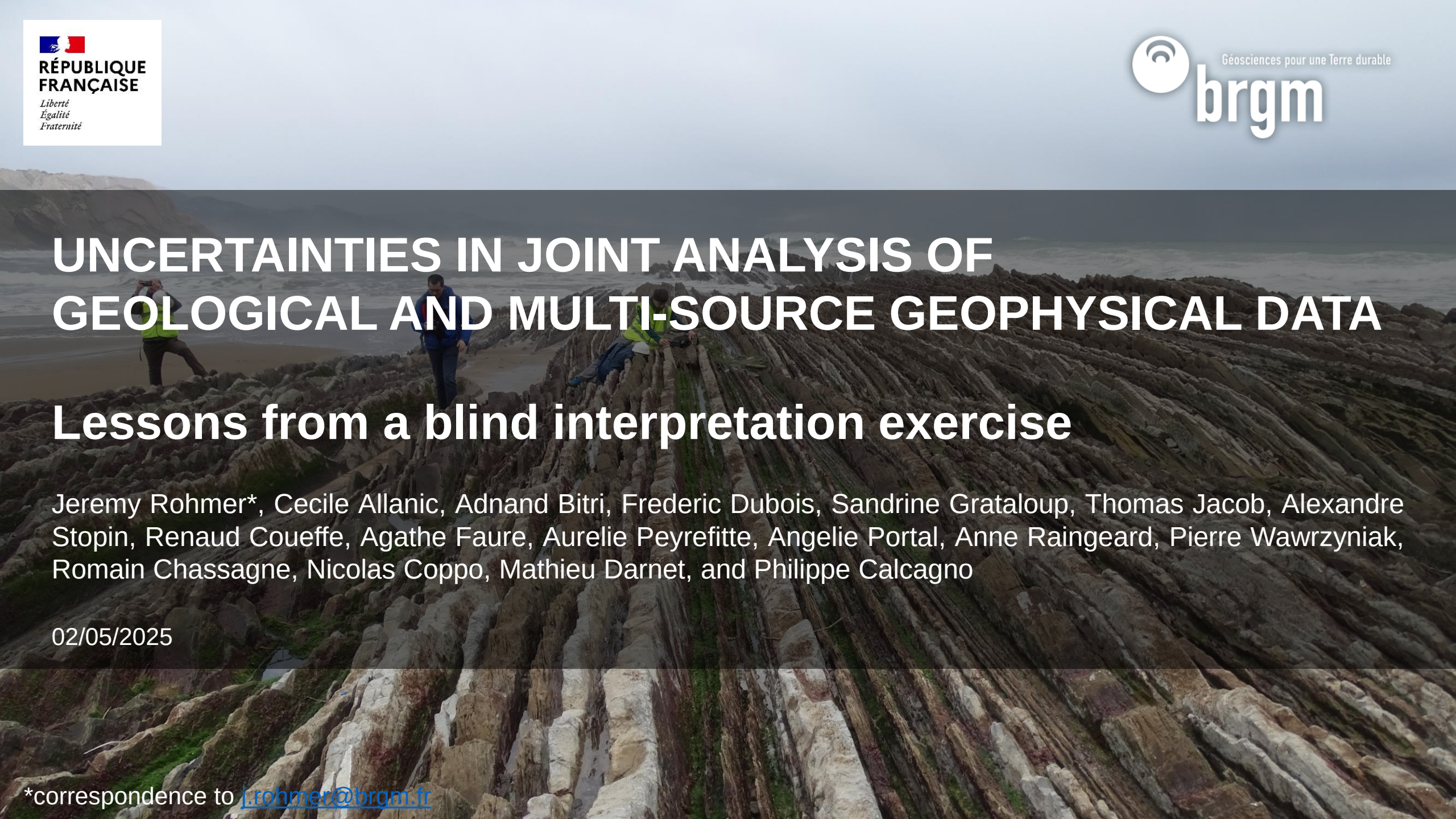


UNCERTAINTIES IN JOINT ANALYSIS OF GEOLOGICAL AND MULTI-SOURCE GEOPHYSICAL DATA

Lessons from a blind interpretation exercise

Jeremy Rohmer*, Cecile Allanic, Adnand Bitri, Frederic Dubois, Sandrine Grataloup, Thomas Jacob, Alexandre Stopin, Renaud Coueffe, Agathe Faure, Aurelie Peyrefitte, Angelie Portal, Anne Raingeard, Pierre Wawrzyniak, Romain Chassagne, Nicolas Coppo, Mathieu Darnet, and Philippe Calcagno

02/05/2025

*correspondence to j.rohmer@brgm.fr

Motivation

Geological reasoning: Geology as an interpretive and historical science

Robert Frodeman *Department of Geological Sciences* and *Department of Philosophy, University of Colorado, Boulder, Colorado 80301*

Geologist

noun.

1. A person who does precision guesswork based on unreliable data.

2. Someone who solves problem you can't.

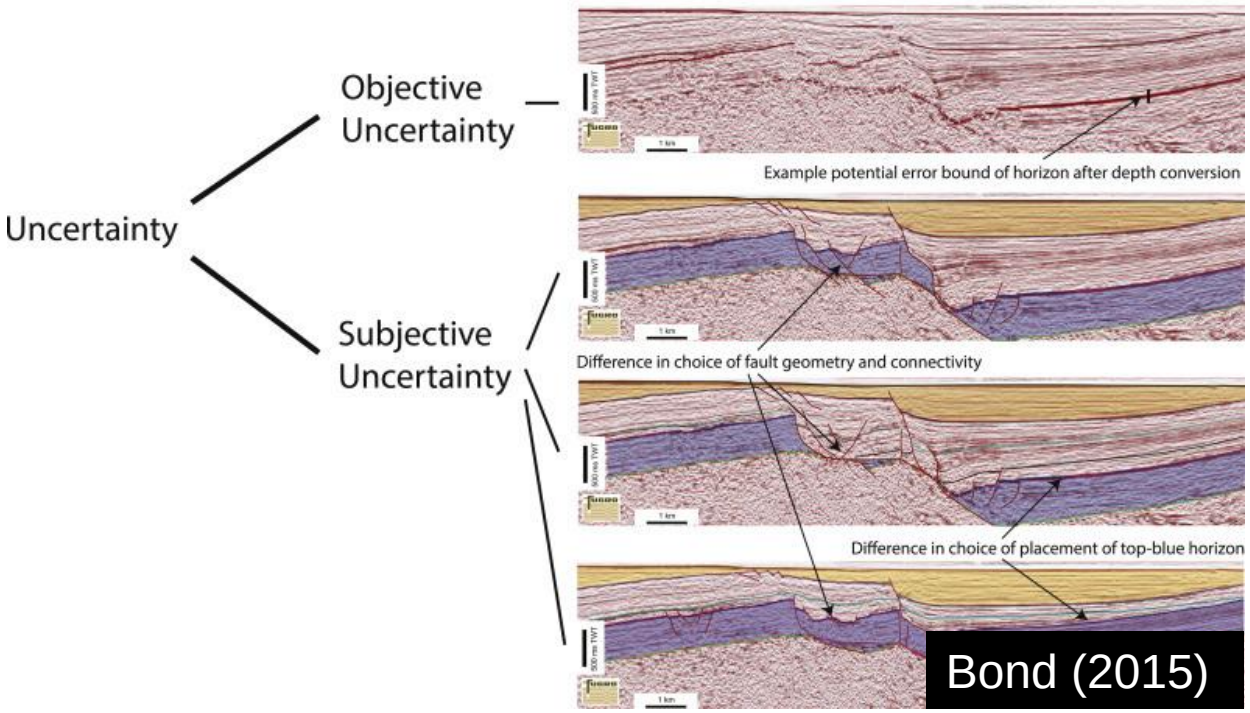
see also: wizard, magician

www.spreadshirt.com.au

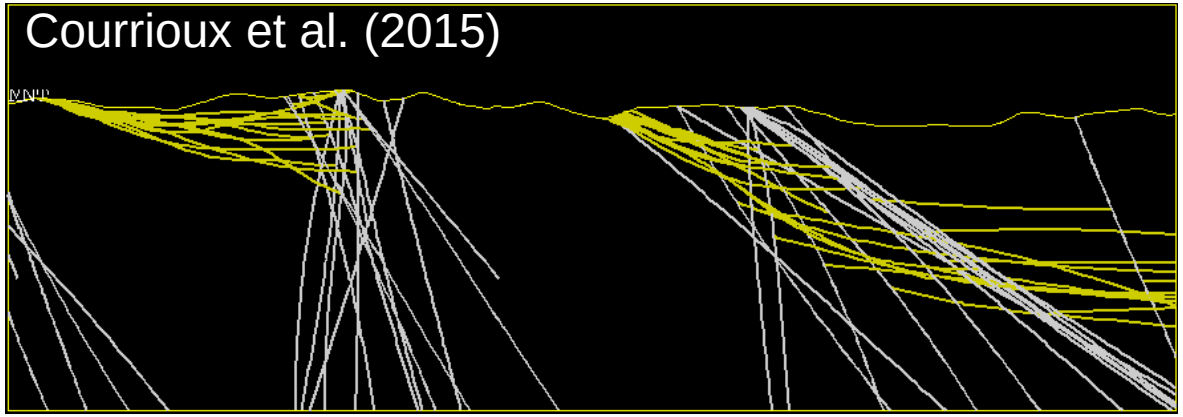
Motivation

Geological reasoning: Geology as an interpretive and historical science

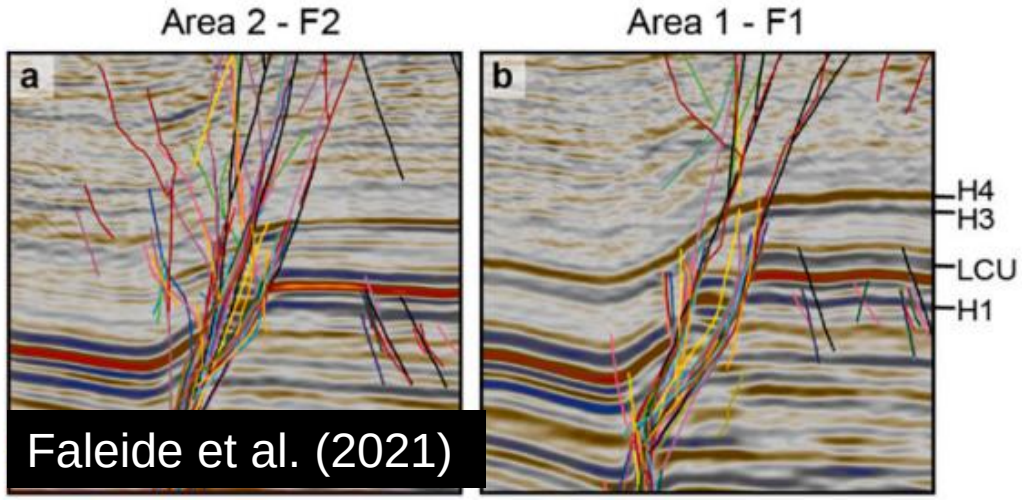
Robert Frodeman *Department of Geological Sciences* and *Department of Philosophy, University of Colorado, Boulder, Colorado 80301*



Bond (2015)



Courrioux et al. (2015)



Faleide et al. (2021)

Géosciences pour une Terre durable
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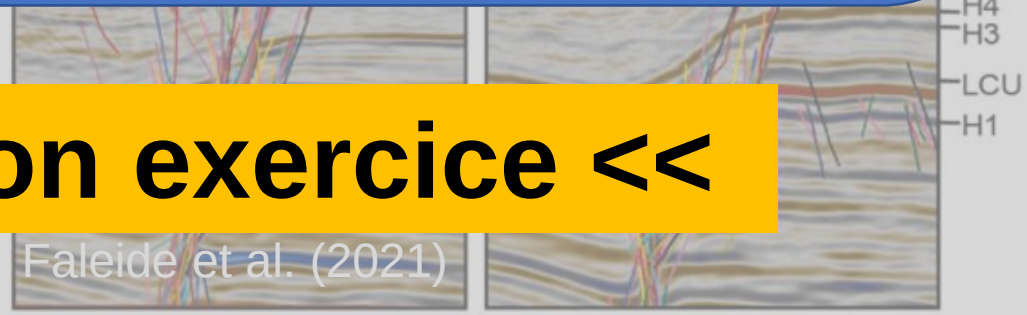
Motivation

When jointly analyzing **geological** and **multi-source geophysical** datasets (seismic, gravimetric, electric/magneto-telluric):

(q1) Is it possible to detect and characterize **structural traps** and potential migration pathways at **several kilometers depth?**

(q2) Do the errors associated with each of the different datasets **influence / affect / bias** the geological interpretation? If so, how?



