RESISTIVITY SURVEY AIMING AT IDENTIFYING HYDROGEOLOGICALLY ACTIVE ZONES IN LIMESTONE AND CLAY FORMATIONS: APPLICATION TO THE TOURNEMIRE EXPERIMENTAL STATION (AVEYRON, FRANCE).

M. Cushing[1], **A. Revil**[2,3], **C. Gélis**[1], **D. Jougnot**[3], **F. Lemeille**[1], **J. Cabrera**[1], **A. De Hoyos**[1], **M. Rocher**[1]
[1]IRSN, France, [2]Colorado School of Mines, USA, [3]LGIT-CNRS-Université de Savoie, France

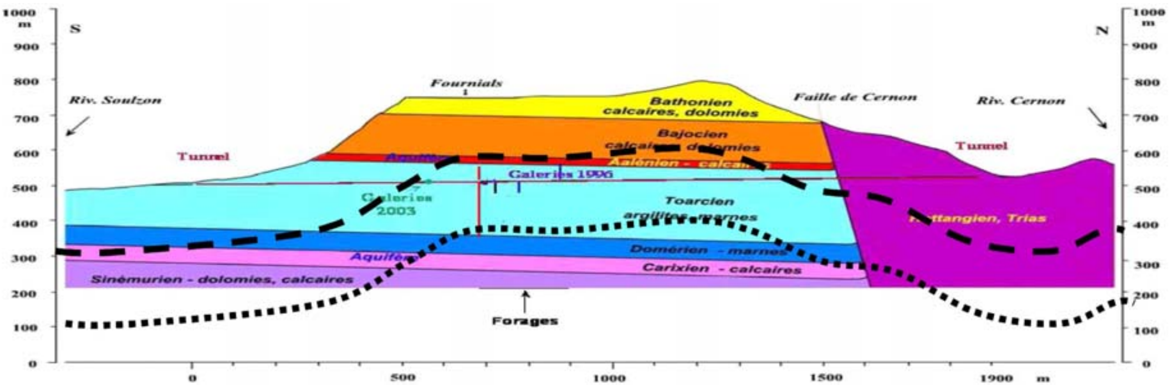
Introduction

IRSN gives a particular attention to the methodology required for the geological survey of a potential repository site in the Callovo-Oxfordian clays (COX) of the Meuse/Haute-Marne (MHM) area, specifically for fault detection. Andra has used standard techniques to detect faults, i.e. fieldwork and seismic reflection studies from the surface and vertical to sub-horizontal boreholes. This survey showed no hydraulically transmissive fault, a conclusion subsequently verified by the excavation of the Laboratory's facilities. South of the MHM study area, several of Andra boreholes have intercepted fractures, both in the Dogger and the Oxfordian limestones, which are open but without any vertical offset. They are located in a western extension of some mapped regional faults and are positioned in an interference zone on a 2-D seismic profile. This could indicate the presence of sub-seismic faults (vertical offset close to the 5 m detection limit). IRSN believes that these structures may relate to strike-slip secondary faults and might affect the COX.

Description of the IRSN experimental station of Tournemire

The IRSN Experimental Station in Tournemire (Aveyron, France) is composed of a tunnel drilled in an argilite layer belonging to a limestone-argilite-limestone sub-horizontal layer sequence (Figure 1).

Figure 1. **Geological cross-section of the Tournemire plateau and location of the tunnel**



A secondary fault zone was intercepted in clays by several drifts and boreholes from the tunnel. This hectometre-sized sub-vertical fault set, displaying a 2 m vertical offset and larger horizontal offset, presents significant variations of aspect, from a dry metre-sized fault gouge showing the same aspect as intact rock, to a draining breccia associated with a 10 m wide fractured zone.

From the surface, IRSN has performed 3-D high-resolution seismic survey which showed faults in the clays' underlying limestone layer and at these two units' interface but not within the clay layer itself (Cabrera, 2002; Cabrera, 2005). IRSN concludes that some locally hydraulically transmissive may be not identified by the classical surveys.

