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Vadose zone water content characterization of a heterogeneous limestone by 3D-SNMR

Clémence Ryckebusch, J-M. Baltassat, A. Legchenko, P. Kessouri, N. Amraoui, J. Deparis, M. Abbas, M. Azaroual

Contact : c.ryckebusch@brgm.fr

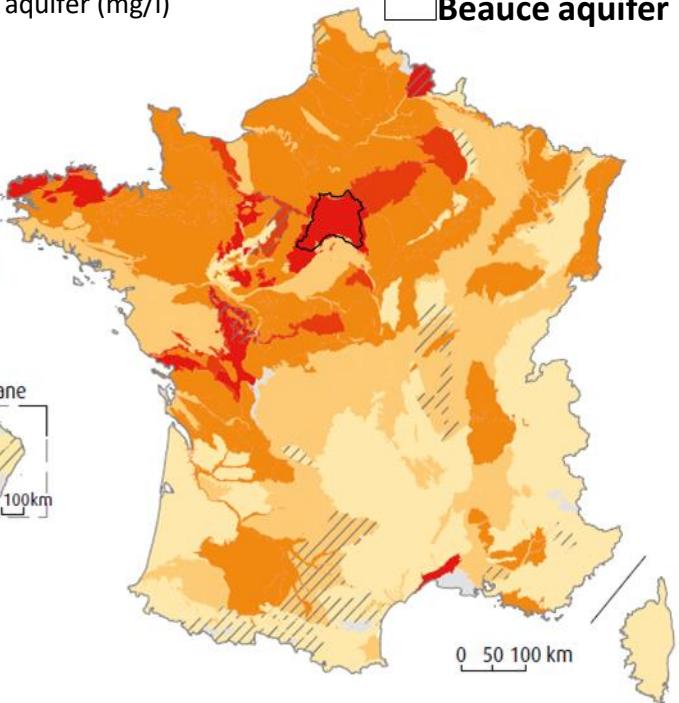
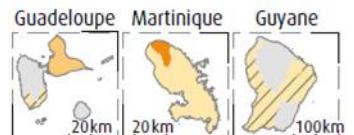
Context of the study

Map of nitrate mean concentration in aquifers, 2011 (Database : ADES)

Mean in 2011 for an aquifer (mg/l)

Beauce aquifer

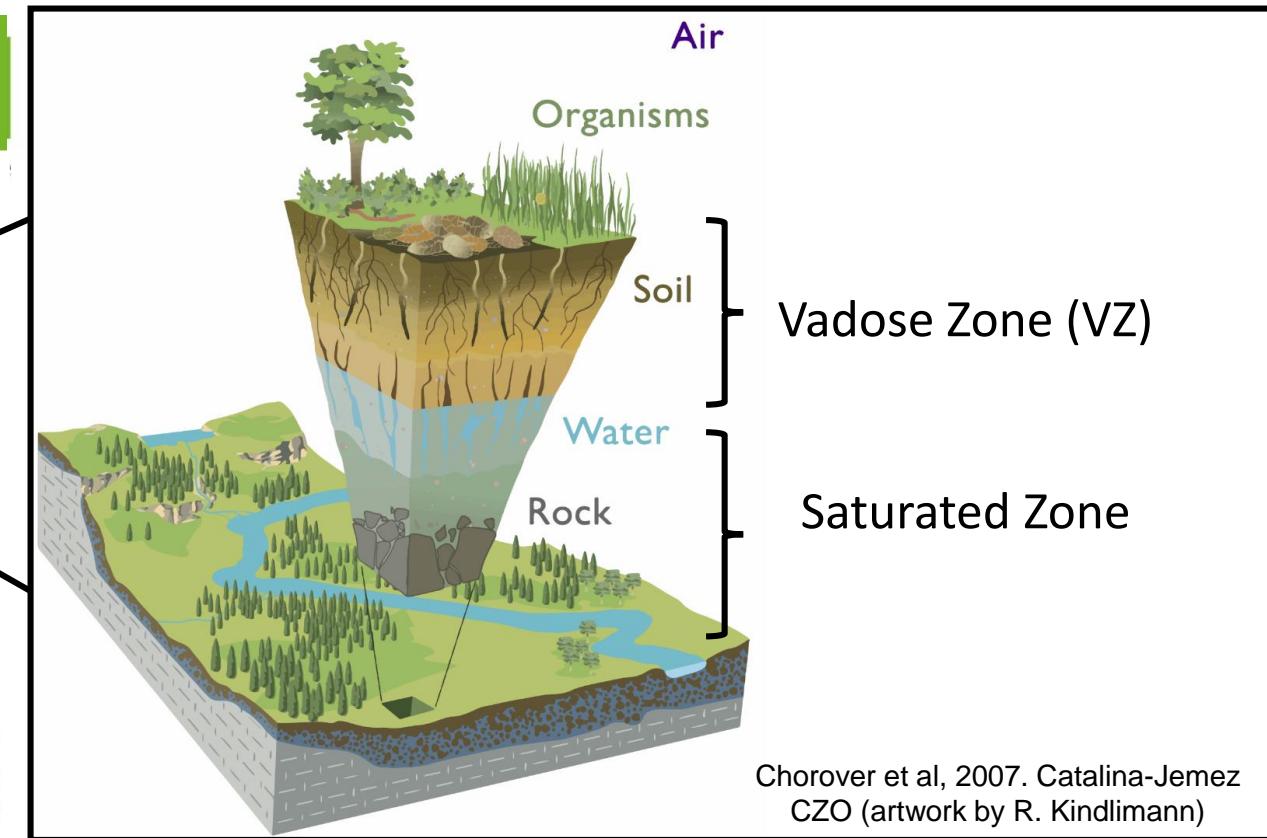
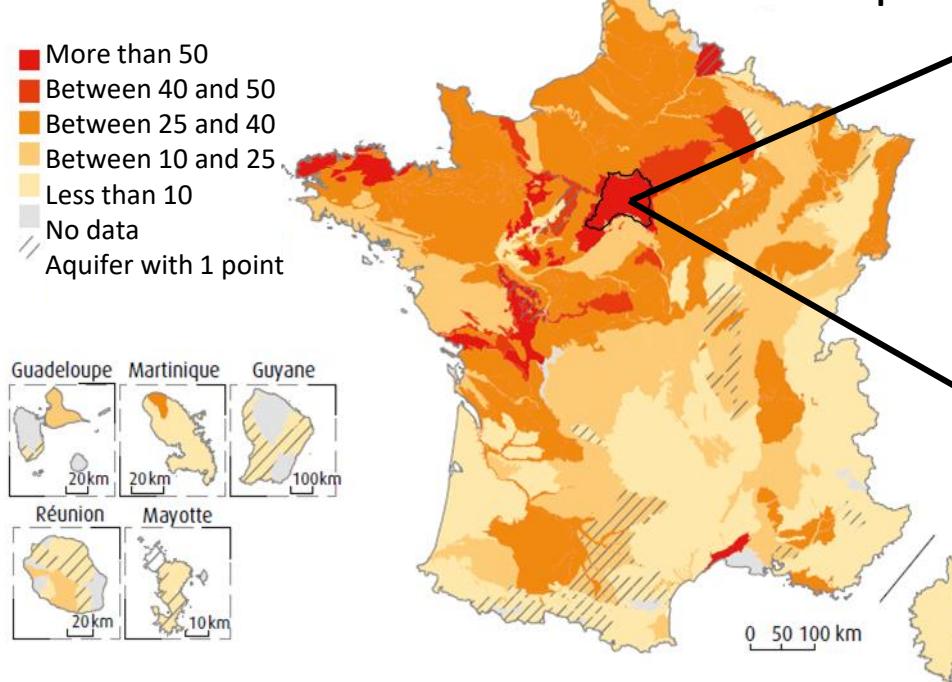
- More than 50
- Between 40 and 50
- Between 25 and 40
- Between 10 and 25
- Less than 10
- No data
- Aquifer with 1 point



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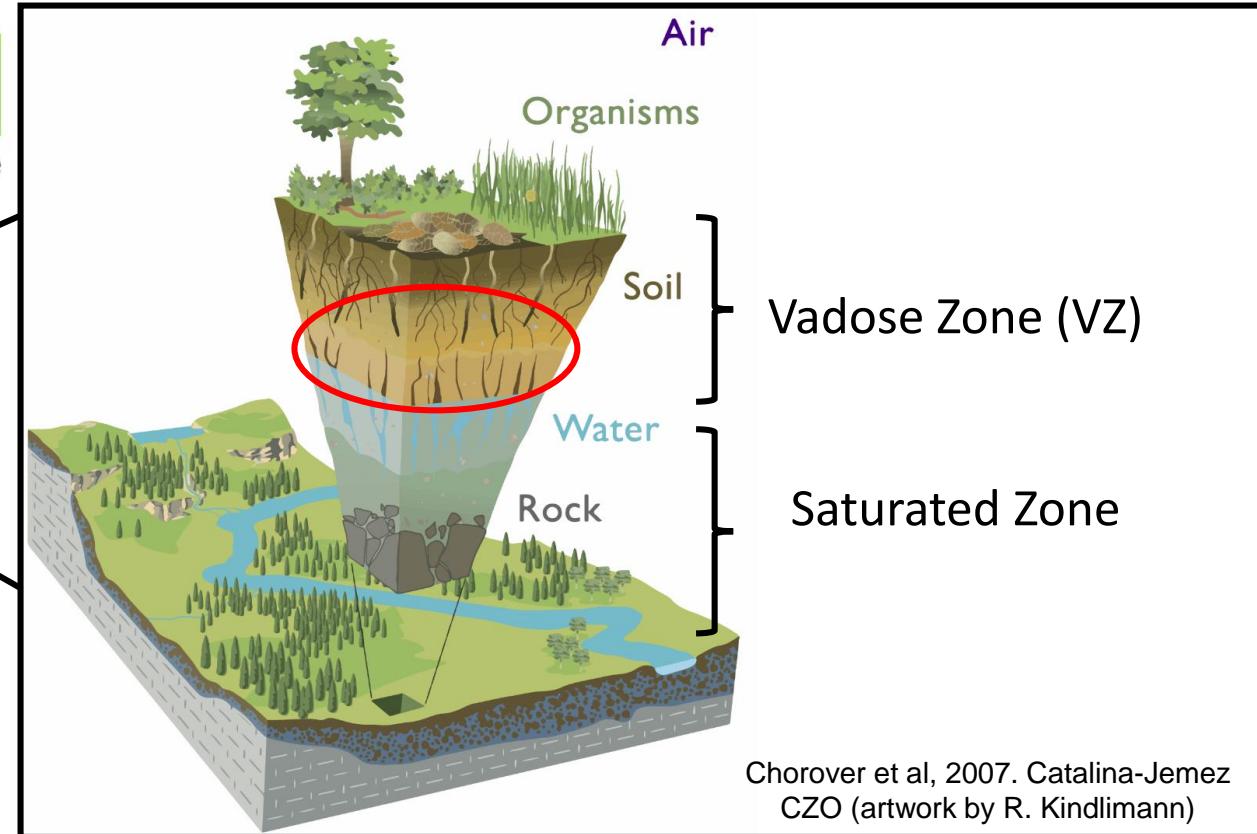
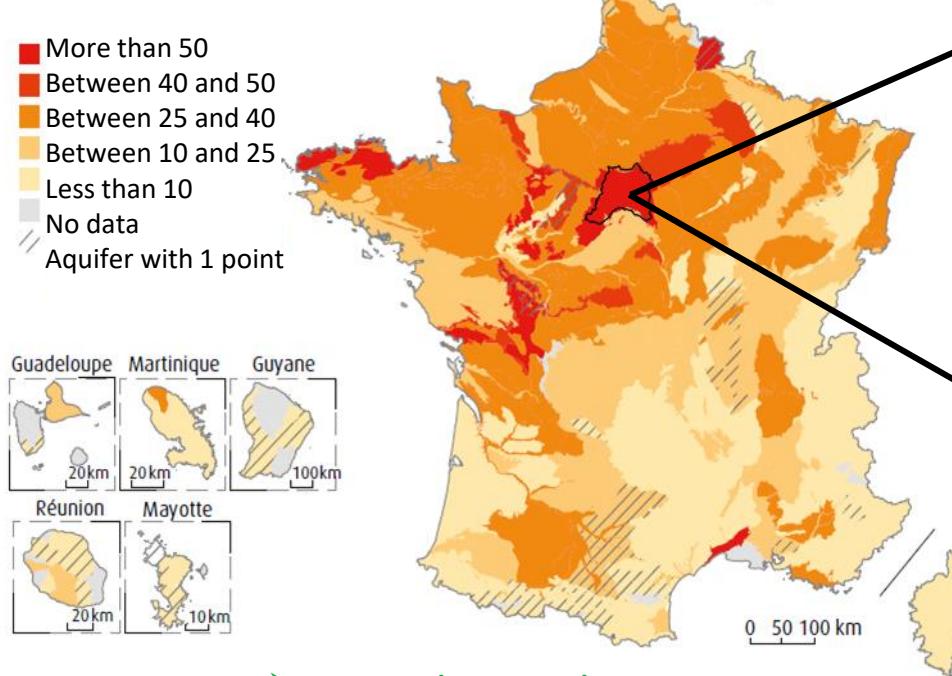
Mean in 2011 for an aquifer (mg/l)



Context of the study

Map of nitrate mean concentration in aquifers, 2011 (Database : ADES)

Mean in 2011 for an aquifer (mg/l)