>> Blind interpretation exercice <<

Géosciences pour une Terre durable
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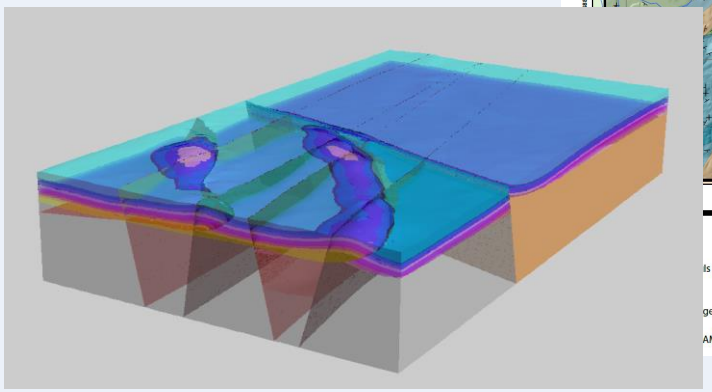
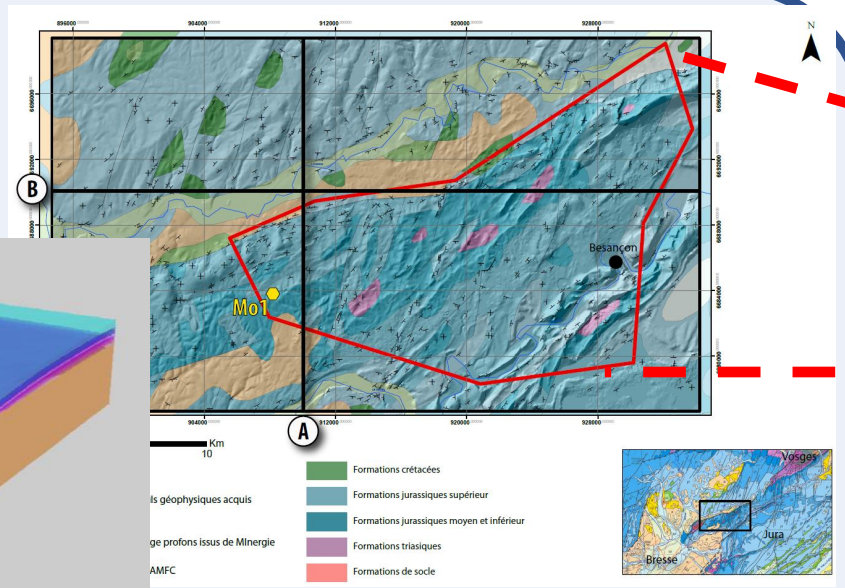
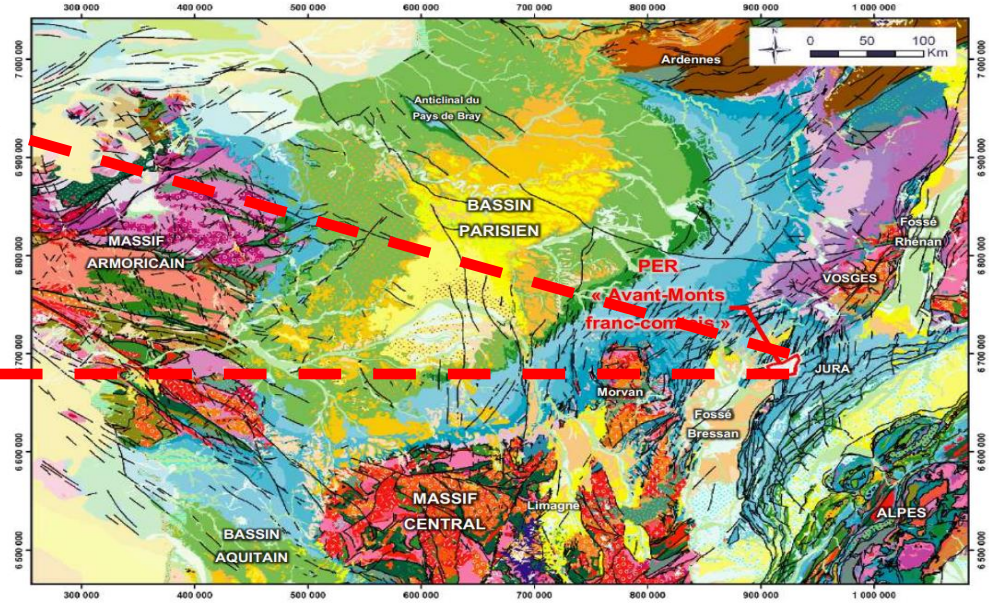
1. Geological ‘truth’





Realistic 3D geological model over a domain of ≈20km x ≈30km



Adapted from a real exploration project dedicated to the characterization of helium reservoirs in a deep Permian sedimentary basin

>> Blind interpretation exercice <<

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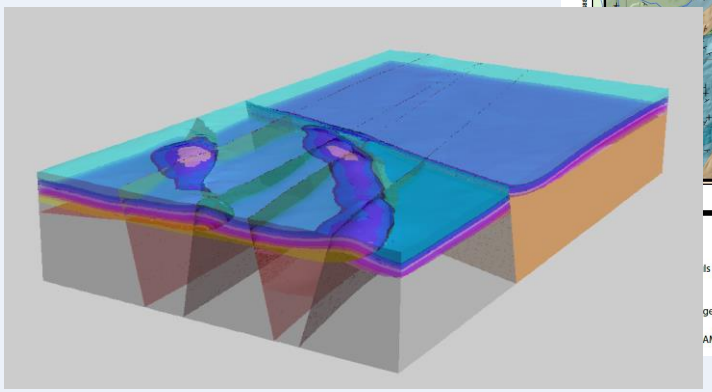
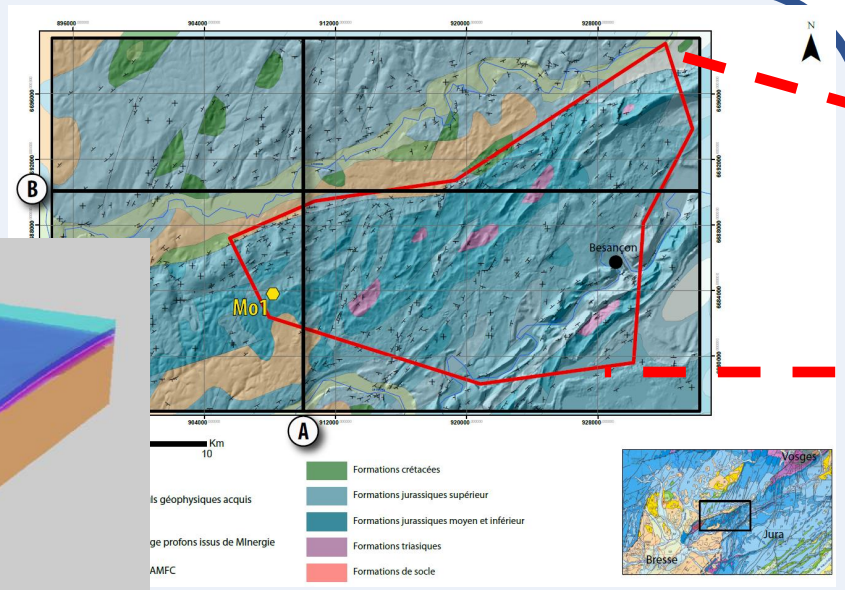
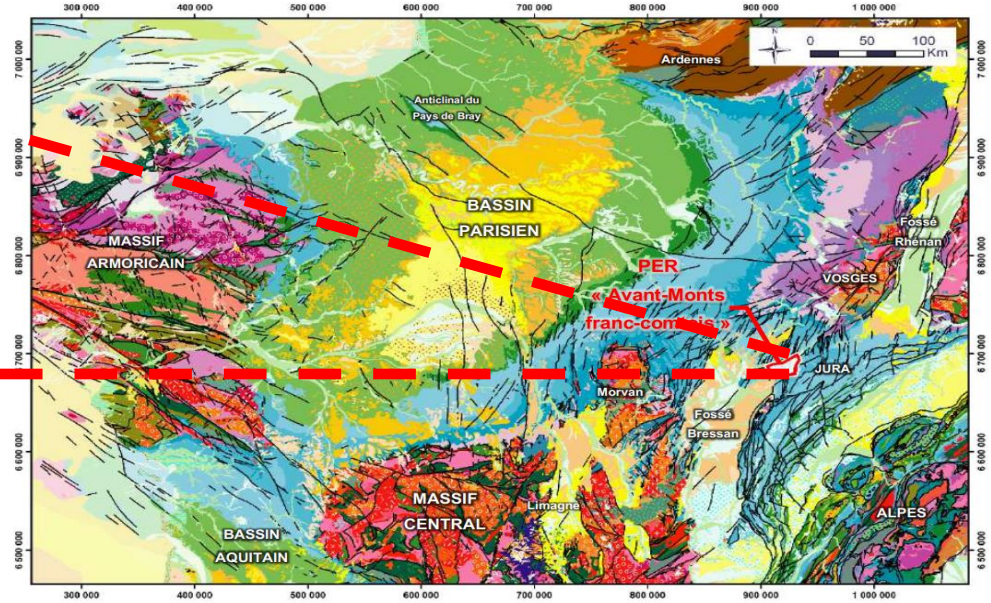
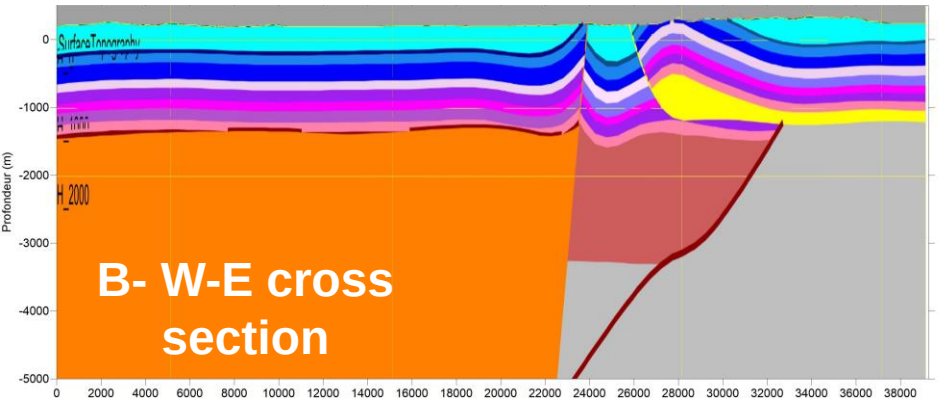
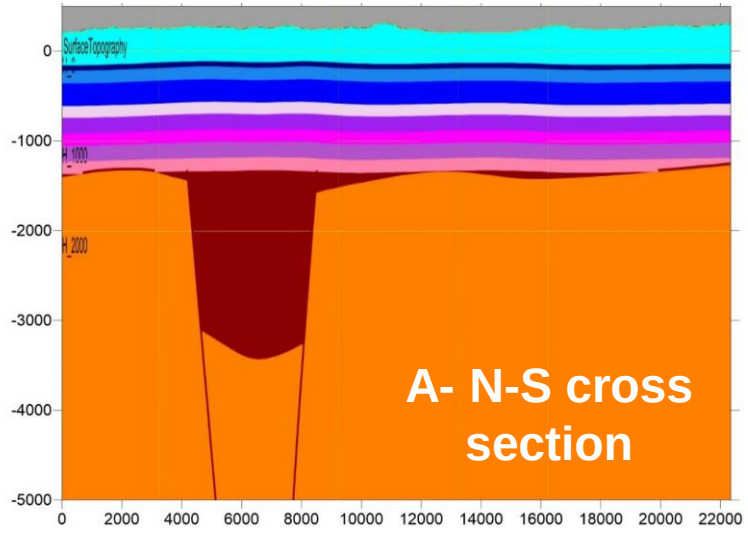






