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Contribution of multi-instrumental geophysics to determine the hydromechanical functioning of a deep-seated coastal landslide (Cirque des Graves, Normandy, France) – EGU2019-2415

1 GENERAL CONTEXT AND ISSUE

The coastline of eastern Calvados (Normandy) is affected by four large deep-seated rotational-translational landslides. Those slopes instabilities took place because of the underlying lithology, composed by numerous sedimentary layers, in link with sediment inflows due to alternating between marine and colluvial deposits.

The “Cirque des Graves” is characterized by an **important size** (1 km x 500 m) and **numerous stakes** (villas & strategic road). Variations of groundwater level in the landslide body is setting Cenomanian chalk panels in motion, sinking on Albian sands and sliding on Oxfordian clays.

It is studied since the major acceleration of 1982, during which around 30 buildings were damaged [Maquaire, 1990]. Previous researches allowed to well constrain the functioning in regards to geomorphology, kinematic and lithology of the unstable area [Maquaire, 1990; Lissak, 2012; Lissak et al., 2013].

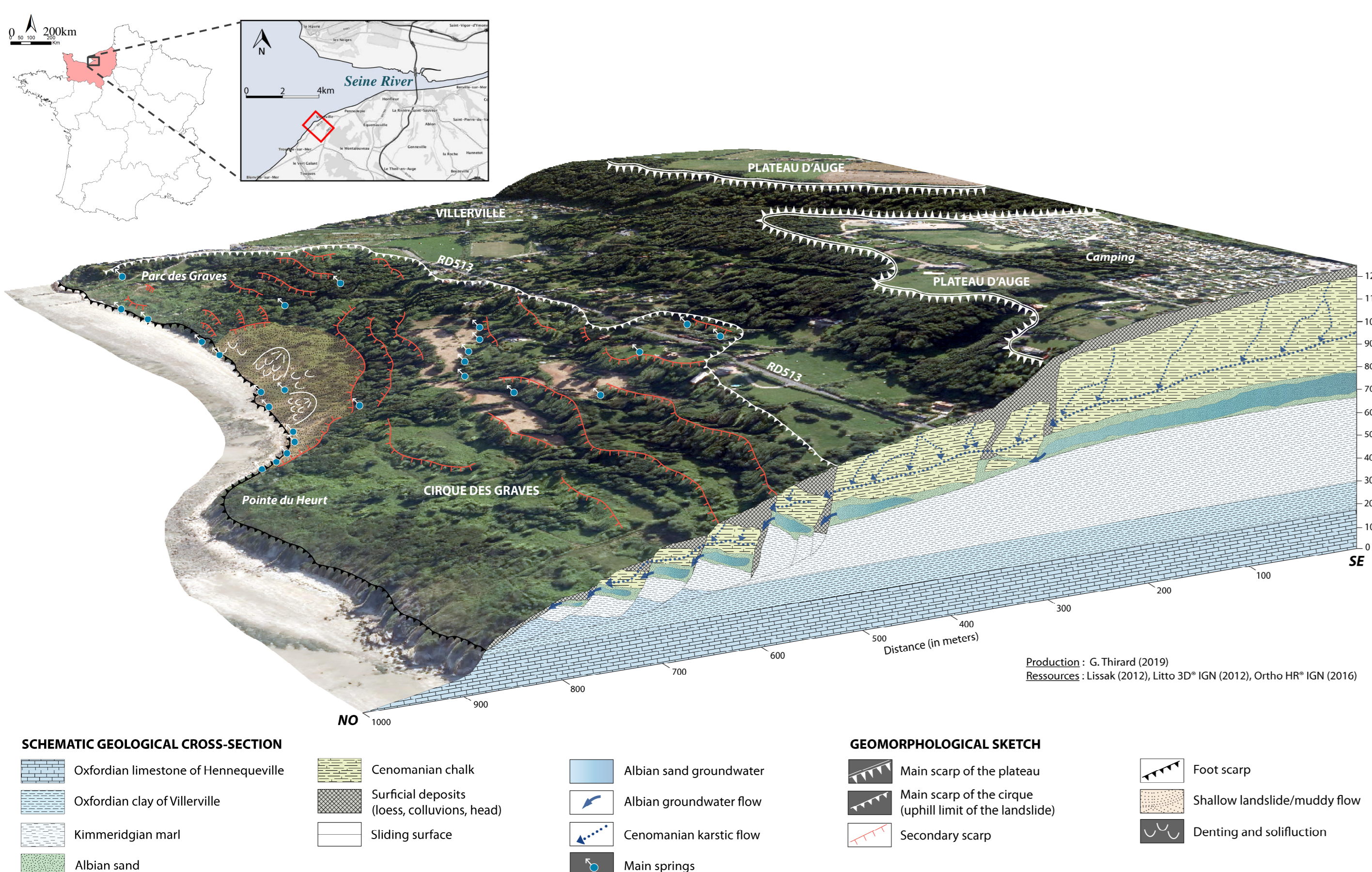


Figure 1. Conceptual geological and geomorphological functioning of the Cirque des Graves

A more robust knowledge is needed in regards with **hydrogeological functioning**. Furthermore, the middle zone (with major stakes), is structurally not as well defined as the eastern extremity.

