REMAPRO - Cartographie 3D de la perméabilité des aquifères par REsonance MAgnétique PROtonique et mesures géophysiques couplées pour une meilleure estimation des risques sur les sites pollués.

REMAPRO project - 3D mapping of hydraulic permeability using PROtonic MAgnetic REsonance and joint inversion of geophysical methods at a site scale for a better estimation of pollution risks.

jf.girard@brgm.fr (project coord.)
Legtchenko A., J. Fourier University, Grenoble
Bernard J., IRIS Instruments, Orléans

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Objectives & main tasks of REMAPRO project

- From MR sounding (pre-existing technology) towards 2D/3D tomography (task 1)
- Quantitative interpretation (task 2)
  - Calibration of the response in various geological contexts
  - Probabilistic & Multi-parameter modelling
- New generation of MR equipment (task 3) to make measurements
  - More accurate
  - More robust: main drawback for application is the electromagnétique noise of industrial electric current (50 Hz harmonics).
- On-site validation of the new methodology (task 4)
  - on polluted areas currently under investigation with detailed and validated documentation used as test-sites (where the aquifer has a complexity).

Impact of the developped methodology & tools for environmental studies

- Increase reliability of aquifer characterization
  - Better flow model
  - Better risk assessment or remediation
- Proton Magnetic Resonance is non-invasive
  - measured from the surface, without borehole
- Combined with other informations (logs, geophysics) it leads to spatialize objectively and quantitatively the aquifer properties

Characterization of heterogeneous near-surface materials by joint stochastic approach

Girard Jean-François,
Lalande Jean-Marie,
Grandjean Gilles,
Roulle Agathe
Bitri Adnand
J-M. Baltassat
Legtchenko A.

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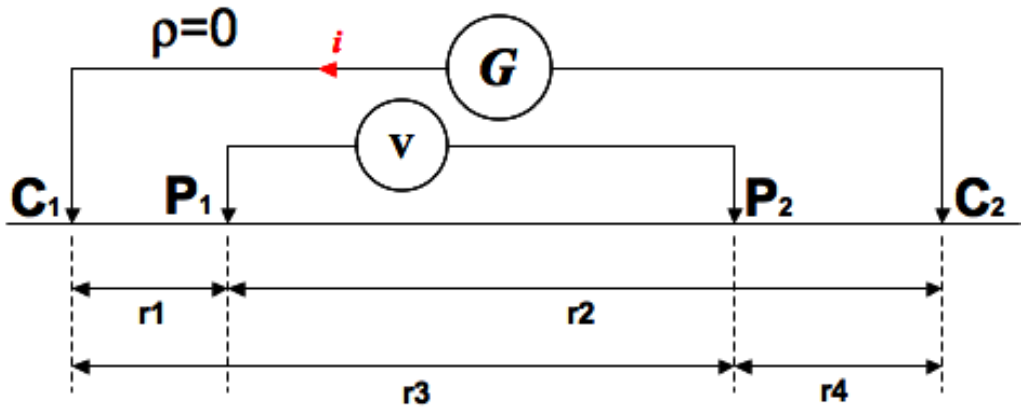
Ground electrical resistivity measurement

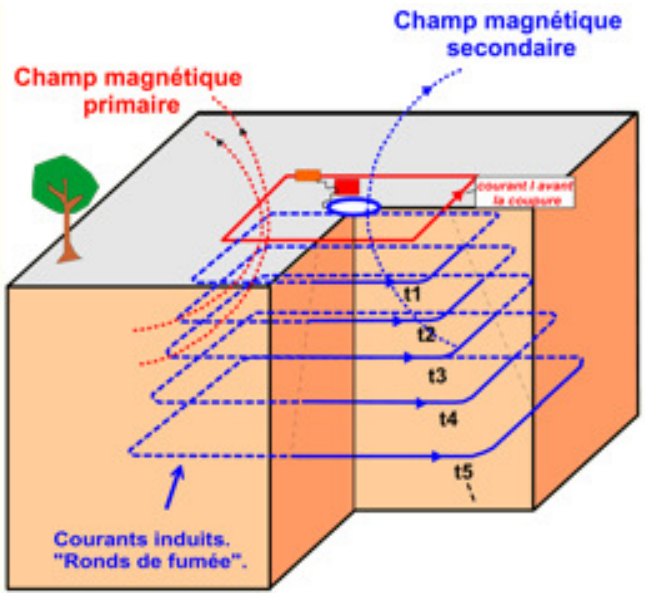
- 4 electrodes array



- Ground electrical resistivity $\rho = \frac{\Delta V}{I} K$

Vertical electrical sounding (VES in 1D) or electrical imaging in 2D/3D

Ground electrical resistivity measurement

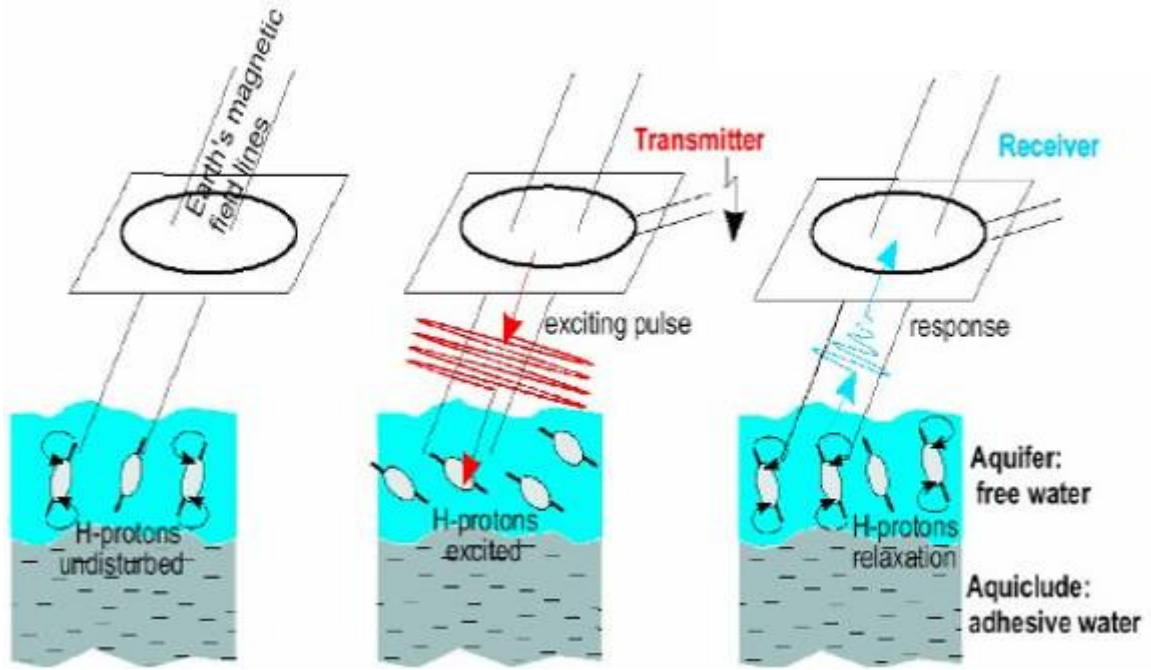


- Mesure de la variation du champ d'induction secondaire
- Distribution de la valeur des résistivités en fonction de la profondeur
- Adapté au milieu stratifié
- Profondeur d'investigation : fonction de la boucle. En général, jusqu'à 200 mètres
- Détection de couches conductrice

Time Domain Electro-Magnetism (TEM)

Magnetic resonance Sounding (MRS or PMR)

- Principle of Nuclear Magnetic resonance used in MRI
- Based on the resonance of the H+ of the water molecule ⇨ method specific to direct detection of groundwater