Extraction of 2 cross-sections from a realistic 3D geological model





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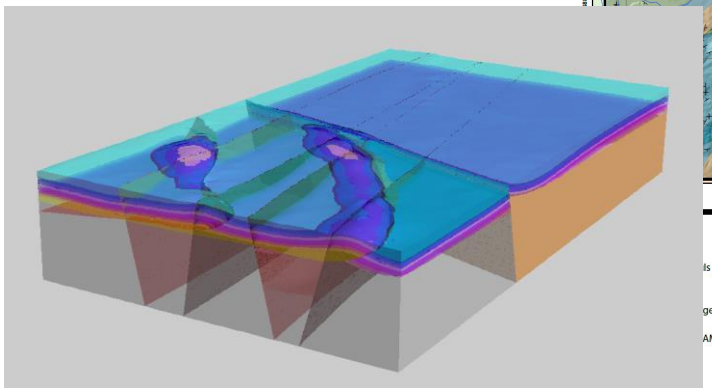
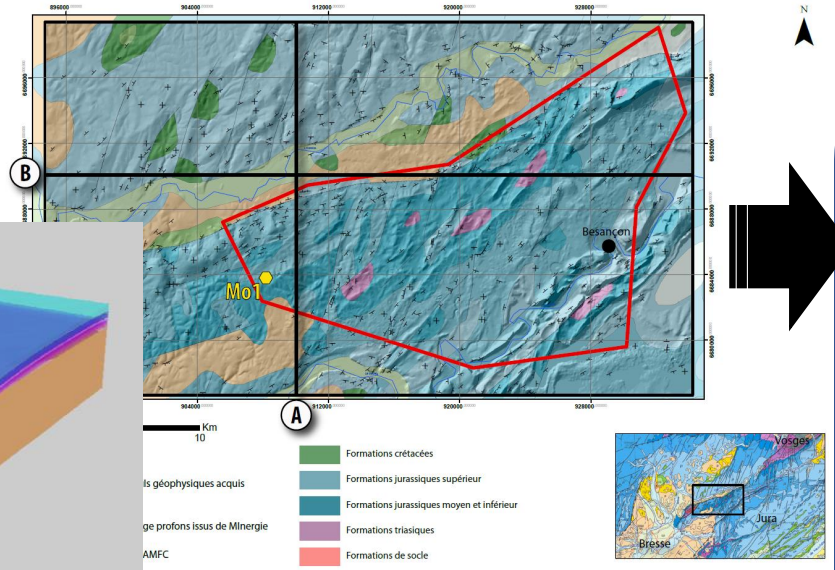
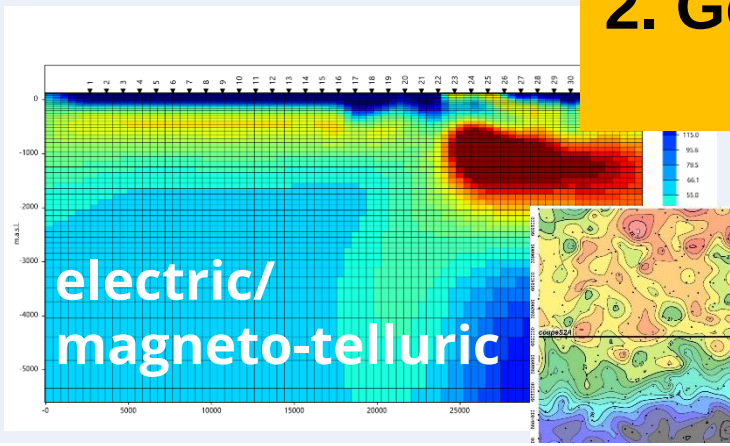
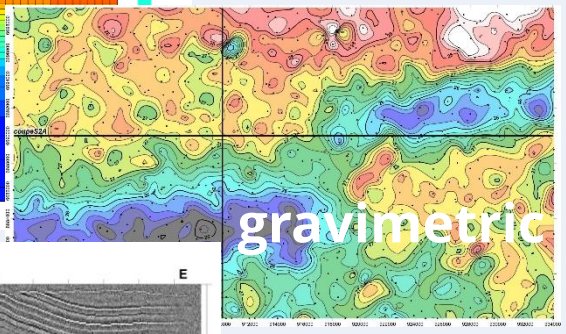
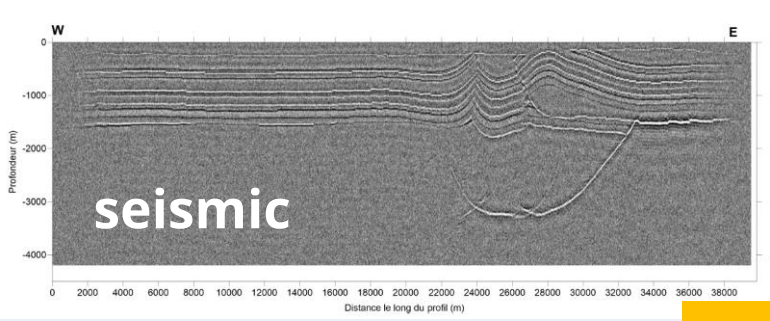




2. Geophysical ‘truth’







Forward geophysical modelling

+

’realistic’ measurement or processing error

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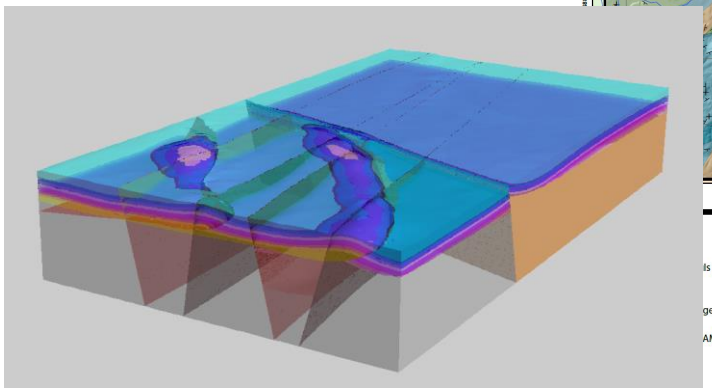

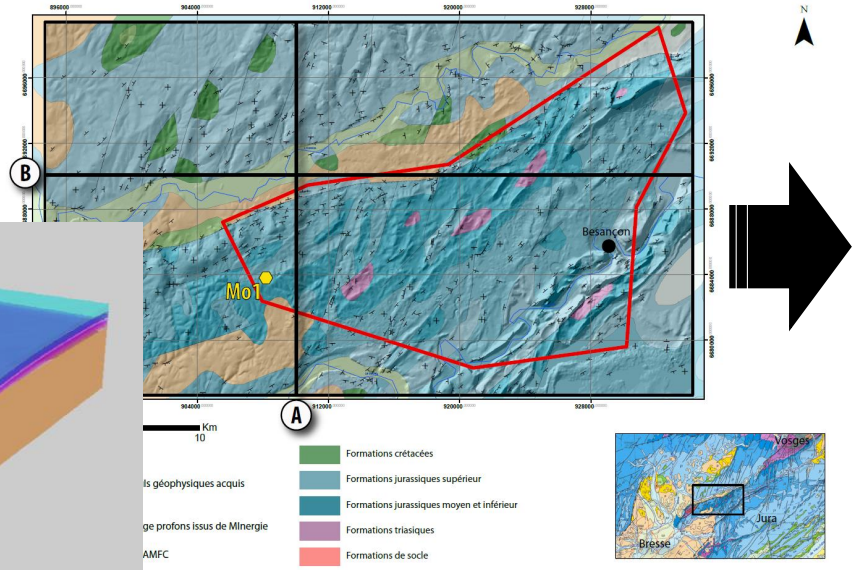

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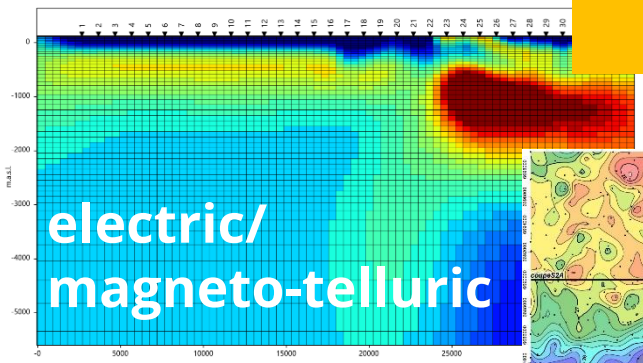

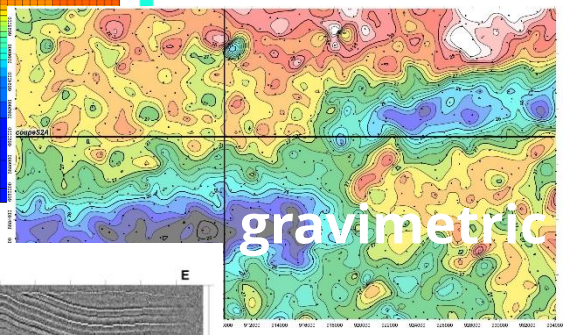

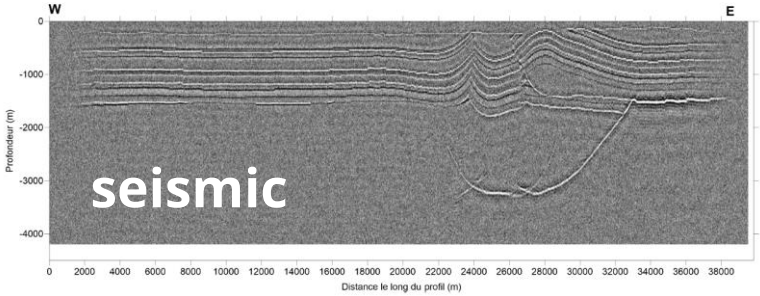

Forward geophysical modelling

+

’realistic’ measurement or processing error

3 teams of interpreters

A geologist + A geophysicist (senior / mid career)

3. Blind exercice

Objective reconstruct the two cross sections

Géosciences pour une Terre durable
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Objective of the blind exercice

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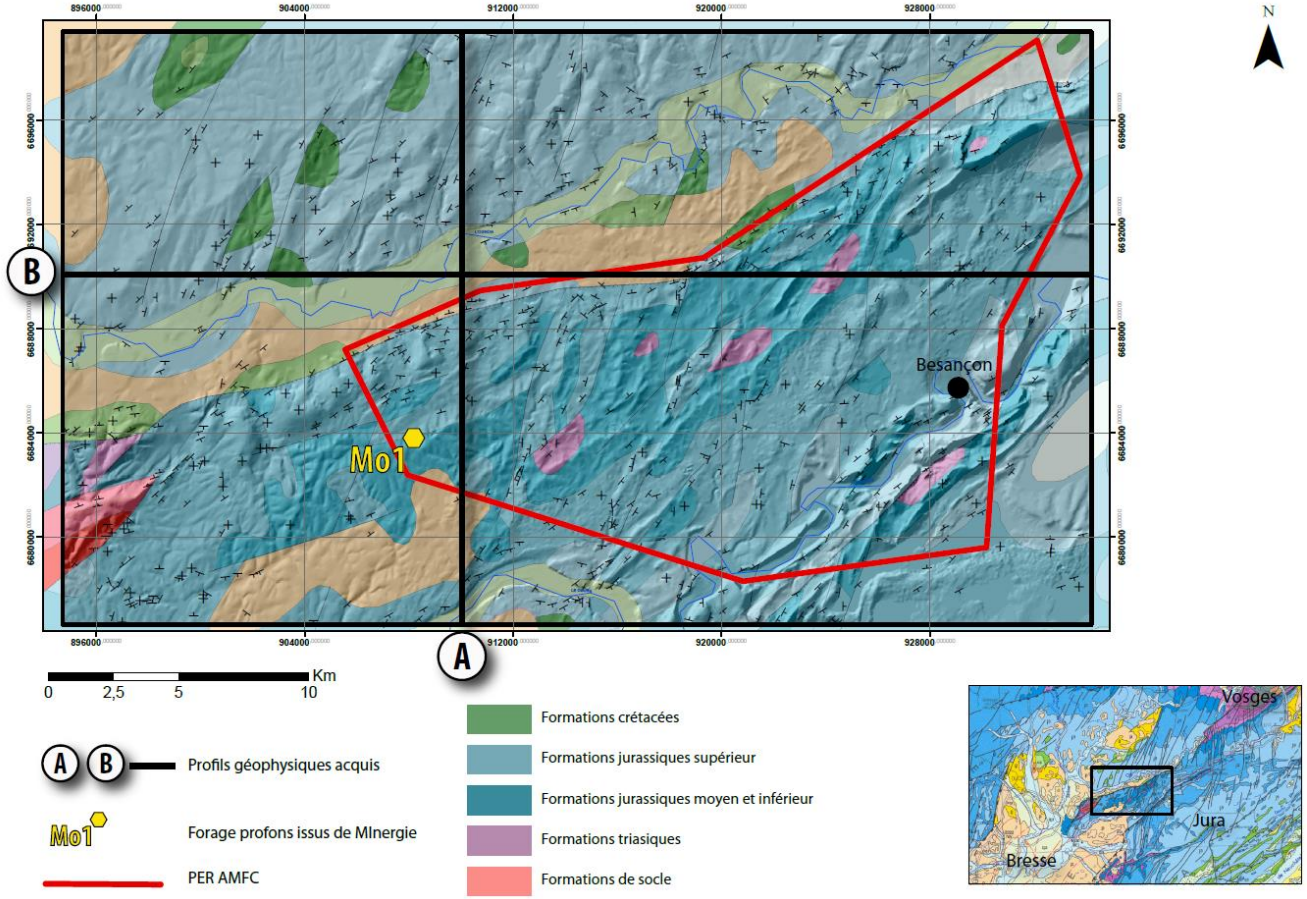
Identify **structural traps** + geometry, identify the **potential migration pathways** on the **two cross-sections**