Problem

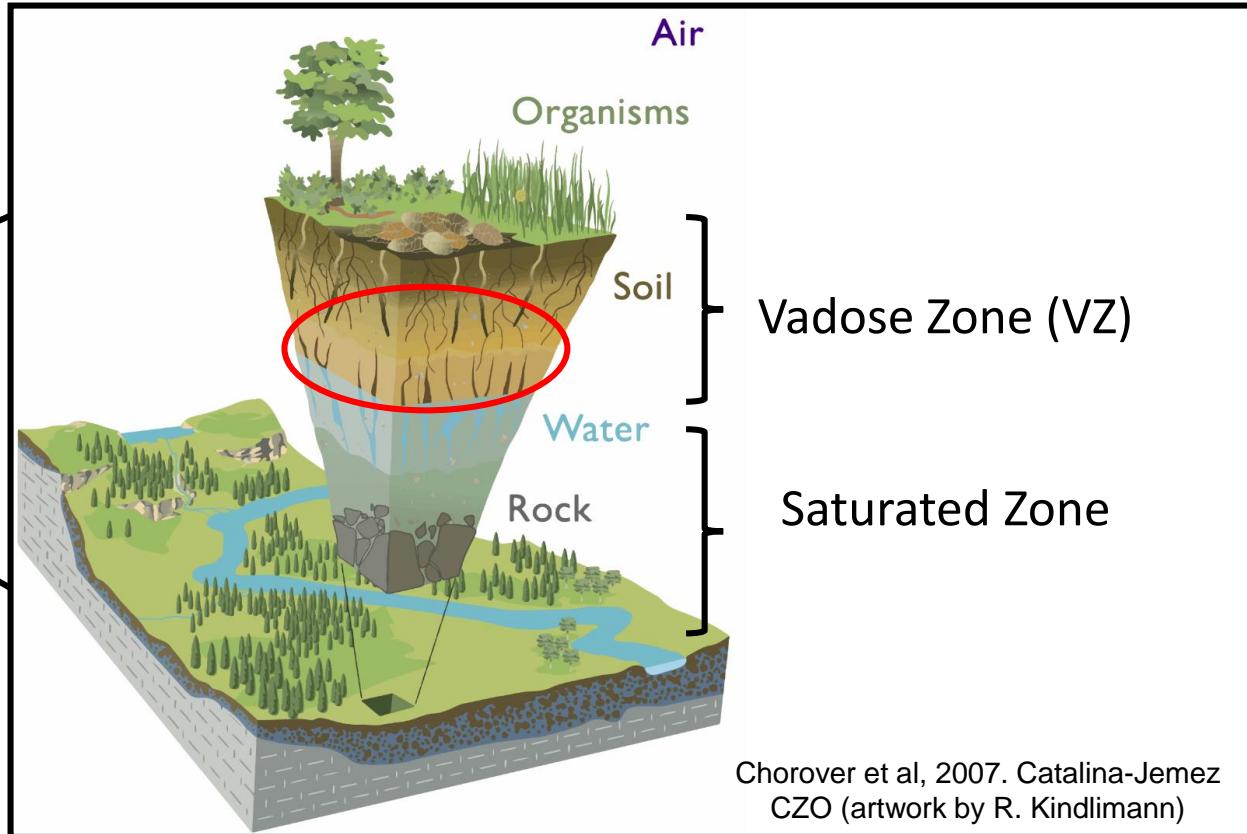
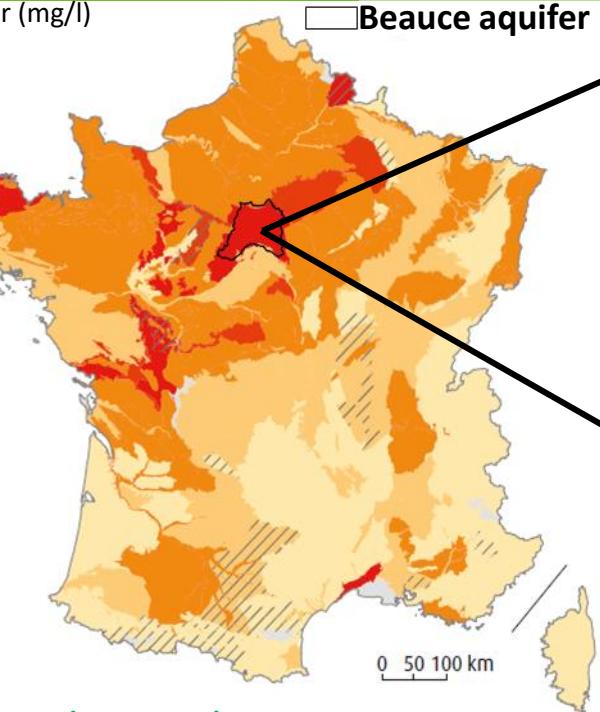
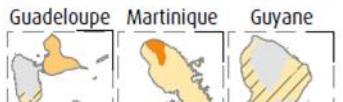
- Sampling and instrumentation to study the deep vadose zone
- Heterogeneity and complex behavior in vadose zone

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- Sampling and instrumentation to study the deep vadose zone
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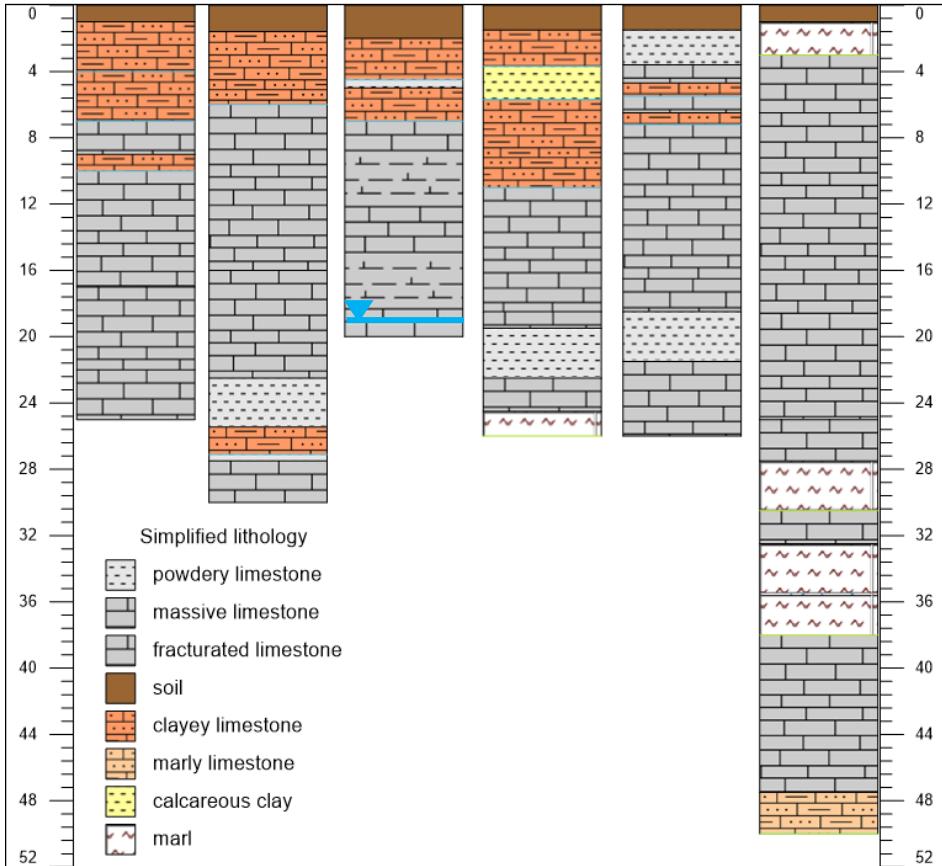
Objective

- ***Thesis :*** Improve the vadose zone flow characterization and modeling by coupling Surface Nuclear Magnetic Resonance (SNMR) monitoring and hydrogeological modeling
- ***This study :*** Characterize the water content spatial heterogeneities in 3D VZ and 3D aquifer with a joint interpretation of 3D-SNMR and 3D electrical data

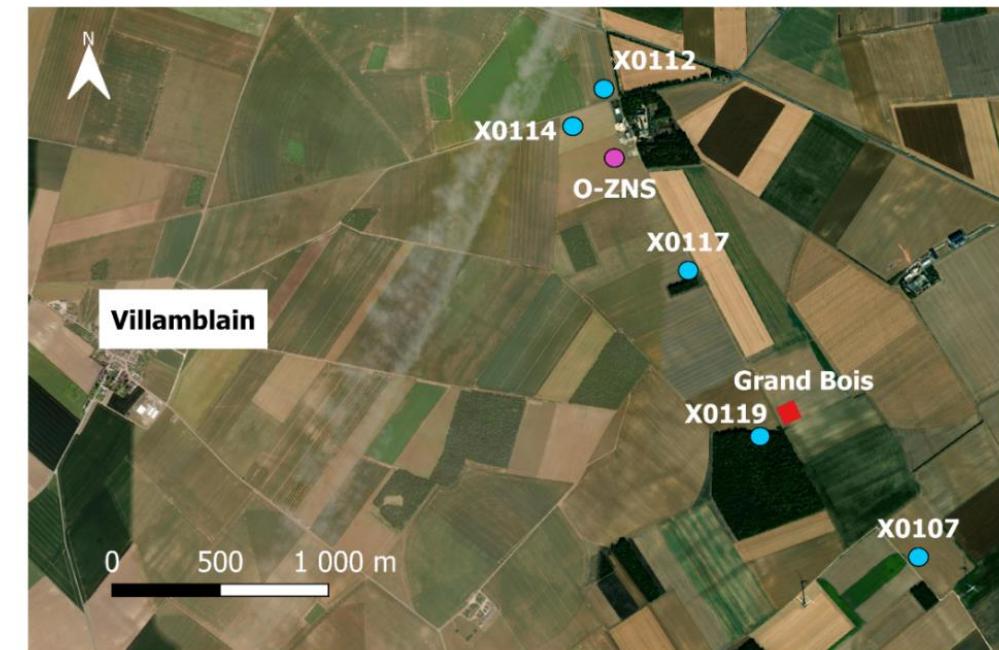
Study site

BSS and OZNS soundings

X0114 X0112 OZNS sounding X0117 X0119 X0107



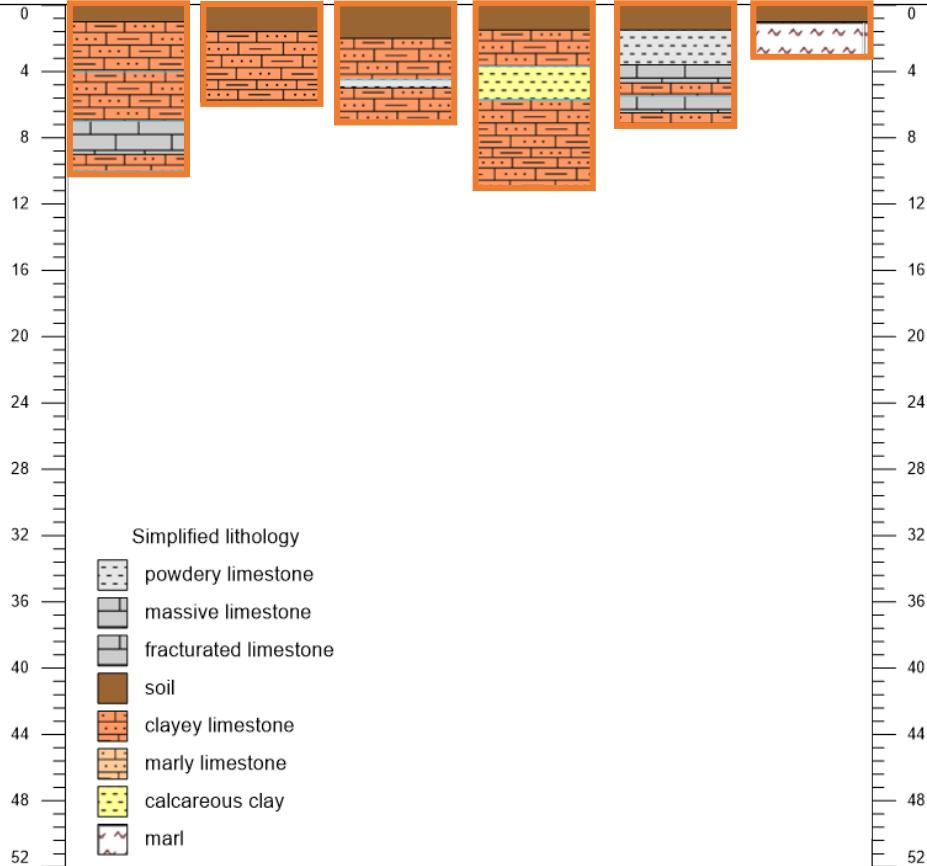
Villamblain study sites and BSS soundings (ID X01--)



Study site

BSS and OZNS soundings

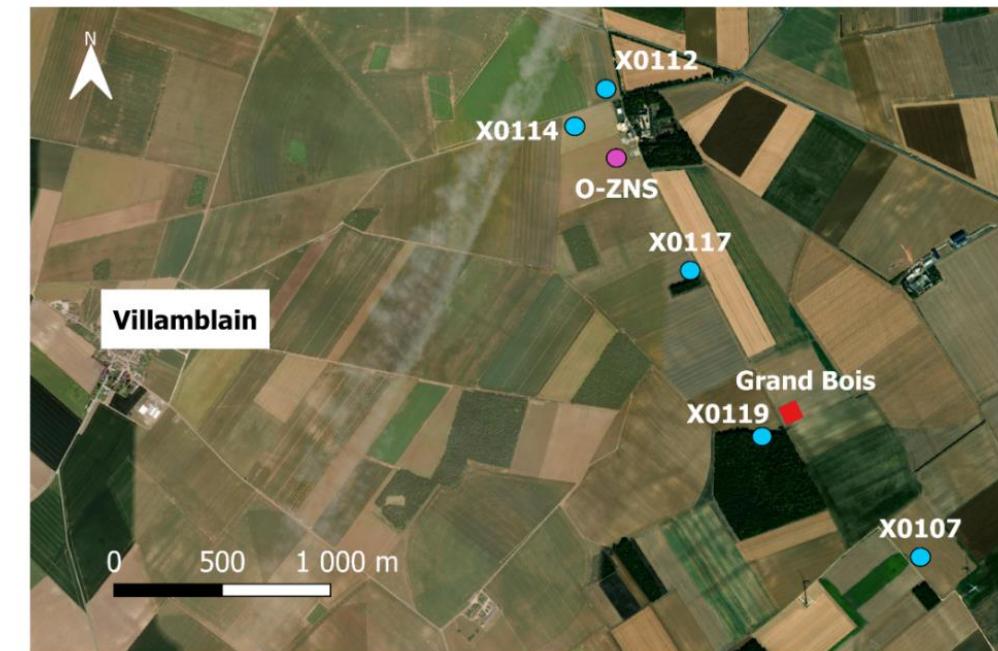
X0114 X0112 OZNS sounding X0117 X0119 X0107



