



Interreg
POCTEFA



UNIÓN EUROPEA
UNION EUROPÉENNE

Fondo Europeo de Desarrollo Regional (FEDER)

Workshop

**From science to praxis:
Experiences employing
Geophysical methods
to characterize
Geothermal anomalies**

26 mayo - mai - May 2021

9:00 - 13:30

Integration of geophysical methods in geothermal characterization

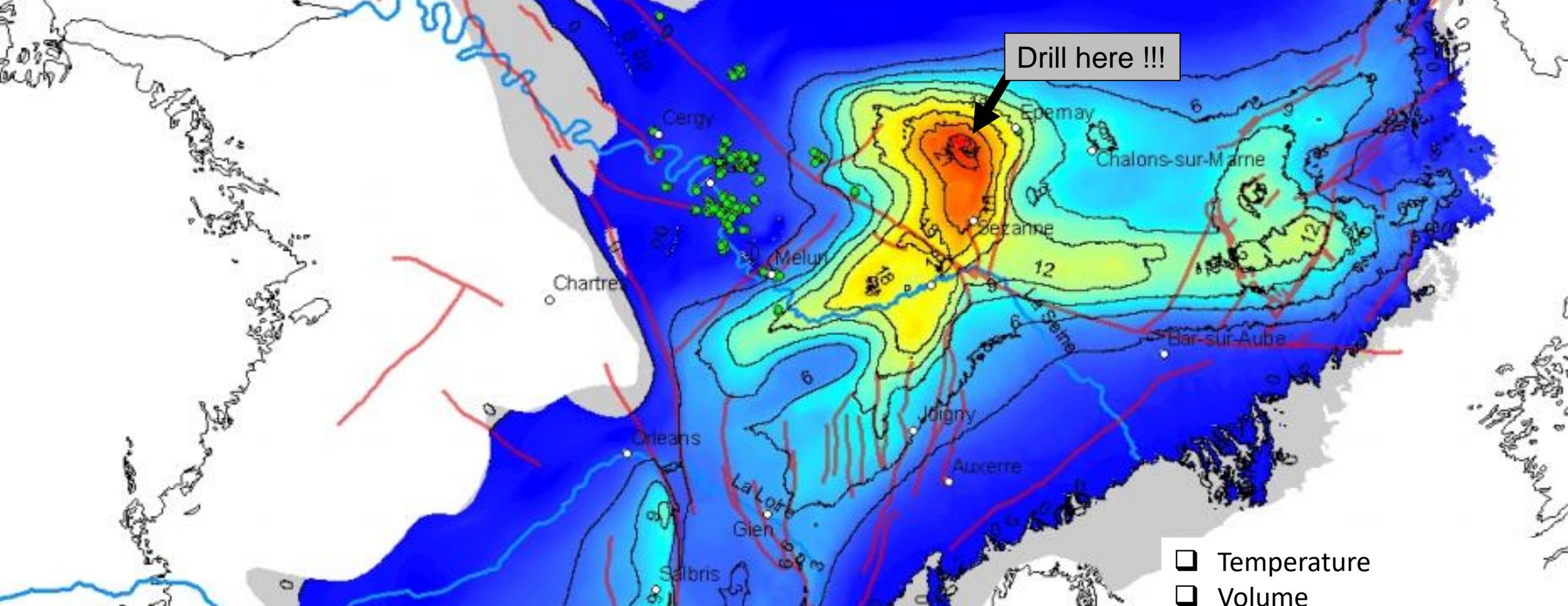
Alexandre Stopin* Mathieu Darnet,
Pierre Wawrzyniak

BRGM, Orléans France

A photograph of the Rittershoffen geothermal plant. The image shows a large industrial building with a corrugated metal facade and a complex network of pipes and machinery. In the foreground, there are large pipes with valves and a blue valve handle. The sky is clear and blue. The text is overlaid on a semi-transparent grey box in the upper left quadrant.