Documents

- 1:1,000,000 scale **geological map + borehole** (with stratigraphy)



Borehole Mo1

05018X0002

DÉPARTEMENT : DOUBS — Pièce I Feuillet I

COMMUNE : JALLERANGE — Indice de classement : 501 8 2

DÉSIGNATION : Mo 1 — Cote du sol (z) = + 299,16m

Coupe établie par : SAPREP

Interprétation de : M. SAPREP

PROFONDEURS de 0m à 540m	NATURE DES TERRAINS	INTERPRÉTATION	COTE
0 m à 402 m	Calcaires blancs massifs	Malm	
402 m à 479 m	Marnes noires	Oxfordien	
479 m à 567 m	Calcaires jaunes et ocres à entroques	Bajocien	
	quelques passages oolithiques. Intercalations de marnes grises.		
567 m à 618 m	Calcaires marneux ferrugineux.	Aalénien	
618 m à 682 m	Argilites et marnes grises à gill de quartz. Pyrite. Rares et minces intercalations de calcaires.	Lias marneux	+254,16m
	Calcaires bruns à passées marneuses.		
682 m à 723 m	Calcaire gris brun à Gryphées. Intercalations marneuses.	Sinémurien	
723 m à 867m	Grès à ciment calcaire	Hettangien	
867 m à 997 m	Marnes gris noires plus ou moins schisteuses et grès blancs siliceux.	Rhétien	
997 m à 1170 m	Argiles bariolées et petits bancs de calcaires dolomitiques beige. Gypse et anhydrite abondants, rares passées dolomitiques.	Keuper supérieur	+22,16m
1170 m à 1304 m	"Dolomie de 15m". Argiles bariolées. "Grès à roseaux" à la base.	Keuper moyen	
1304 m à 1481 m	Marnes grise et fines passées gréseuses	Muschelkalk	

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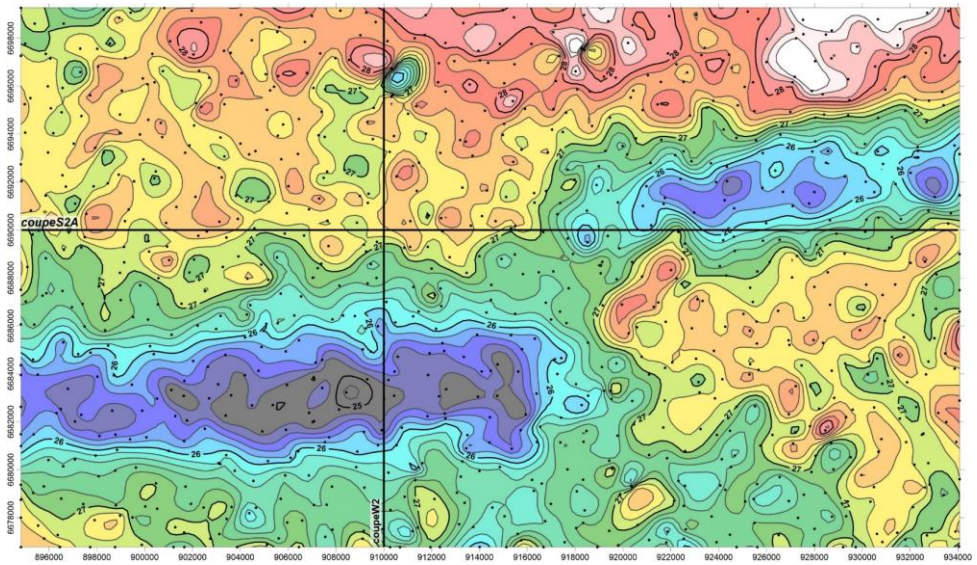
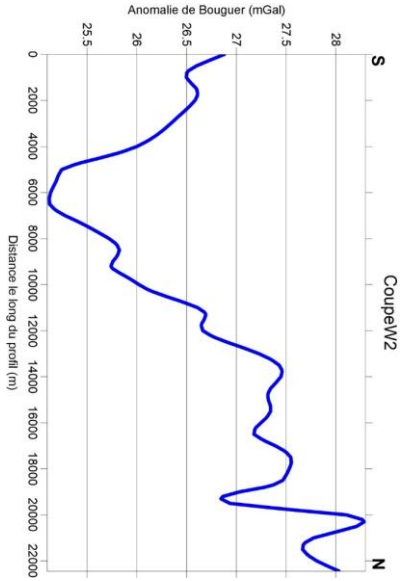
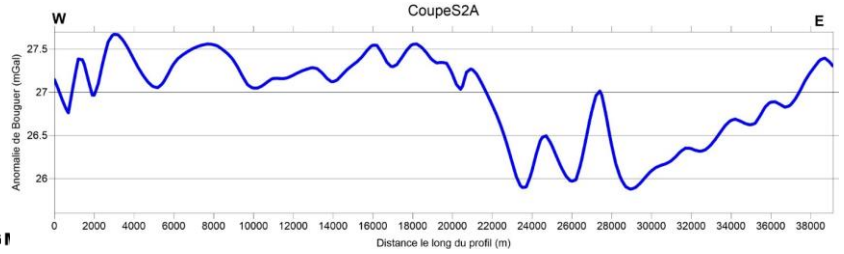
- Map of **Bouguer anomaly (gravimetry)** **+** profiles along the cross sections







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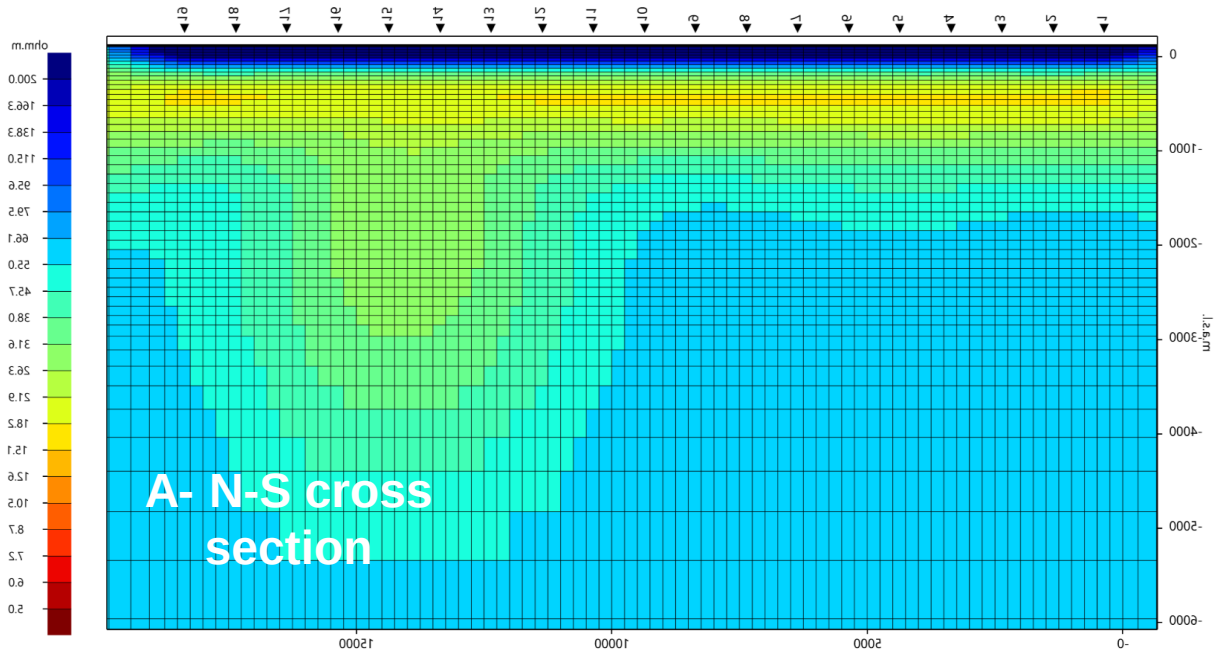
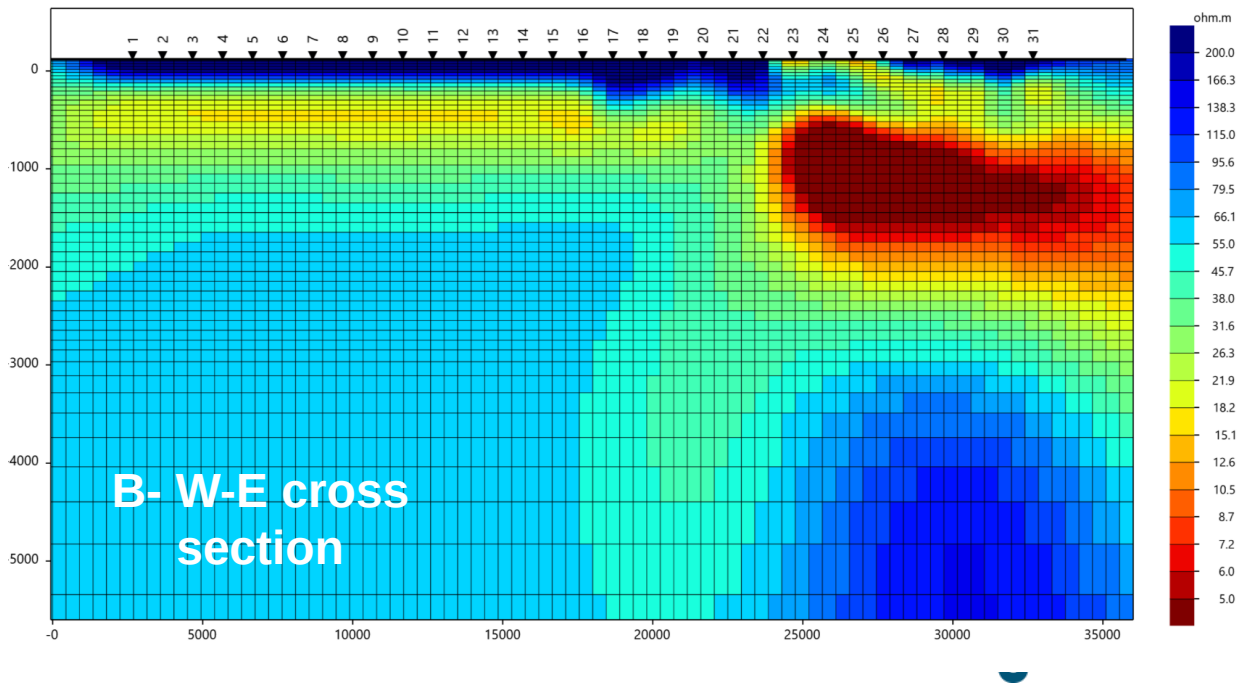
- Cross sections of **electrical resistivity** from processing of magneto-telluric (**MT**) surveys