Simplified
geology

Highly weathered
limestone

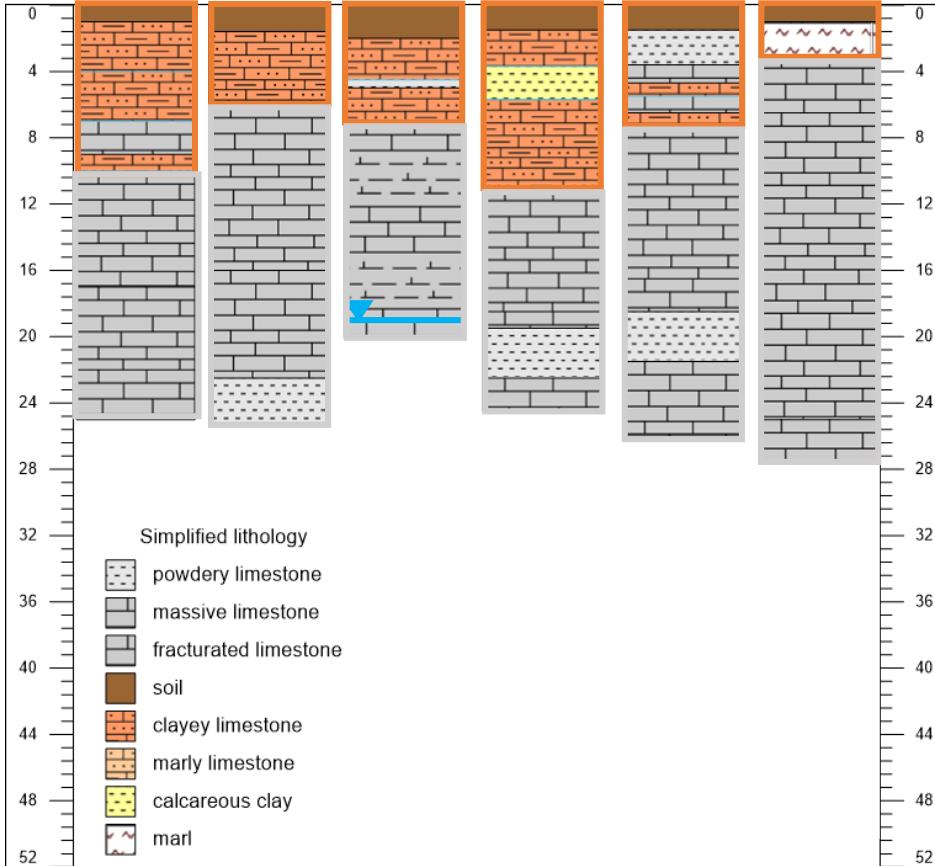
Villamblain study sites and BSS soundings (ID X01--)



Study site

BSS and OZNS soundings

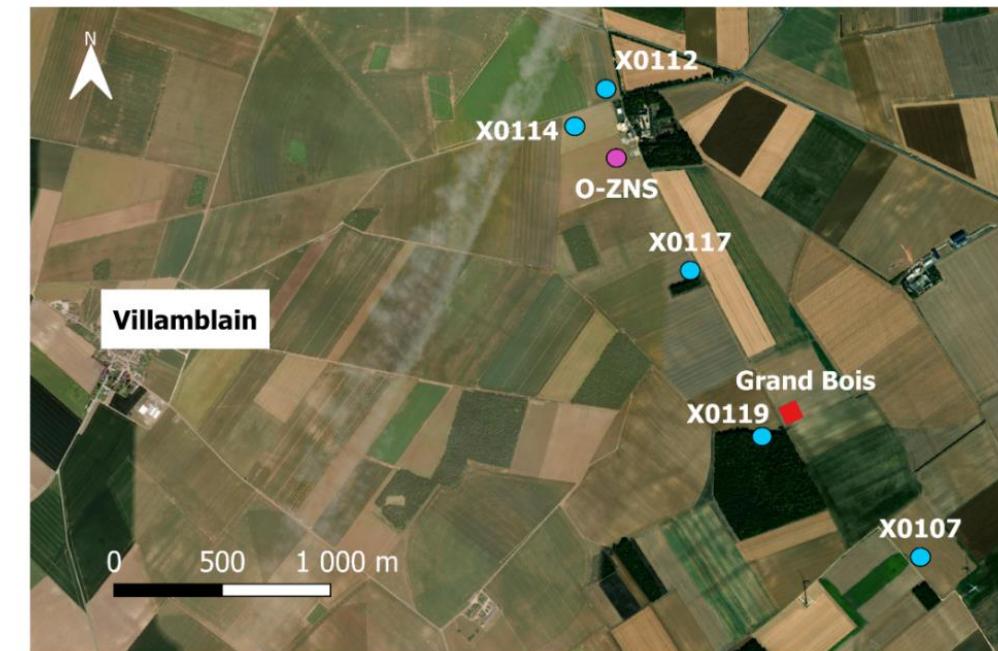
X0114 X0112 OZNS sounding X0117 X0119 X0107



Simplified geology

Highly weathered limestone
Upper fractured limestone (Pithiviers)

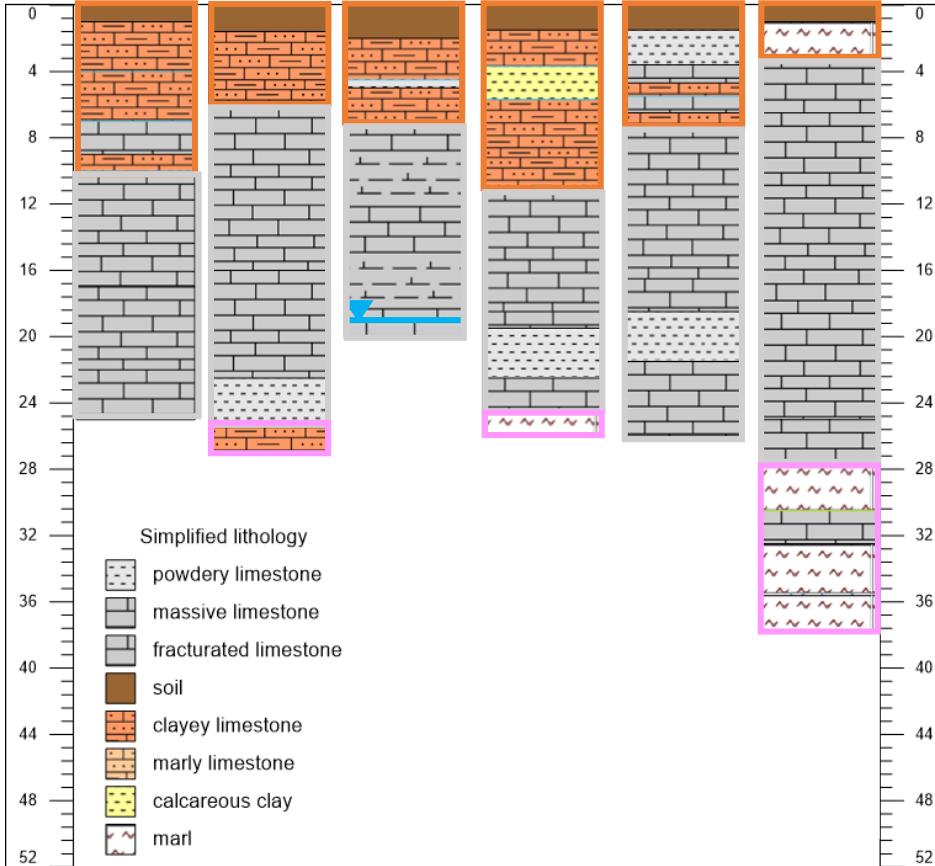
Villamblain study sites and BSS soundings (ID X01--)



Study site

BSS and OZNS soundings

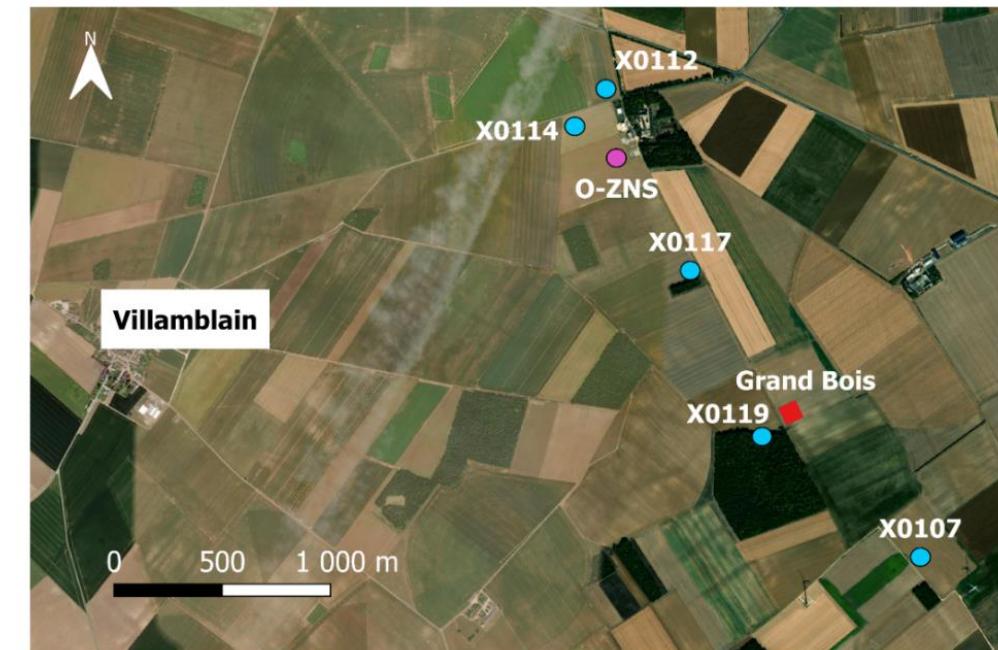
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Simplified geology



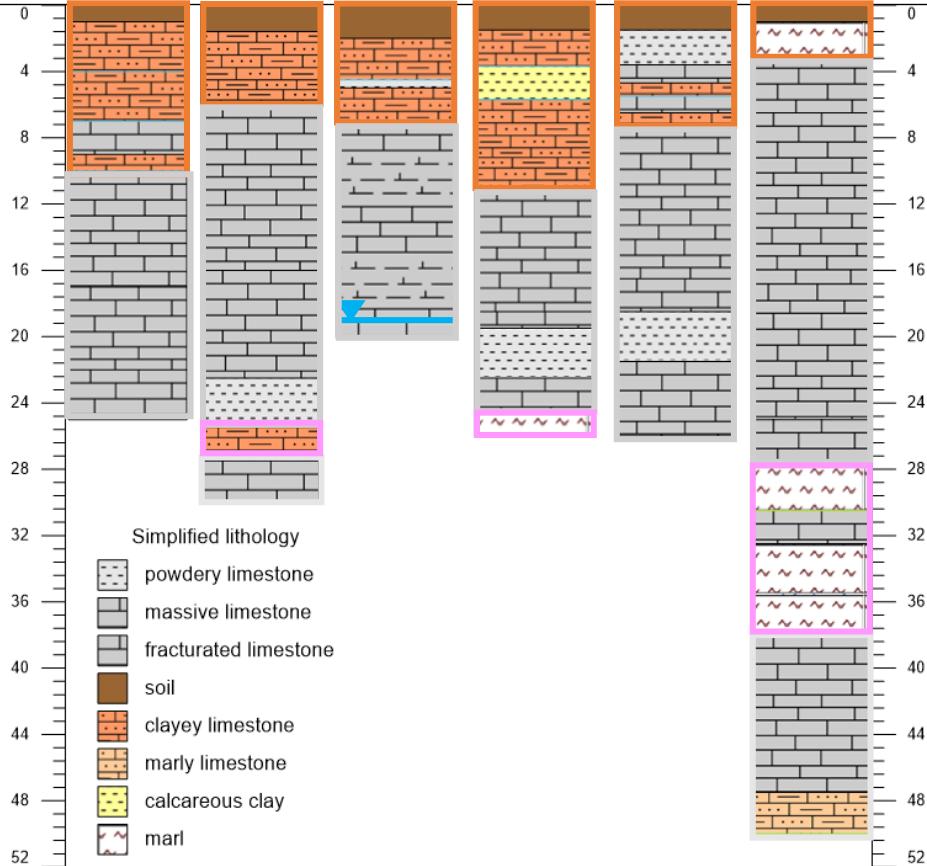
Villamblain study sites and BSS soundings (ID X01--)



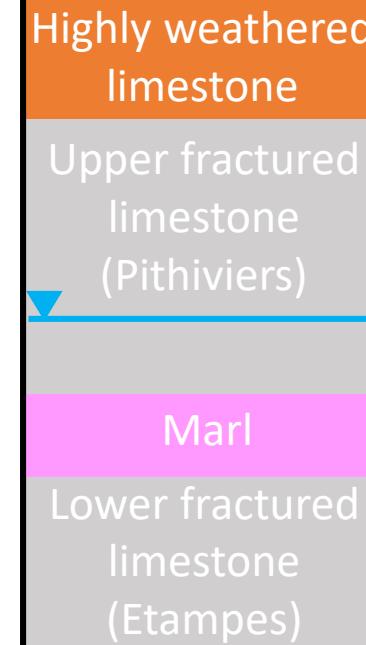
Study site

BSS and OZNS soundings

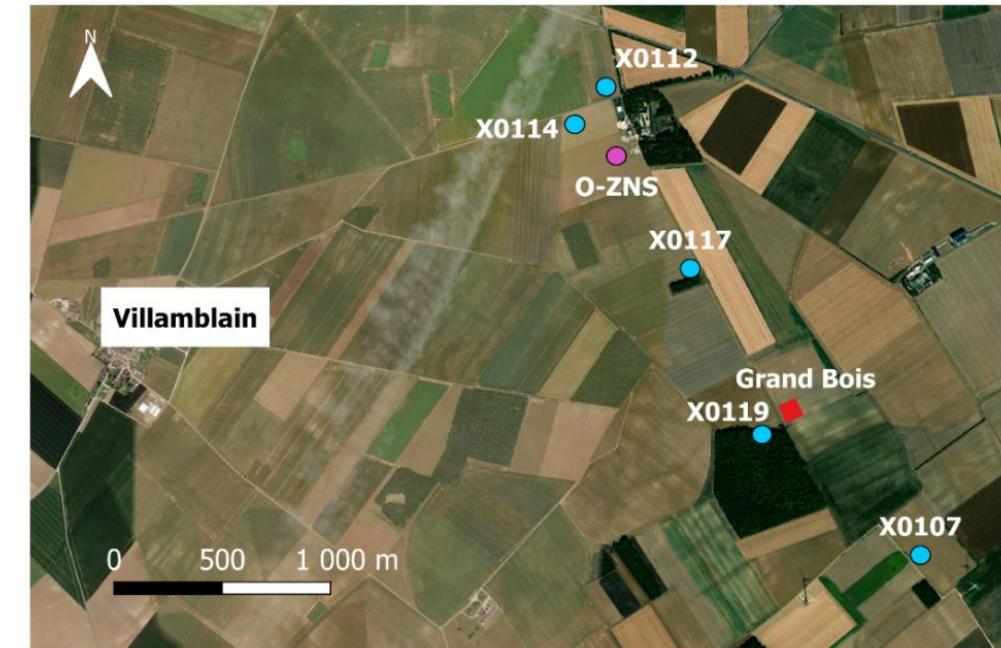
X0114 X0112 OZNS sounding X0117 X0119 X0107