What parameters are we after ?
Which geophysics ?
Example of integrations and
technology development

*Rittershoffen geothermal plant 25MWth
165deg in => 70deg out
2500m reservoir depth
Avoiding CO2 emission equivalent of heating 12K housings*



In place Heat: $Q = A[\varphi\rho_f c_f + (1 - \varphi)\rho_r c_r] \int_{z_b}^{z_t} (T_i - T_f) dz$

Geothermal potential: $Q_r = QR_f$

Map of the Geothermal potential of Donnemarie Sandstone (BRGM report RP56463)

From geophysics to reservoir properties. Which method ?

Static parameters

Dynamic parameters

- 😊 Possible
- 😐 To be developed
- 😞 Difficult

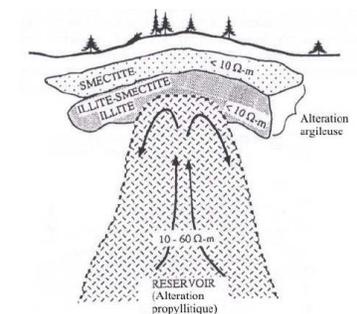
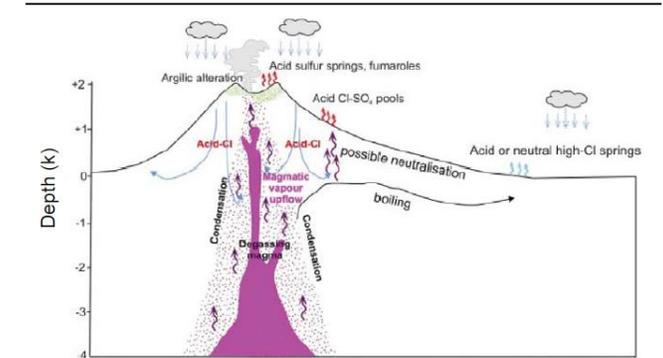
- Cost
- Operational constraints
- Resolution
- Value Of Information

	Static parameters					Dynamic parameters		
	Area extent of the reservoir	Gross thickness of the reservoir	Reservoir porosity	Reservoir temperature	Aqueous phase saturation	Recovery factor (permeability)		
						intrinsic permeability of reservoir units	anisotropy inherited from rock layering and existing fracture sets	live structural components affecting permeability (including faults, fractures and dikes)
Gravimetric Surveys	😐	😞	😞	😞	😞	😞	😞	😊
Geomagnetic Surveys	😐	😞	😞	😞	😞	😞	😞	😊
Magnetotelluric Surveys	😊	😞	😞	😐	😞	😞	😐	😐
Controlled Source Electromagnetic Surveys	😊	😞	😞	😐	😞	😞	😐	😐
Electrical Resistivity (Direct Current)	😐	😞	😞	😞	😞	😞	😞	😞
Self-Potential Methods	😞	😞	😞	😞	😞	😞	😞	😞
Active Seismic Surveys	😊	😊	😊	😞	😊	😐	😐	😊
Passive Seismic Surveys	😐	😞	😞	😞	😞	😞	😞	😞
Ground Temperature Mapping	😞	😞	😞	😞	😞	😞	😞	😞
Heat Flow (or Thermal Gradient) Drilling	😞	😞	😞	😞	😞	😞	😞	😞
Satellite Imagery, Aerial Photogrammetry, and LIDAR	😞	😞	😞	😞	😞	😞	😞	😞

Application to High enthalpy magmatic system

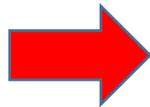
Classic hydrothermal system

- 👍 Reservoir Geometry (Low res), temperature/saturation?
- 👎 Reservoir Geometry (High res) (seismic)? Alteration, present or old? Permeability?