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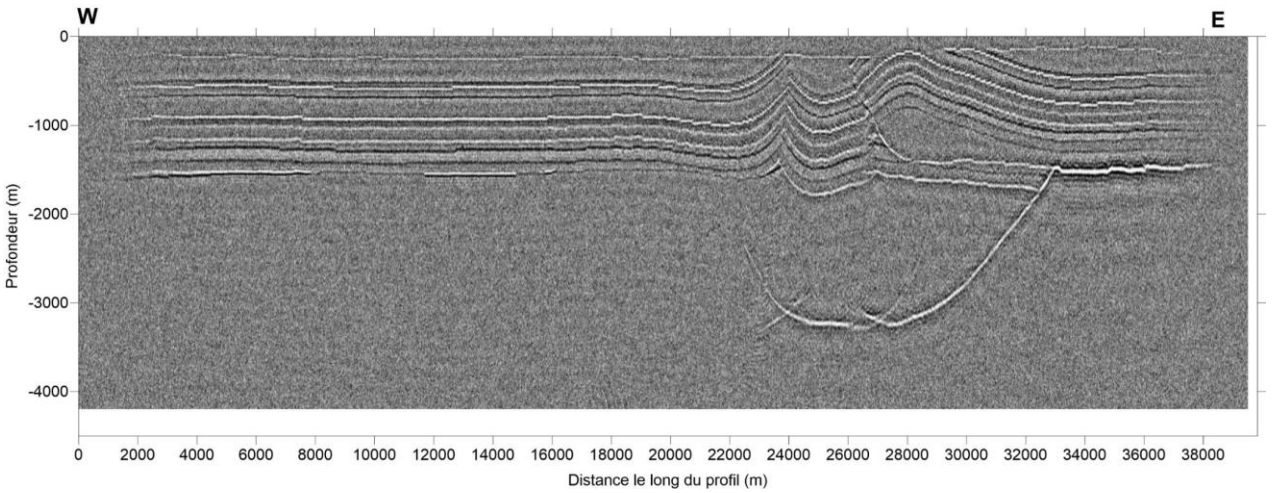
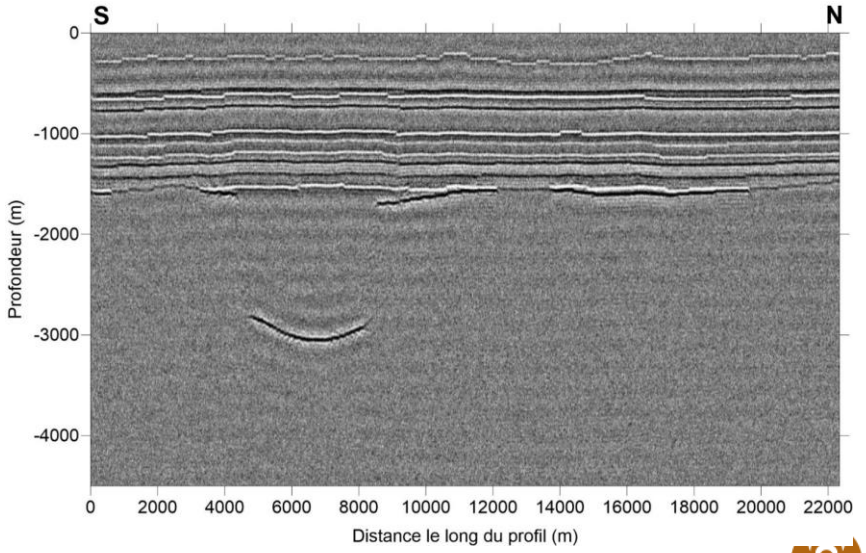
- Cross sections of electrical resistivity from processing of magneto-telluric (MT) surveys
- **HR seismic**: on the two cross sections

Assumption: seismic campaign had some delays and the data were provided in a second phase!





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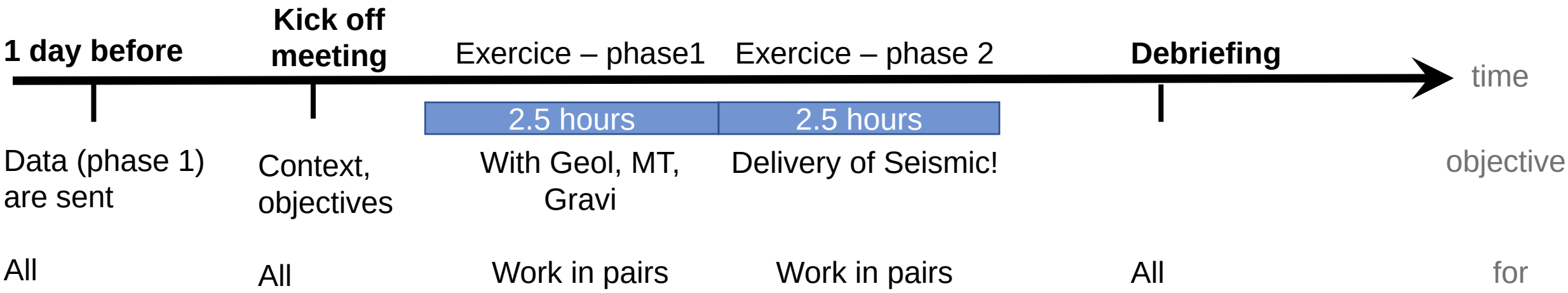

A series of difficulties

1. Inherent to the imperfections in the **geophysical / geological data**
- Effect of noise in the data
- Effect of mis-specifications (model uncertainty) in the processing
- Resolution of the data

2. Inherent to the **exercice**
- 3D effect: two cross sections not necessarily orthogonal to main structures
- Choice of representation format incl. colorscale

3. Inherent to the '**human nature' of the interpreters**
- Different past experiences (senior and mid career)
- Different working practices incl. tools
- Different perceptions / understanding / biases

A series of difficulties

Egu presentation

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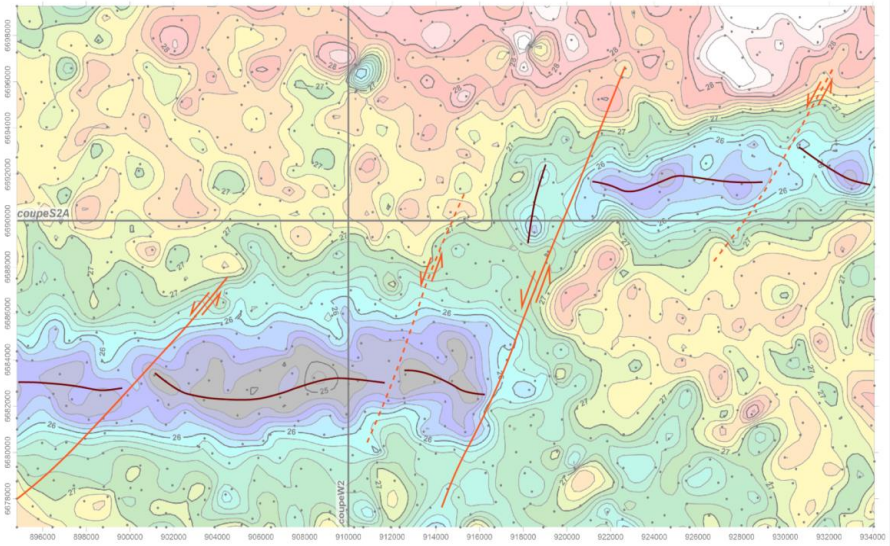
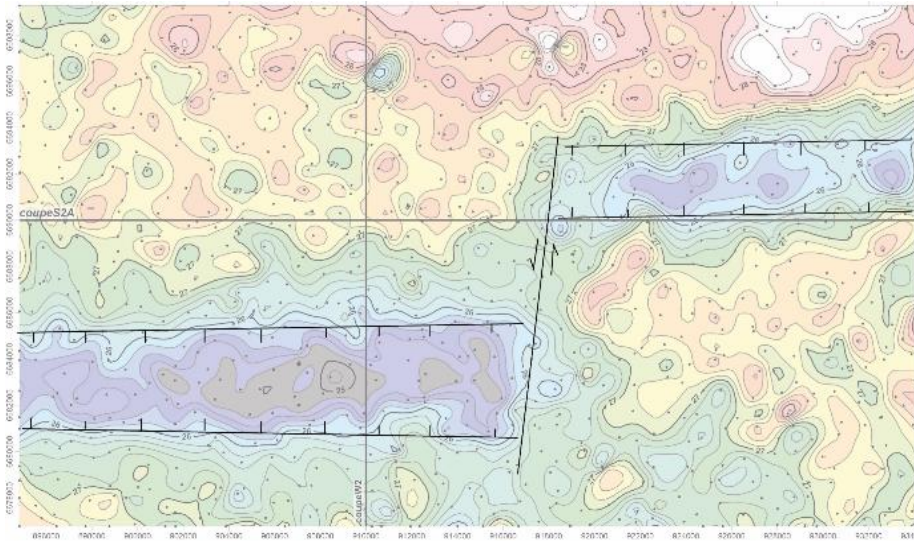
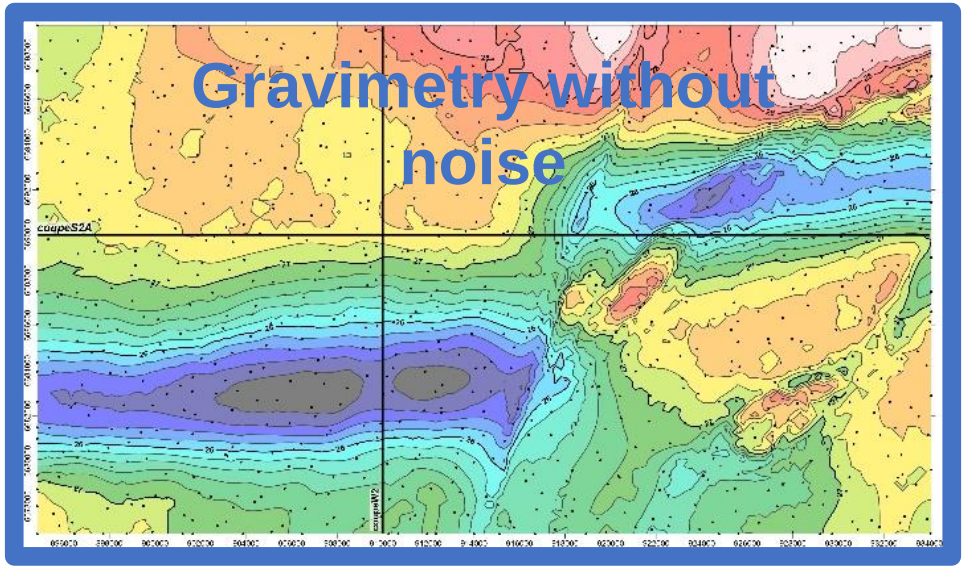
1. data imperfection: noise

Interpretations of the map of Bouguer anomaly

Large noise of 0.2 µgal = mimick the processing of gravimetry measurements of early 1950s





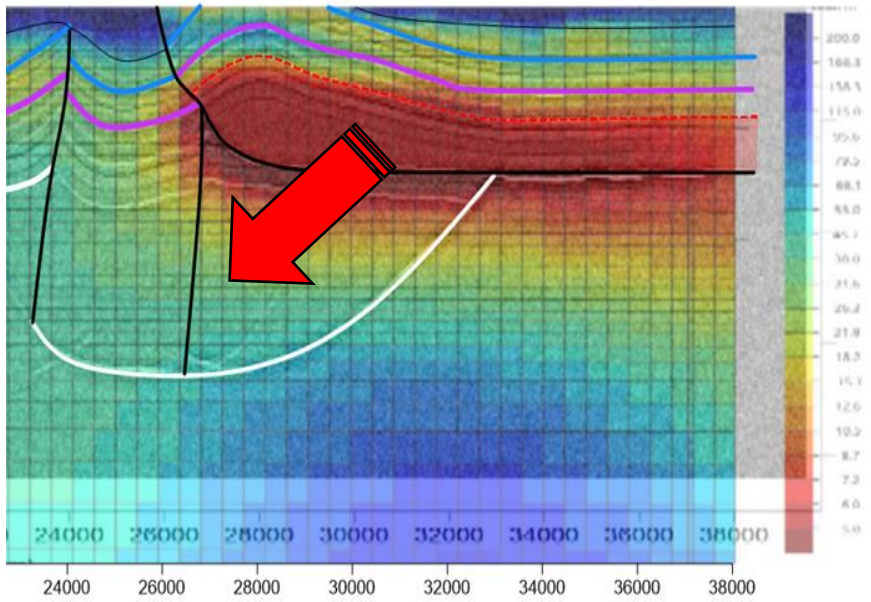


Despite the large-but-realistic noise, gravimetry was useful to **identify large scale structures**