Simplified geology



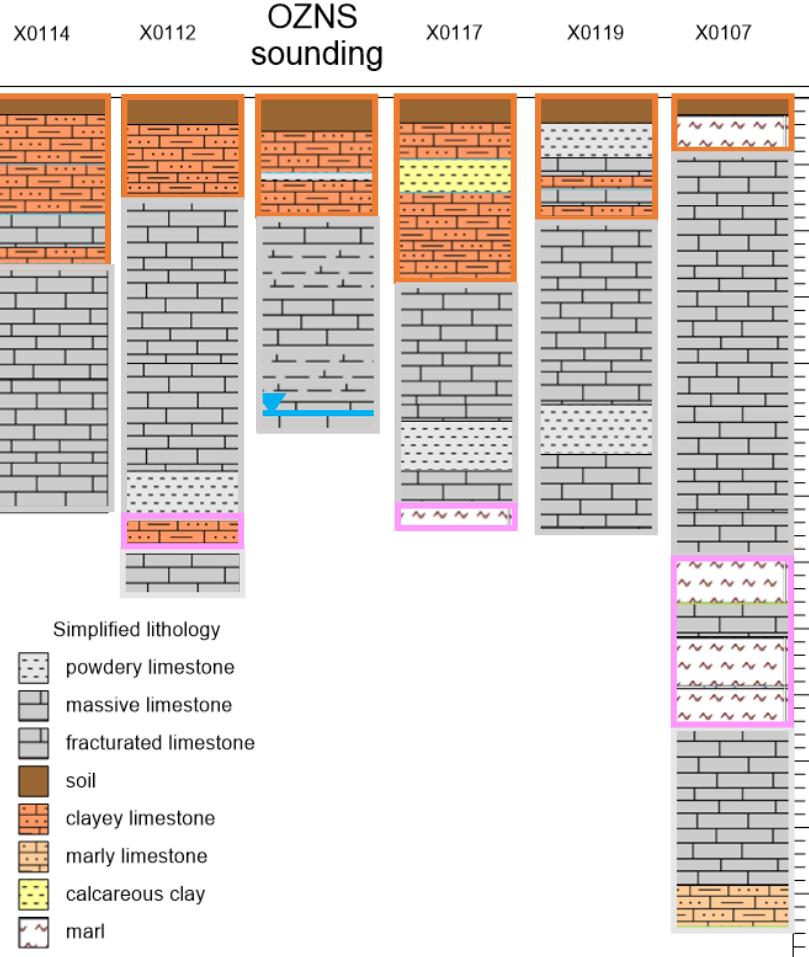
Villamblain study sites and BSS soundings (ID X01--)



➤ Weathered and highly heterogeneous limestone in VZ

Study site

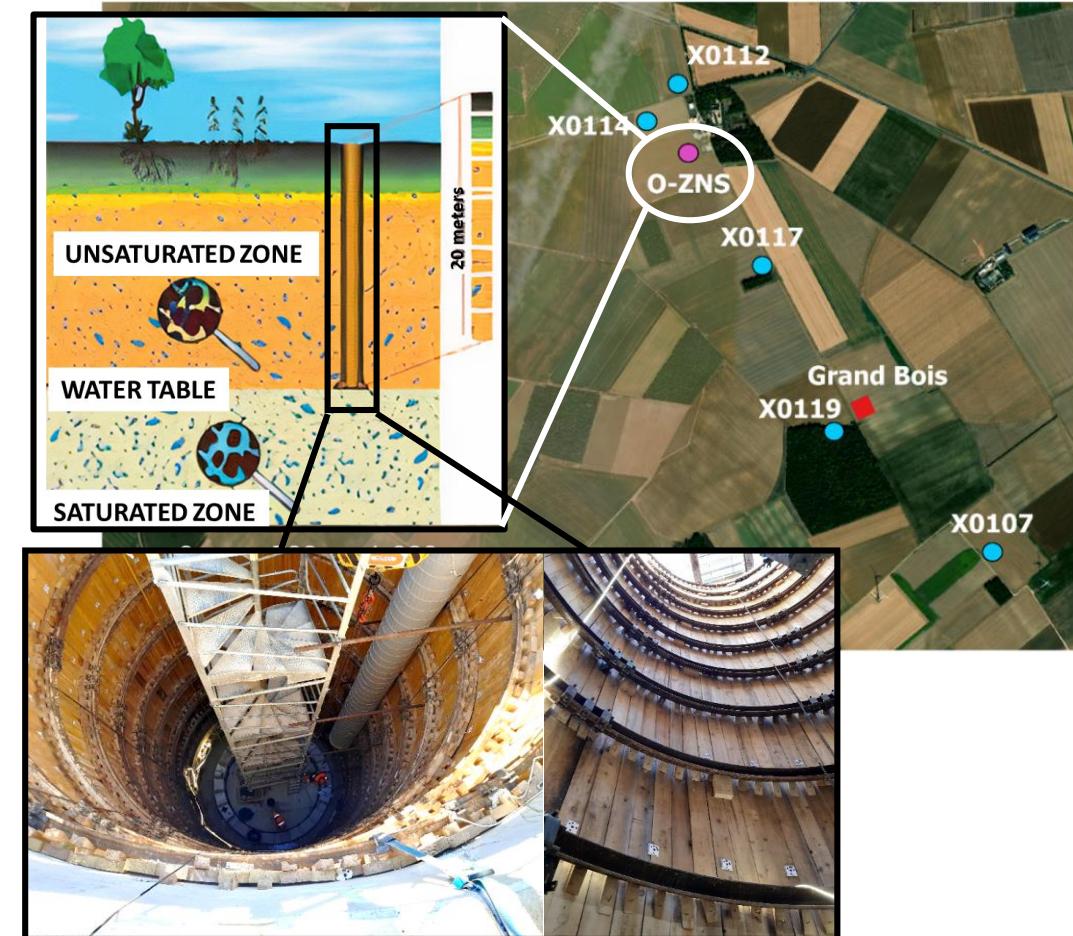
BSS and OZNS soundings



Simplified geology

Highly weathered limestone
Upper fractured limestone (Pithiviers)
Marl
Lower fractured limestone (Etampes)

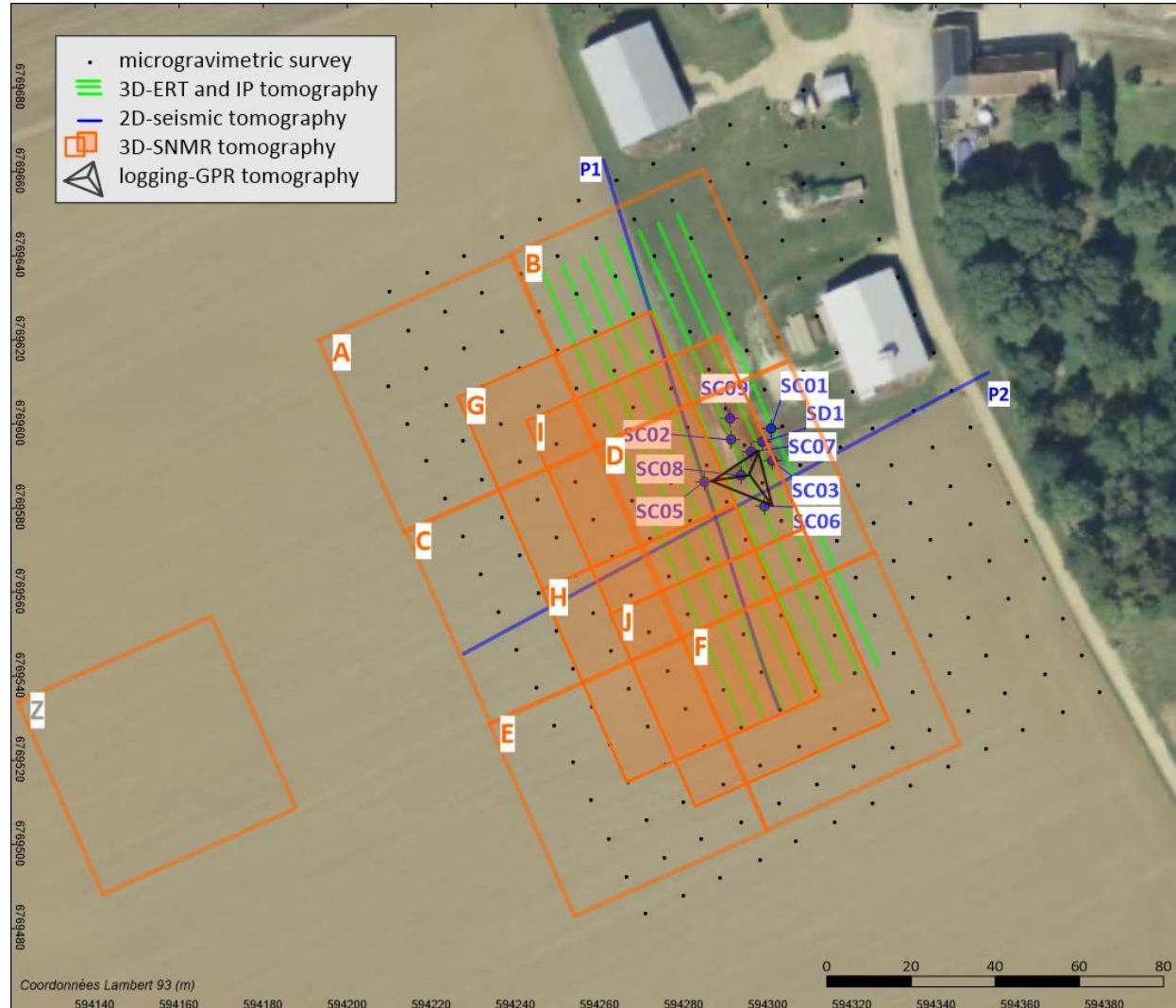
Villamblain study sites and BSS soundings (ID X01--)



<https://plateformes-pivots.eu/o-zns/>

- Weathered and highly heterogeneous limestone in VZ
- O-ZNS study site

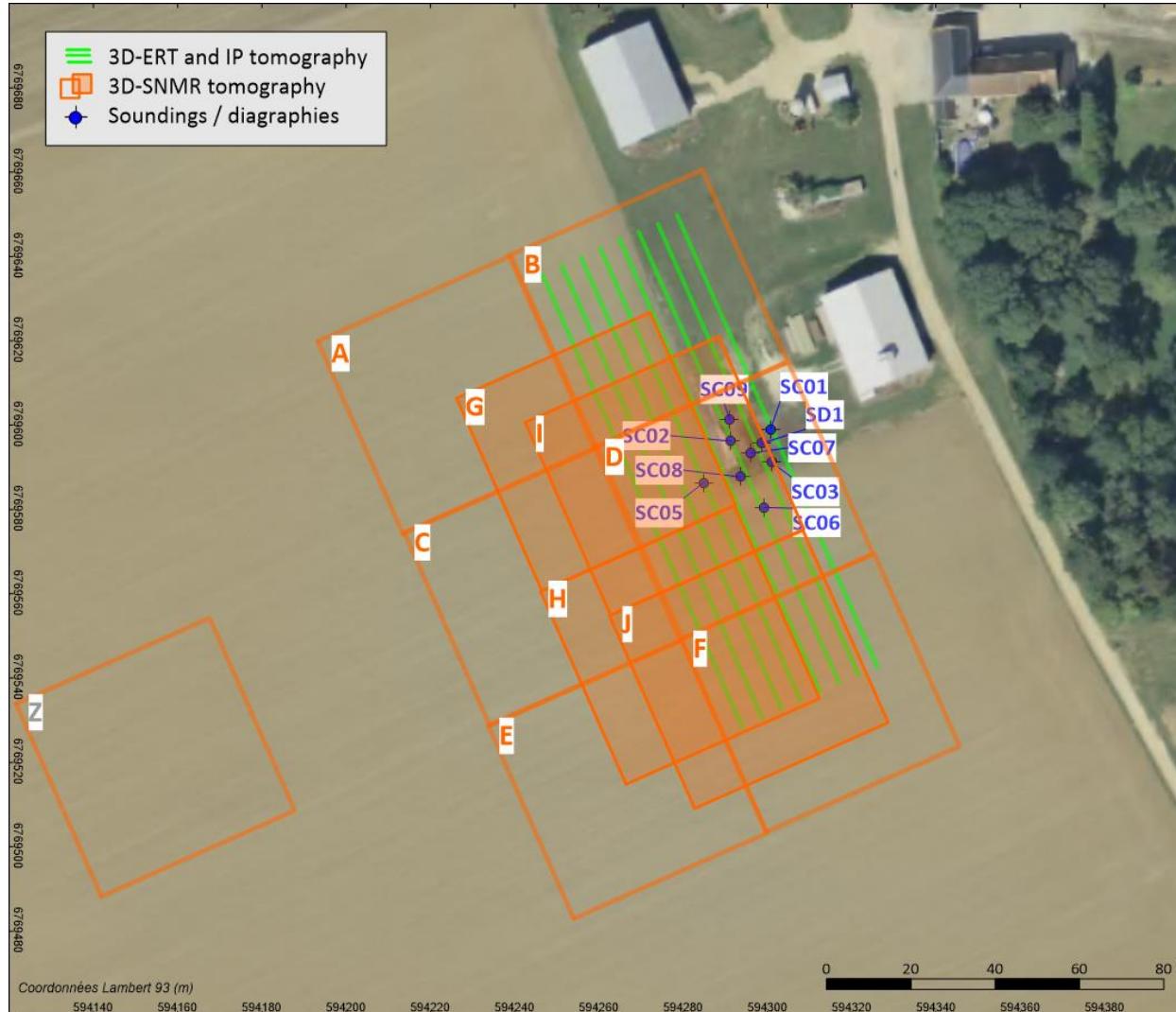
Geophysical investigation and data processing



Map of geophysical investigations done simultaneously
(09/2020) on OZNS study site before the well drilling

