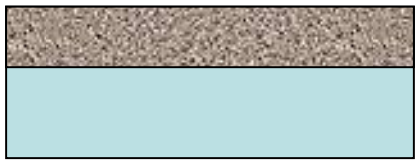
2) Homogeneous crust, WHITH heat production

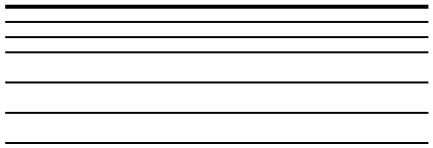


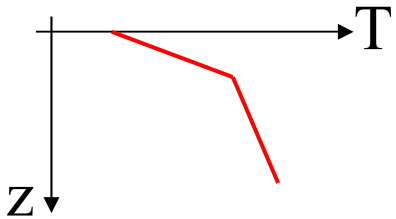




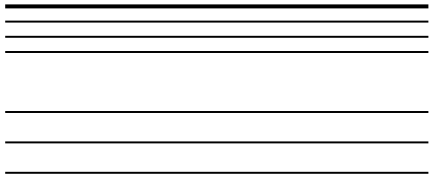
3) 2 layers crust, first one isulating

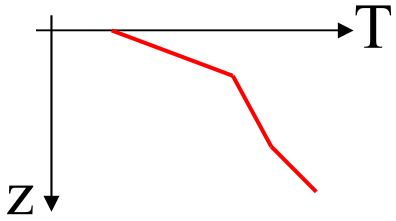






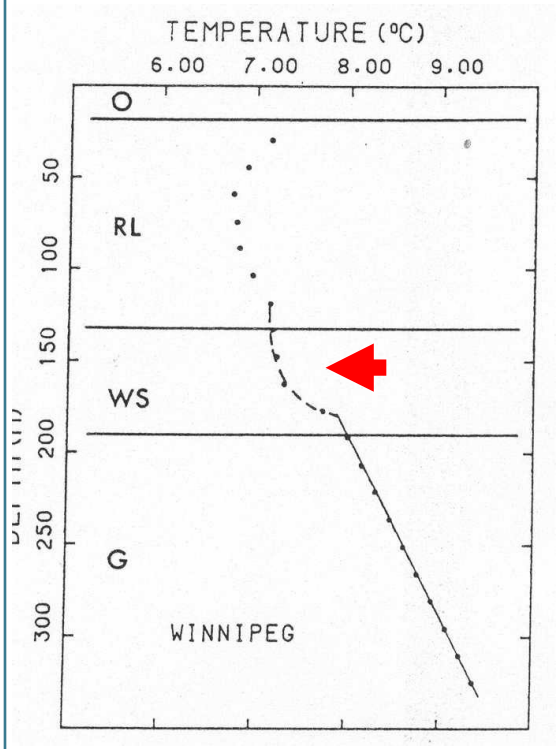
4) 3 layers crust, different conductivity