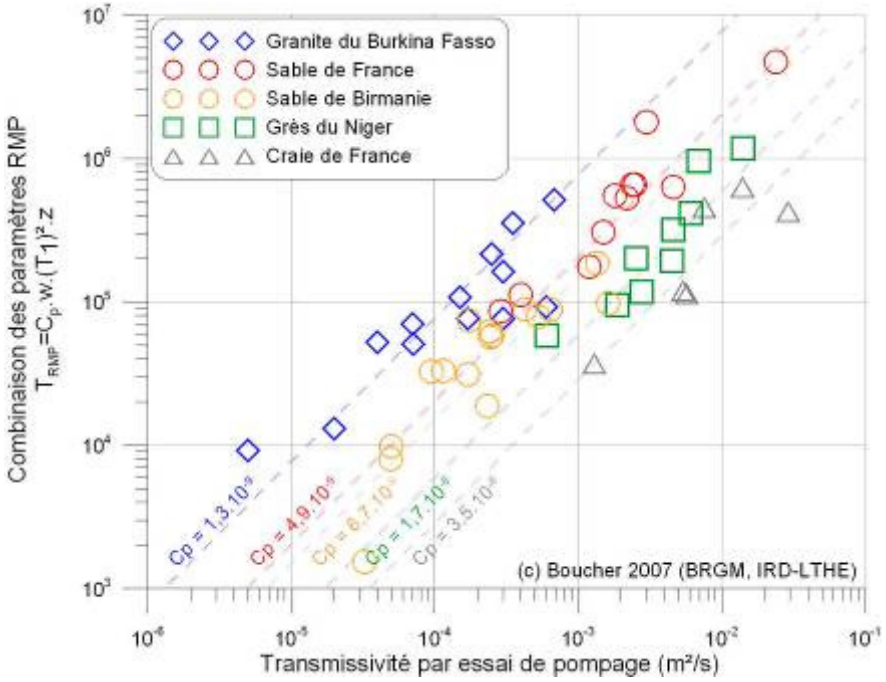


Magnetic resonance Sounding (MRS or PMR)

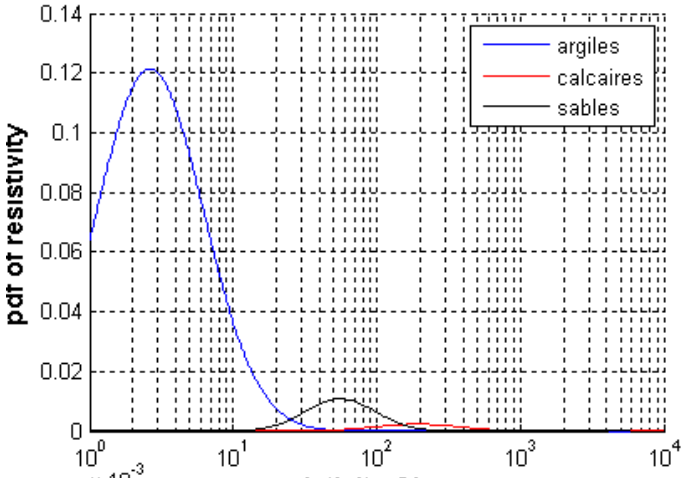
PMR parameters :

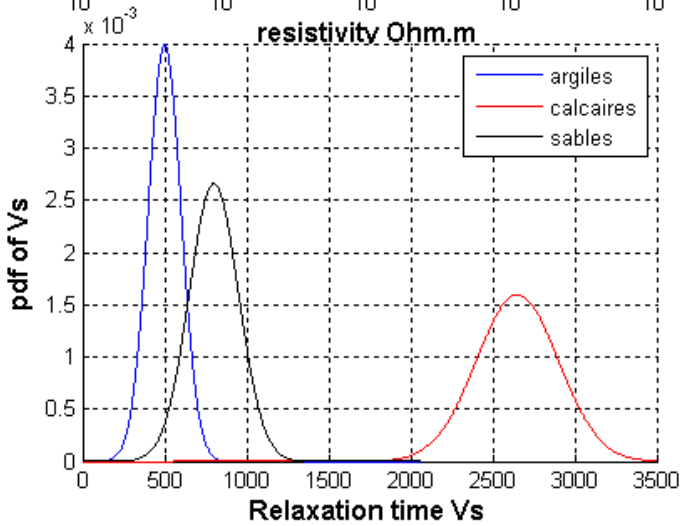
- Water content (porosity)
- Relaxation time (pore size)

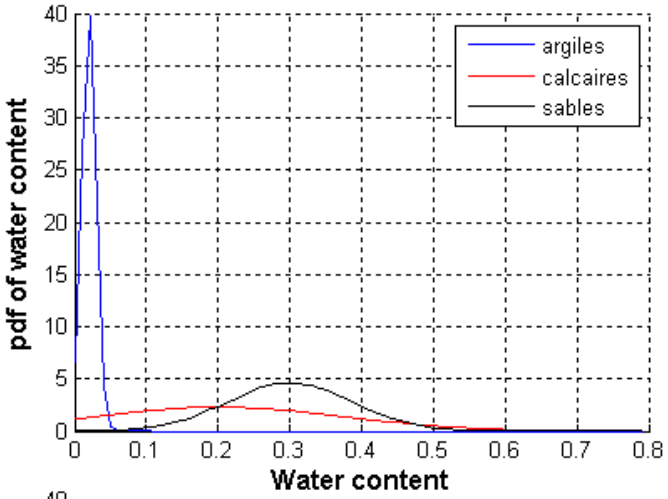
Estimate of hydraul permeability

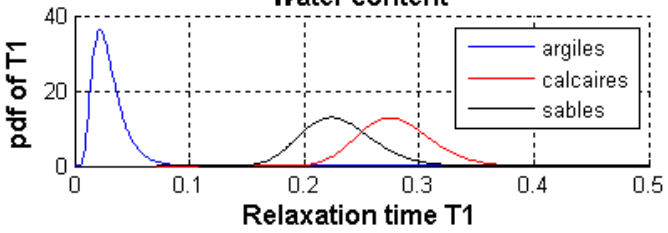


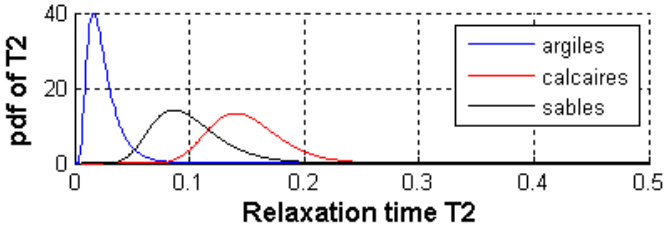
A priori information : lithofacies











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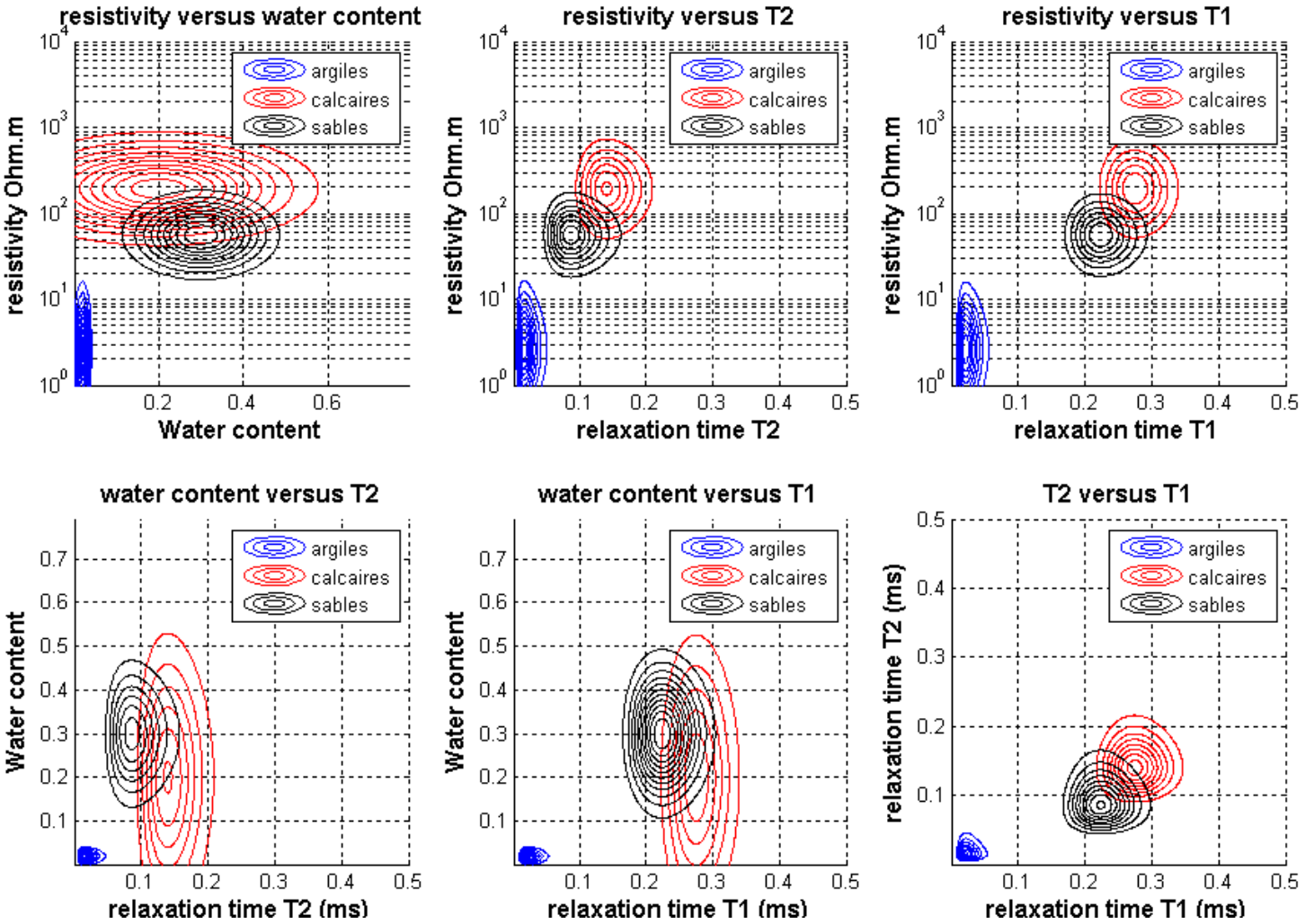