Recently, IRSN performed complementary investigations in order to identify possible related fault draining corridors. A resistivity survey test case has been conducted in the Tournemire experimental site in an attempt to visualise secondary structures and strike-slip faults that have already been identified. This technique could be seen as a complement to those previously mentioned.

The electrical tomography resistivity (ERT) experiment

A 2.5-km long baseline was set up from the surface to survey about 300 m of depth and inversion of electrical resistivity measurements were carried out to try to detect the top of clay layers and the upper limestone beds. Because of its sensitivity to water and clay contents, electrical resistivity tomography (ERT) should be an efficient tool to depict fractured and karstified zones, as the presence of water in these zones should cause low resistivity values.

In this case test, ERT images were obtained along three 2 520-m long profiles, two of them being oriented in the WNW-ESE direction and one in the NNE-SSW direction (Figure 2). These perpendicular oriented lines should somewhat give a 3-D vision of the Tournemire plateau.

The apparent resistivity measurements are used as observed data to perform an inversion with the Res2DInv computing code (Loke and Barker, 1995) based on a Gauss-Newton method allowing to get 2-D electrical resistivity model images by minimising the absolute differences (L1 norm) or the square of differences (L2 norm) between observed data and calculated data in the electrical resistivity model (Locke *et al.*, 2003). In Res2DInv, higher resisitivity contrasts can be obtained using the L1 norm (Figure 3), the L2 norm tends to smooth lateral contrasts (Figure 4).

Tests were first performed considering Wenner-Alpha configuration data alone and then coupled with Dipole-Dipole configuration data. Since Dipole-Dipole data were more sensitive to noise (Dahlin and Zhou, 2003), we decided to perform the inversion only with Wenner-Alpha data. The role of a priori knowledge is assessed by imposing (or not) the horizontal argilite layer electrical resistivity at an altitude of 550-560 m based on geological knowledge. Laboratory experiments have shown that the Toarcien argilite electrical resistivity range bewteen 30 and 150 Ohm m (Cosenza *et al.*, 2007), therefore a mean value of 90 Ohm m was chosen to characterise the argilite. A finite element numerical method was used and topography was taken into account to get calculated resisitivity values (Loke and Barker; 1995).

The electrical tomography resistivity (ERT) results

The obtained tomography images show the main characteristics of the layered structure with three separate sets of resistivity values: low to medium values with large variations corresponding to the Bathonian karstified dolomites, high values which clearly correspond to the Bajocian limestones and very low values corresponding to the argillite layer (Figures 3 and 4).

Figure 2. **Map of electrical resistivity lines in the Tournemire plateau and location of the underground tunnel. In red: secondary faults observed by drilling from the tunnel. Distance between points is 40 m**