Funded by the ANR RICOCHET project (ANR-16-CE03-0008), this research aims to **improve this knowledge** on the landslide structure and the groundwater flows, which requires the use of various geophysical methods.

2 METHODS OF INVESTIGATION & OBJECTIVES

Three different geophysical methods were used to understand the internal morphostructure and its dynamics, especially in the middle zone:

1- **Spontaneous Polarization (SP)** to map the drainage paths, quantifying the natural electric potential (without information about the depth). From this data, we selected a profile with an interesting gradient in the middle of the landslide, for further analysis.



Figure 2. SP and GPS surveys during the spontaneous polarization survey

2- **Seismic refraction** investigations to complete the acquaintances thanks to waves propagation to the bedrock.

3- **Electrical Resistivity Tomography (ERT)**, for giving informations on shallow structures, lateral edges and water saturation.

SP was conducted in the **entire landslide**, while seismic and ERT investigations were **focused on a cross-section** comprising an interesting SP gradient.



Figure 3 – Seismic streamer on the upstream-downstream profile



Figure 4 – Seismic in-vehicle source on the transverse profile

3 SPONTANEOUS POLARIZATION SURVEY

This method allows to identify the main water flows in the structure of the landslide. Around **1,200 measurement points** were acquired to realize a **map of the electrical potential** over this great landslide of 47 ha, using the electrofiltration method, adapted to porous environments [Aubert, 1997; Naudet, 2004].