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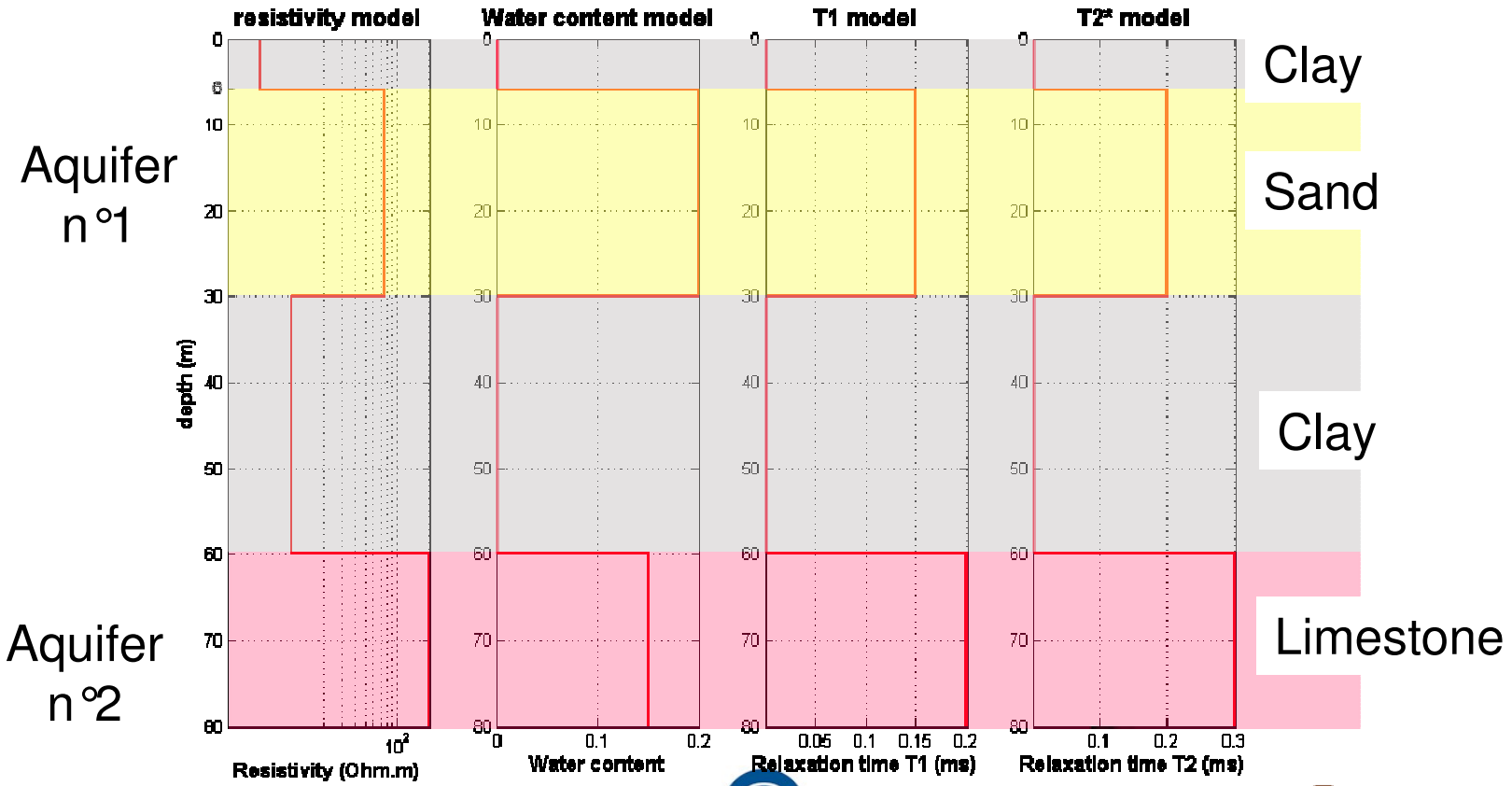
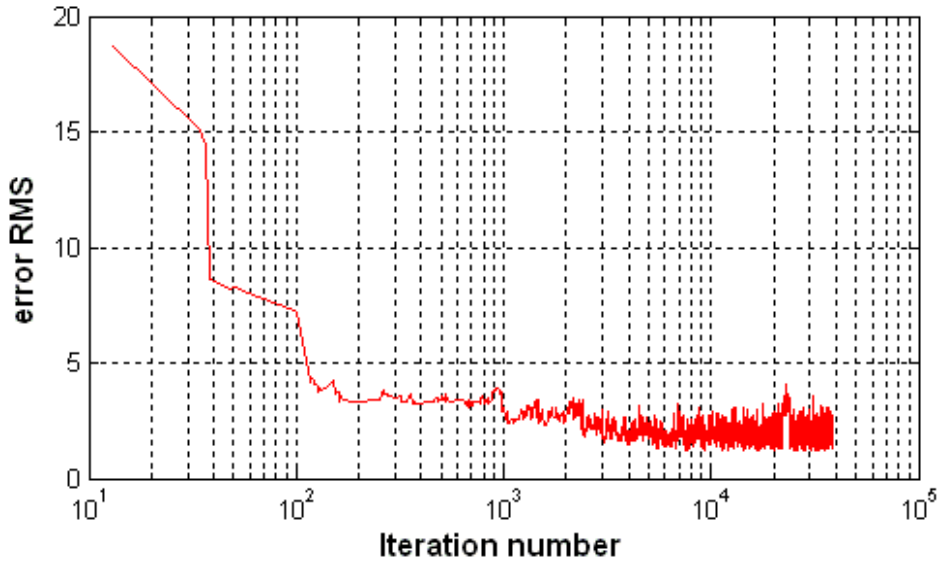
Application to a synthetic case

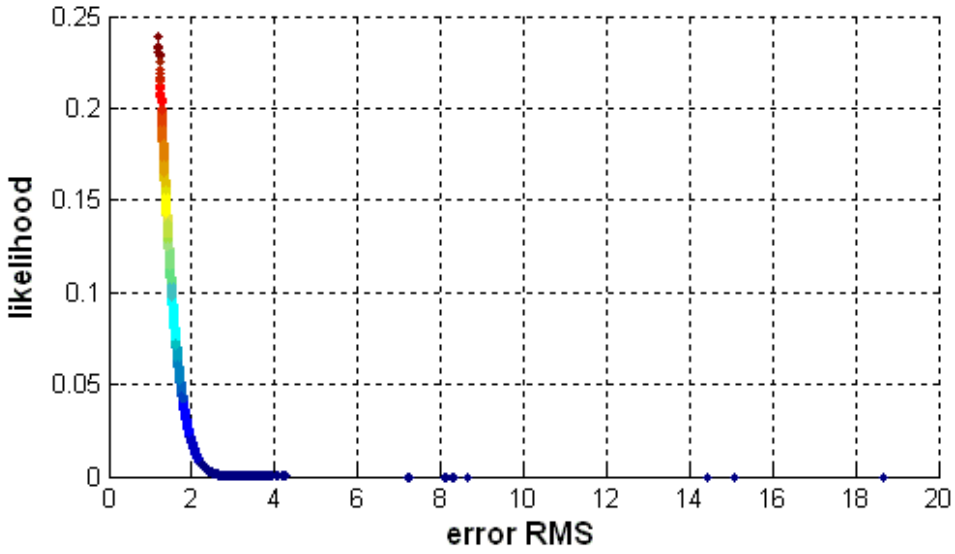
> Inversion of a synthetic VES / RMP dataset