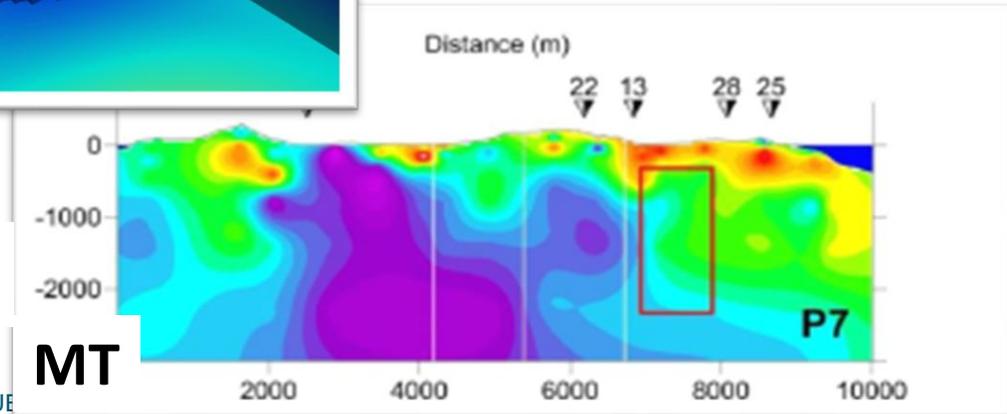
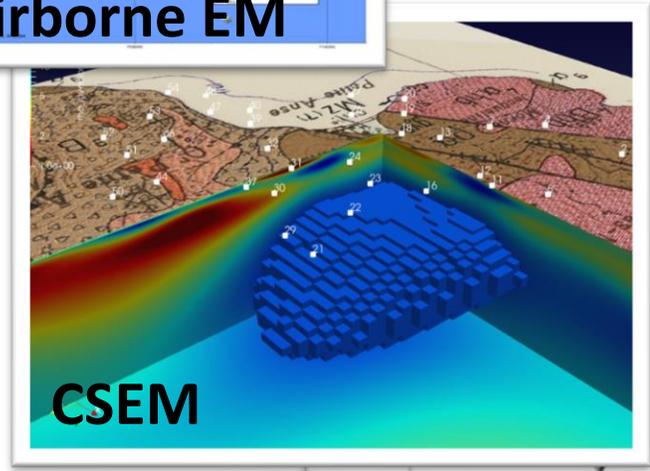
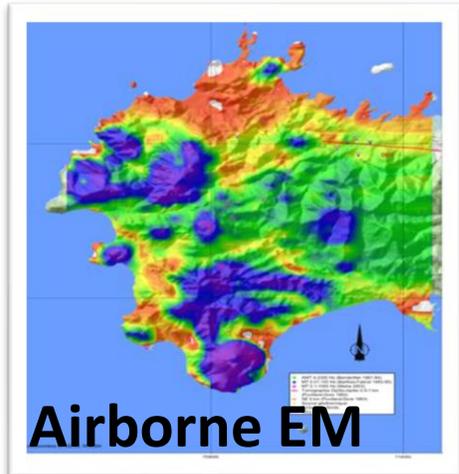
Modèle géoélectrique conceptuel d'un système géothermique typique (d'après Johnston et al., 1992).