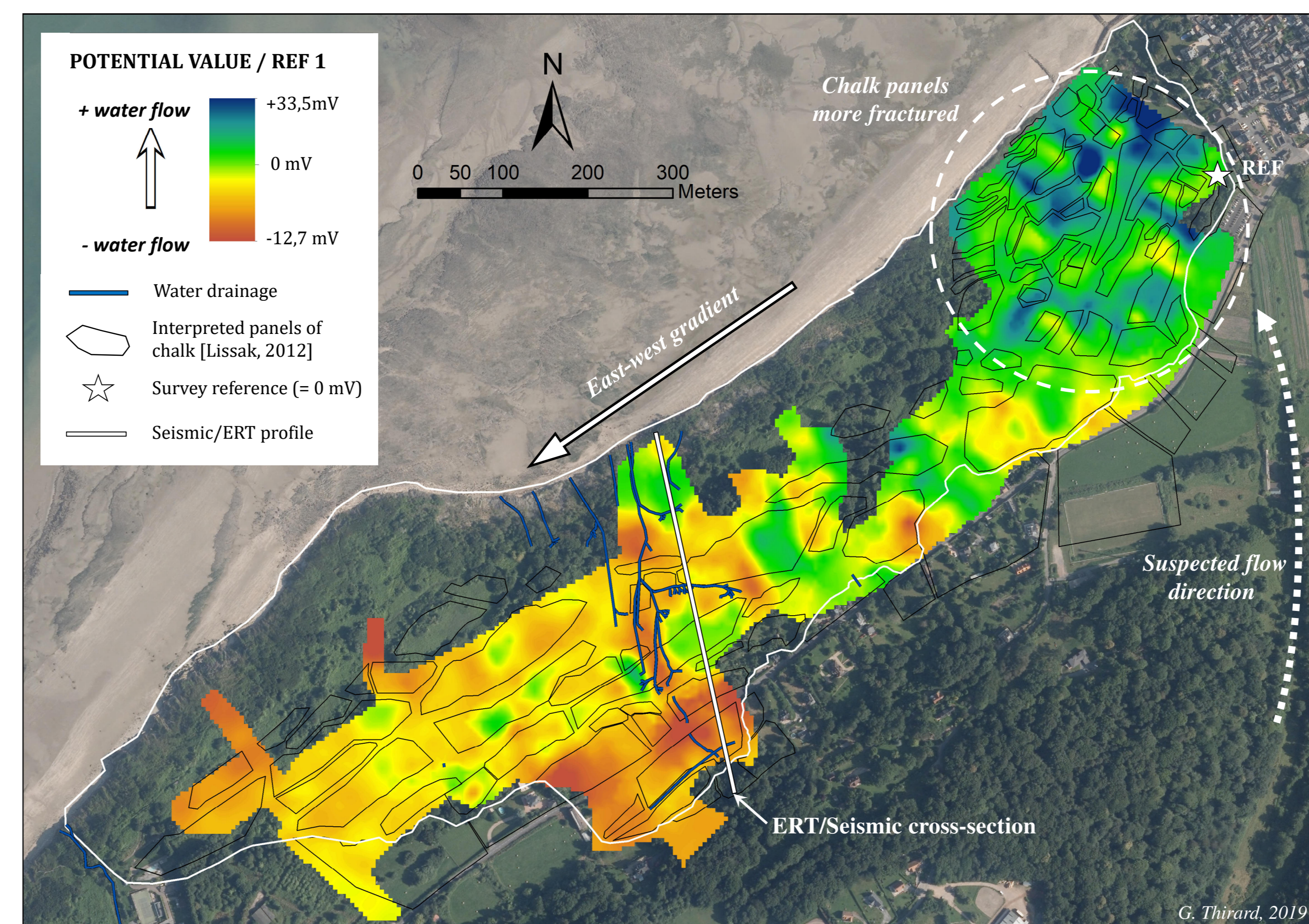


Figure 5. Spontaneous polarization anomalies on the Cirque des Graves after kriging measurement points

An east-west gradient and some discontinuities appear. Thanks to **landforms analysis and previous knowledge** on the morphostructural units, **three assumptions** can be made:

- 1- A link exists between very fractured chalk panels and an **intensive drainage** in the east part;
- 2- The dry valley located upstream of the east part is a **preferential path** for water inflows;
- 3- On the west half of the cirque, the lowest values corresponds to a **drainage area** of surface water and springs, which **reduce infiltration** and the electrical response in surface.

4 INTERPRETATION BY SEISMIC REFRACTION

Seismic refraction allows to **constrain the interpretation in depth**. The speed propagation of P-waves brings us an overview about the thickness of the layers. Seismic refraction is adapted for discriminating between loose and compact materials [Coulouma et al, 2012].

Two seismic sources were used depending on the possible accesses:

- 1- Double-hammer on an upstream-downstream cross-section;
- 2- More powerful in-vehicle source on an additional transverse profile for the deepest limits at the cross with the first survey.