Clémence RYCKEBUSCH – BRGM, France

Geophysical investigation and data processing

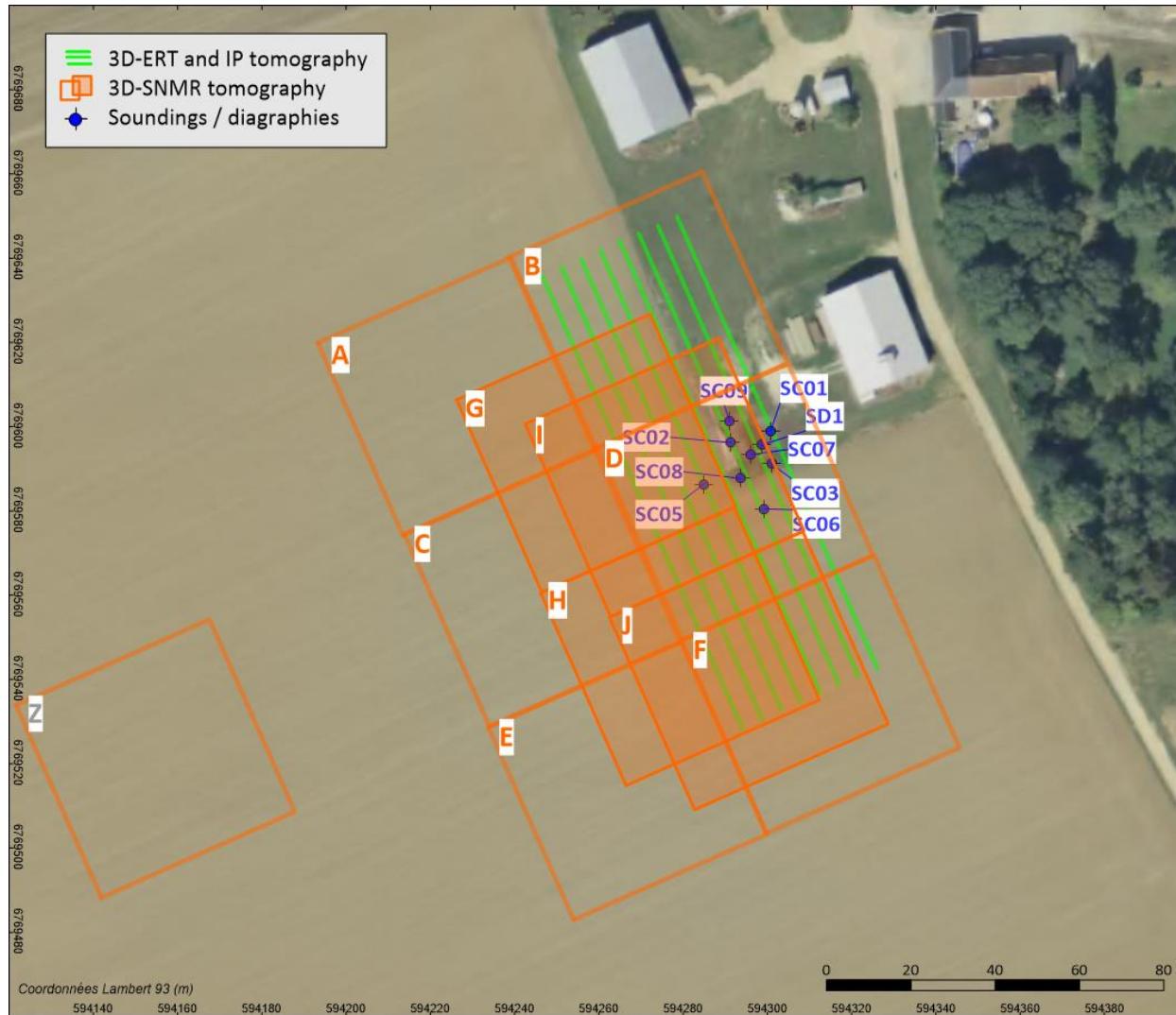


Map of geophysical investigations done simultaneously
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Clémence RYCKEBUSCH – BRGM, France

	SNMR	ERT/IP
Acquisition	10 soundings	8 profiles
Configuration	SQ 50m 2 tours Tx-Rx 16 pulses	48 electrodes 2.5m dipole-dipole
Device	Numis POLY (IRIS Instrument)	Syscal Pro switch (IRIS Instrument)
3D-inversion	Samovar	BERT

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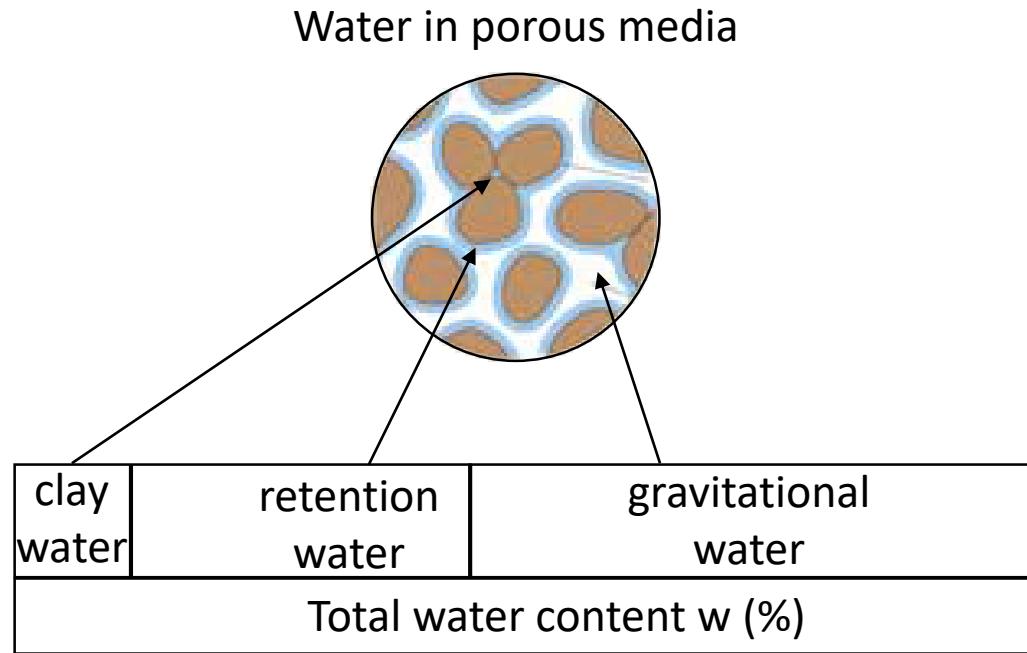
SNMR data

- S/N between 1.5 and 6.6 ; RMSE = 16.2 nV ; Noise level = 50 nV

Electrical data

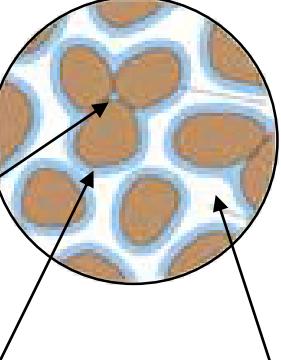
- ERT : RMSE = 7 %
- IP : preliminary result

Data interpretation in the Beauce limestone context



Data interpretation in the Beauce limestone context

Water in porous media

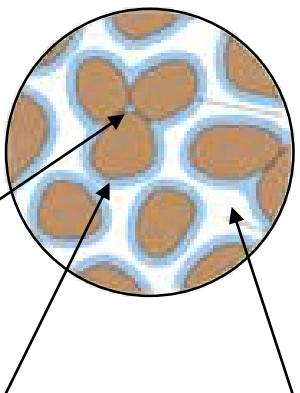


The diagram shows a circular cross-section of a porous medium containing several irregularly shaped brownish-orange regions representing clay particles. Between these particles are blue and white spaces representing different types of water.

clay water	retention water	gravitational water
Total water content w (%)		
30	Relaxation time T_2^* (ms)	1000

Data interpretation in the Beauce limestone context

Water in porous media

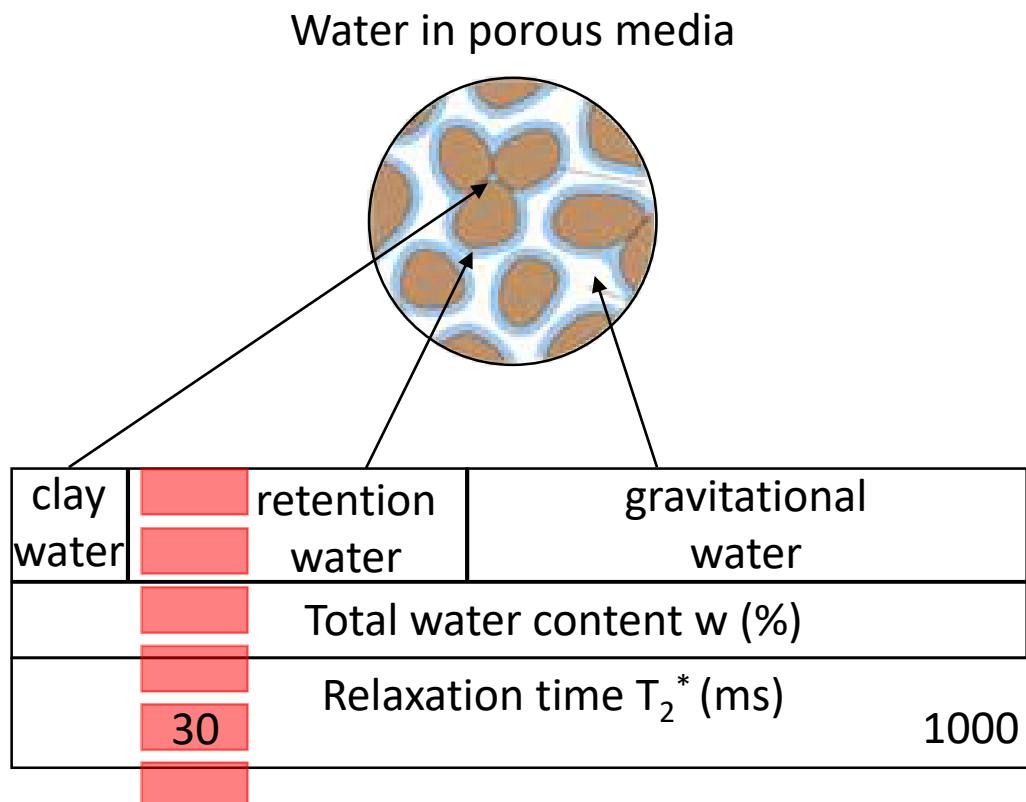


clay	retention	gravitational
water	water	water
Total water content w (%)		
Relaxation time T_2^* (ms)		
30		1000

SNMR detection threshold
in Beauce limestone

Geophysical method	Parameter measured	Interpretation
SNMR	Water content	Decrease with clay content or with decreasing porosity
	Time relaxation	(Not used to date)