- 😊 Possible
- 😐 To be developed
- 😞 Difficult



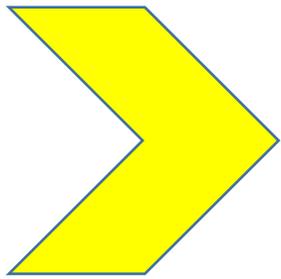
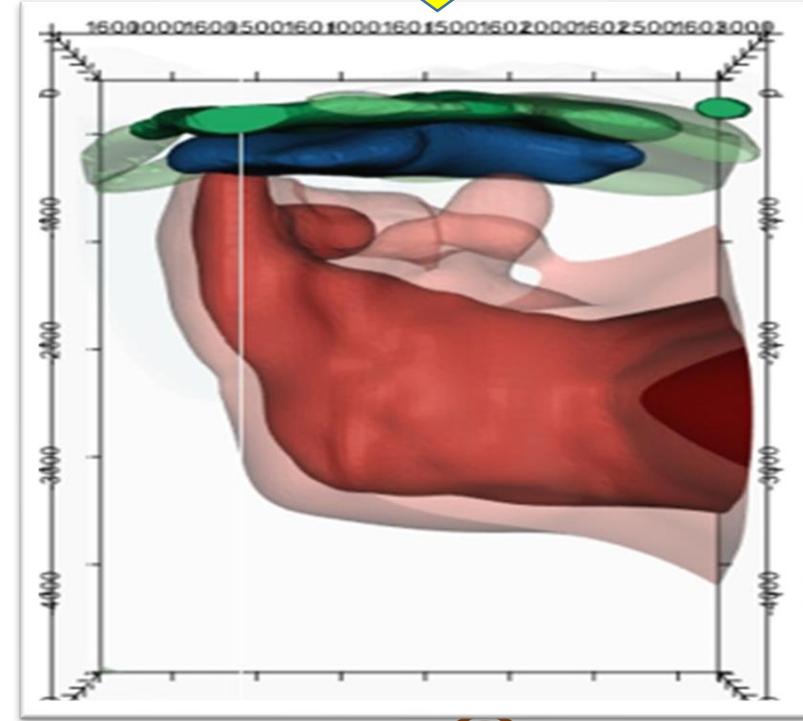
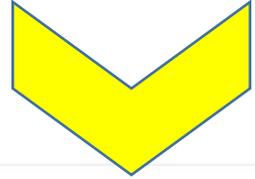
	Area extent of the reservoir	Gross thickness of the reservoir	Reservoir porosity	Reservoir temperature	Aqueous phase saturation	Recovery factor (permeability)		
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Gravimetric Surveys	😊	😞	😞	😞	😐	😞	😞	😊
Geomagnetic Surveys	😊	😞	😞	😞	😞	😞	😞	😊
Magnetotelluric Surveys	😊	😊	😐	😐	😐	😞	😞	😊
Controlled Source Electromagnetic Surveys	😊	😊	😐	😐	😐	😞	😞	😊
Electrical Resistivity (Direct Current)	😊	😊	😐	😐	😐	😞	😞	😊
Self-Potential Methods	😊	😞	😞	😞	😐	😞	😊	😊
Active Seismic Surveys	😞	😞	😞	😞	😞	😞	😞	😞
Passive Seismic Surveys	😊	😐	😐	😐	😐	😞	😞	😊
Ground Temperature Mapping	😊	😞	😞	😐	😐	😞	😞	😊
Heat Flow (or Thermal Gradient) Drilling	😊	😞	😞	😊	😊	😞	😞	😊
Satellite Imagery, Aerial Photogrammetry, and LIDAR	😊	😞	😞	😞	😞	😞	😞	😊

Integrating different EM techniques. Martinique magmatic hydrothermal system



- ❑ A shallow conductive ($<5 \Omega.m$) 500m-thick layer -
> (“cap-rock”) covered by resistivity bodies at each topographic highs, corresponding to the recent unaltered lavas
- ❑ A deep more resistive (5-20 $\Omega.m$) layer in the Eastern part of the survey area, most likely ->the targeted (relict ?) geothermal reservoir
- ❑ A deep highly resistive ($>50 \Omega.m$) layer in the Western -> volcanic dyke
- ❑ Three Targets identified

**Geochemical information
Geology**



Application to high enthalpy system. EGS

EGS in sedimentary basins

- 👍 Structural elements
- 👎 Reservoir Geometry? Porosity, Temperature ? Permeability ?

