Permeability in deep-seated granitic rocks: lessons learnt from deep geothermal boreholes in the Upper Rhine Graben (URG)

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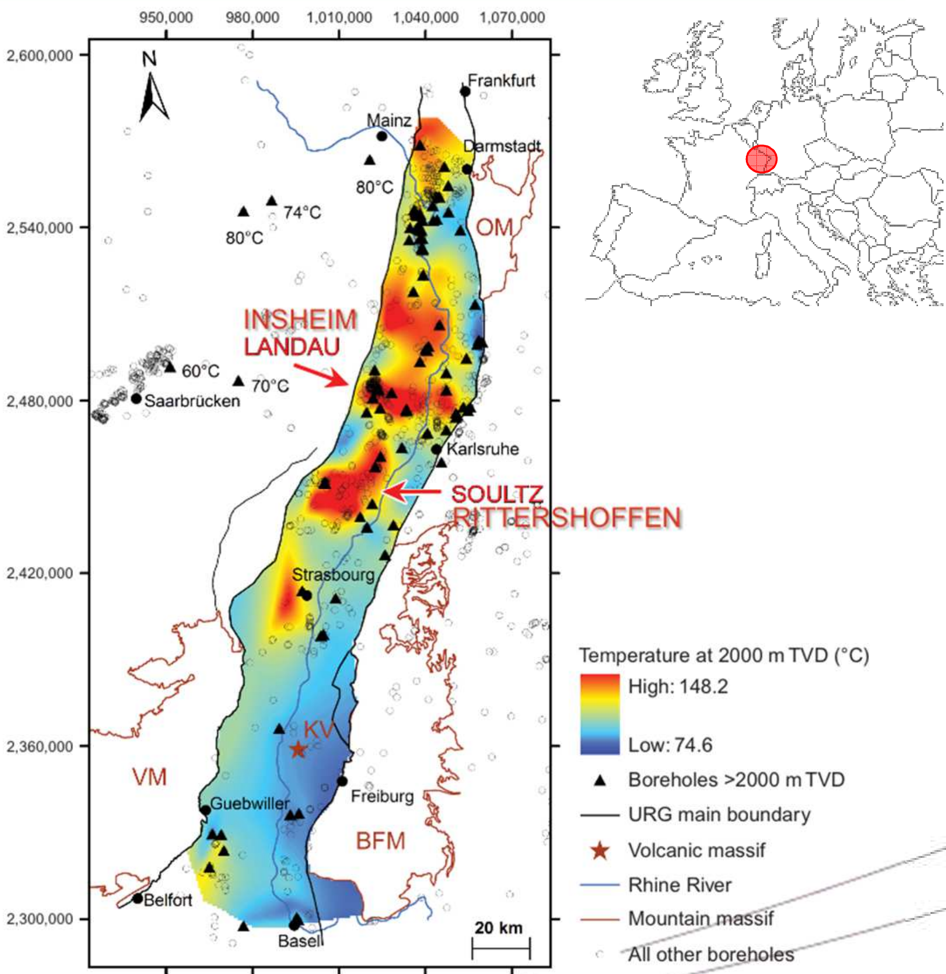
Context of the study

- Several thermal anomalies in Upper Rhine Graben (Europe) associated with **hydrothermal circulations in the Triassic clastic sediments and Paleozoic crystalline basement**

- Geothermal boreholes drilled from 2.5 to 5 km depth

→ Bottom hole temperatures range from **170°C to 200°C**

- **Water bearing fractures** characterized by geothermal brines (TDS 100g/L)



Temperature map in the URG (Bailleux et al., 2013)