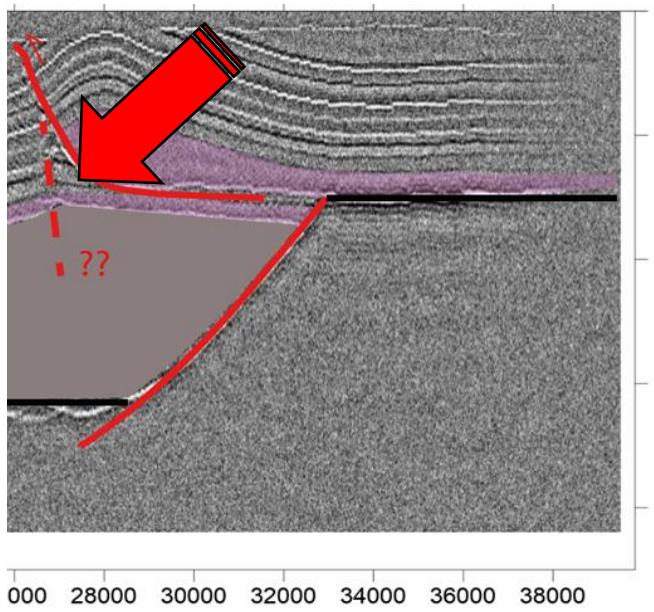
Some tendencies for **over-interpretation of small-scale structures** (<1km) that are purely related to noise

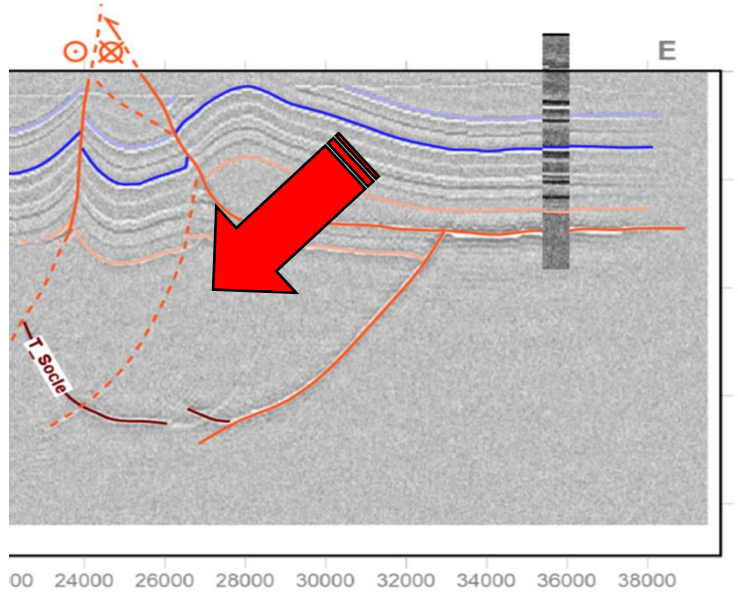
Uncertainty on the fault dip angle ~15-20°

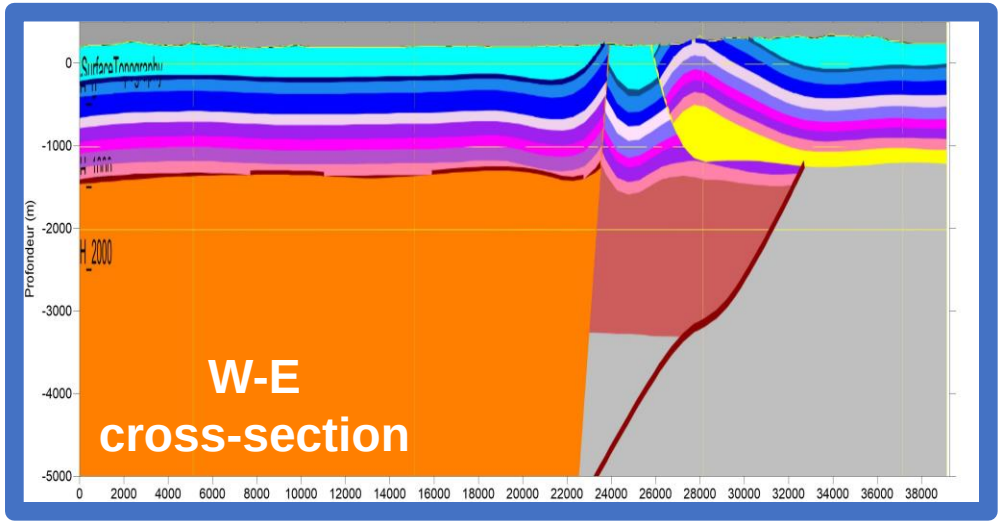
1. data imperfection: noise



Truth







Some tendencies for over-interpretation of noise-related artefacts in seismic

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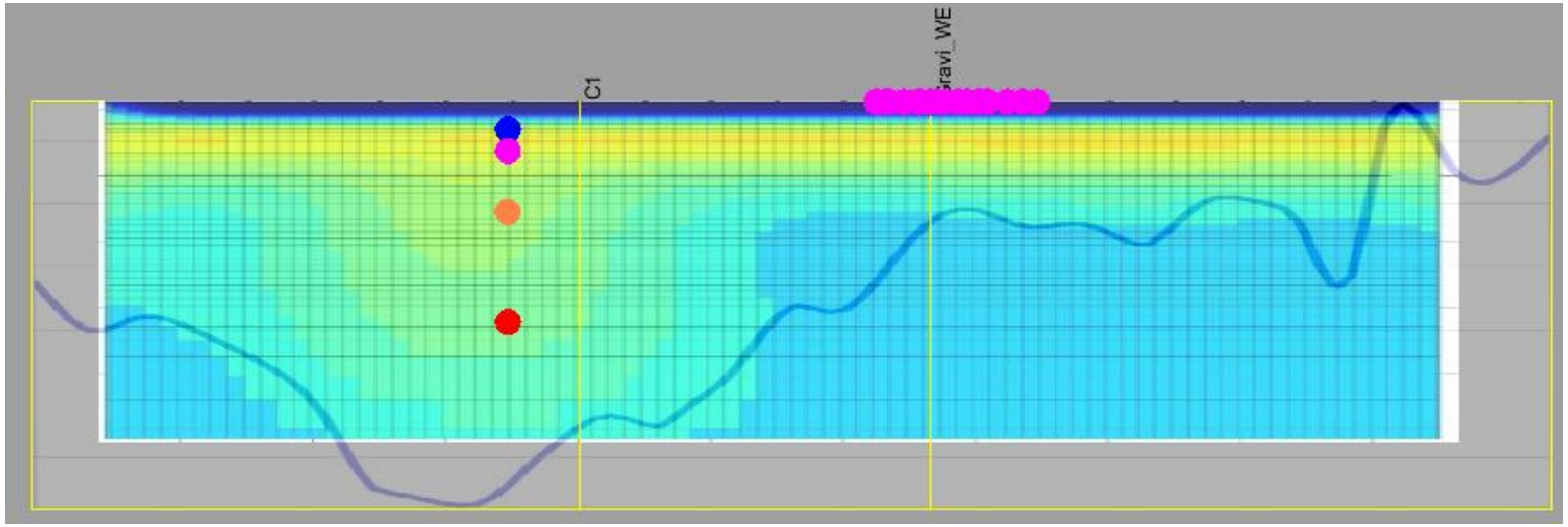
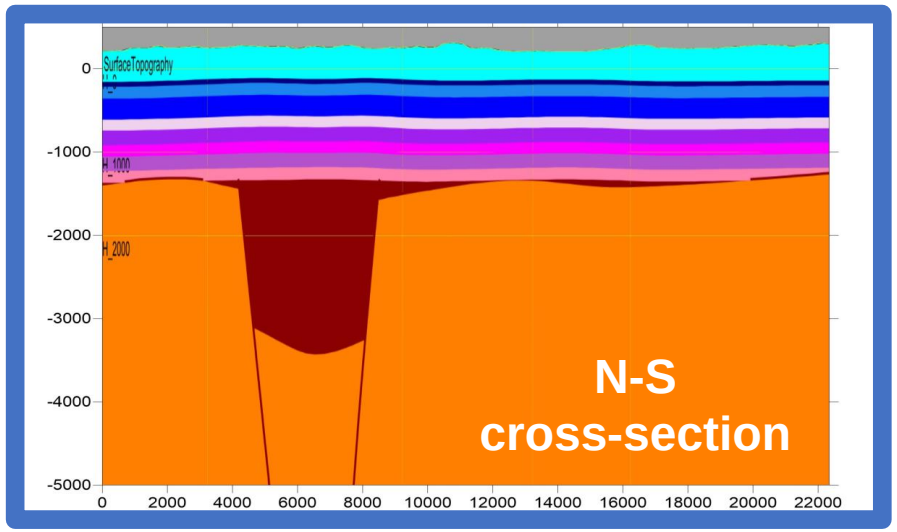
1. data imperfection: resolution

MT was not corrupted with noise

By nature MT provides a ‘diffuse’ vision



Truth



When **combined with gravimetry**, the ‘diffuse’ imaging is alleviated and some hypotheses can be formulated

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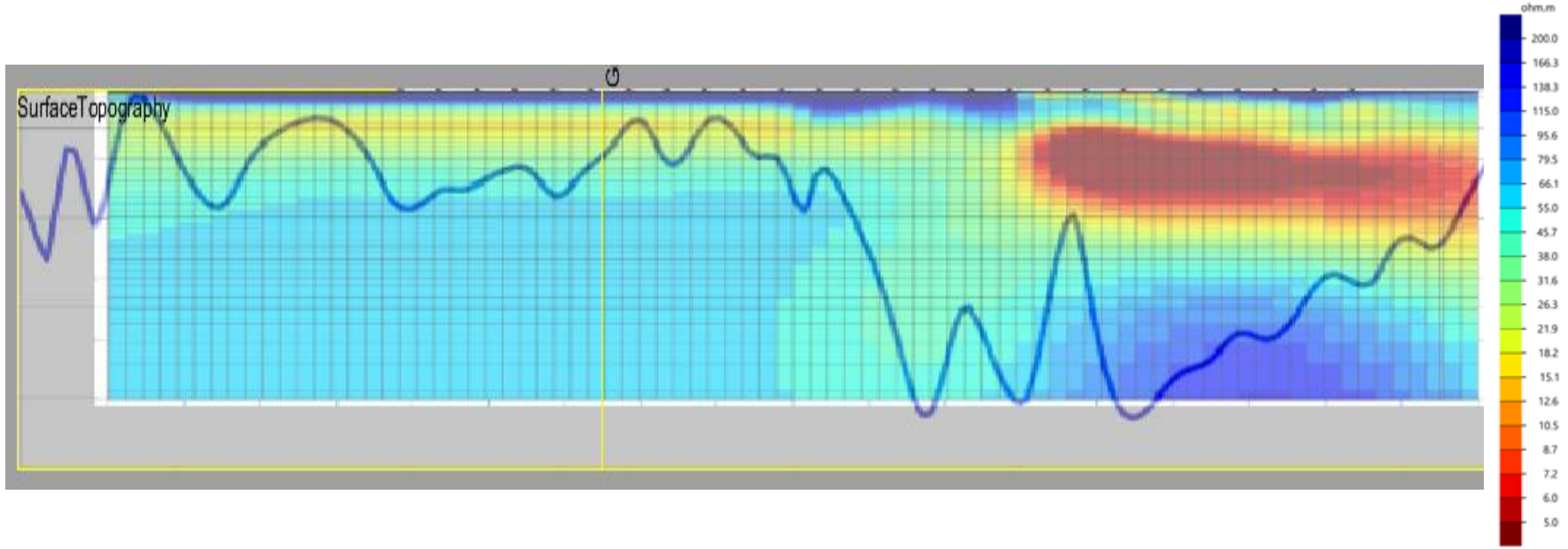
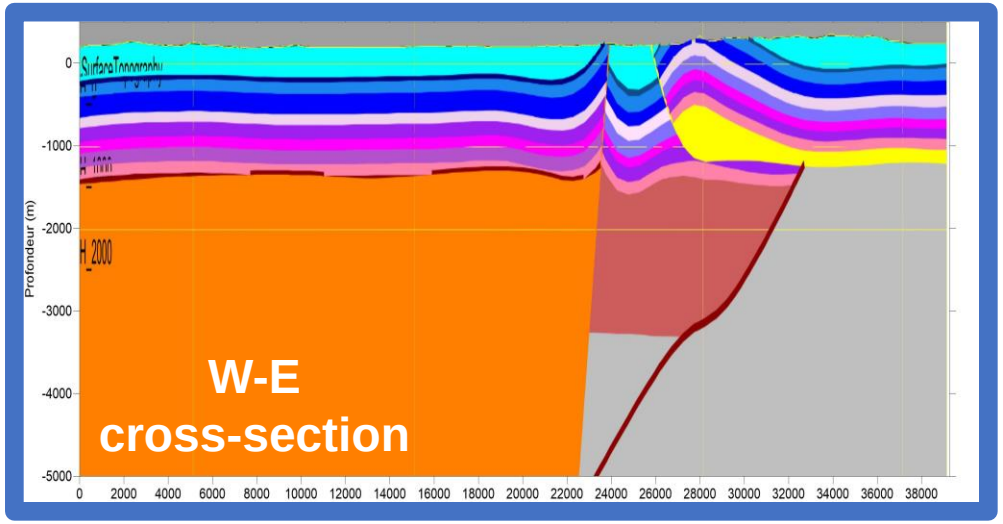