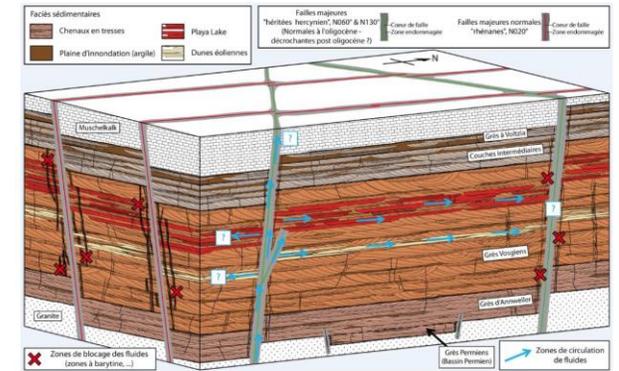
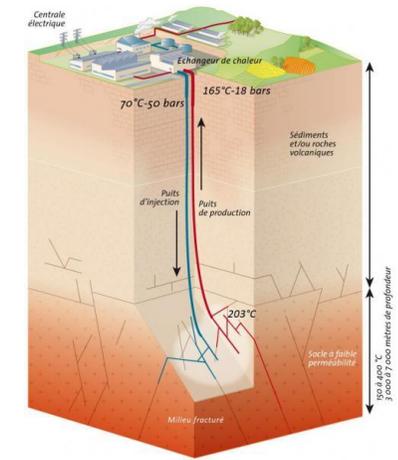
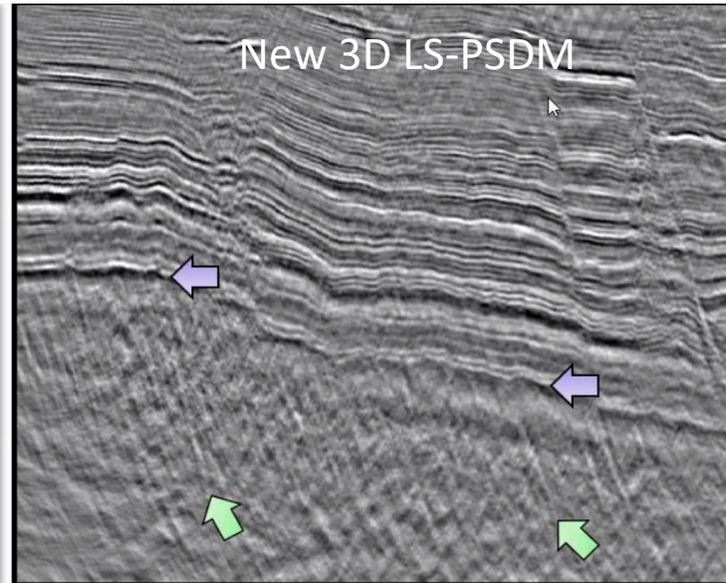
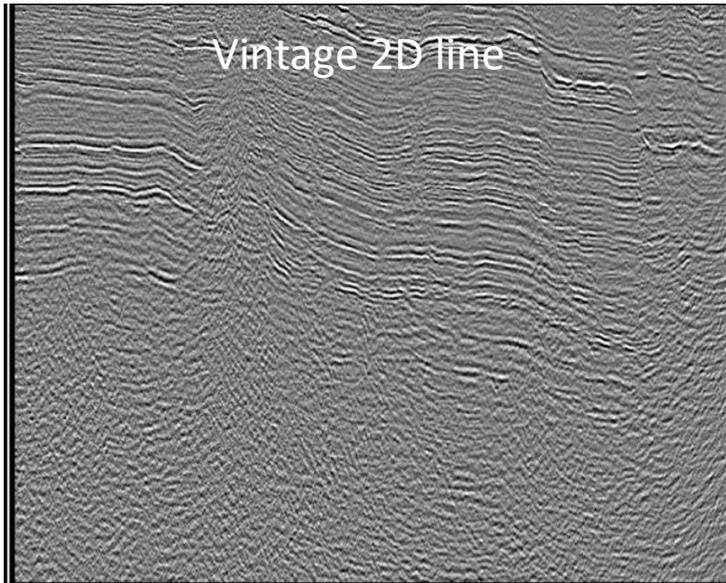


Figure 80 - Modèle conceptuel d'un bloc délimité par des failles majeures dans la formation gréseuse du Buntsandstein du fossé rhénan (schéma sans échelle).