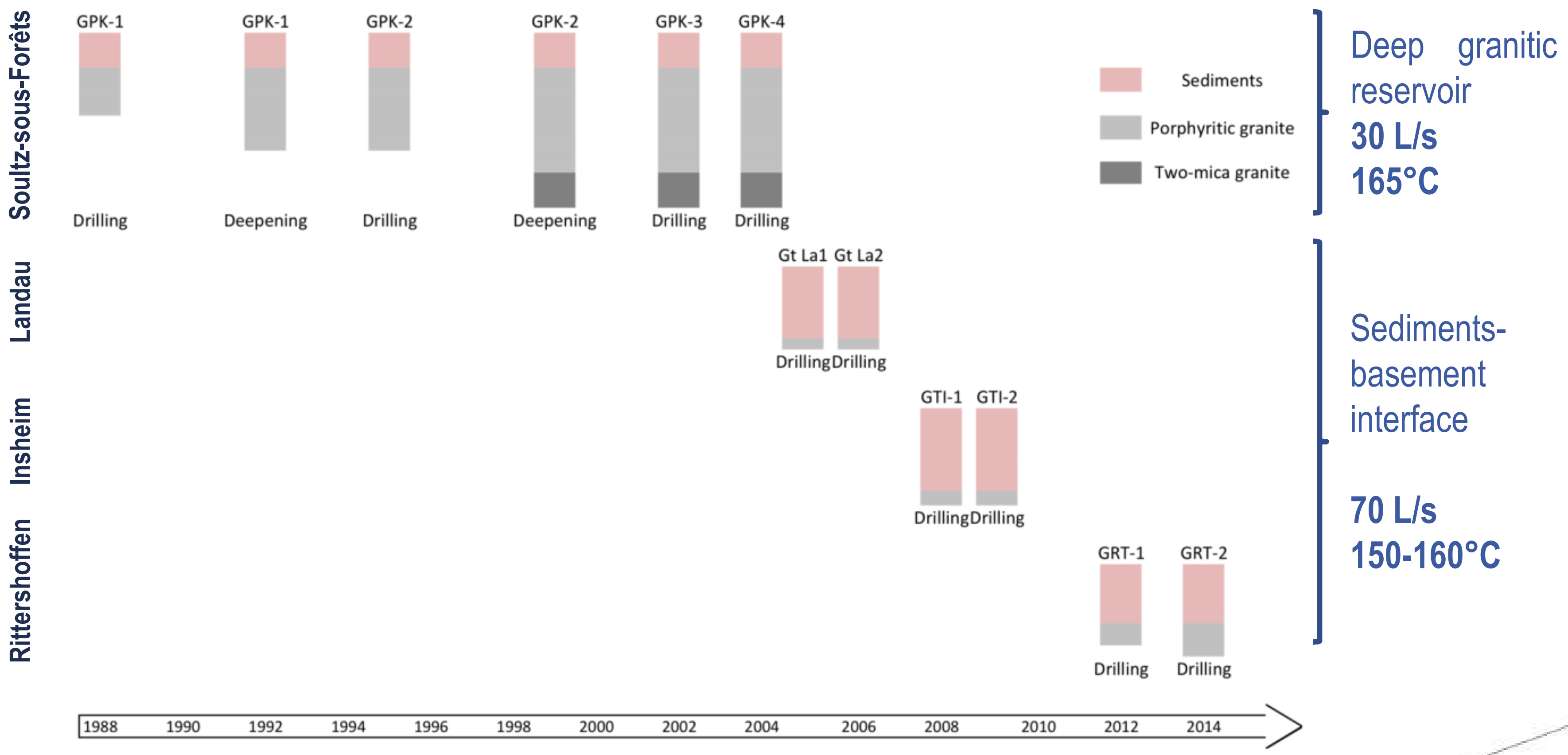
Geothermal projects in the URG

- **Experimental pilot project**
  Soultz-sous-Forêts
- **Industrial projects** based on lessons learned from Soultz
  Landau, Insheim, Rittershoffen
- **Several ongoing projects**
  4 projects around Strasbourg

→ URG is the **most active zone** for deep geothermal energy exploration and exploitation in France