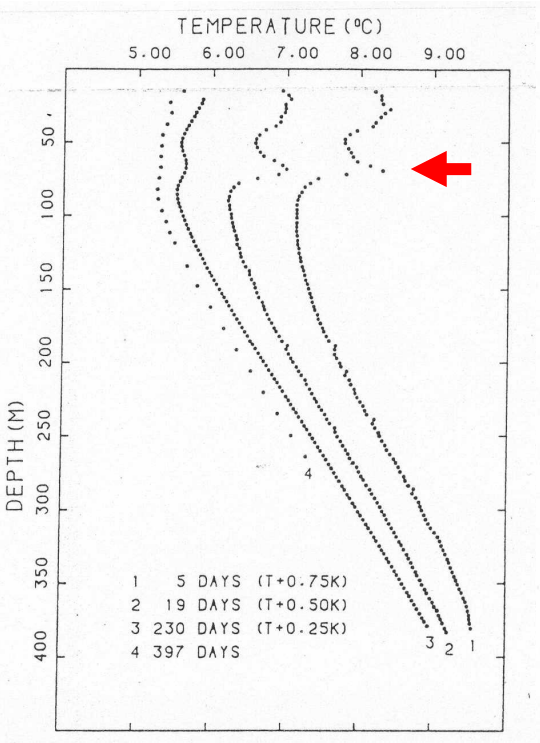


Geothermal gradient variation

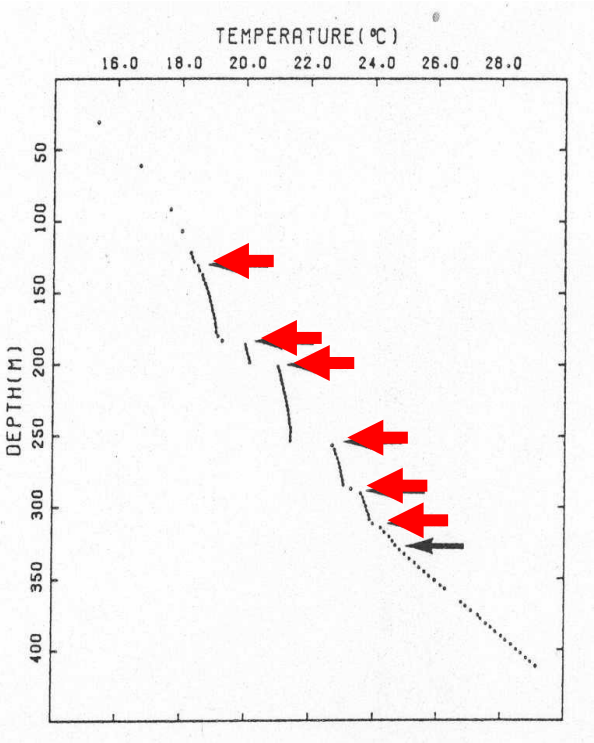
Fluid flow



Permanent down-flow in a sandy layer

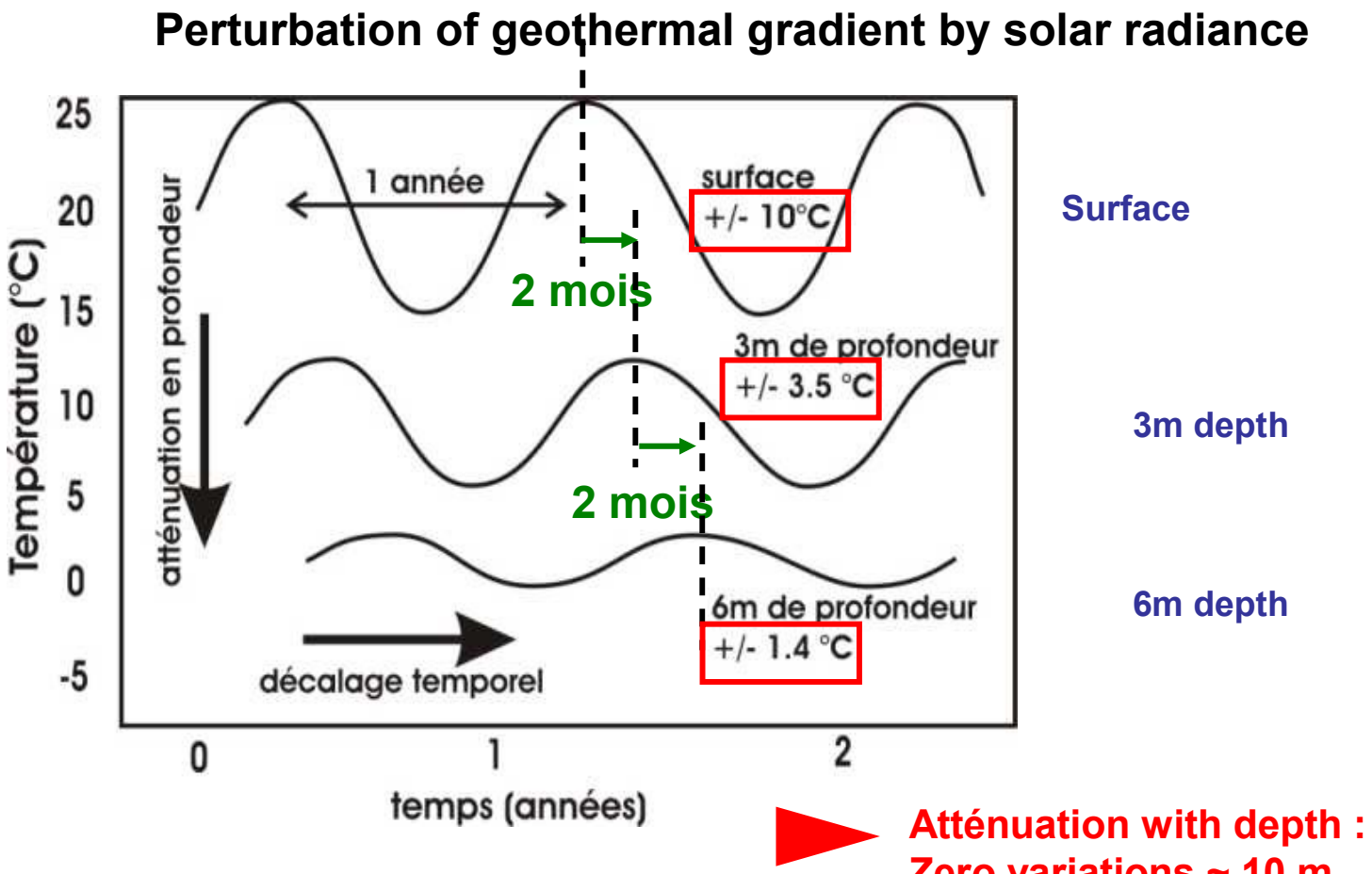


Thermal footprint of a fracture that socked warm drilling fluid. Re-equilibration takes more than a year