Truth



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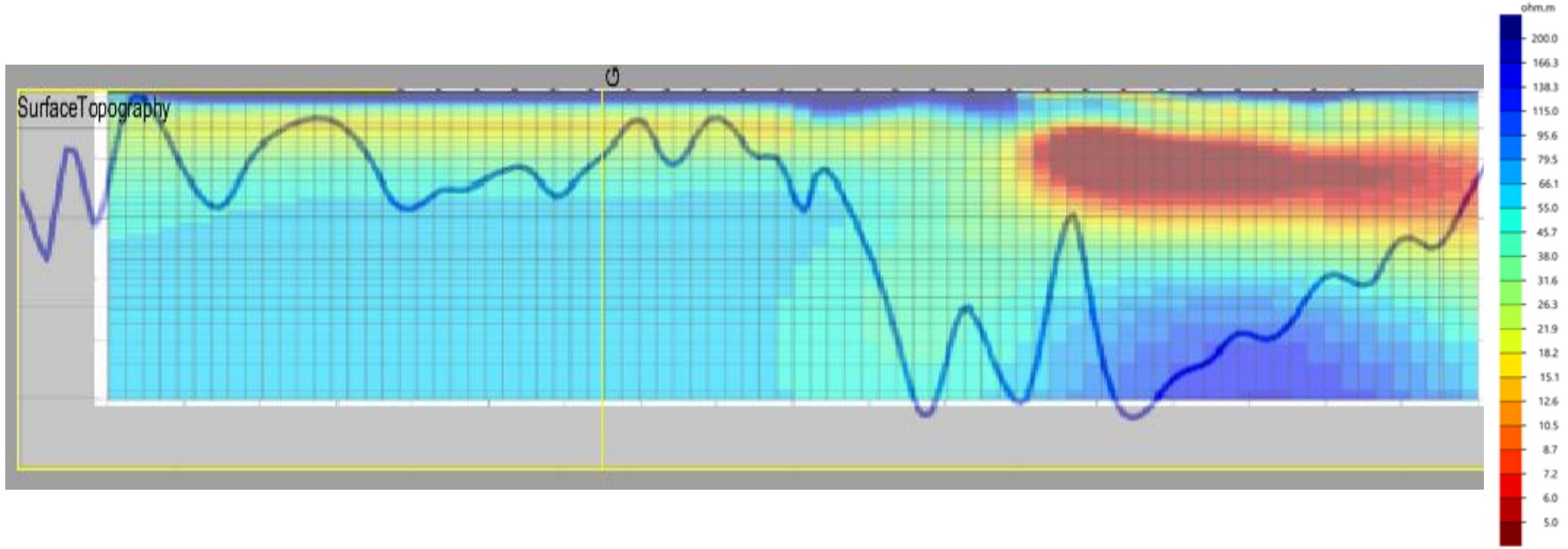
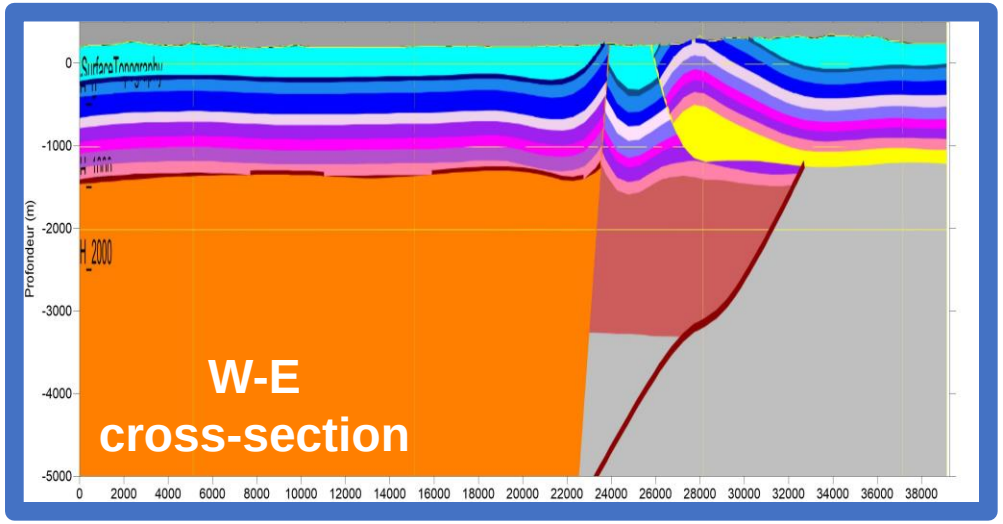
2. representation format: colorscale

MT was not corrupted with noise

By nature MT provides a ‘diffuse’ vision



Truth

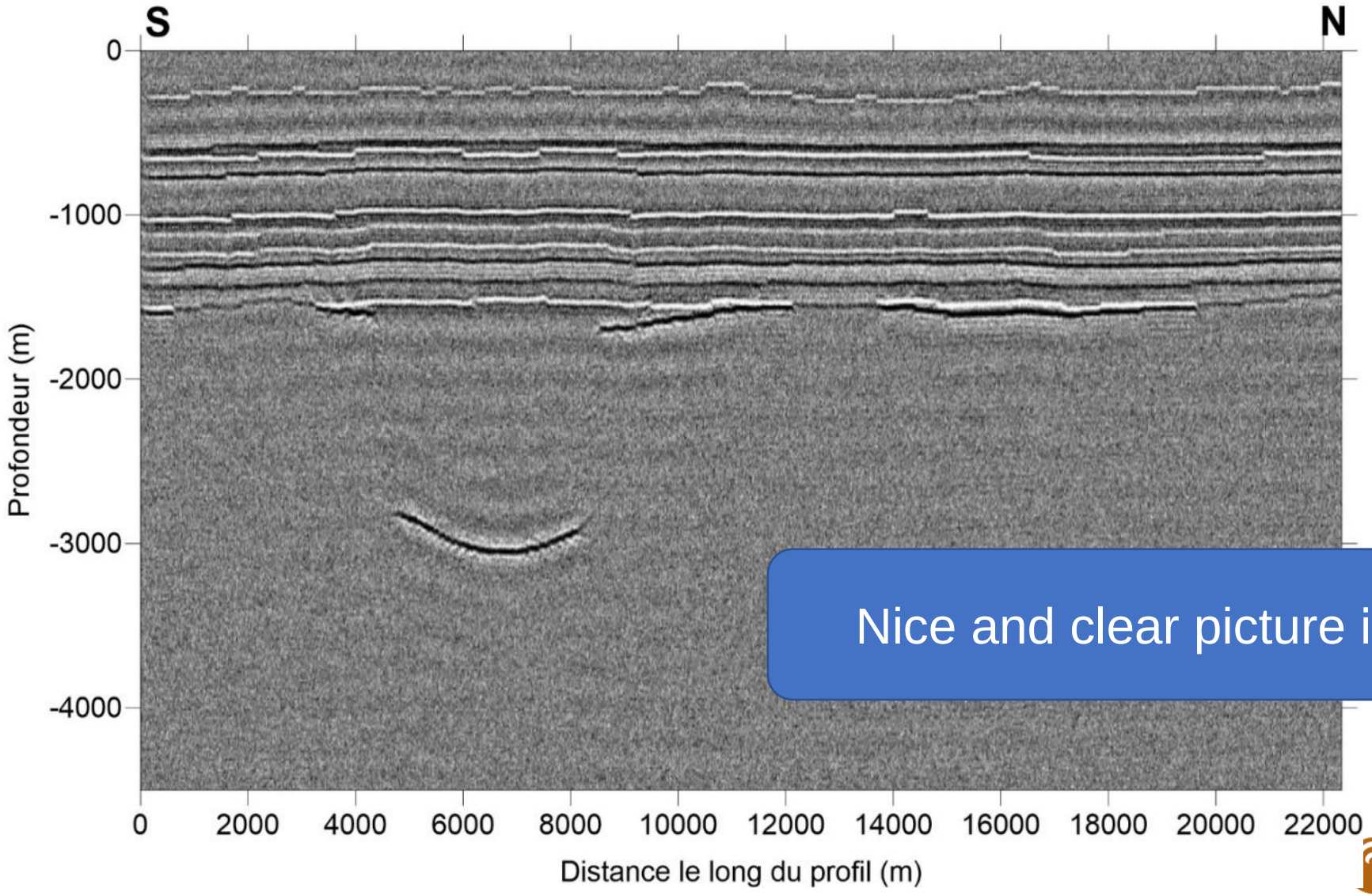


But made difficult by the choice of the **colorscale…**

=‘dark-is-more’ effect (Robinson et al. 1984)