Map of the geothermal projects in the URG

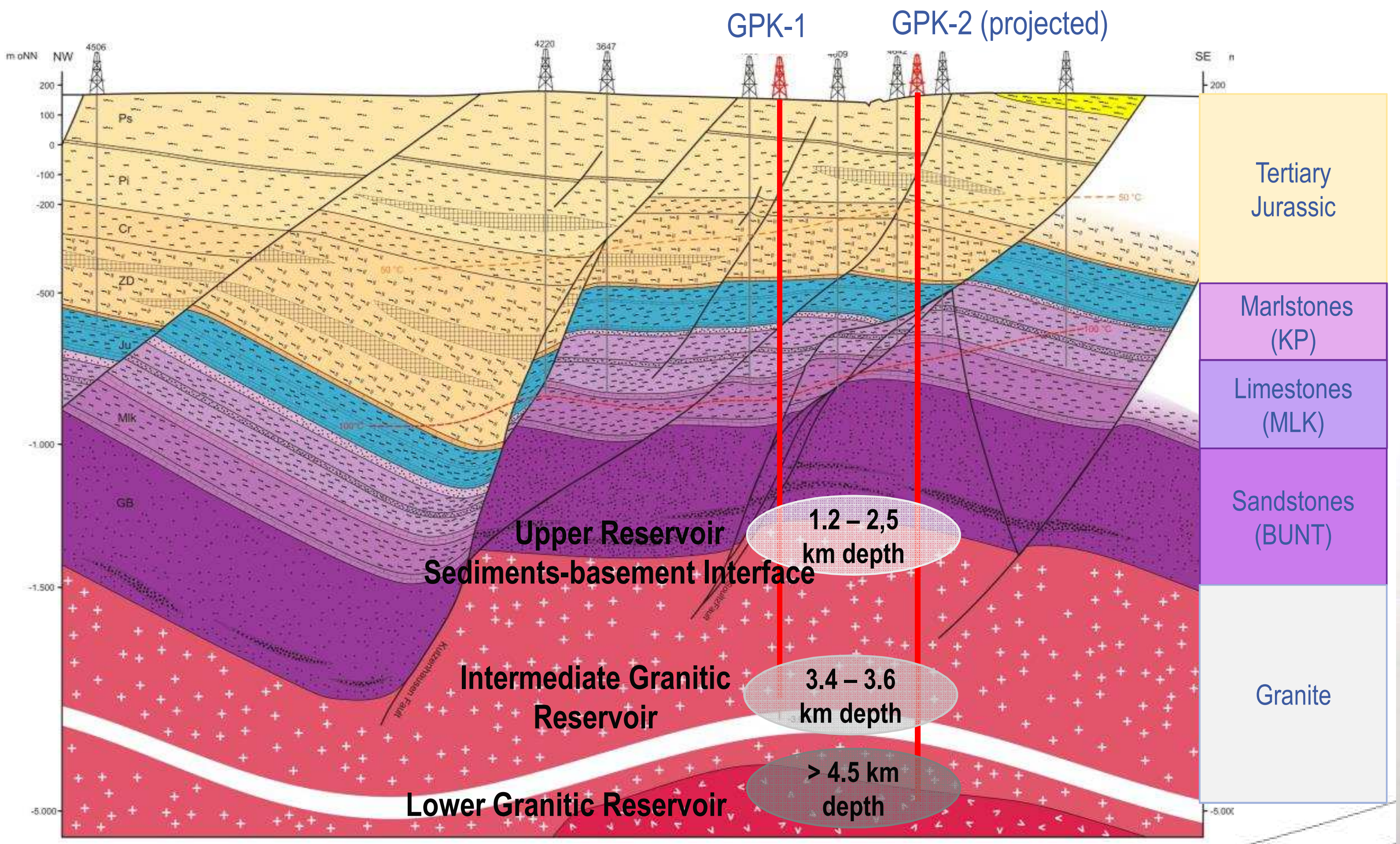
Deep geothermal wells in the URG



Chronology of the geothermal projects and associated deep wells in the URG

→ **Evolution of concepts for the deep geothermal resource**

Soultz geothermal project



Geological cross-section interpretation based on seismic profile (Re-darwn Koelbel et al., 2011)