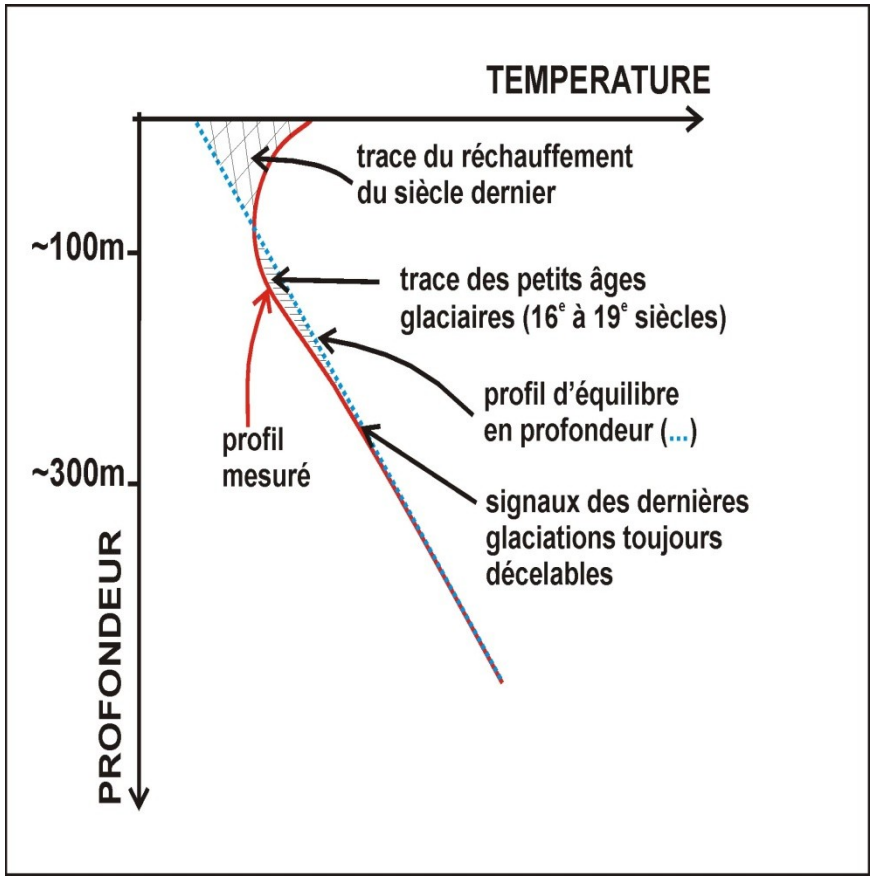


Fluid arrivals through fractures

Annual variation



Climate variations



- Influence of more durable climate variations. for example, effect from last glaciations (20000 ans) can be detected up to 1000m depth
- More recent small ice ages are recognisable on most of the profile, between 100 et 300m depth.

Geodynamics
and
Geothermal resources

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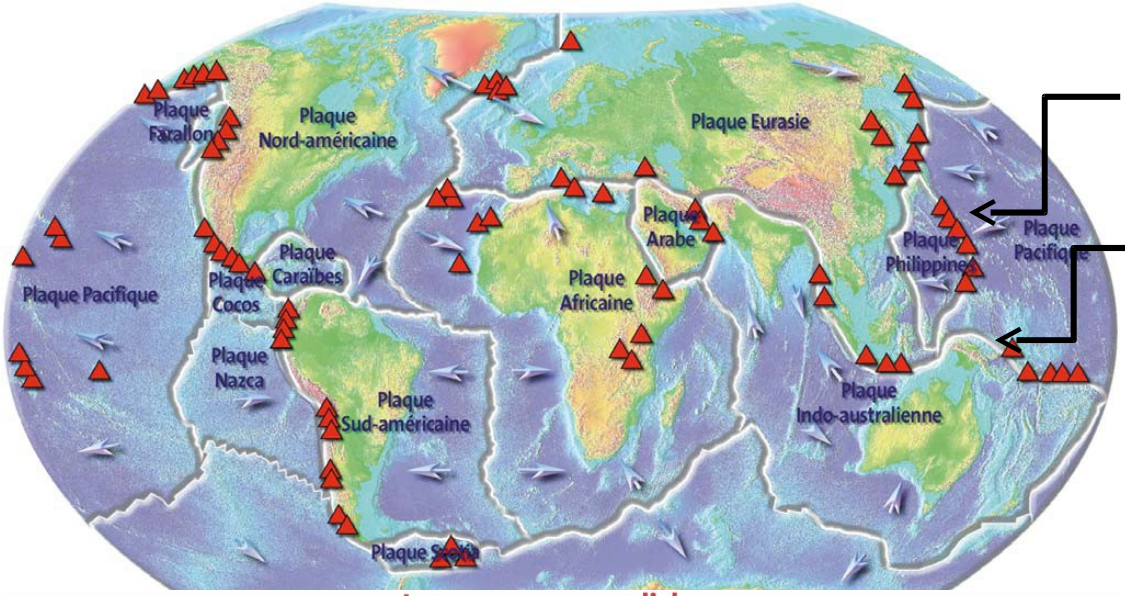
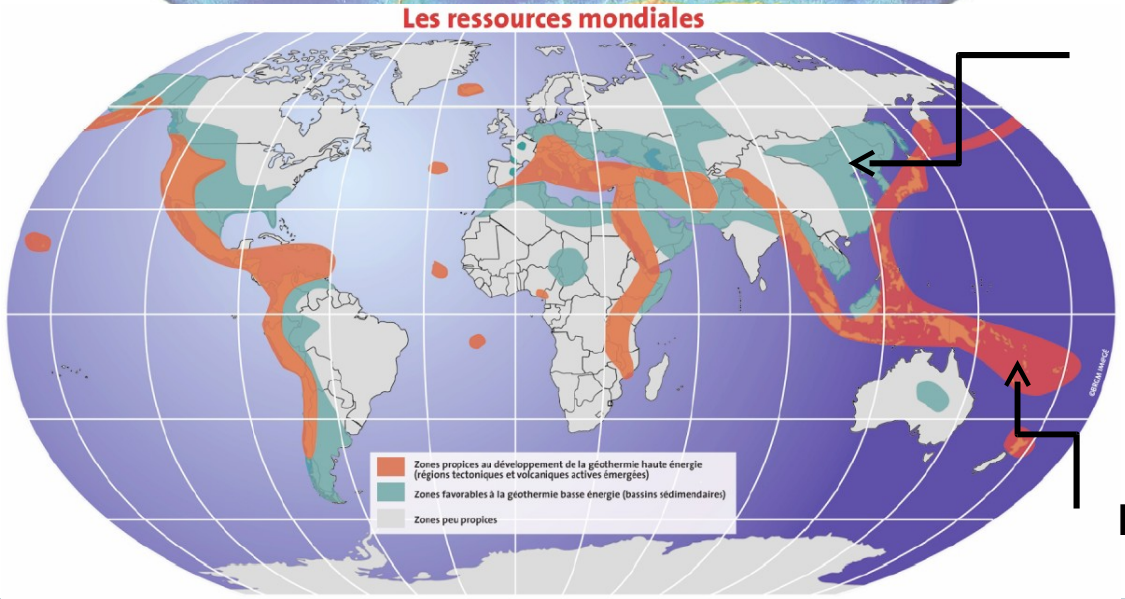
World resources