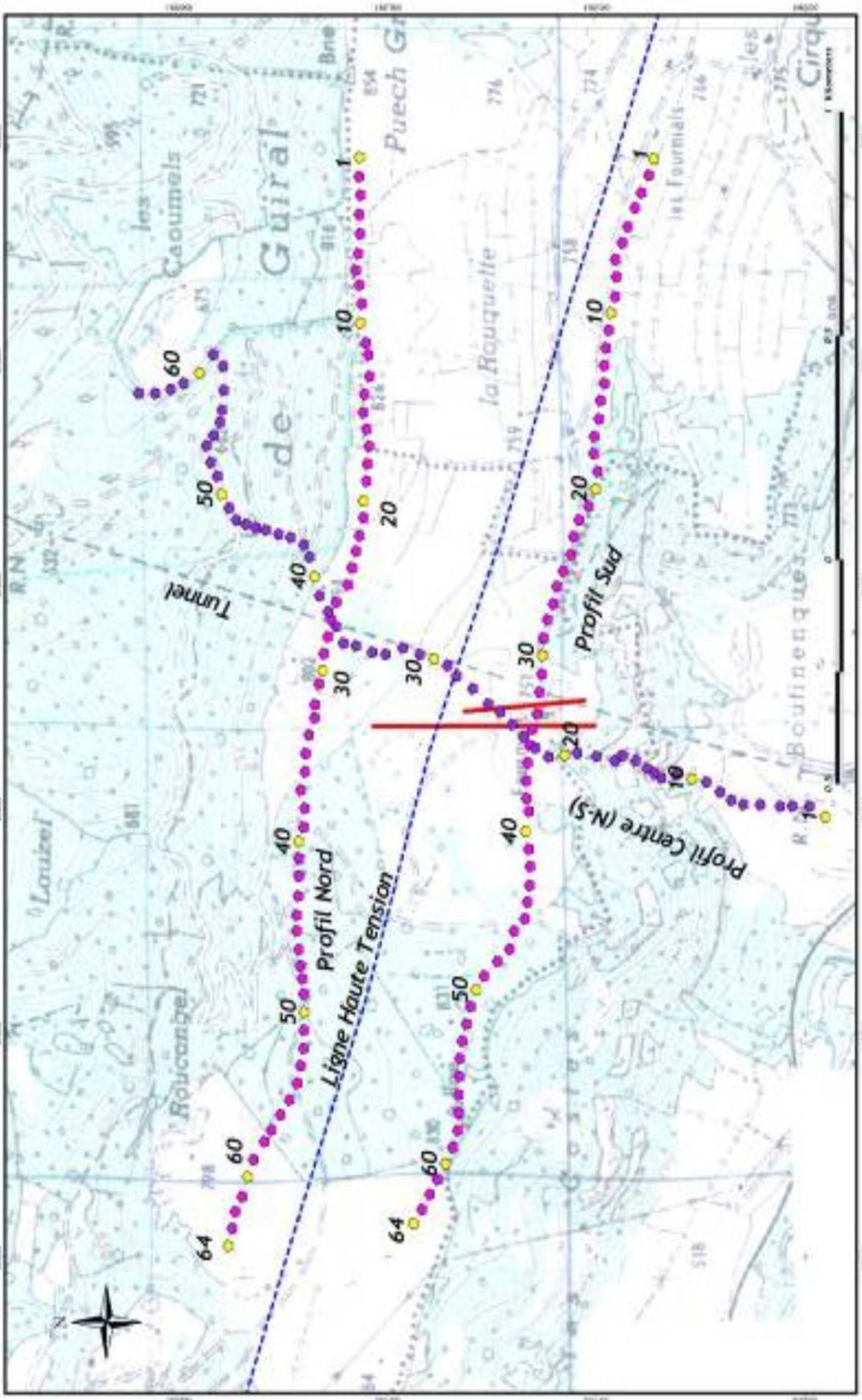


Figure 3. **Electrical resistivity image after inversion (L1 norm) of Wenner-Alpha configuration data for the Southern profile (A) and for the Northern profile (B). No constraint is added for the argilite layer location**