- with 5% gaussian noise



Application to a synthetic case





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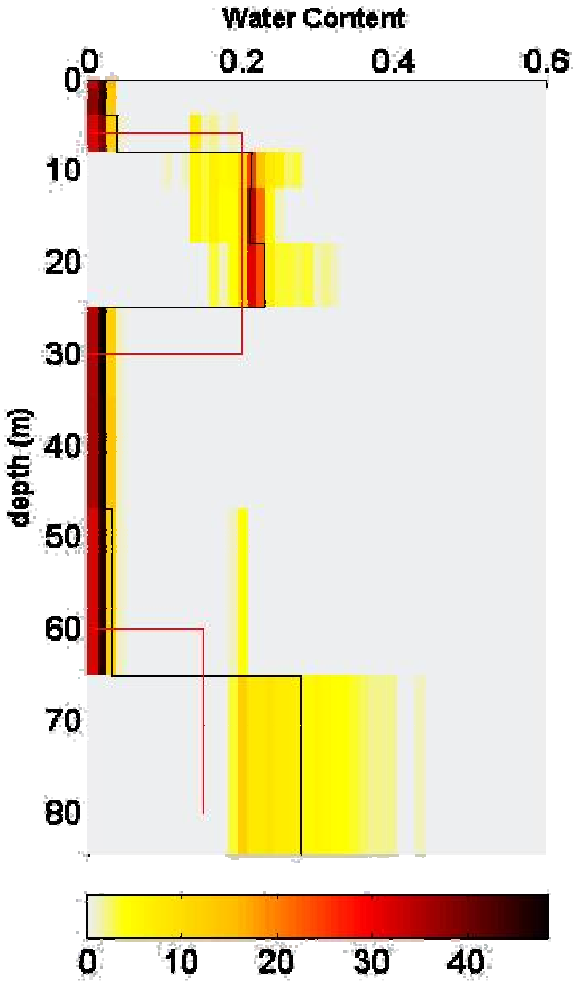
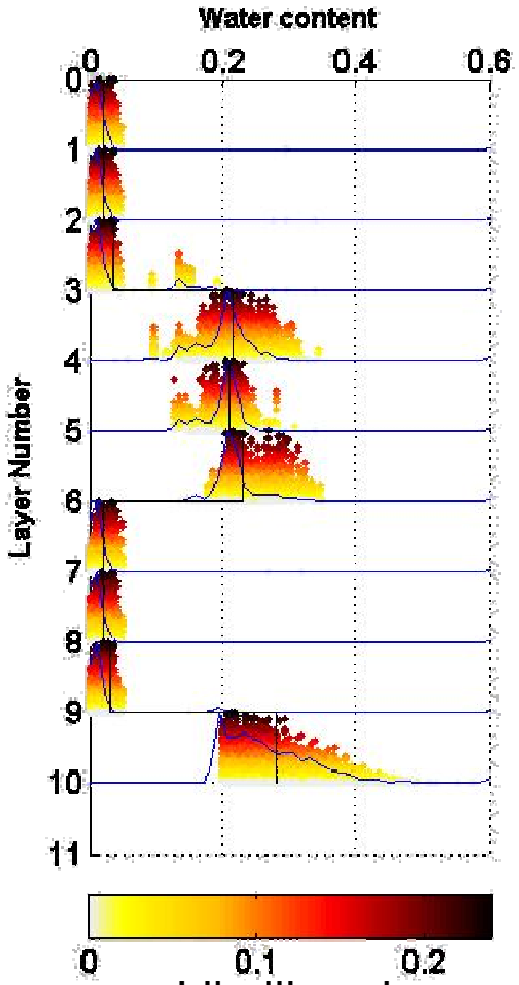
Inversion VES / **RMP**



MRS water content (%)



Likelihood

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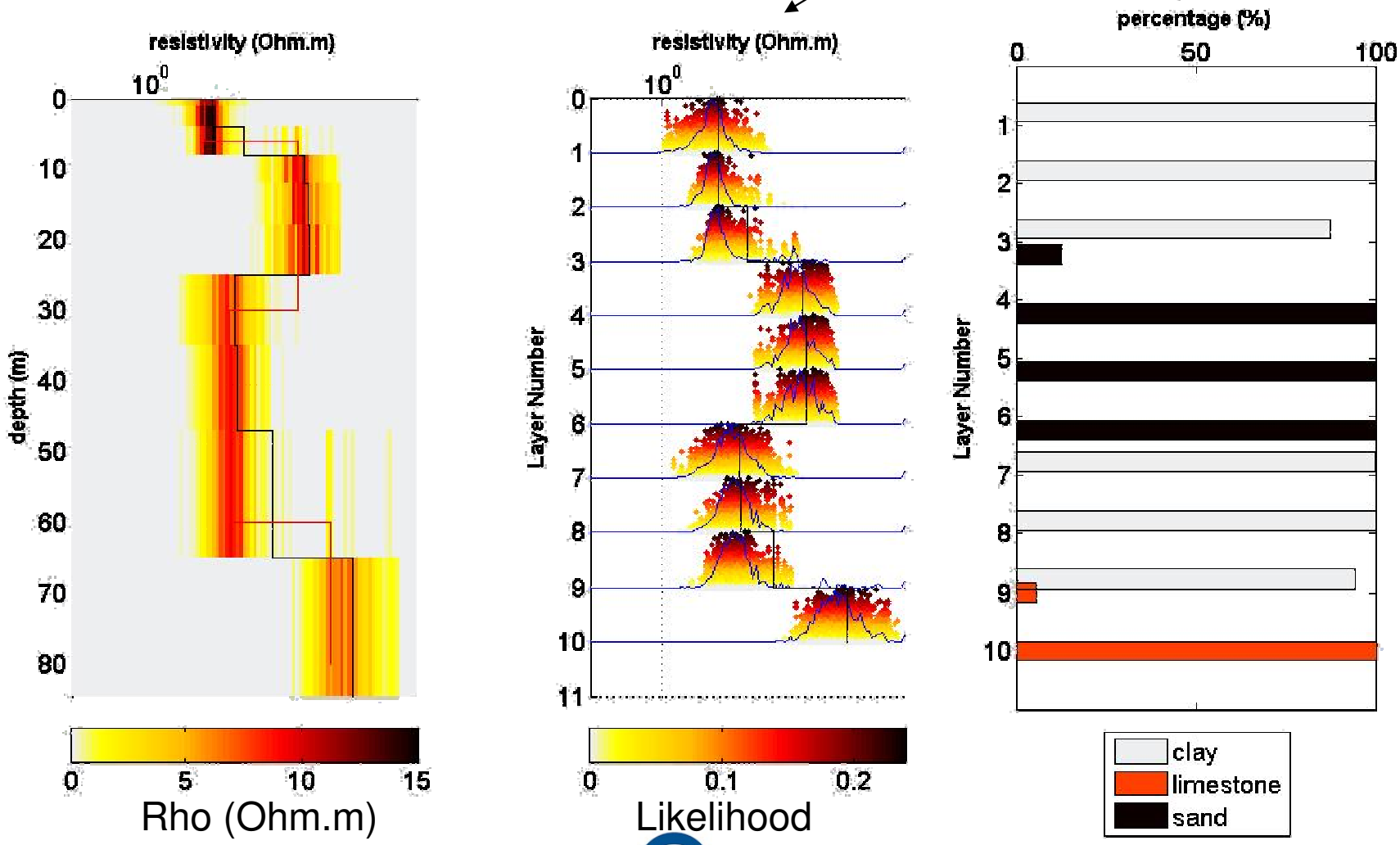
Inversion **VES** / RMP