Volcano

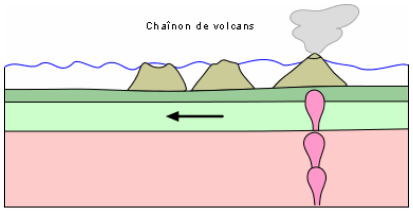
Plate boundary

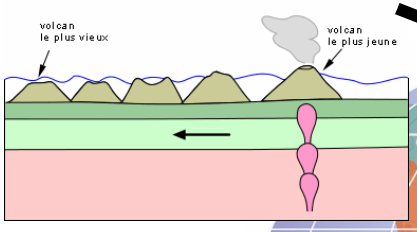


Heat production

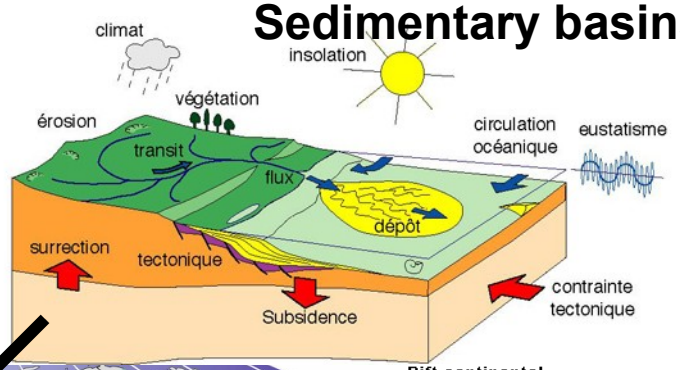
Electricity production

Tectonic structures

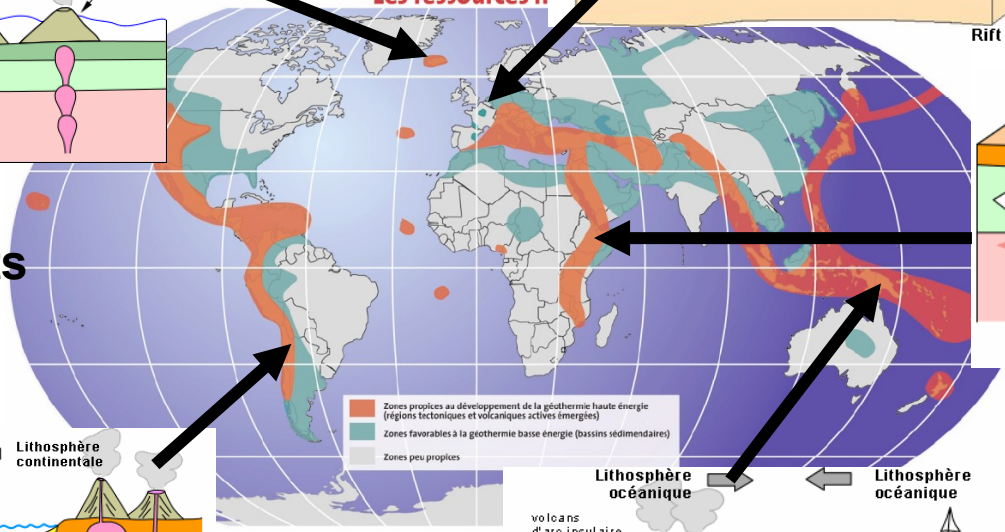


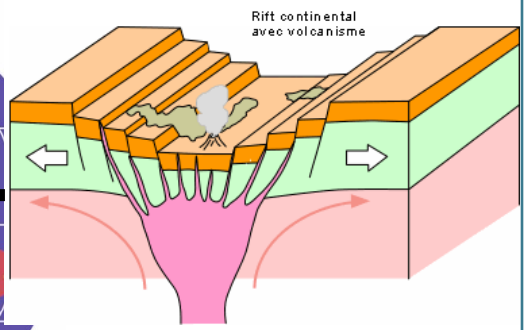


Hot spots

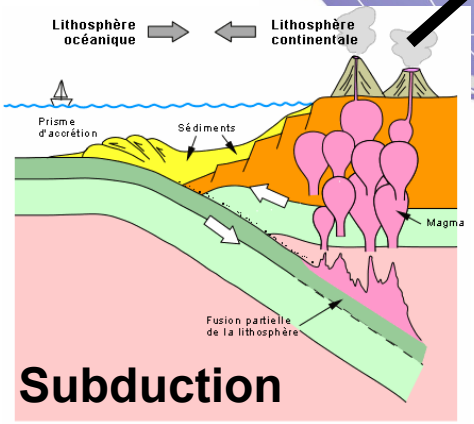


Sedimentary basins

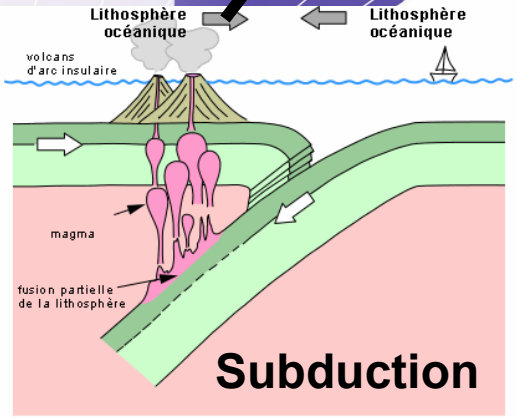




Continental rift



Subduction



Subduction

Not the same geothermal gradient giving the presence or absence of magmatic up-flow