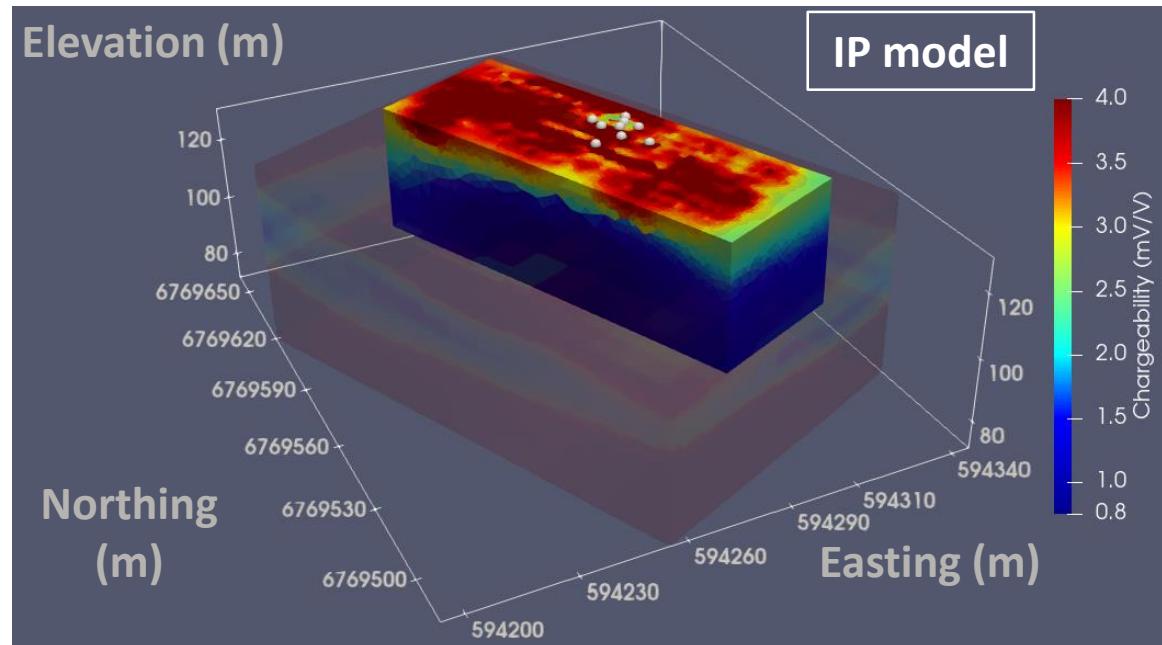
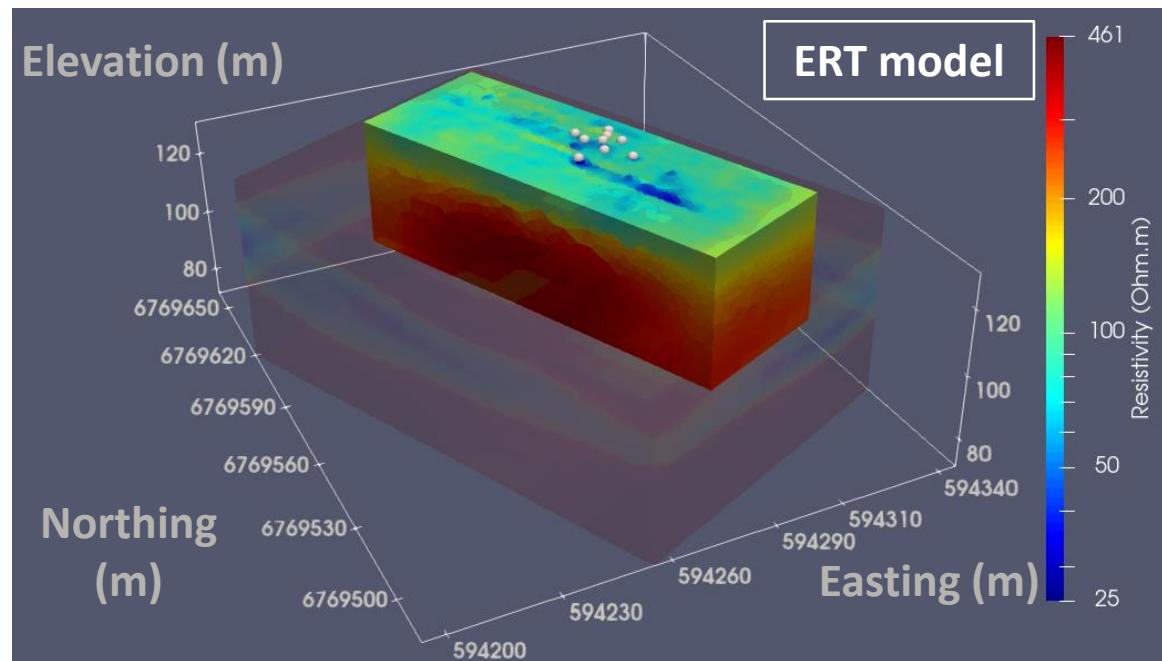
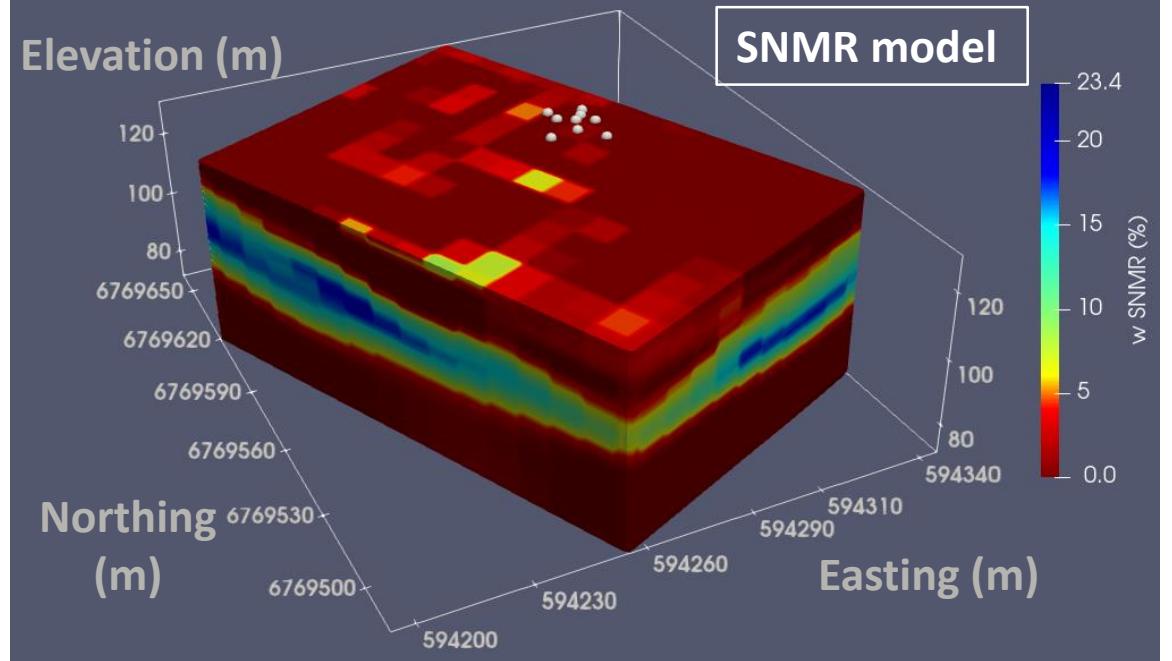
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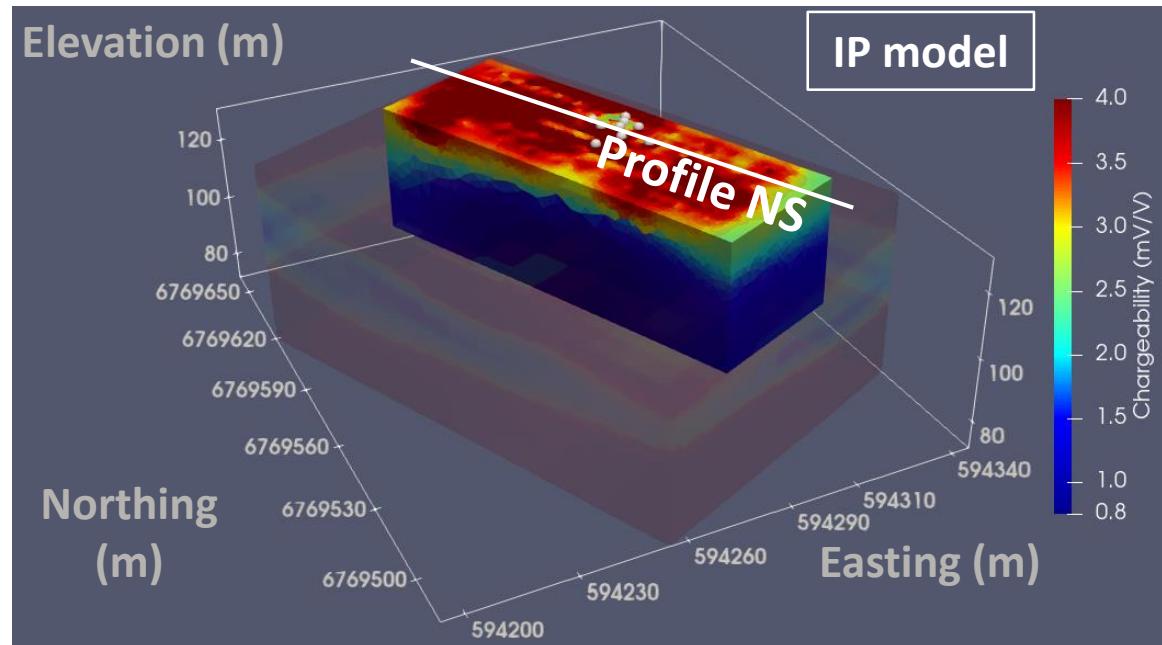
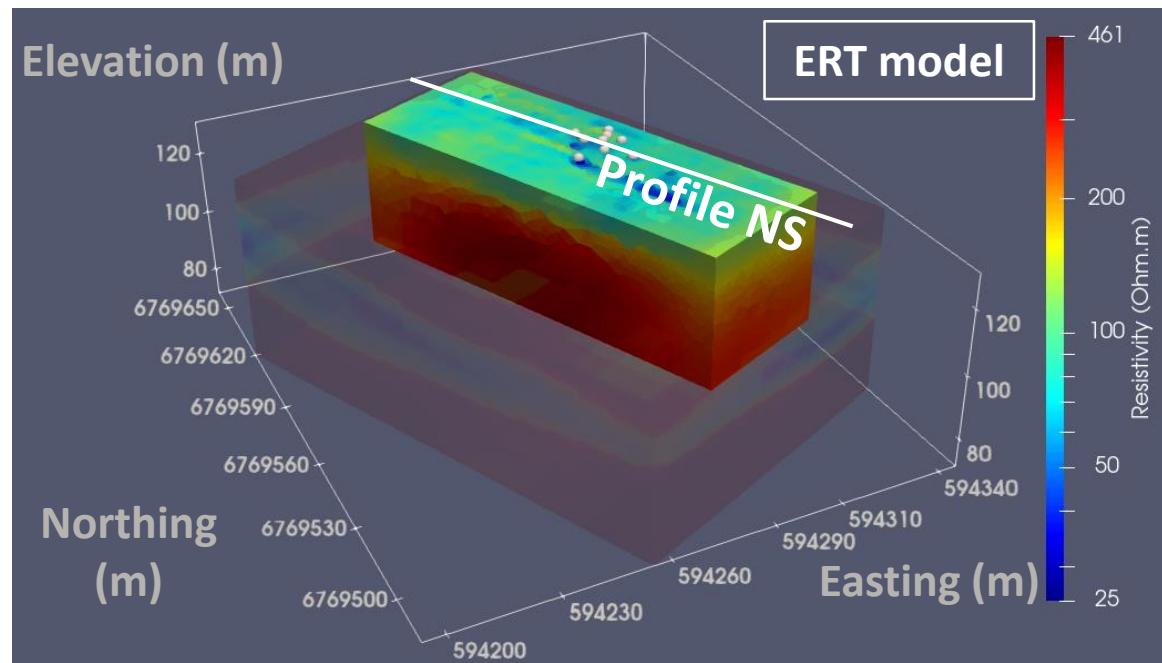
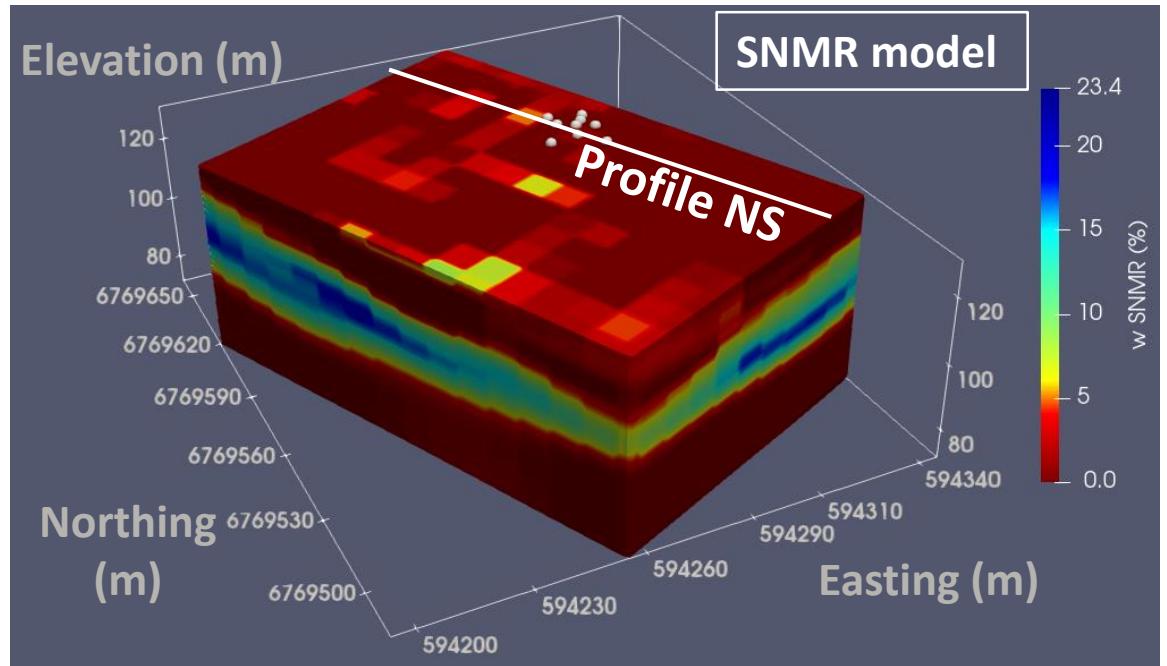
SNMR detection threshold
in Beauce limestone

Geophysical method	Parameter measured	Interpretation
SNMR	Water content	Decrease with clay content or with decreasing porosity
	Time relaxation	(Not used to date)
ERT	Electrical resistivity	Decrease with clay content and/or limestone alteration
IP	Chargeability	Increase with clay content