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Permeable natural fractures

CORE SAMPLE

- **EPS-1** = exploration well → 800 m of core samples + borehole images

More than **3000 natural fractures** observed in Triassic sediments and in the **granitic basement**

- All fractures show **hydrothermal fillings** (barite, galena, secondary quartz, clays...)

Fillings are **partial** and **channelized**

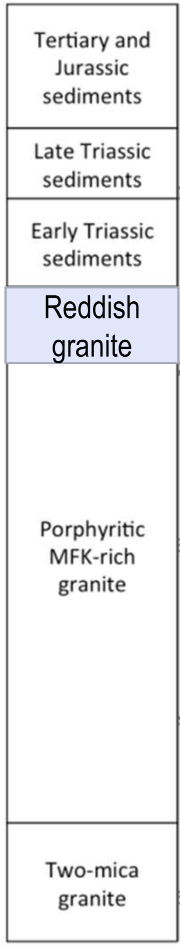
→ **Less than 1% of fracture are permeable** at the borehole scale

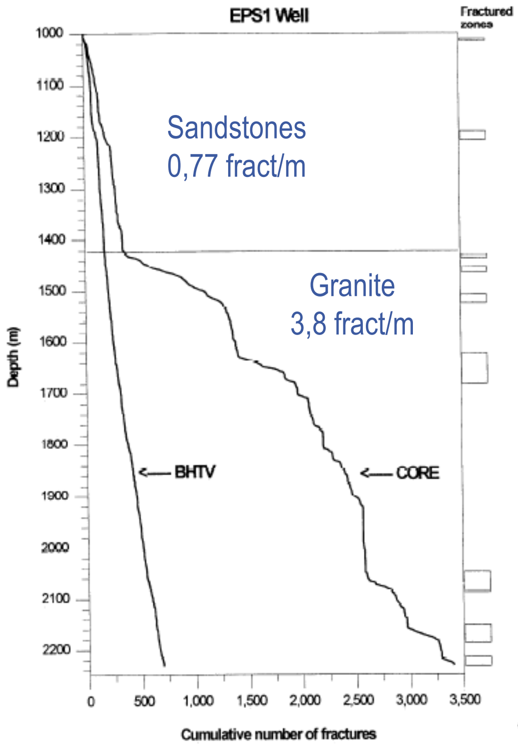
- Sealing is caused by **alteration of granite and circulation of brine**

Fracture zone in the well EPS-1 at 1220 m depth, filled with barite and galena and correlating partial mud losses

Fracture zone in the well EPS-1 at 2156 m depth, filled with secondary quartz and correlating total mud losses and temperature variation