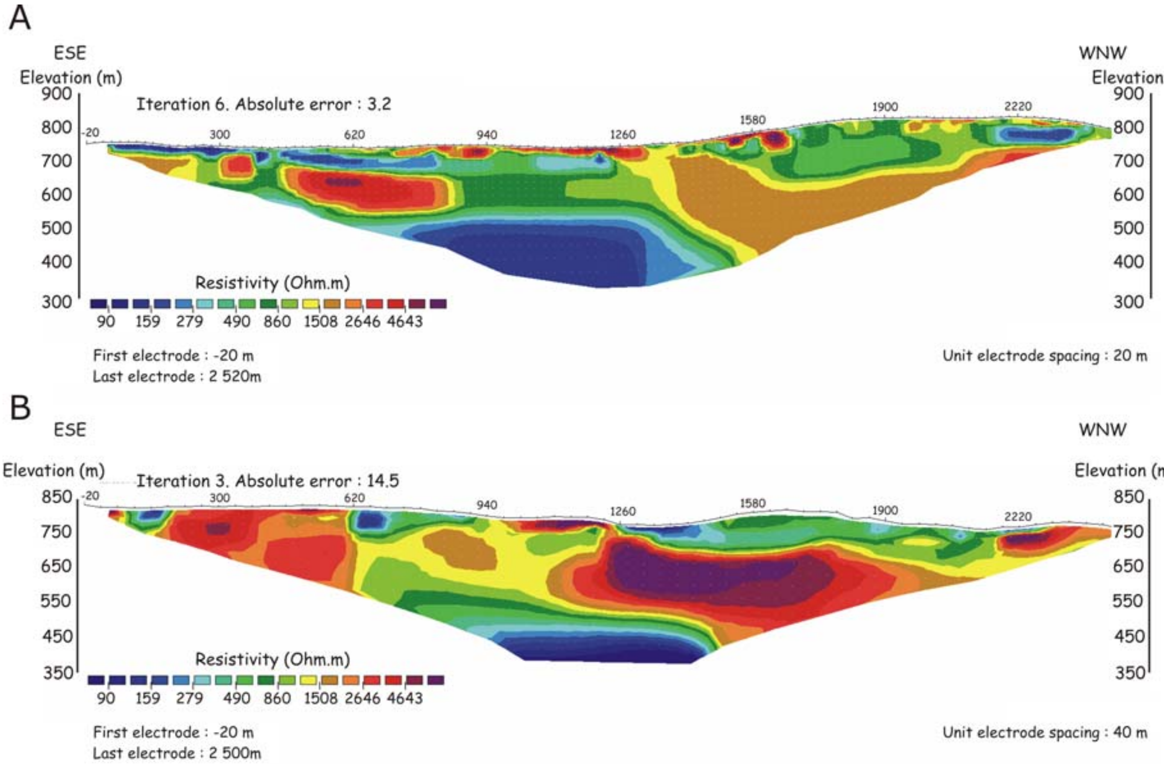
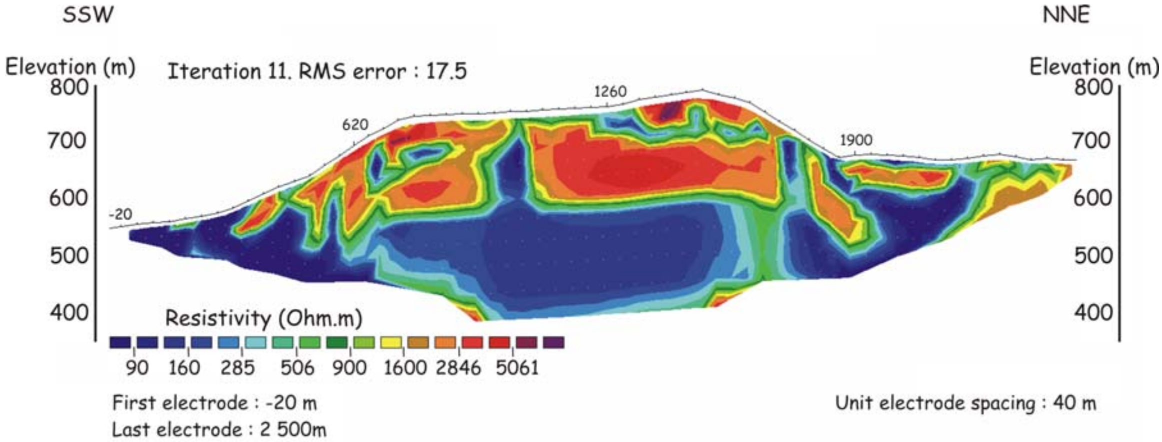


Figure 4. **Electrical resistivity image after inversion (L2 norm) of Wenner-Alpha configuration data. The argilite layer location is imposed in the inversion**



In the WNW-ESE oriented Southern profile (Figure 3), a large more conductive zone is seen between points 920 and 1 340 m, borders zone may be associated with faulted material. The N-S-trending and N130-trending fault zones seen from the tunnel (Cabrera *et al.*, 2001) (Figure 1) could correspond to fault zones identified around the point 1 340 m in Figure 3.