Quantitative interpretation



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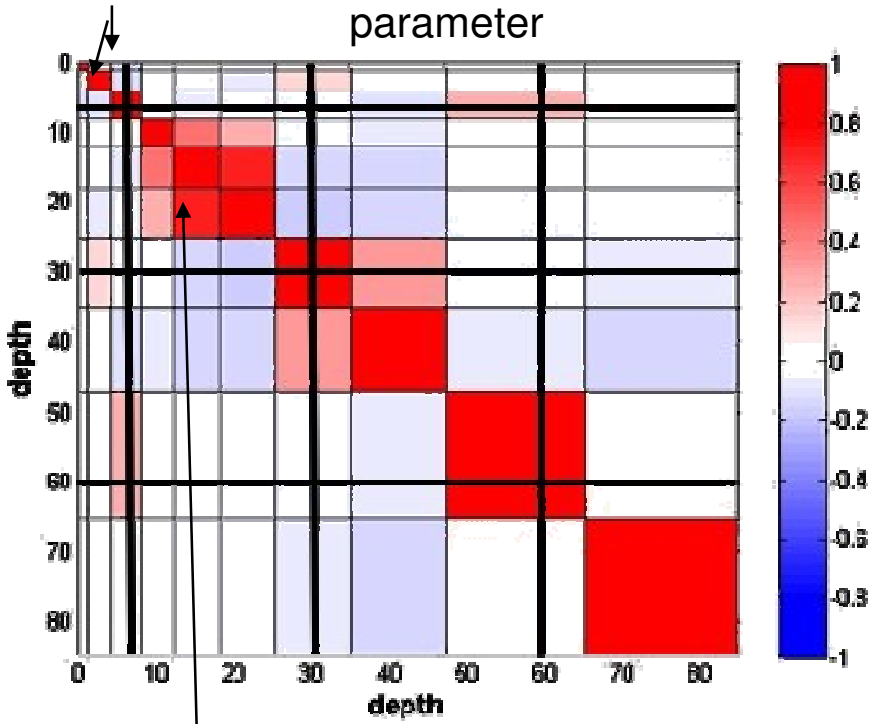
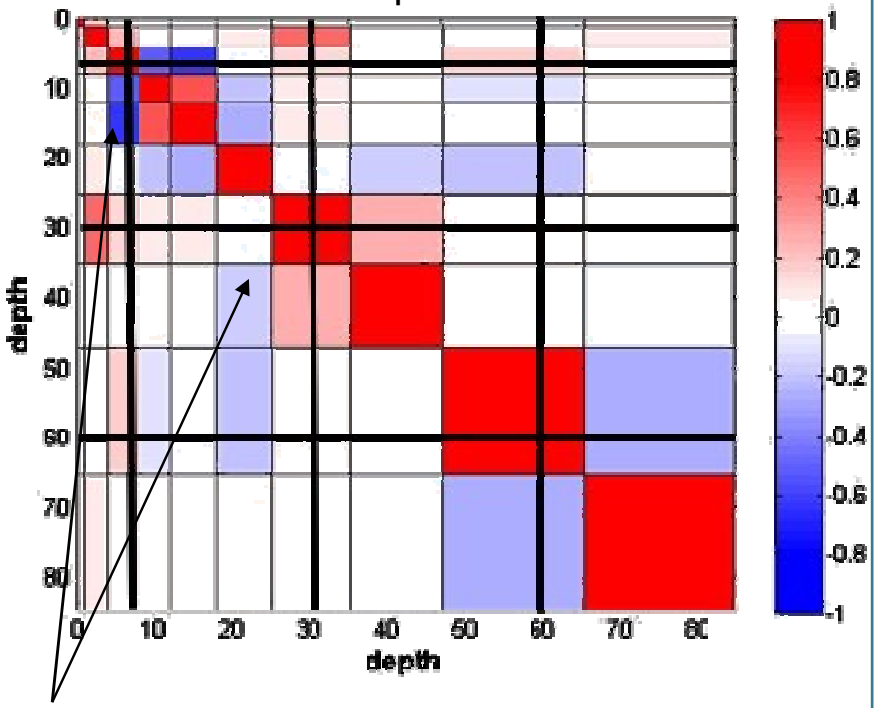
Correlation matrix ≈ resolution matrix

Correlation matrix: rho parameter



Correlation matrix: water content parameter



Layers strongly dependent = 1 single layer

Strong anti-correlation = equivalence phenomenon = limit of resolution without additional extern contraint

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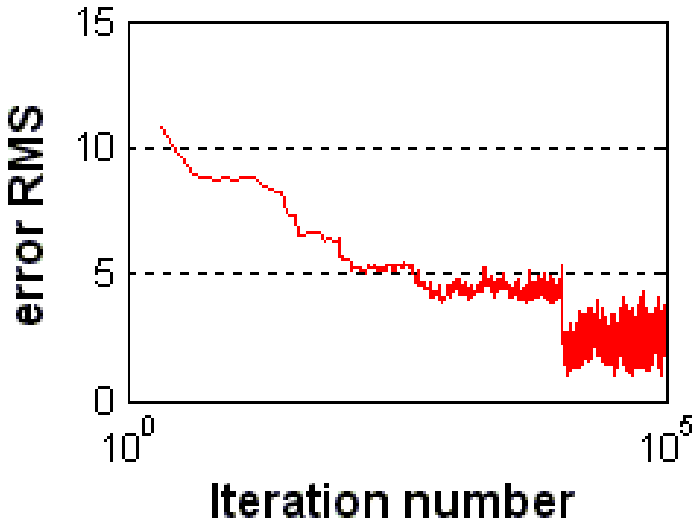
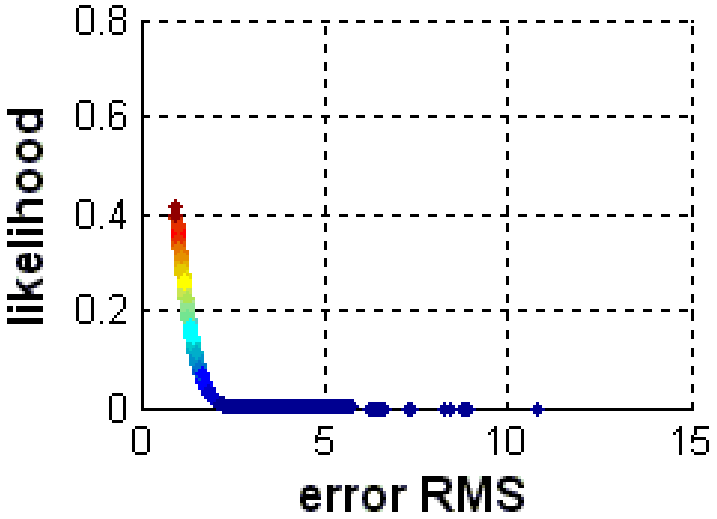
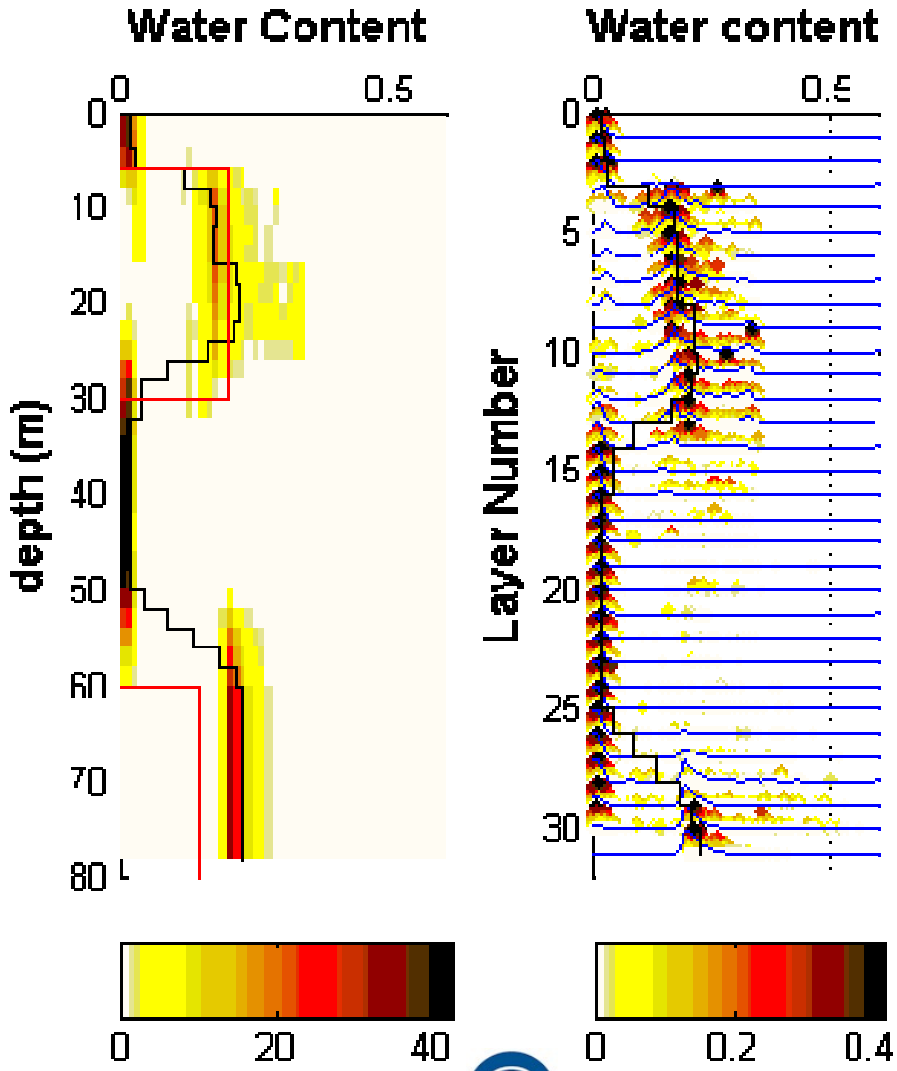
Smooth model inversion