Matrix permeability $= 10^{-18} - 10^{-21}\ m^2$

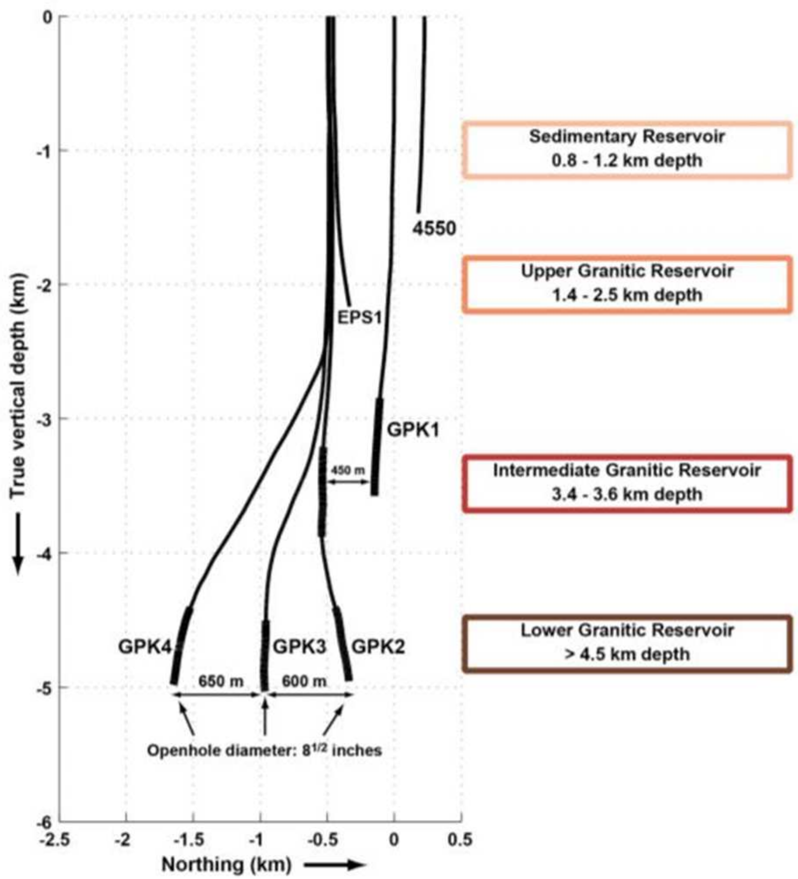




Fracture density:
Granite >> Sandstone

(after Genter et al., 1997)