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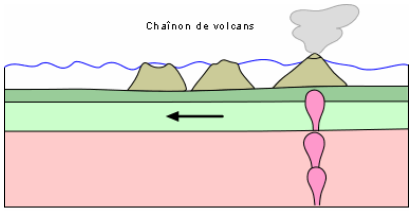
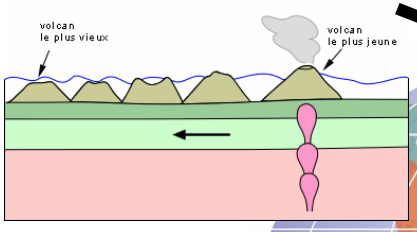
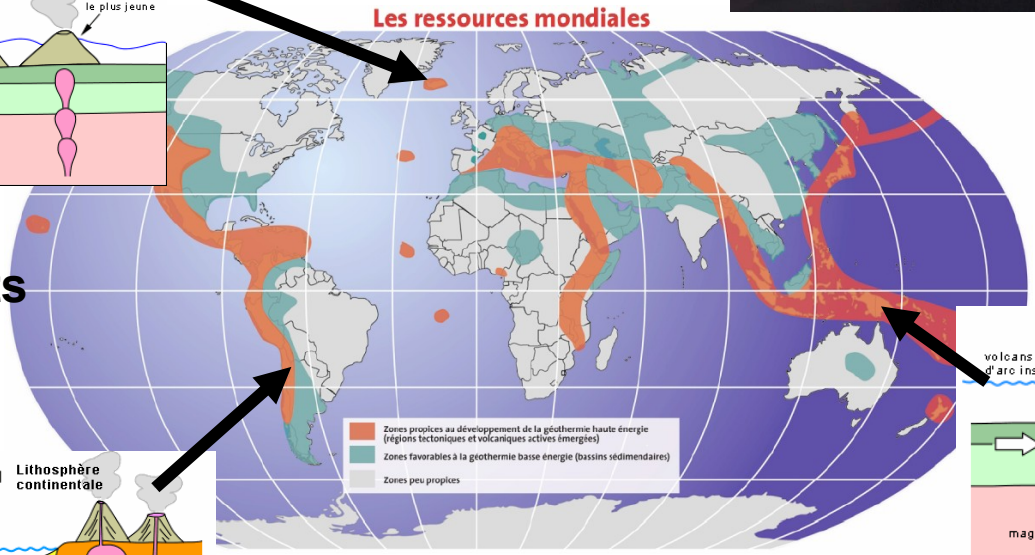
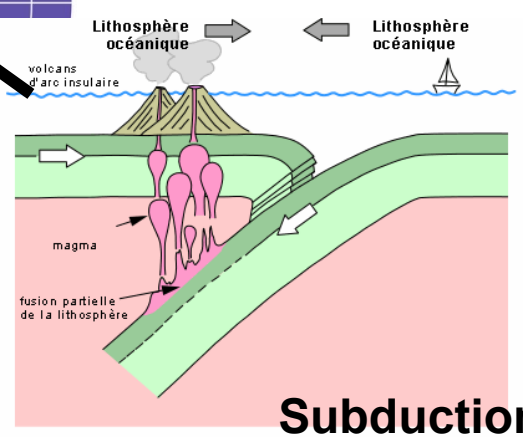
Volcanic zones