Géosciences pour une Terre durable
brgm

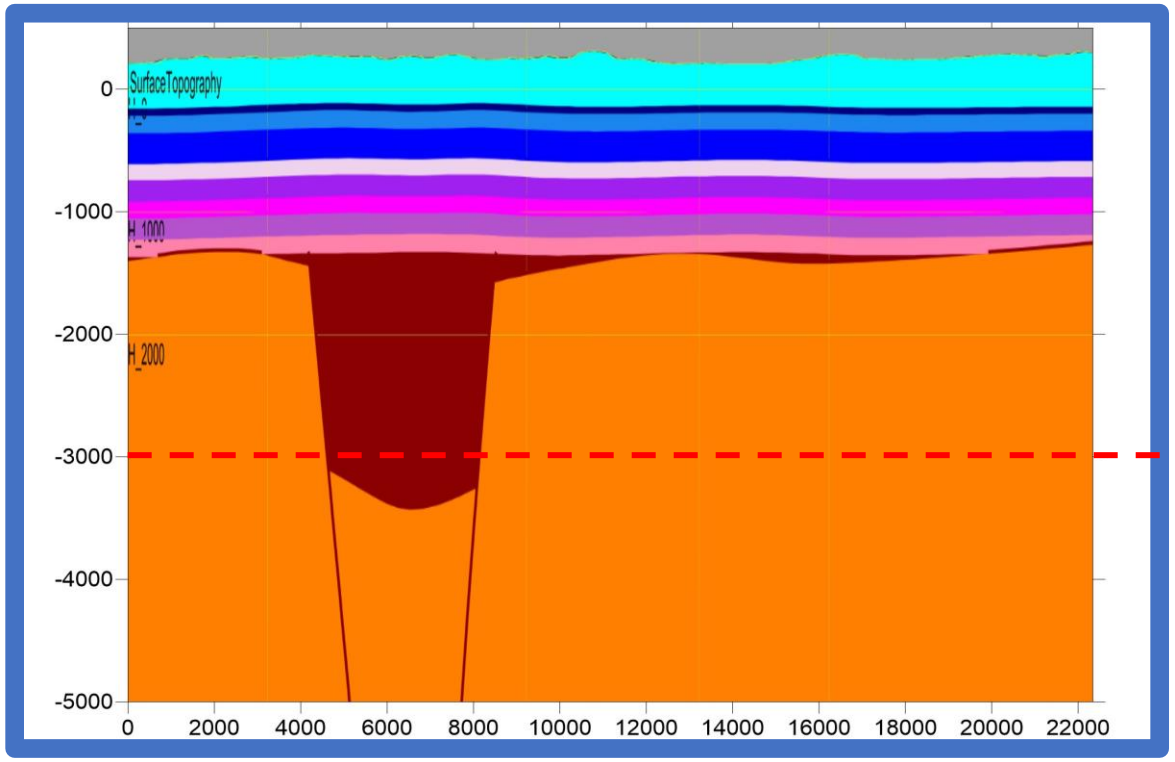
3. human-related difficulty

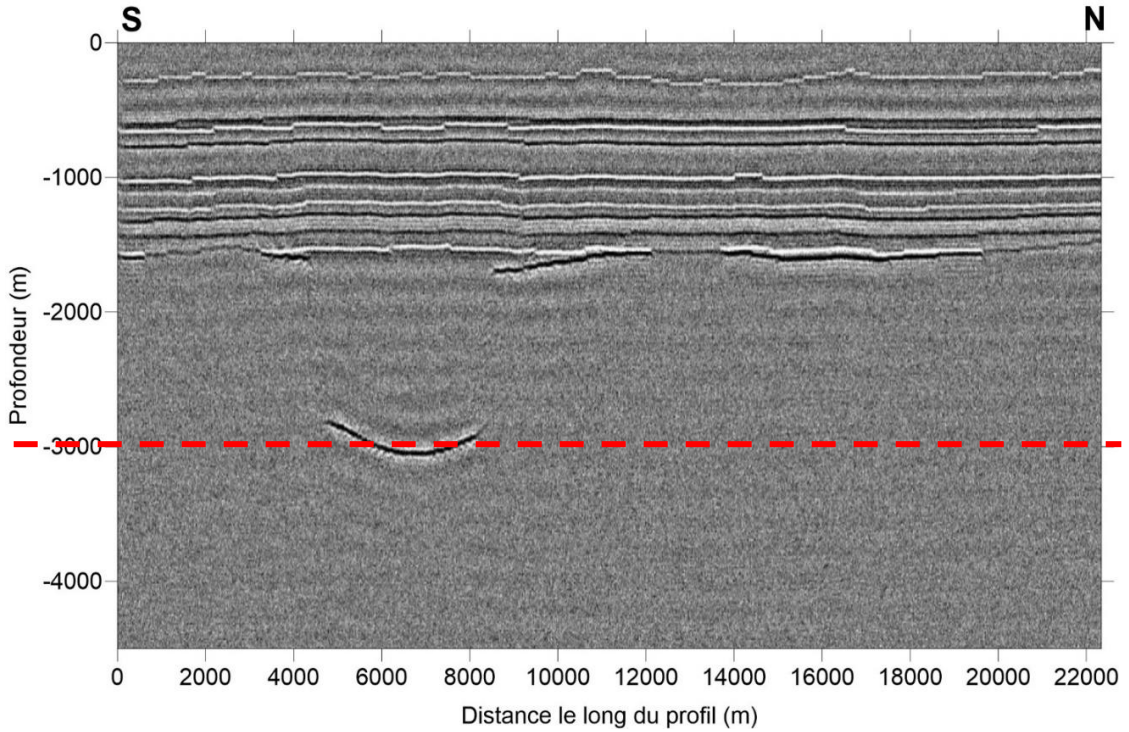


Nice and clear picture isn’t it?

3. human-related difficulty: misleading precision

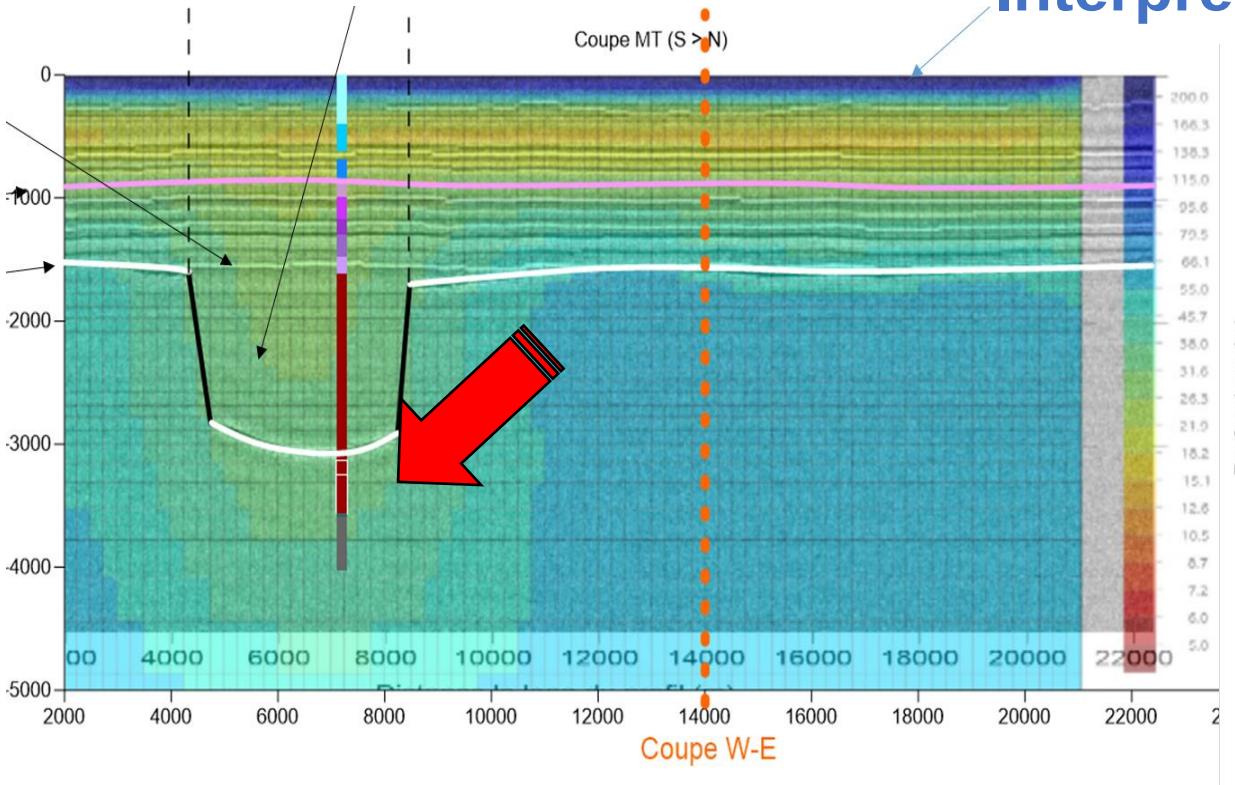
Truth

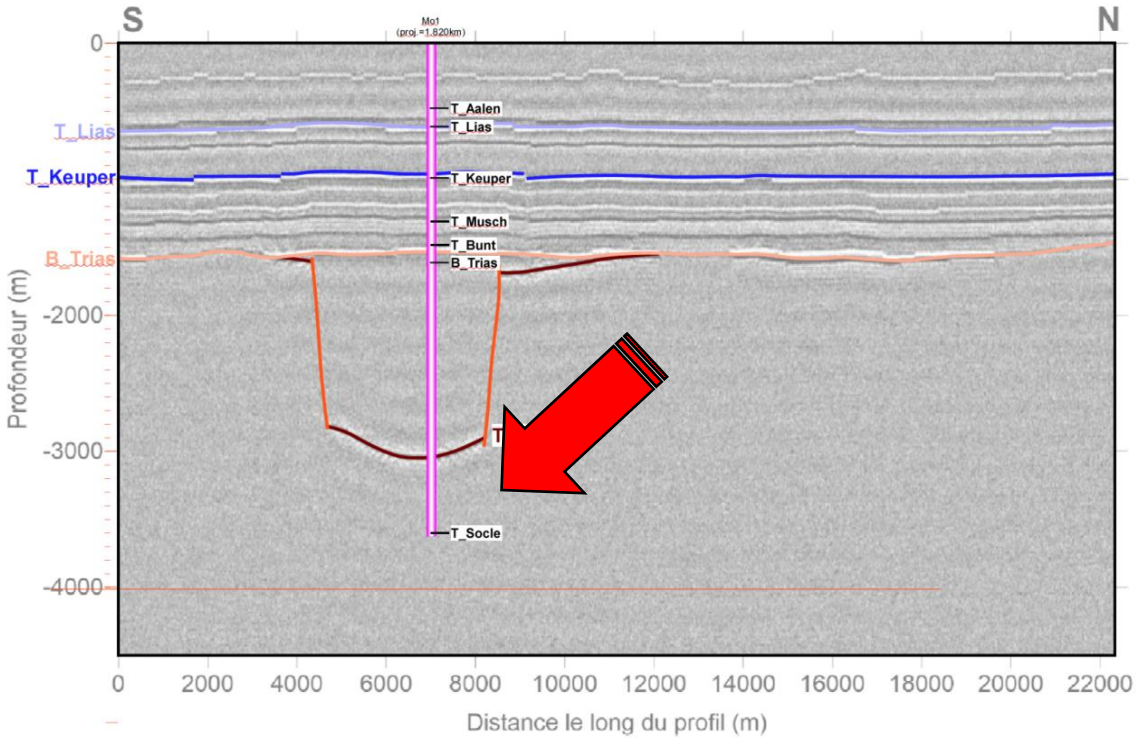




3. human-related difficulty: misleading precision

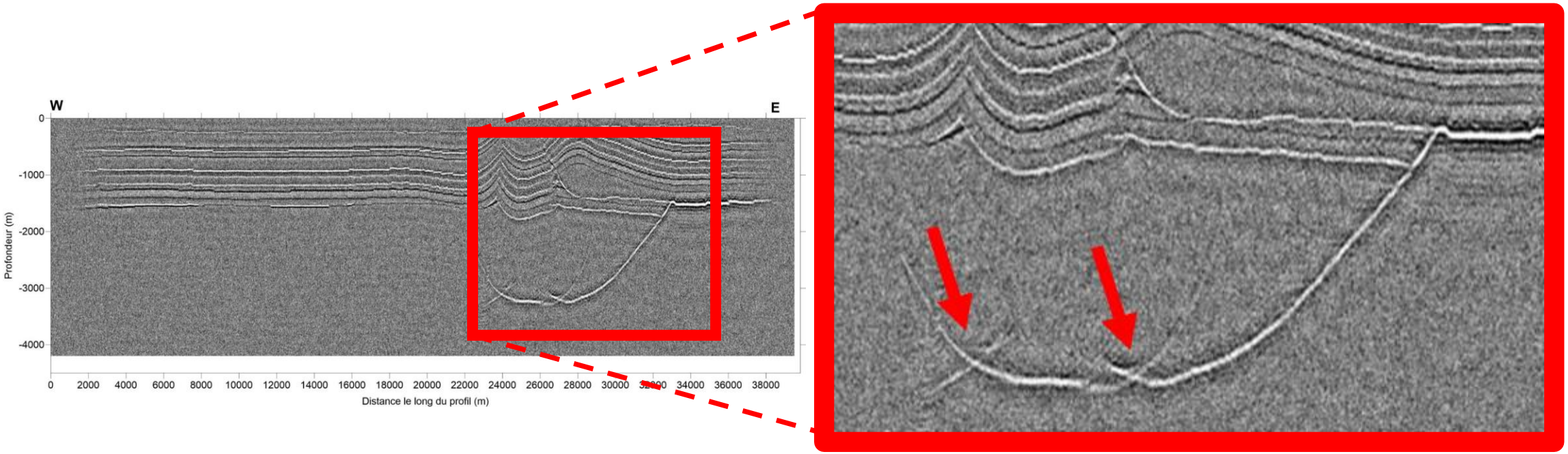
Interpretations





A clear discrepancy betw. borehole and seismic was minimised…

3. human-related difficulty: misleading precision



… although artefacts in W-E cross sections should have indicated **mis-specifications** in the time-to-depth conversion

Summary

(q1) Is it possible to detect and characterize structural traps and potential migration pathways at several kilometers depth?

The blind exercise gives **confidence** in the ability of the interpreters to **formulate hypotheses to support discussions on further characterization campaigns**

Despite:

- **The 3D effect:** cross sections not necessarily orthogonal to the structures
- **The differences in practices** and tools of each team of interpreters
- **The cascade of different types of error** (noise, #borehole, resolution)

Summary

(q2) Do the errors associated with each of the different datasets influence / affect / bias the geological interpretation? If so, how?

- Despite the noise in gravimetry, the interpretation of moderate-large scale structures was possible
- Despite the ‘diffuse’ nature of MT, hypotheses could be formulated when combined with other sources of data

Summary

(q2) Do the errors associated with each of the different datasets influence / affect / bias the geological interpretation? If so, how?

!CAUTION!

- Seismic was perceived as the **'perfect' dataset** although some artefacts were present
- Being able to question his/her first guess is not straightforward = linked to **'anchoring' bias [1,2]**
- Forstering **exchanges betw. interpreters and data providers = key**

[1] Bond (2015); [2] Alcalde et al. (2019)

Thank you for your attention!

We acknowledge financial funding by ANR-HOUSES
(grant number: **ANR-22-CE56-0006**)
https://anrhouses.github.io/
As well as the BRGM funded research project PEX ‘incertitudes’