Natural injectivity of the Soultz wells



N-S cross-section through Soultz site

- Natural injectivity **very variable** in reservoirs and in Soultz wells

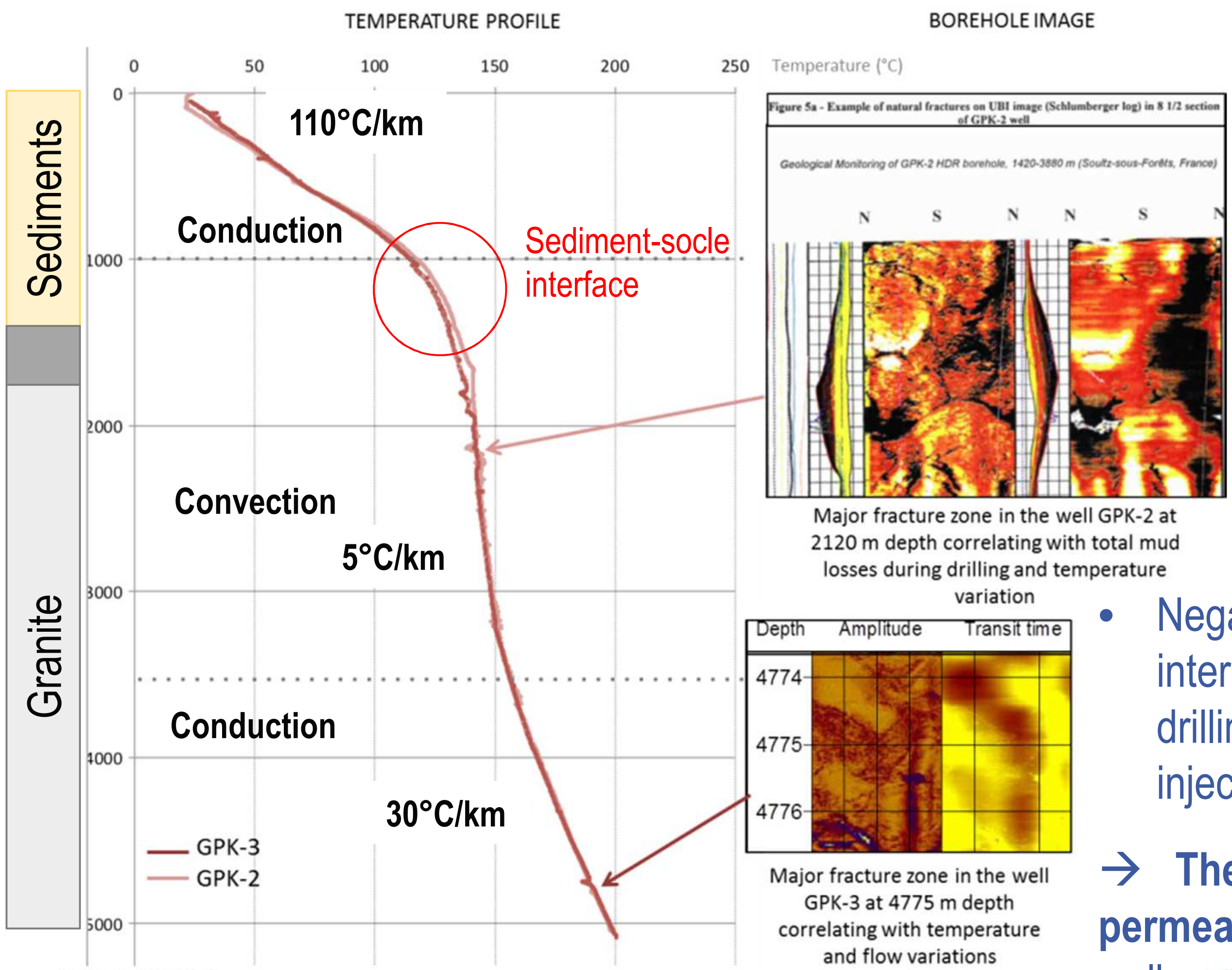
→ **3 L/s/bar**

- Major fracture zones with total mud losses during drilling operations
- Top granite = 200 m of reddish granite paleoemersion → paleoweathering process and fractured zones

→ **0,01-0,02 L/s/bar**

- Need of stimulation of deep granitic reservoir

Natural hydrothermal circulation



Temperature profile in Soultz wells (after Genter et al., 2010)

- **Convective cells** circulating between 1-3.5 km depth

→ Contribution to thermal anomaly in the uppermost part

- Negative thermal anomalies are interpreted as cooling after drilling operations or water injection

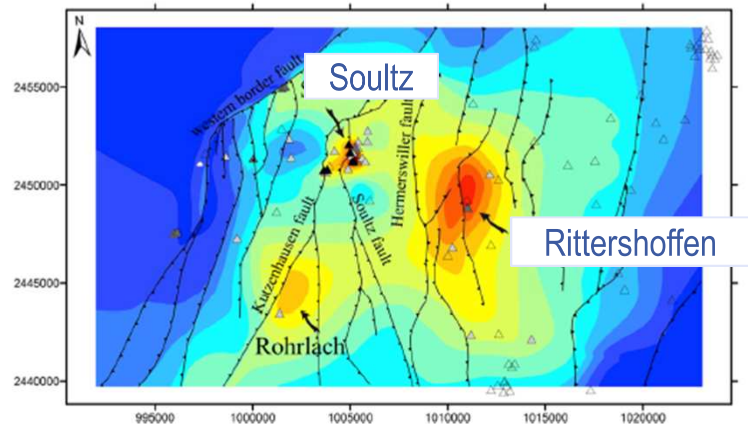
→ **Thermal signature of major permeable fracture zones** into the wells

Rittershoffen industrial project

- **2 wells (2.5 - 3 km)**

Expected temperature **170 °C**
Expected flow rate **70 L/s**
Thermal Power **24 MWth**