> **Mesh is composed of 30 layers 2 meters thick + half-space**





Inversion VES / **RMP**



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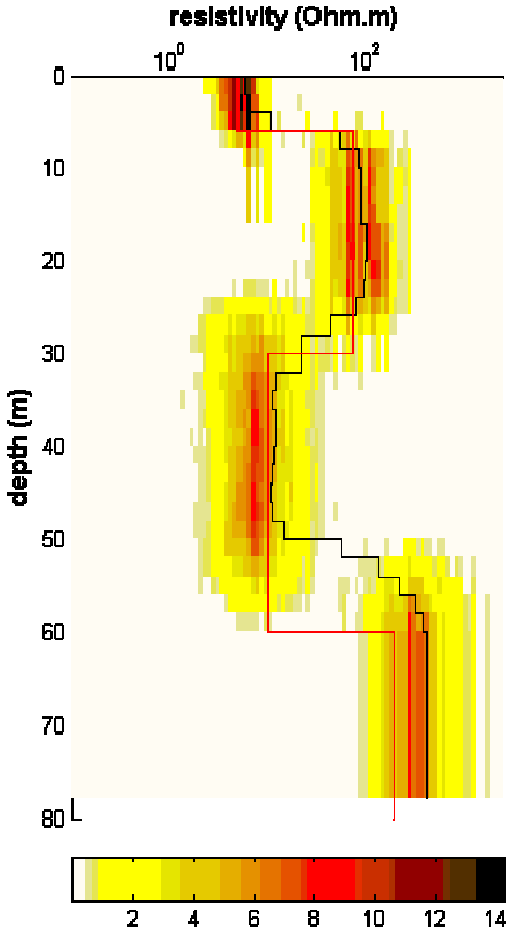

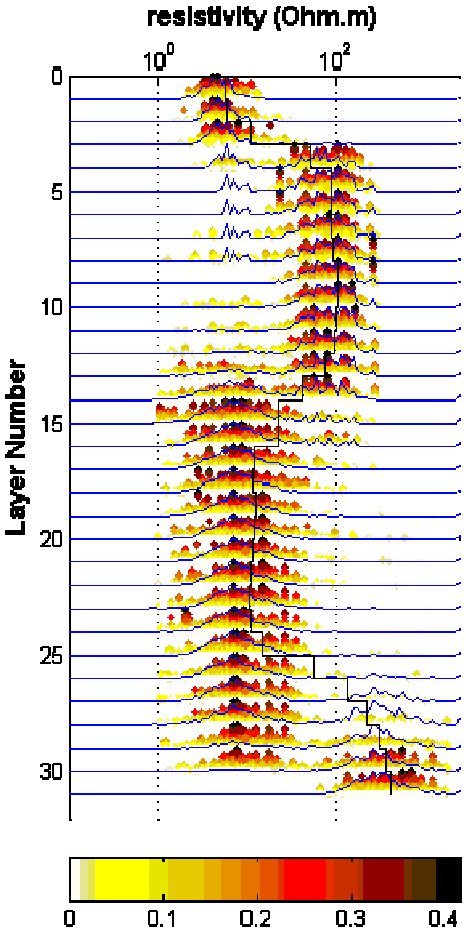

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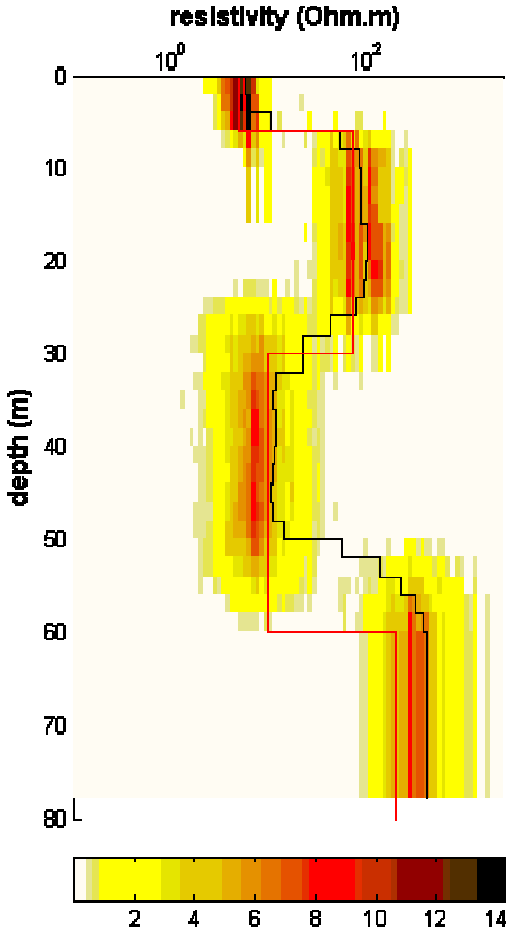