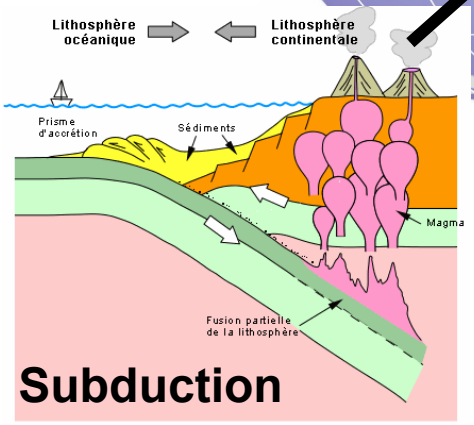


Hot spots





Subduction



Subduction

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Volcanic manifestations

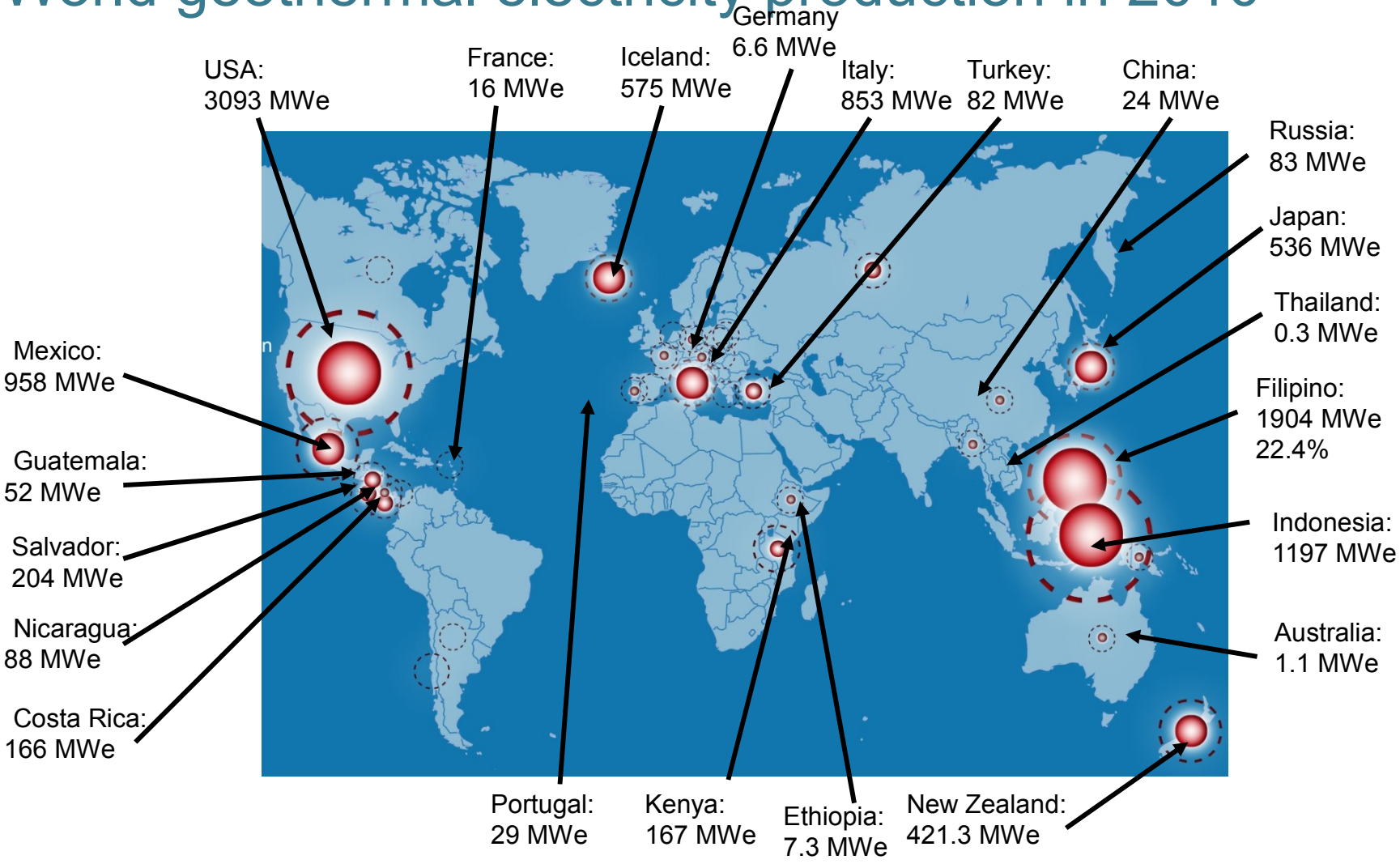
Islande

Toscane,

Piton de la Fournaise, La Réunion
Octobre 2000

Nevada, USA

World geothermal electricity production in 2010



Installed power in the 25 producing country : 10.7 GWe (Bertani, 2010).

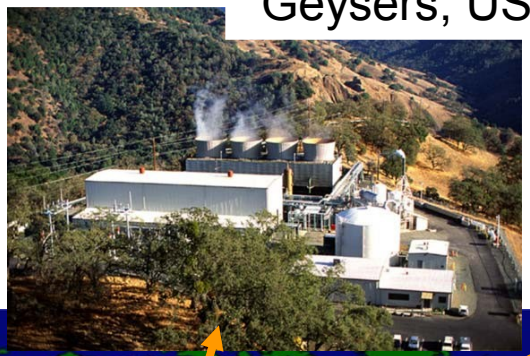
Prevision at 2015 : 18.5 GWe ; at 2050 : 70 GWe (Bertani, 2010)

(Production EDF in 2008: 97GWe)