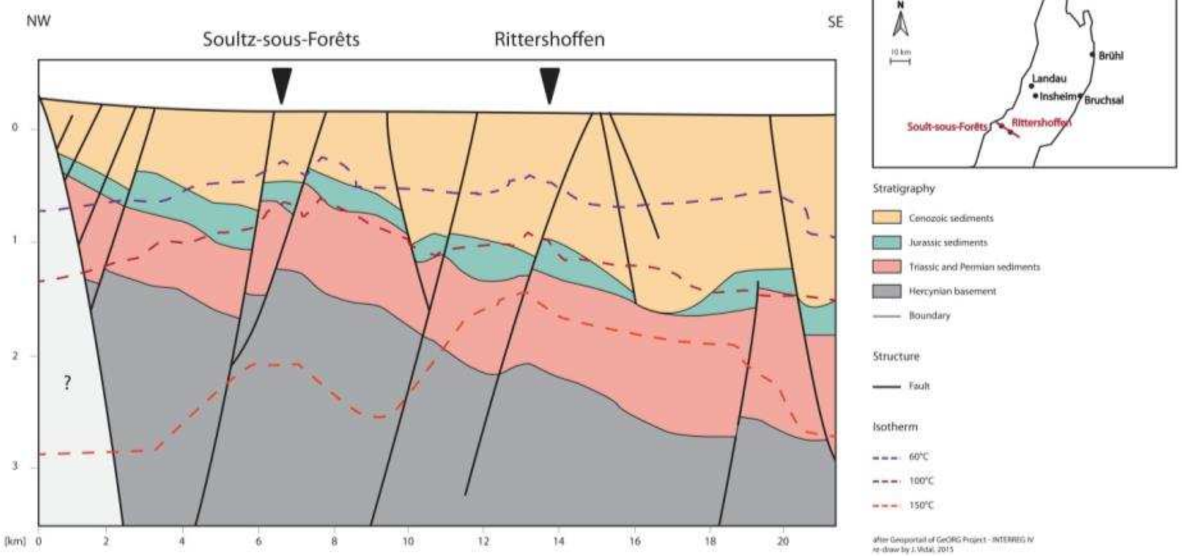
→ **Industrial injectivity reached at shallower depth (<2.5 km depth)**



Temperature map (after Bailleux et al., 2013)

- **Same batholith** than Soultz with an altered and fractured granite at the top of the basement

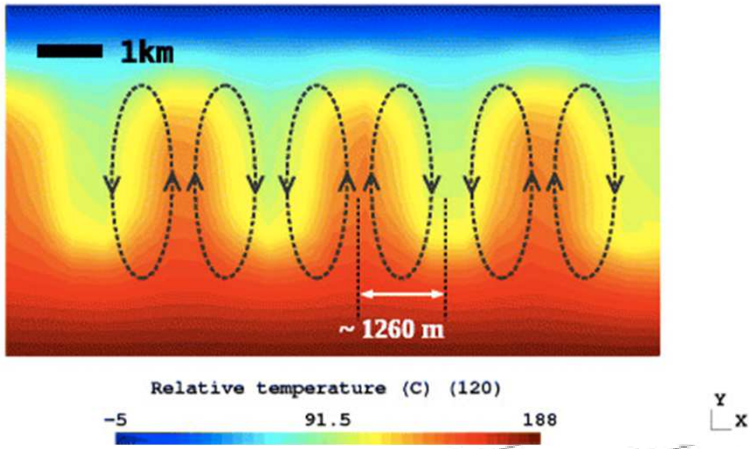
- **Same thermal profile** than Soultz with convective cells



Geological cross-section re-draw after GEORG

Conclusion

- Industrial projects are based on lessons learned from Soultz pilot project
- Permeability is higher at the top basement where the granite is hydrothermally altered and fractured
  → **More permeability at shallower depth** = new economic challenge
- Fracture network is multiscale (from microfractures into minerals to large scale fractures)
- Convective cells circulate through fracture network
  → Fracture sealing and deposits decrease permeability



Convective cell modeling (Magnenet et al., 2014)

QUESTIONS?

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