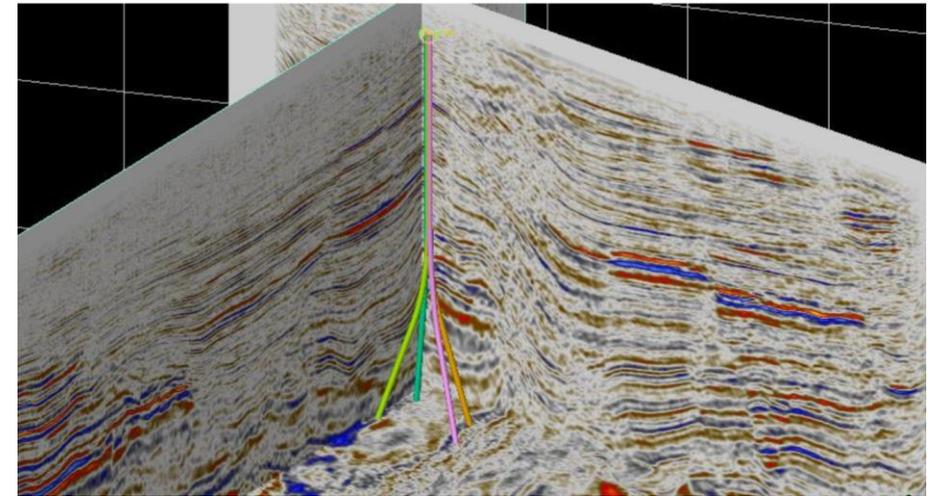
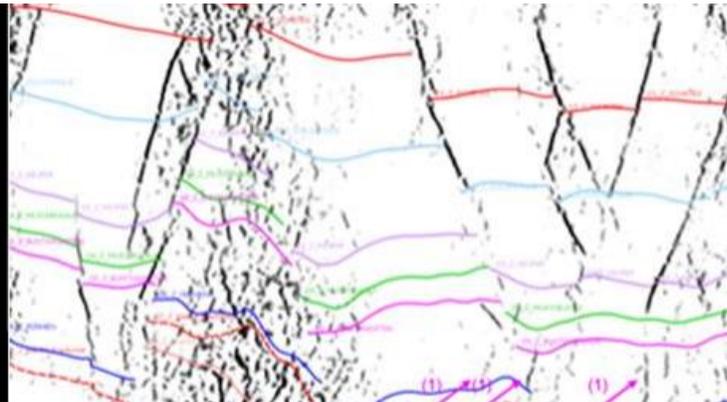
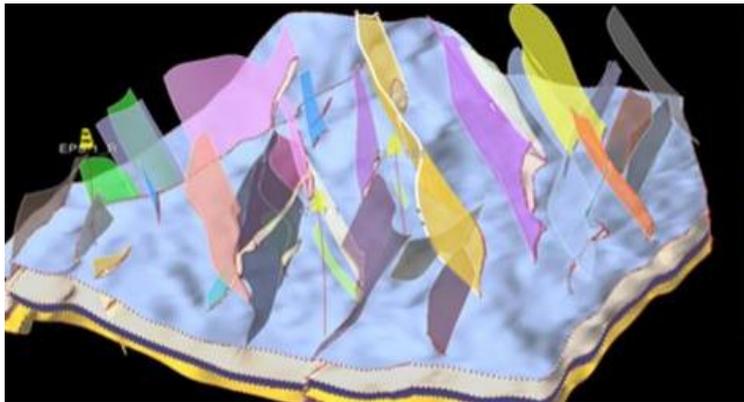
- 😊 Possible
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Gravimetric Surveys	😊	😞	😞	😞	😞	😞	😞	😊
Geomagnetic Surveys	😊	😞	😞	😞	😞	😞	😞	😊
Magnetotelluric Surveys	😊	😞	😞	😊	😞	😊	😊	😊
Controlled Source Electromagnetic Surveys	😊	😞	😞	😊	😞	😊	😊	😊
Electrical Resistivity (Direct Current)	😊	😞	😞	😞	😞	😞	😞	😞
Self-Potential Methods	😞	😞	😞	😞	😞	😞	😞	😞
Active Seismic Surveys	😊	😊	😊	😞	😞	😊	😊	😊
Passive Seismic Surveys	😊	😞	😞	😞	😞	😞	😞	😞
Ground Temperature Mapping	😞	😞	😞	😞	😞	😞	😞	😞
Heat Flow (or Thermal Gradient) Drilling	😞	😞	😞	😊	😞	😞	😞	😞
Satellite Imagery, Aerial Photogrammetry, and LIDAR	😞	😞	😞	😞	😞	😞	😞	😞