HT worldwide

Okoy 5, Filipino

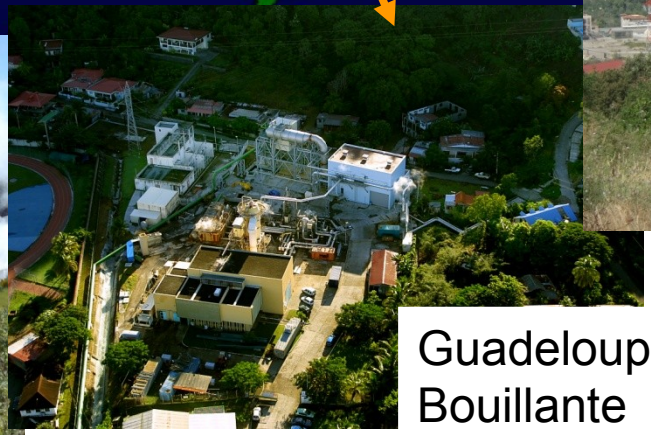
Geysers, USA



Iceland

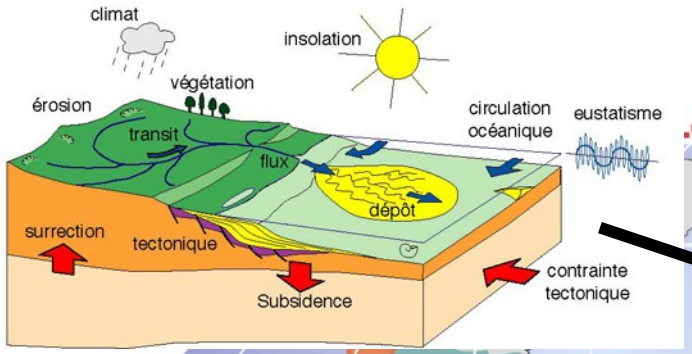
Larderello, Italy

Wairakei, New Zealand



Guadeloupe
Bouillante

Sedimentary basins and continental rifts



Sedimentary basins

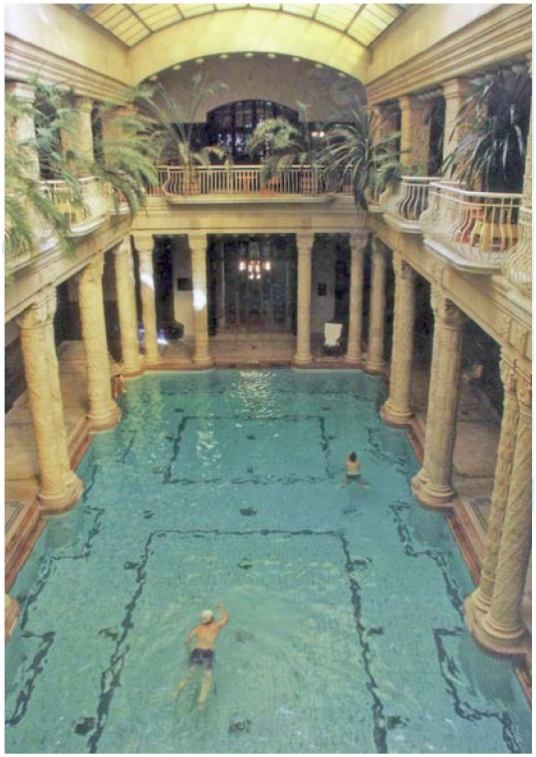
Continental rifts

- **EGS electricity production (Enhanced Geothermal System)**
- **Heat production**

Heat production : direct use

Sturgeon farm, France

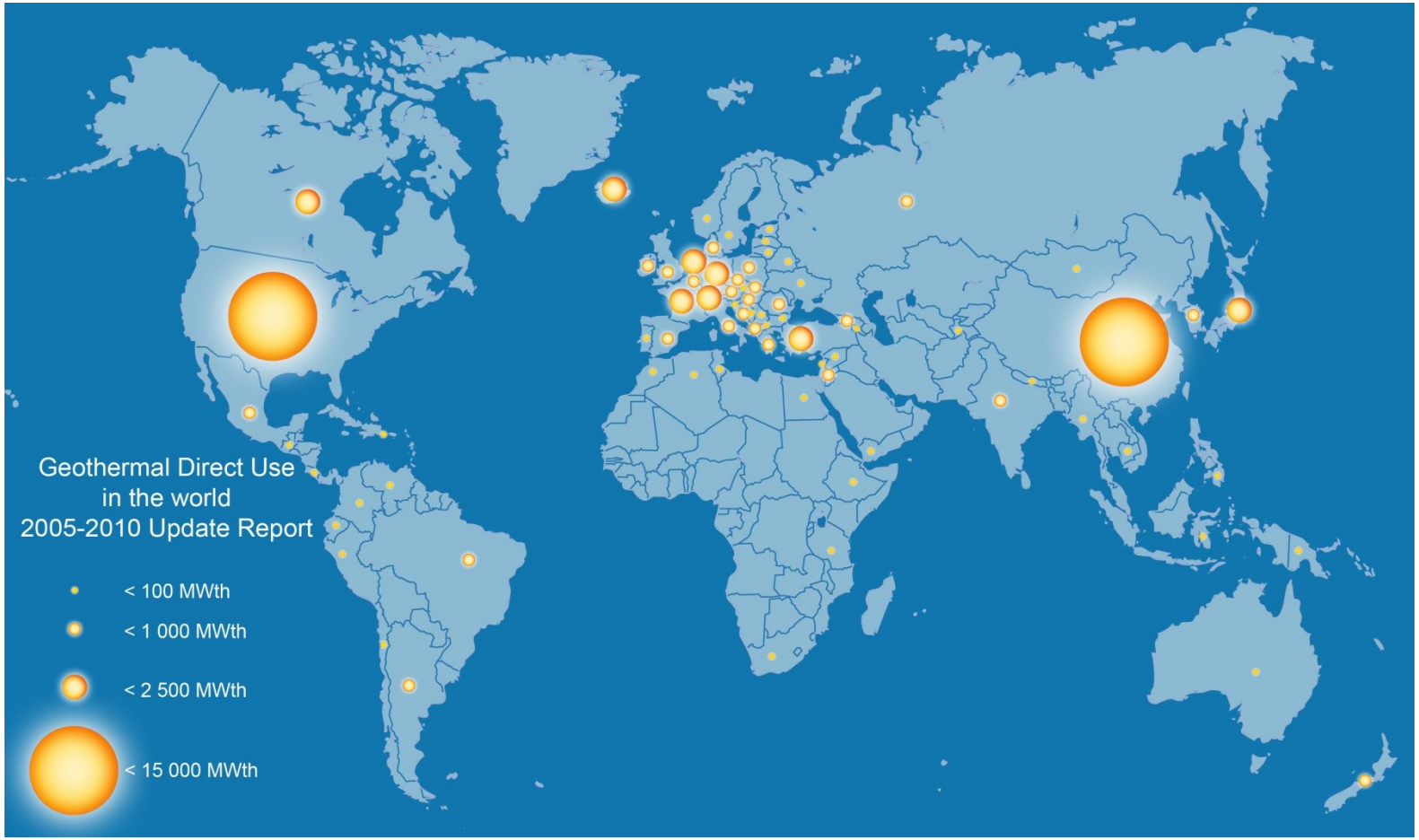
Crocodile farm, Nevada



Swimming pool, Budapest

Greenhousheating

Worldwide heat production in 2010



Installed power in the **79 countries** using geothermal heat was estimated at

43 GWt

Different types of geothermal energy

Geothermal energy, how to classified….