In the WNW-ESE oriented Northern profile (Figure 3), a low-resistivity zone is located from points 620 m to 1 250 m, in the continuity of the Southern profile's fractured zone. The abrupt transition from medium to high resistivity at point 1 250 m may be interpreted as a fault. Geological data show that the interface between the Bathonian and Bajocian layers is located at an altitude of 570 m, which is in agreement with the interface location in the electrical resistivity images.

In the Southern and Northern WNW-ESE oriented profiles, the argilite layer is identified at the bottom of the resistivity images with resistivity values ranging from 90 to 150 Ohm m. These values are consistent with the range of 30 to 150 Ohm m range measured by Cosenza *et al.* (2007).

The NNE-SSW profile (Figure 4), almost parallel to the tunnel (Figure 2), cross-cuts the Cernon regional fault. Due to field conditions, this profile does not have a true 2-D geometry, especially in its northern part, and high topography variations occur along the profile. The argilite layer position was imposed by fixing a resistivity equal to 90 Ohm m for altitudes lower than 560 m and between points 0 and 1 850 m (position of the Cernon fault) (Figure 4). To the North of the 1 850 m point, only one Triassic limestone and dolomite layer is present in the Tournemire plateau (Figure 1). Because of the strong topography, the numerical mesh is deformed, which explains the apparent dip of the argilite layer's top.

At point 1 040 m of the NNE-SSW profile (Figure 4), a highly conductive zone appears to dip vertically. This could be related to a more hydraulically conductive zone related to the secondary fault system already detected in the tunnel in argilite. Between points 1 720 m and 1 860 m, a highly conductive corridor appears; that should correspond to the Cernon fault but its position is shifted towards the South with respect to the fault position in the geological map and observed in the tunnel. This could be due to a geometrical effect of the non-2-D measurement line shape or to the presence of tectonic slices, mapped to the West and East of the cross-section and located to the South of the Cernon fault. They could lead to a more fractured zone in Bajocian and Bathonian layers. The top of the argilite layer remains located at an altitude comprised between 550 and 600 m, as imposed in the model.