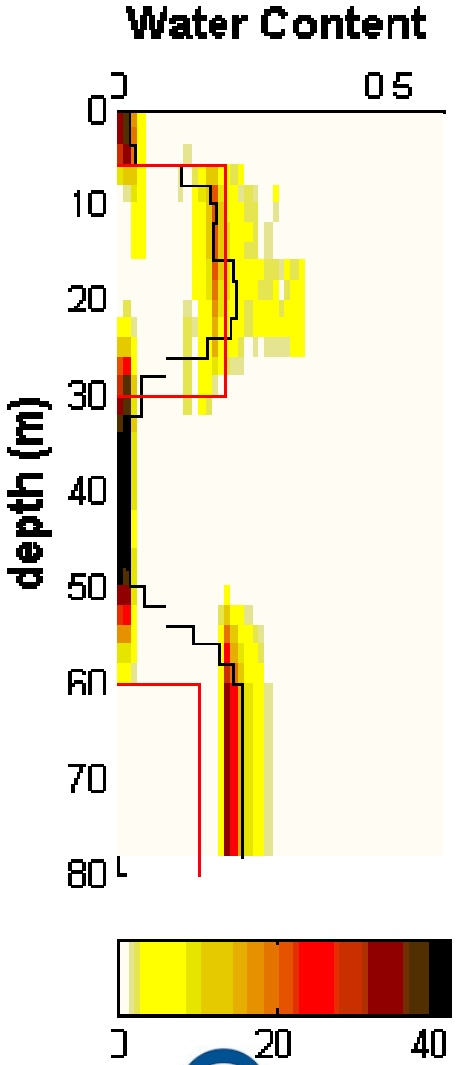

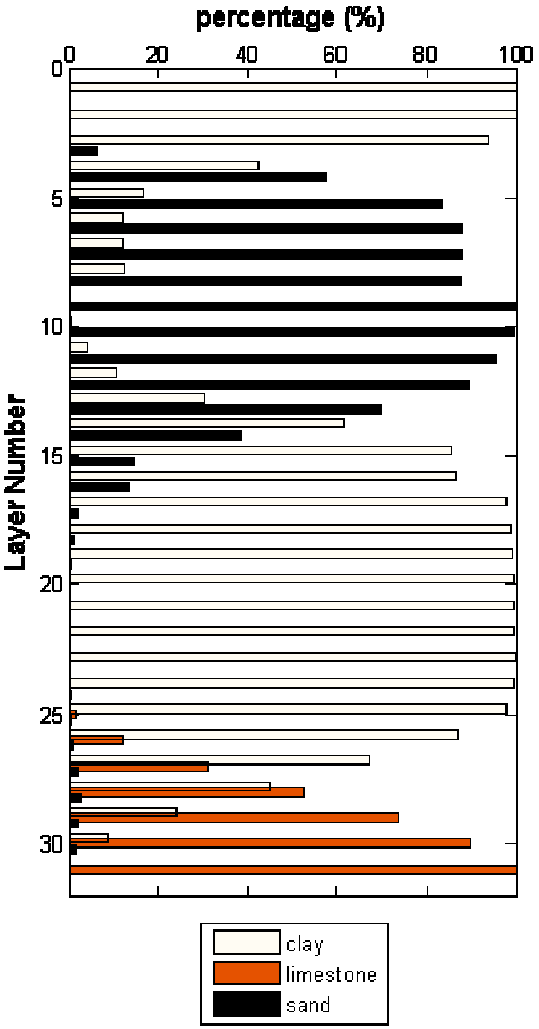

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Characterization of heterogeneous near-surface materials by joint stochastic approach

> Joint inversion of geophysical data

- Reduce equivalence problem by multiphysics / independent methods
- « facies » inversion (lithologic inversion etc..)

> Stochastic approach (Metropolis algorithm)

- Statistical results of interpretation
- Sensitivity and accuracy estimation of the model
- Scenarii Analysis (filtering the satisfying models trhough additional criteria)

> Outlooks

- Seismic (SASW) integration with MRS and electrical methods
- Use physical laws (Archie etc..) between parameters as an additional constraint
- Apply it in 2D / 3D (MRS is ruled by linear with water content equations: fast !)
- Use spatial variability as an input information (correlation length etc..)

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2D – 3D MR tomography

Girard Jean-François,
Legtchenko A.

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LTHE

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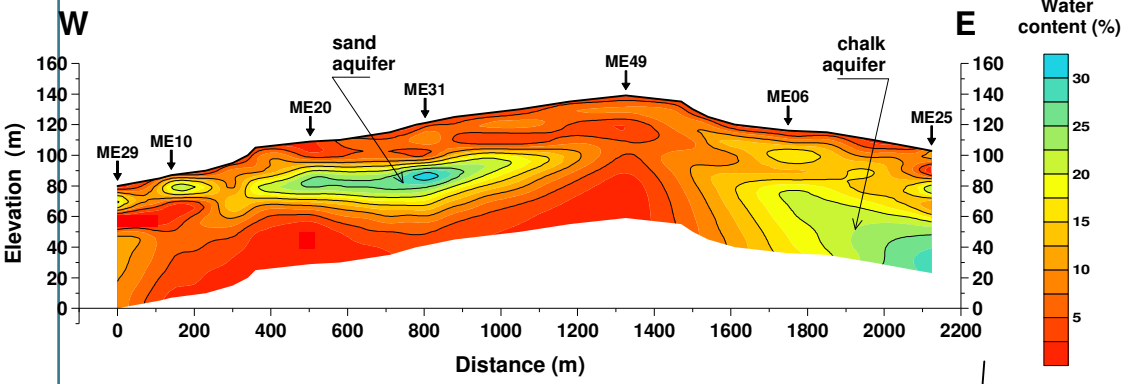
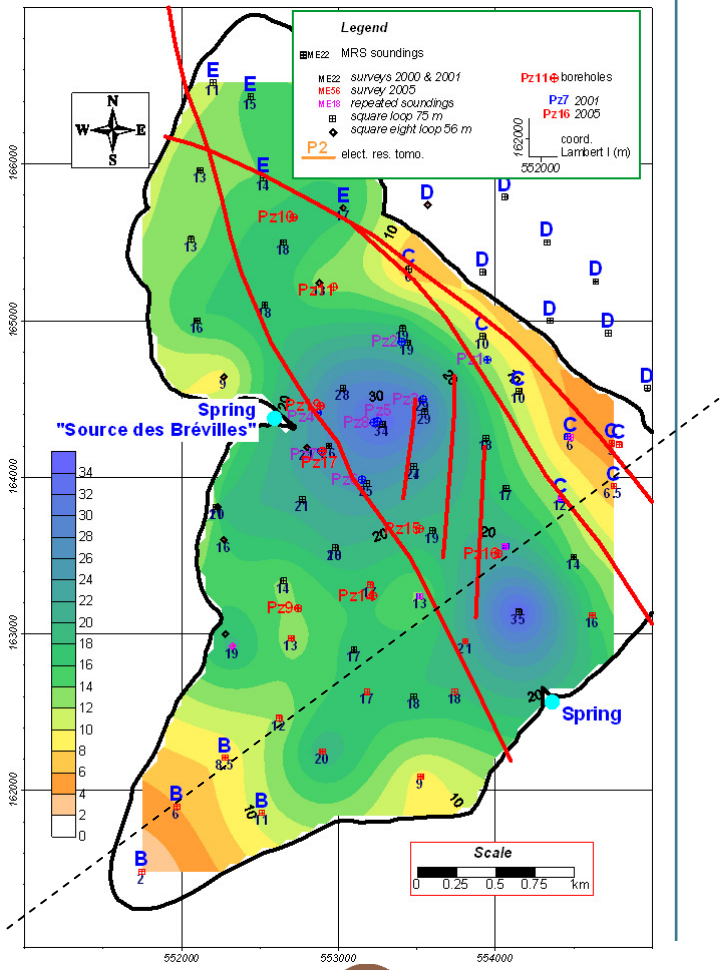
From interpolation of 1D results…
… towards a true 2D/3D tomography.



Test-site Montreuil-sur-Epte: 2D vertical section (above) & wter content map (right)



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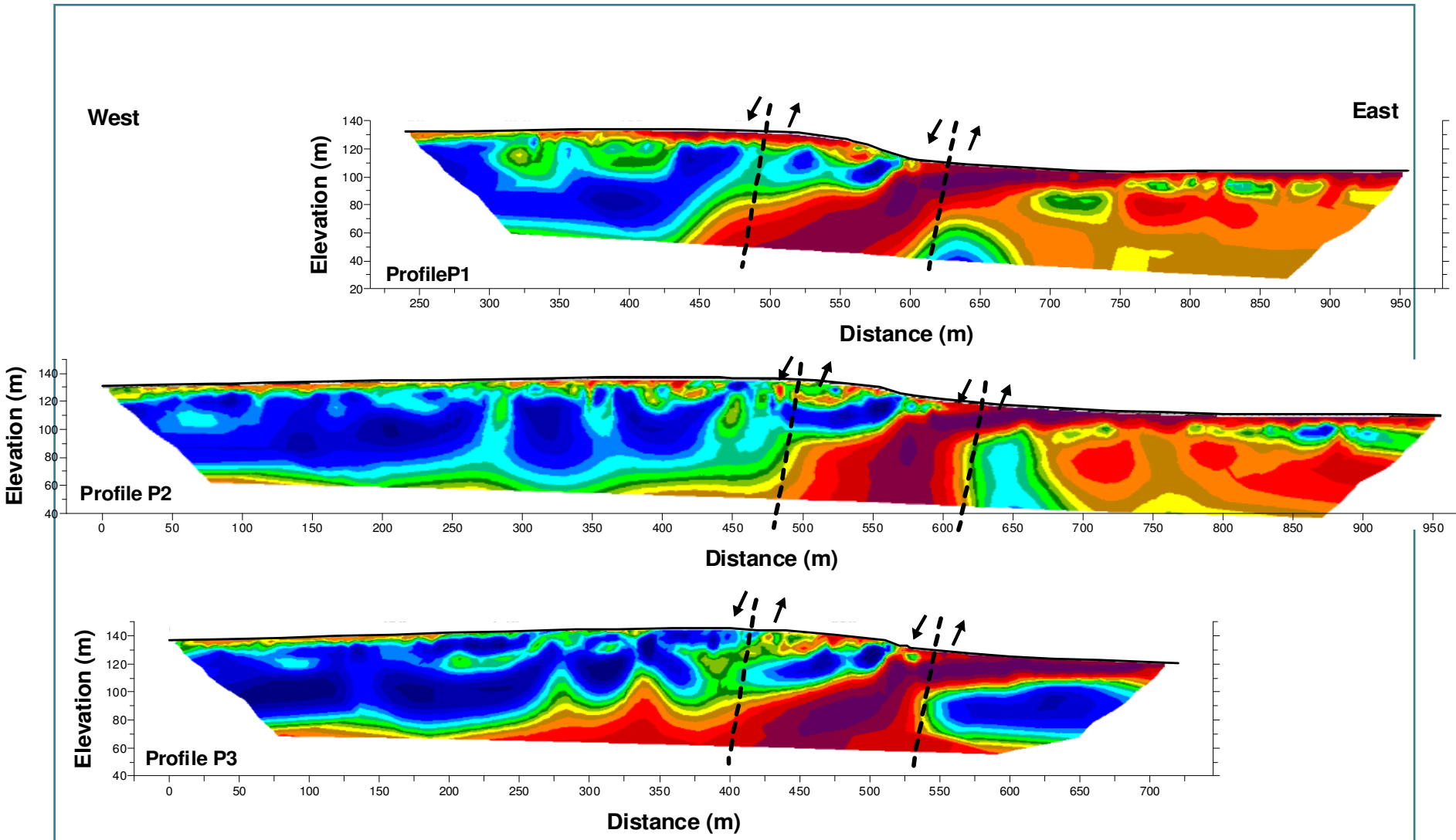