3D seismic and latest imaging technology. From to be developed to possible



- 3D WAZ acquisition with sparse sampling
- Velocity model building accounting for faults
- LS-PSDM
- Faults clearly visible and better positioned
- Optimized well design

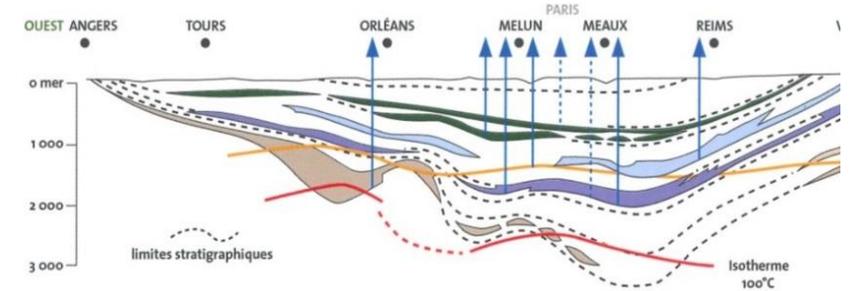


Application to low enthalpy system

Case of the Dogger in the Paris Basin

👍 Reservoir Geometry (High res), porosity, structural elements

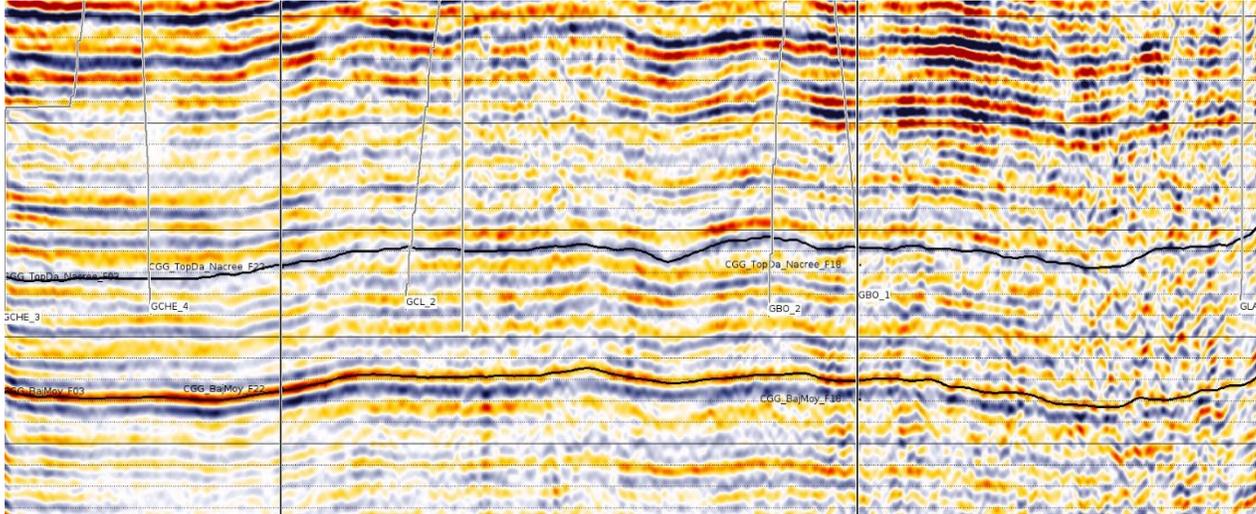
👎 Temperature ? Permeability



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Geomagnetic Surveys	😊	😞	😞	😞	😞	😞	😞	😊
Magnetotelluric Surveys	😊	😞	😞	😊	😞	😊	😊	😊
Controlled Source Electromagnetic Surveys	😊	😞	😞	😊	😞	😊	😊	😊
Electrical Resistivity (Direct Current)	😊	😞	😞	😞	😞	😞	😞	😞
Self-Potential Methods	😞	😞	😞	😞	😞	😞	😞	😞
Active Seismic Surveys	😊	😊	😊	😞	😊	😊	😊	😊
Passive Seismic Surveys	😊	😞	😞	😞	😞	😞	😞	😞
Ground Temperature Mapping	😞	😞	😞	😞	😞	😞	😞	😞