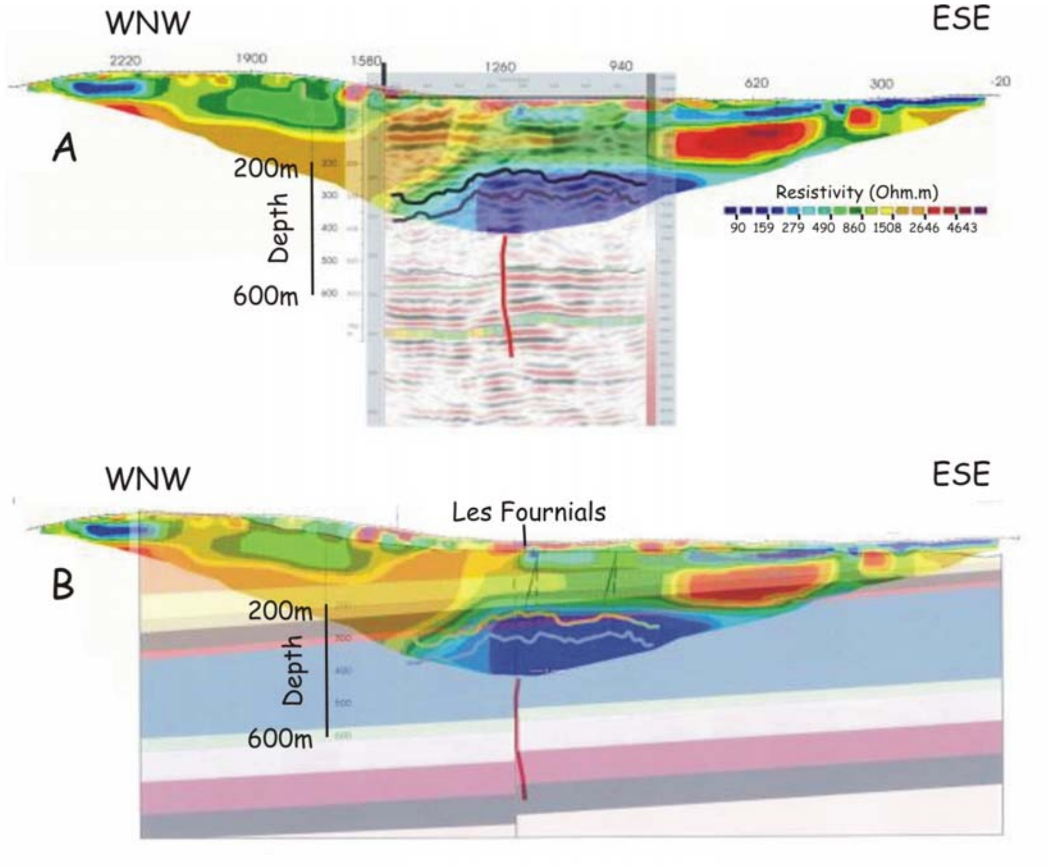
Comparison of ERT results and other data

The depth of the argilite layer's top inferred from the electrical resistivity images' interpretation is consistent with the one based on 3-D HR seismic reflection data and geological studies (Figure 5). Moreover, a fault identified in the underlying limestone in the 3-D HR Seismic data (Figure 5) is consistent with the prolongation of the expected fault located in the West border of the lower resistivity zone in the Bathonian limestone of the Southern profile.

Conclusion

This electric tomography test turns out to be very promising for conducting resistivity surveys aiming at locating hydraulically conductive zones. Such a "light" geophysical investigation method could therefore be a useful complement to heavy geological and geophysical survey. These kinds of investigations could complete the regional hydrogeological framework used in high-level waste disposal safety assessment.

Figure 5. **Comparison between ERT results and (A) 3-D high resolution seismic reflection results where the top of argilite layer is identified as well as a fault in underlying limestone and (B) geological cross-section**



References

Cabrera J., C. Beaucaire G. Bruno, L. de Windt, A. Genty, N. Ramambasoa, A. Rejeb, S. Savoye, P. Volant, 2001. *Projet Tournemire: synthèse des résultats des Programmes de Recherche 1995/1999.* IRSN report.

Cabrera J., 2002. Evaluation of the 3-D seismic high resolution method at the argillaceous Tournemire IRSN site. Eurosafe Berlin 2002, 4/5 novembre.

Cabrera J., 2005. *Évaluation de la méthode sismique 3-D haute résolution pour la détection de failles à déplacement sub-horizontal*, IRSN unpublished report DEI/SARG/2005-050.

Cosenza P., A. Ghorbani, N. Florsch, A. Revil, 2007. Effects of Drying on the Low-Frequency Electrical Properties of Tournemire Argilites, Pure and Applied Geophysics, 164, 2043-2066.

Dahlin T., B. Zhou 2004.. A numerical comparison of 2-D resistivity imaging with 10 electrode arrays, Geophysical Prospecting, 52, 379-398.

Loke et Barker, 1995. Least-square deconvolution of apparent resistivity pseudo-sections. Geophysics, 60, 6, pp 1682-1690.

Loke M.H., I. Acworth, T. Dahlin, 2003. A comparison of smooth and blocky inversion methods in 2-D electrical imaging surveys, 2003. *Exploration Geophysics*, 34, 182-187.