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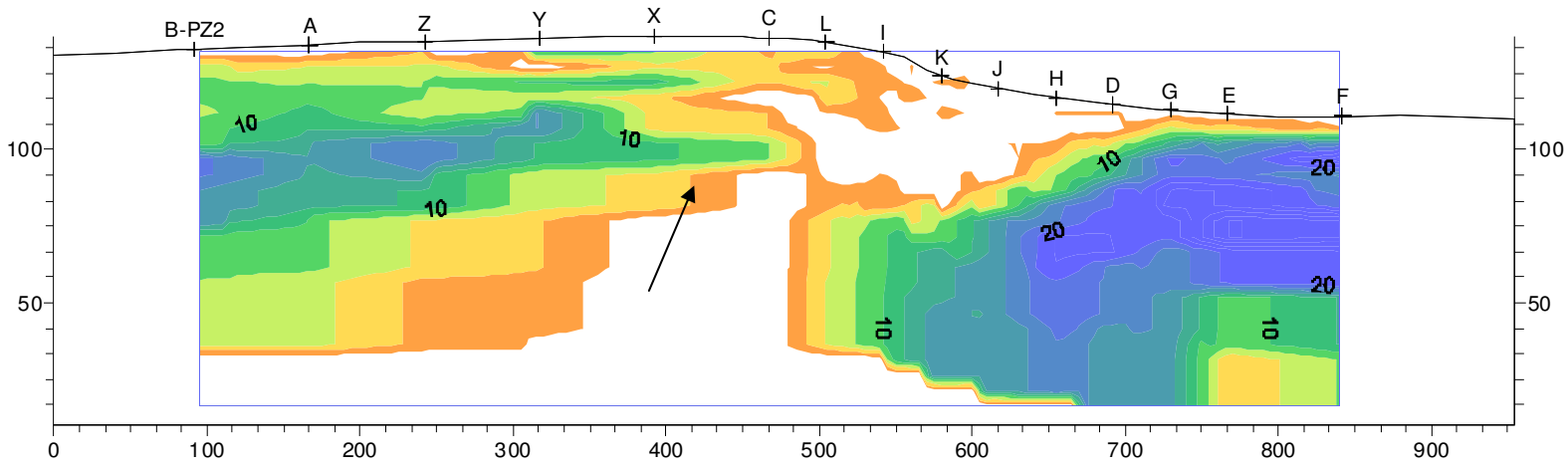
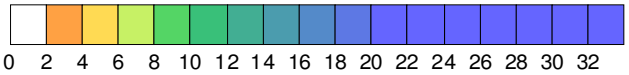
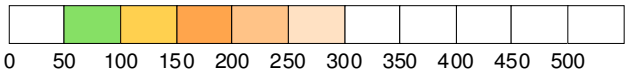


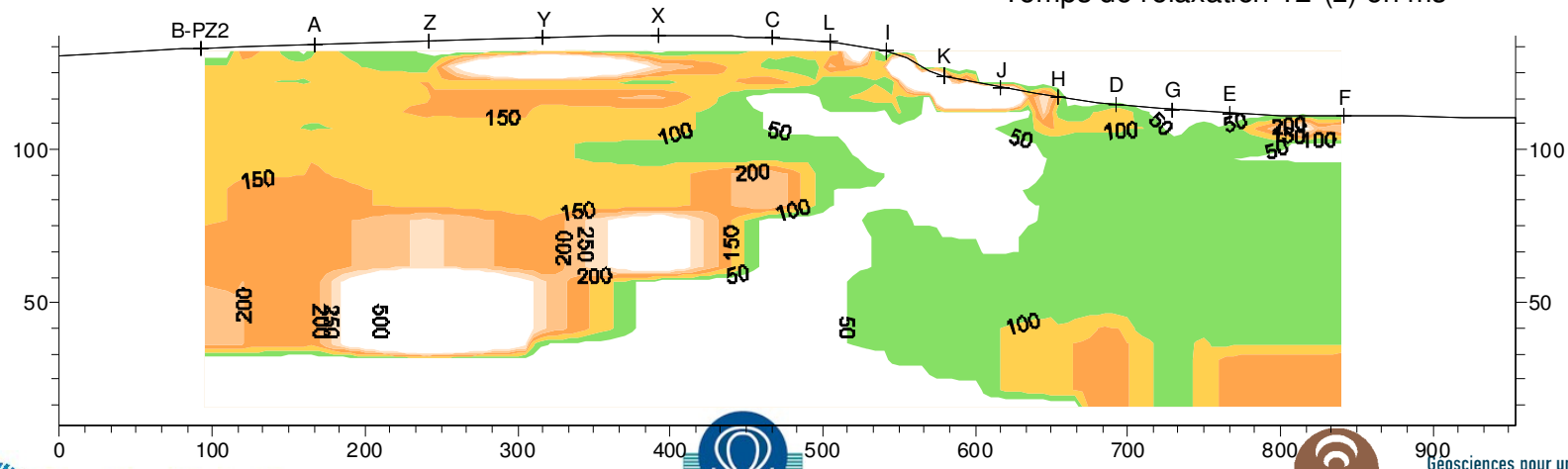
Profil P2: RMP en profilage 1D



Teneur en eau RMP (%)



Temps de relaxation T2*(z) en ms



Profil P2: RMP en profilage 1D

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Conclusion

> **A new methodology with a large potential of application**

> **After the project (end in december 2009)**

- Industrializing the prototype in a commercial equipment
- Diffusion of the methodology and the results of the on-site validation

> **Thanks for your attention !**

Recent bibliography

- Girard, J-F., Boucher M., Legchenko A, Baltassat J-M., 2007, **2D magnetic resonance tomography applied to karstic conduit imaging**, Journal of Applied Geophysics 63, 103-116.
- Girard, J-F., Baltassat J-M., Boucher M., Legchenko A., Vouillamoz J-M., Gutierrez A., Noyer M-L., Lachassagne P., 2007, **Aquifers imagery and hydrodynamic parameters estimation using proton Magnetic Resonance Soundings.** *Aquifers systems management: Darcy's legacy in a world of impending water shortage: selected papers from the International Association of Hydrogeologists (IAH) Dijon Symposium, 30th May-1 June 2006, Dijon, France*, Taylor & Francis / Balkema, part I, chap. 6, p71-85.
- Legchenko A., Ezersky M., Camerlynck C., Al-Zoubi A., Chalikakis K. and Girard J-F., **Locating water-filled karst caverns and estimating their volume using magnetic resonance soundings**, *Geophysics*,vol. 73, n°. 5 , sept-oct 2008; pp. G51–G61.
- J.-F. Girard, A. Legchenko, M. Boucher, J-M. Baltassat, **Numerical study of the variations of magnetic resonance signals caused by surface slope,** *Journal of Applied Geophysics* 66 (2008) 94–103.
- A. Legchenko, M. Ezersky, J-F. Girard, J-M. Baltassat, M. Boucher, C. Camerlynck, A. Al-Zoubi, **Interpretation of magnetic resonance soundings in rocks with high electrical conductivity**, *Journal of Applied Geophysics* 66 (2008) 118–127.