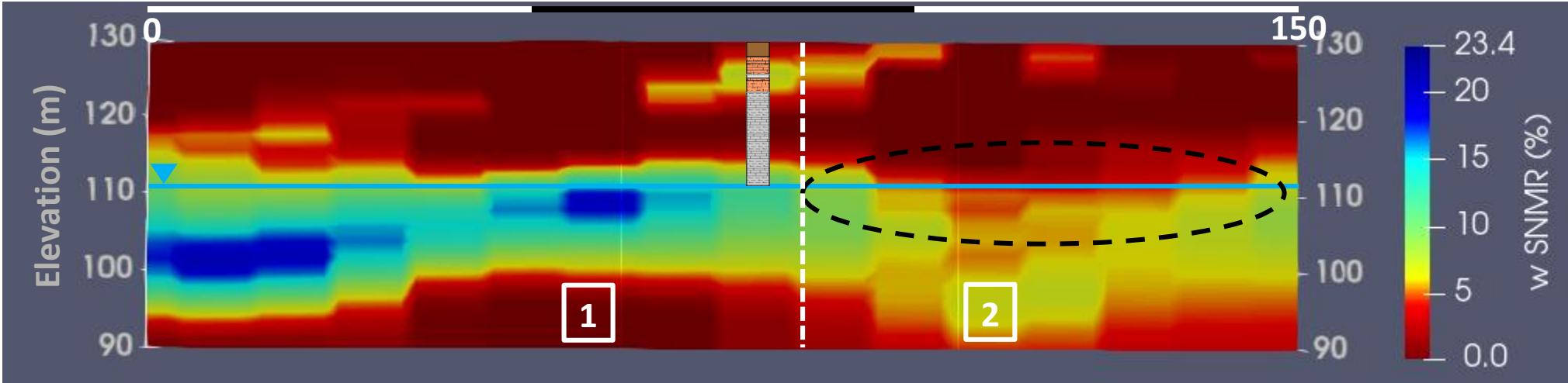
3D SNMR and ERT/IP inverse models



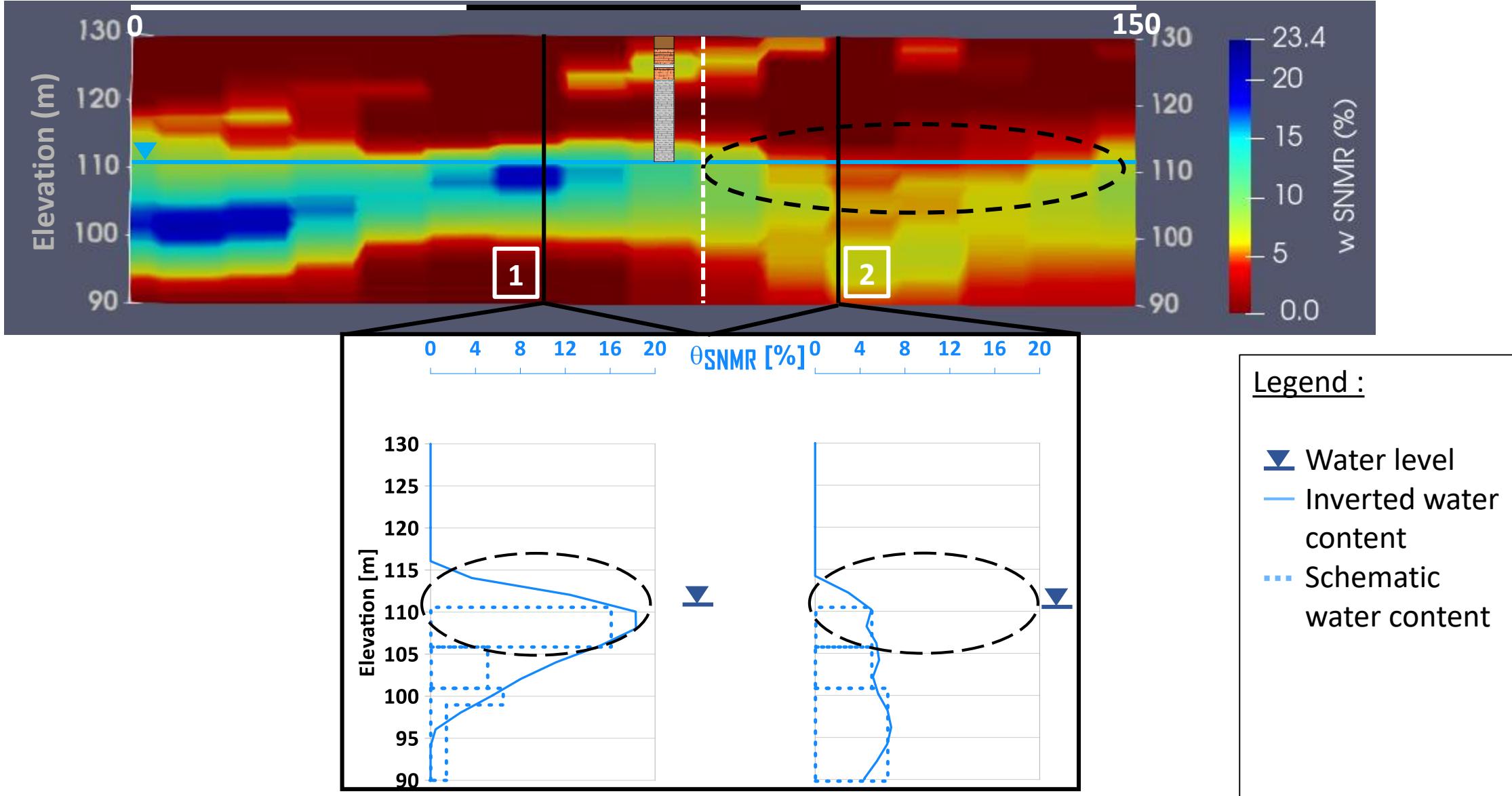
3D SNMR and ERT/IP inverse models



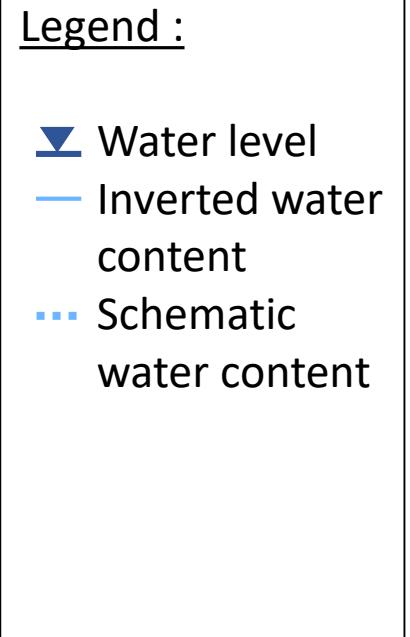
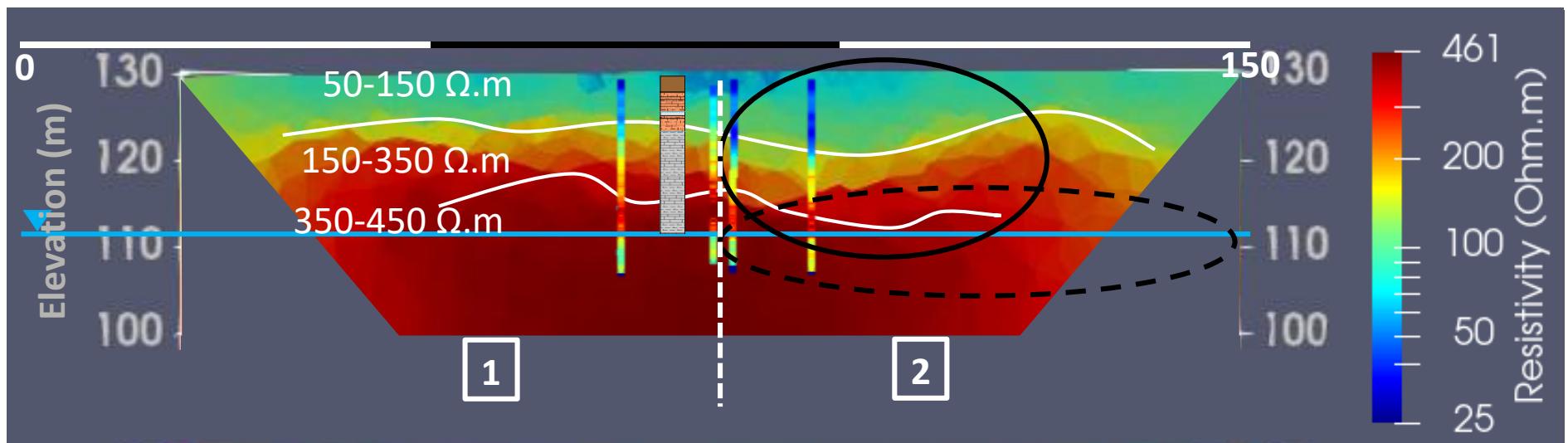
Water content heterogeneities resulting from SNMR 3D inversion



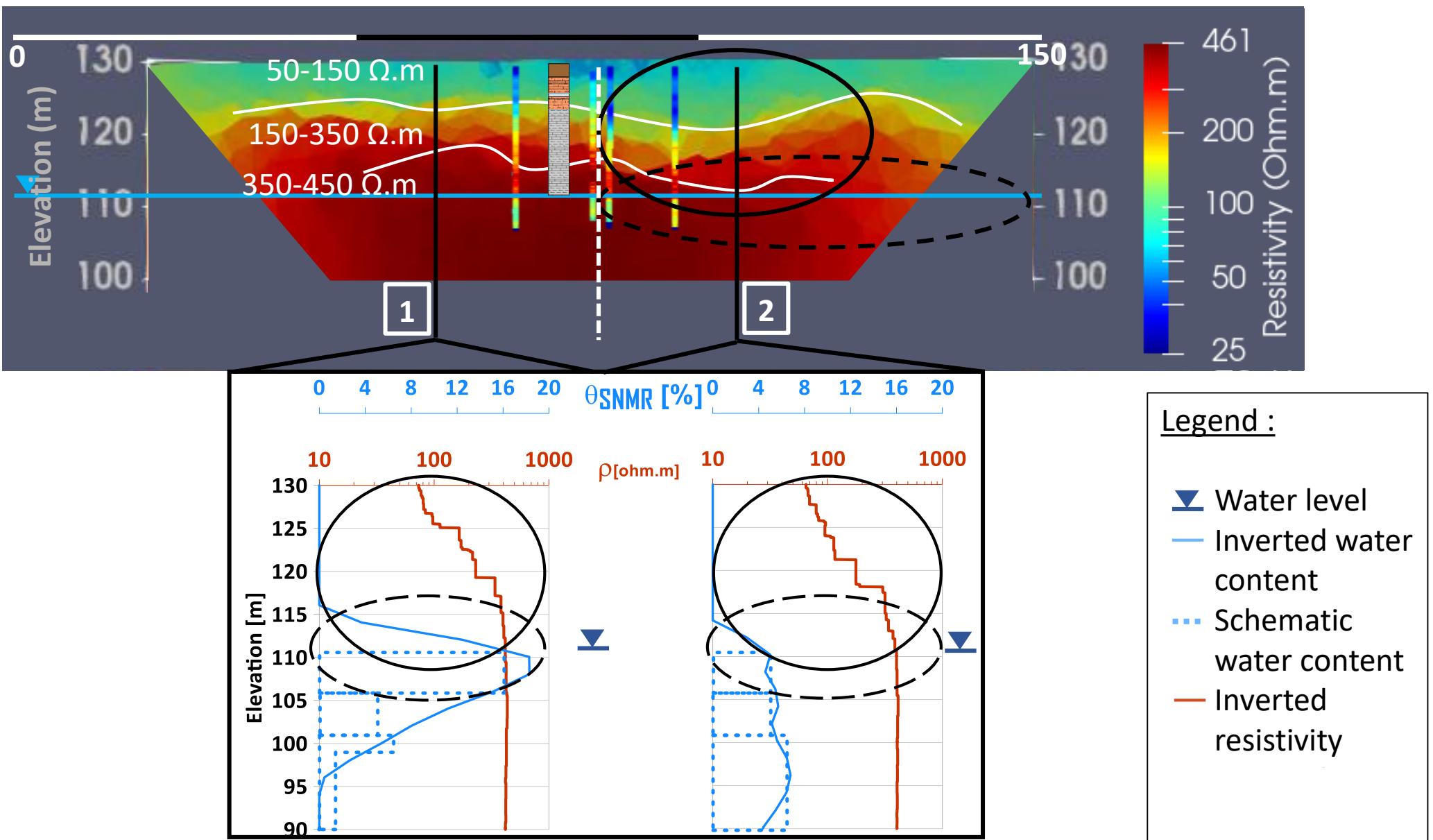
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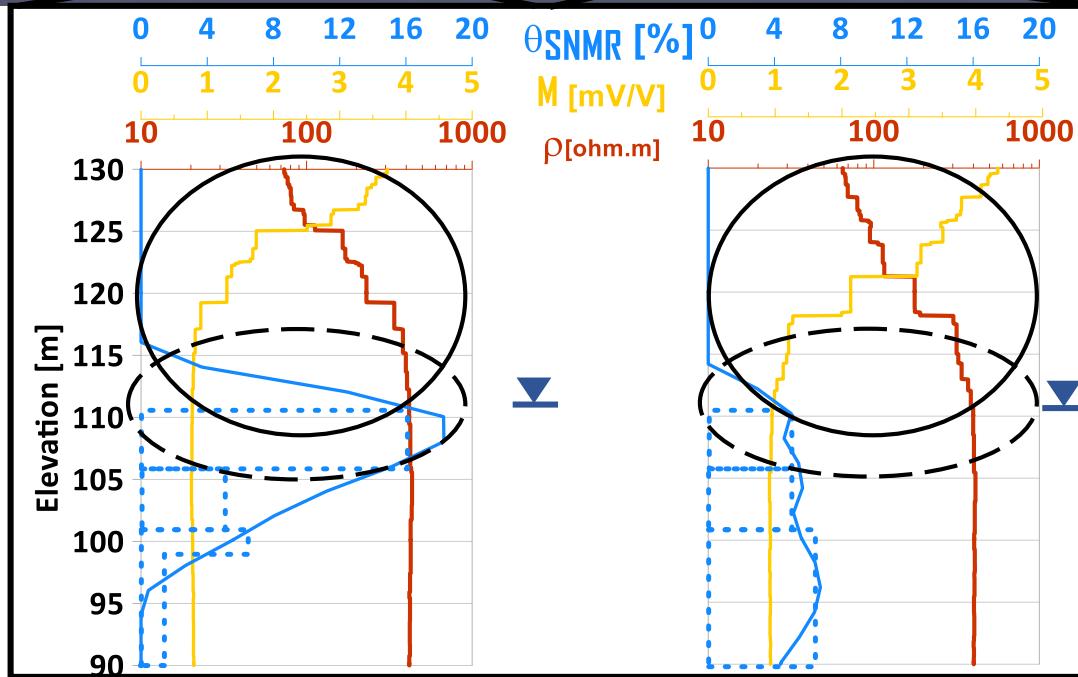
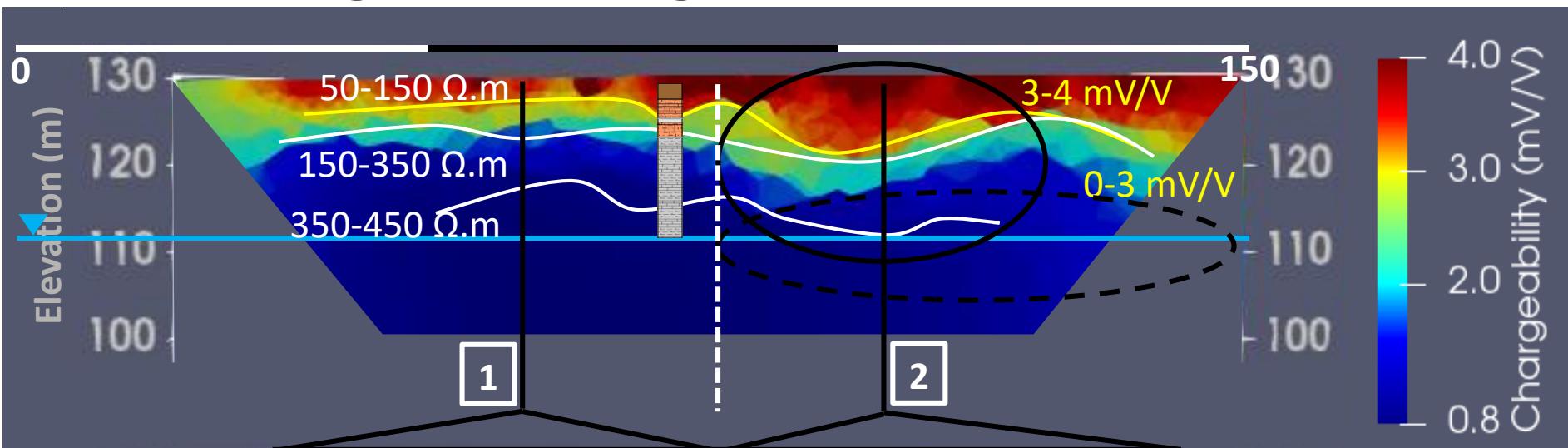
Identification of lithological heterogeneities from electrical 3D inversion results



Identification of lithological heterogeneities from electrical 3D inversion results