Heat Flow (or Thermal Gradient) Drilling	😞	😞	😞	😞	😞	😞	😞	😞
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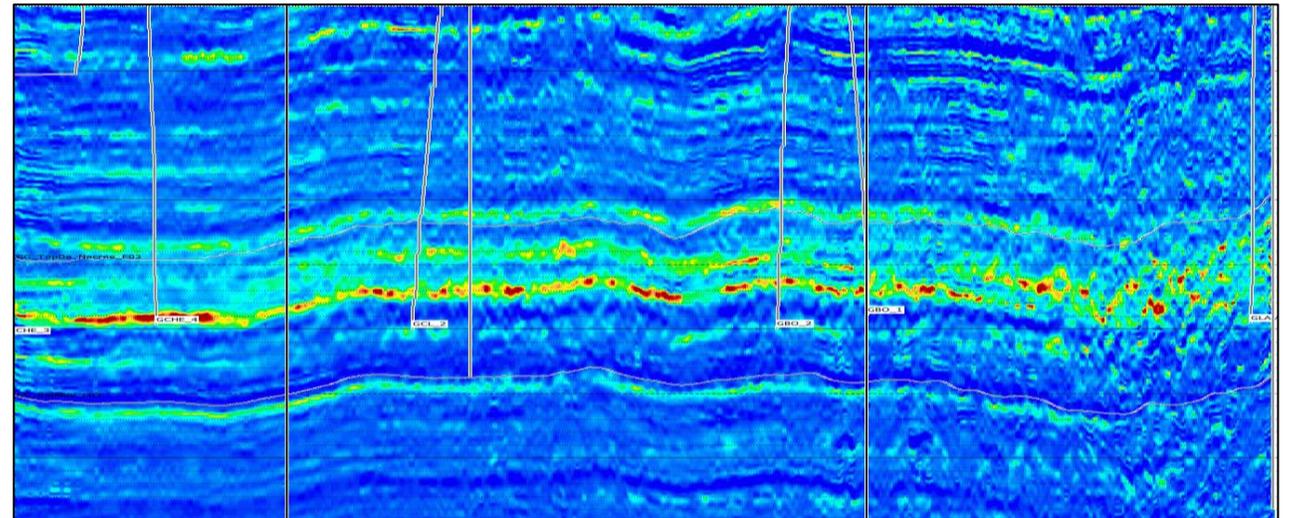
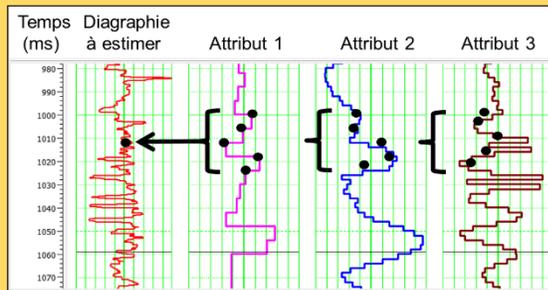
Towards quantitative interpretation. One step for better evaluation of geothermal potential



- ❑ Target is the Dogger reservoir North East of Paris
- ❑ Legacy data from the 80s reprocessed in true amplitude
- ❑ Key role of Petrophysics
- ❑ Effective porosity obtained from porosity and shale volume predicted from stack by neural net trained on synthetic data
- ❑ Porosity in agreement with well observations

Seismic

Training



Effective porosity

Conclusions

- Definition of target and evaluation of Stored heat
- Different setting require different methods
- Integration of geophysical methods but also geology, geochemistry
- Still some work to do to obtain reservoir properties

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