> USE

- Electricity
- Heat
- Heat and/or cooling – Stocking
- Co-generation

> ACTORS/CLIENTS

- Industrials
- Collectivities
- Institutionals
- Individuals

> RESOURCE

- Shallow aquifers or formations
- Deep reservoirs
- Stimulated deep formation

Geothermal uses typology

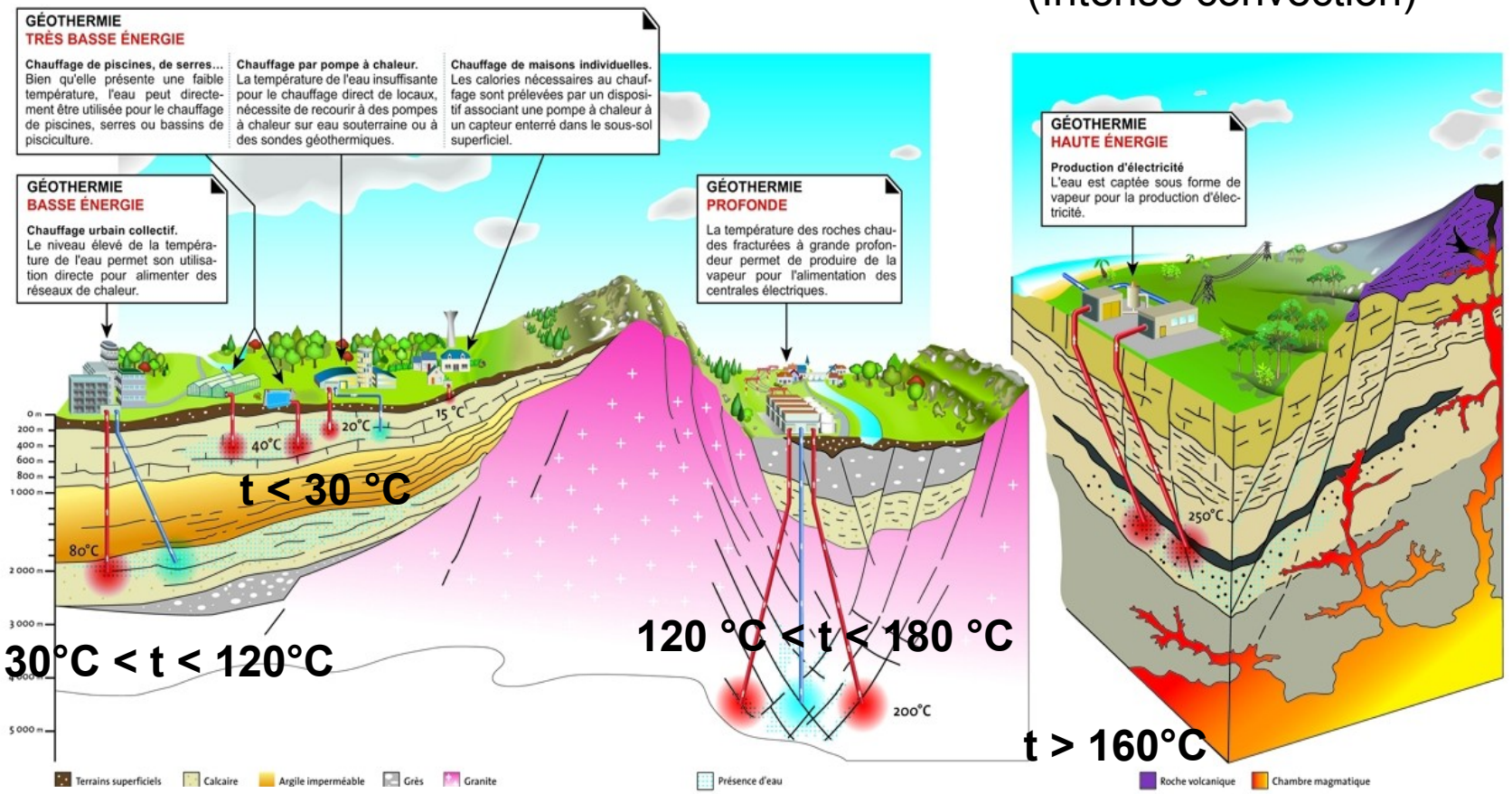
Fluid temperature

- **High Temperature** (~ T > 160°C) “efficient” electricity production
- **Middle Temperature** (100 °C < T < 160 °C) electricity generation with binary cycle, industrial uses
- **Low Temperature** (30°C < T < 120°C) direct heat use
- **Very Low Temperature** (T < 30 °C) usually requiring the use of heat pumps

Geothermal uses typology

Shallow underground; solar influence

Volcanic formation
(Intense convection)



Sedimentary basins rock property often known from oil and gas exploration (conduction and convection)