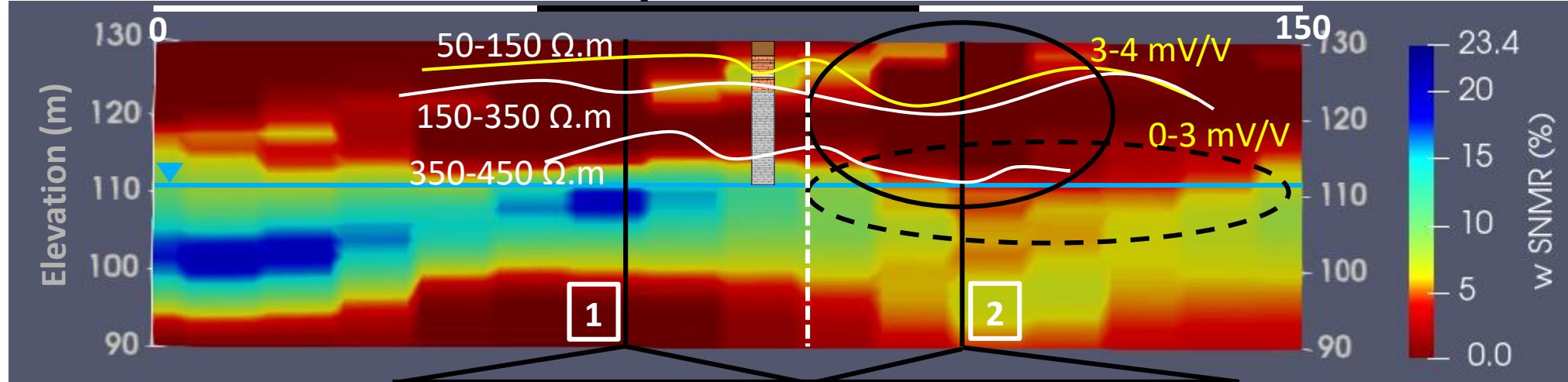
Identification of lithological heterogeneities from electrical 3D inversion results



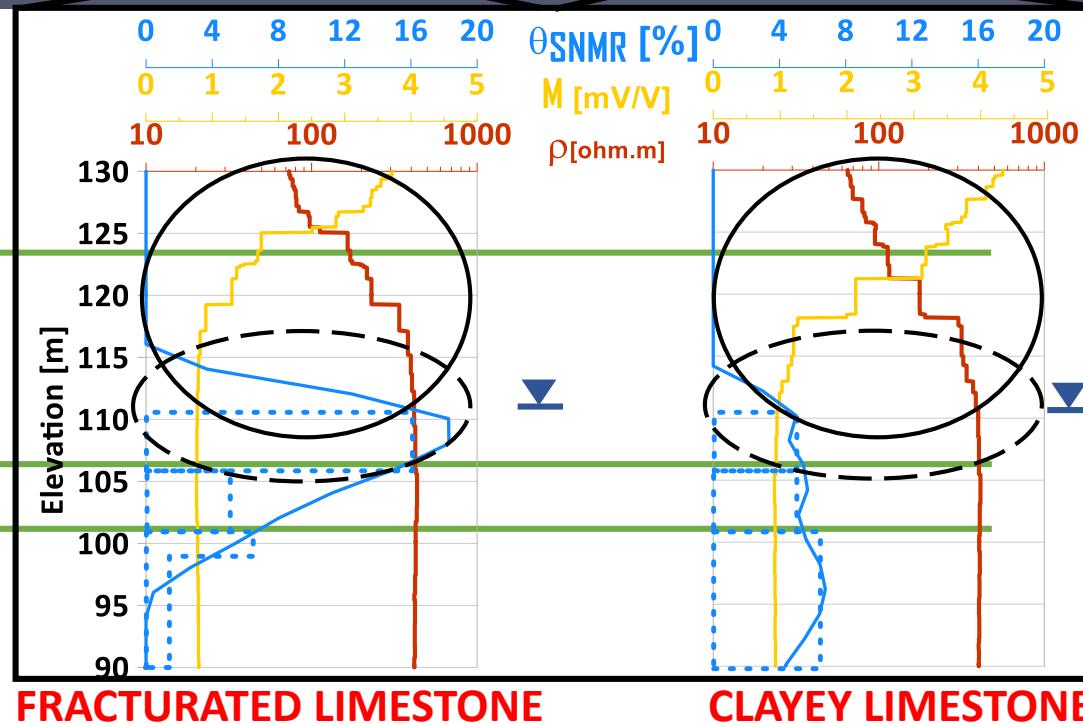
Legend :

- Water level
- Inverted water content
- Schematic water content
- Inverted resistivity
- Inverted chargeability

SNMR water content and geoelectrical model of an anomalous area in weathered Beauce Limestone aquifer and ZNS



Highly weathered limestone
Upper fractured limestone (Pithiviers)
Marl
Lower fractured limestone (Etampes)



Legend :

- Water level
- Inverted water content
- Schematic water content
- Inverted resistivity
- Inverted chargeability

Conclusion and perspectives

Conclusion :

Joint interpretation of SNMR and ERT/IP data in a 3D aquifer and VZ :

- Identify spatial heterogeneities
- Variable hydrogeological properties : Lithology + water content

Conclusion and perspectives

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Variable hydrogeological properties => variable hydrodynamic and VZ flow properties ?

Conclusion and perspectives

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- Identify spatial heterogeneities
- Variable hydrogeological properties : Lithology + water content

Variable hydrogeological properties => variable hydrodynamic and VZ flow properties ?

Future work :

Use these results to characterize the VZ hydrodynamic and flow properties with :

- Time-lapse SNMR monitoring
- Hydrogeological modeling



Thank you

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SNMR principles

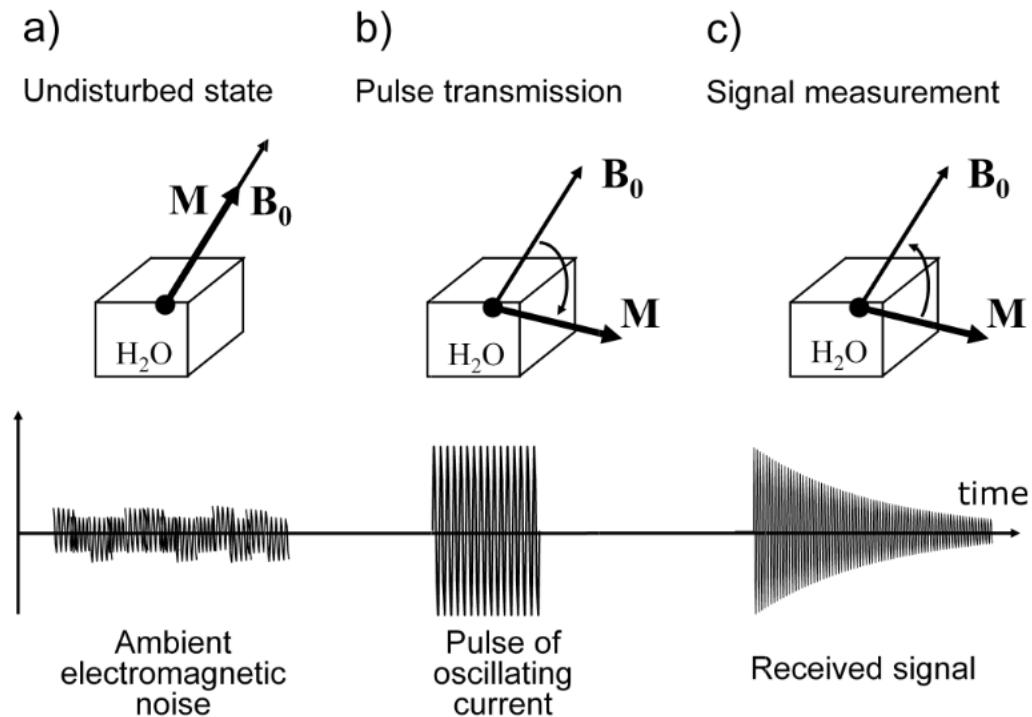


Figure 1.1. Typical phases of a magnetic resonance experiment (top) and corresponding magnetic resonance measurements (bottom)

Source : LEGTCHENKO, Anatoly, 2013. *Magnetic Resonance Imaging for Groundwater*. John Wiley & Sons. ISBN 978-1-118-64947-3

Measurement scale :

Multidecametric (field)

Data measured :

Signal amplitude, relaxation time

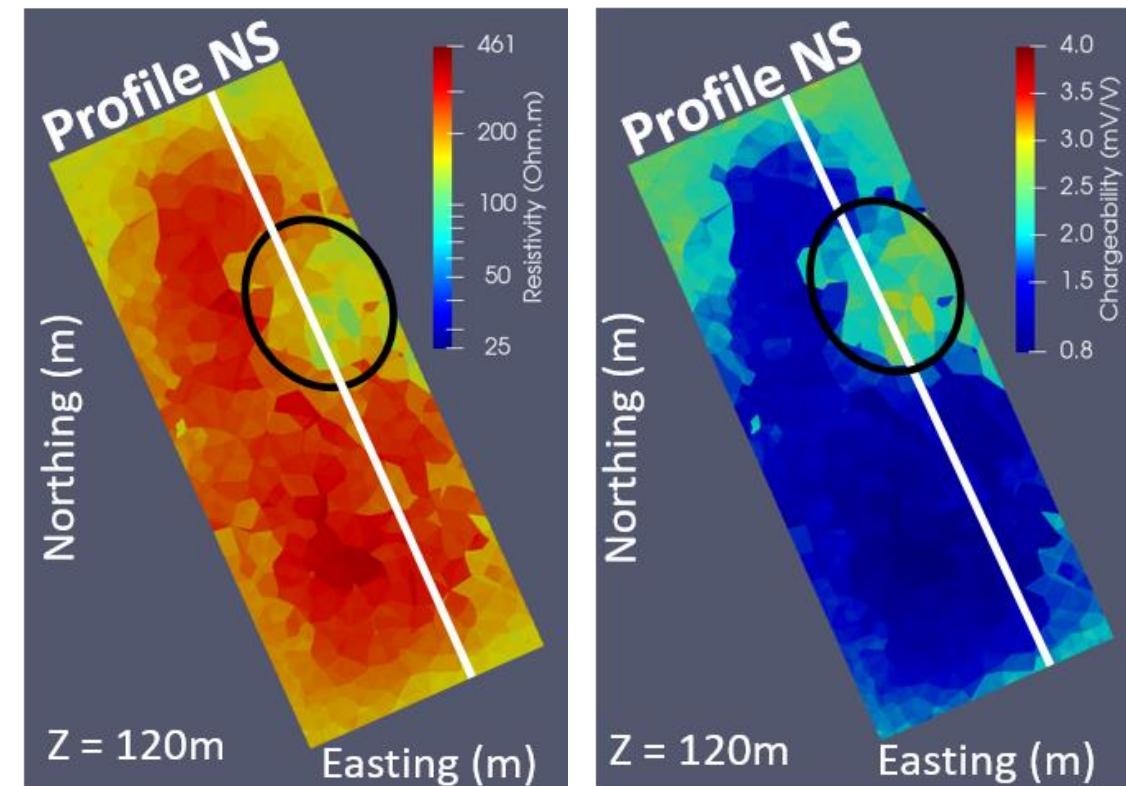
Parameters :

Water content, mean porosity distribution

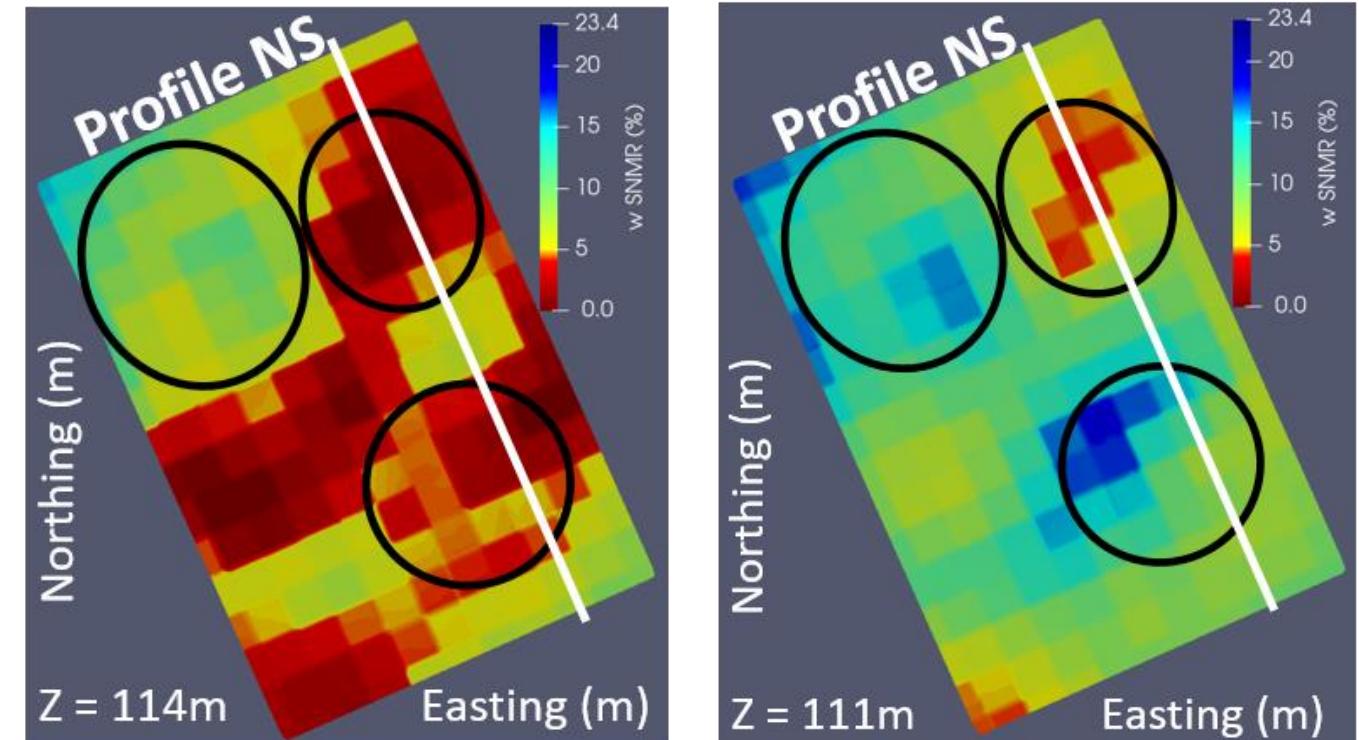
Particularity of field NMR :

No detection of water content for smaller pore sizes

3D water content and lithological spatial heterogeneities



Maps of electrical resistivity (left) and chargeability (right) at an elevation of 120 m (vadose zone)



SNMR Water content maps at an elevation of 114 m (vadose zone) and 111 m (aquifer)