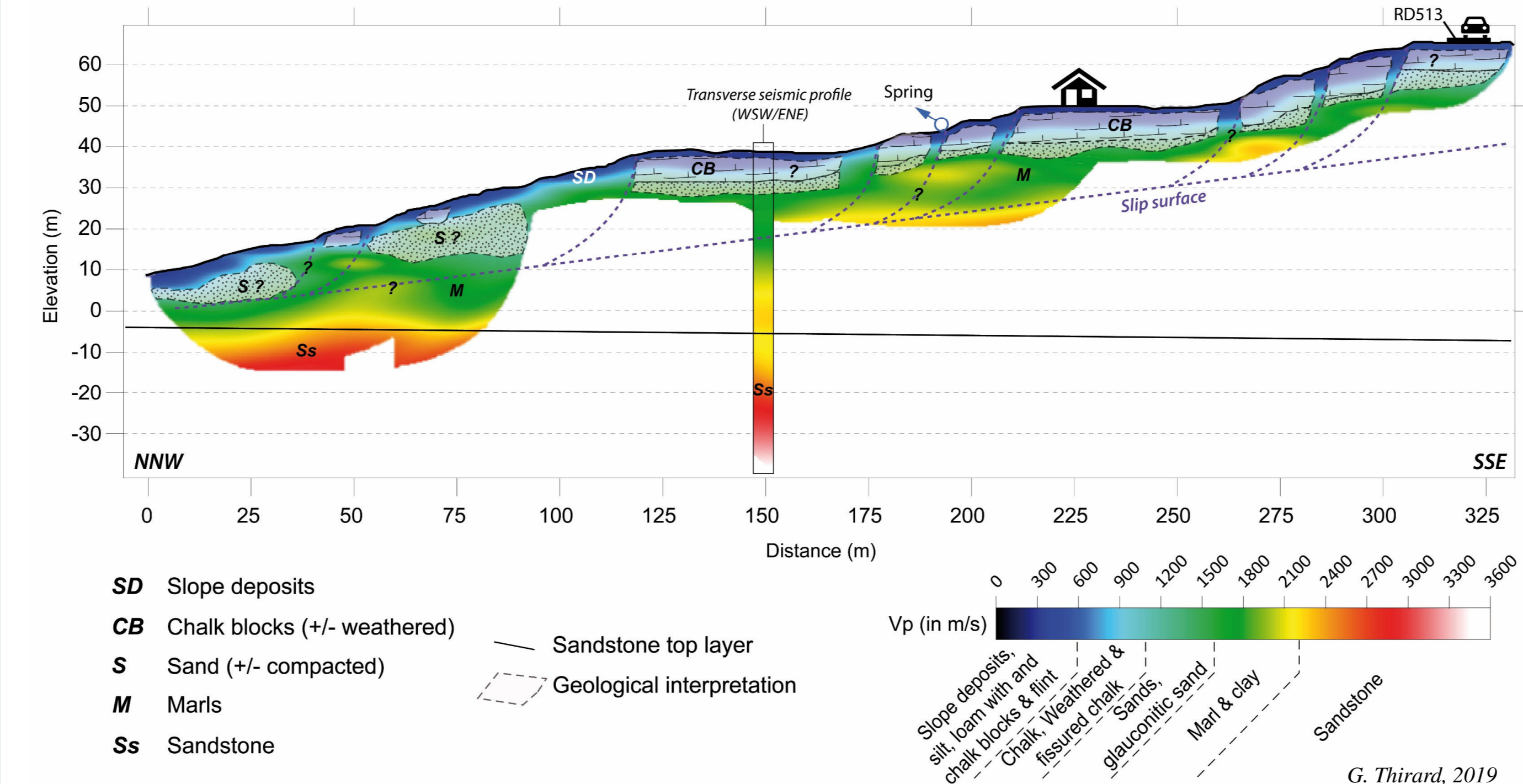


Figure 6. Interpretation of the lithostratigraphy with the help of seismic refraction (RMS error = 3.8% or 3.37ms) The values ranges are based on Lissak (2012)

5 REFINEMENT OF THE MODEL BY ERT

Two methods of data acquisition were combined for Electrical Resistivity Tomography (ERT) survey :

- 1- Dipole-dipole for the sub-surface;
- 2- Wenner-Schlumberger for the deepest structures.

ERT enables to get a **better sight of the lateral limits** and allow to identify the water content and rock weathering/fracturing [Bellanova et al., 2018]. The survey was conducted in dry conditions (end of summer).

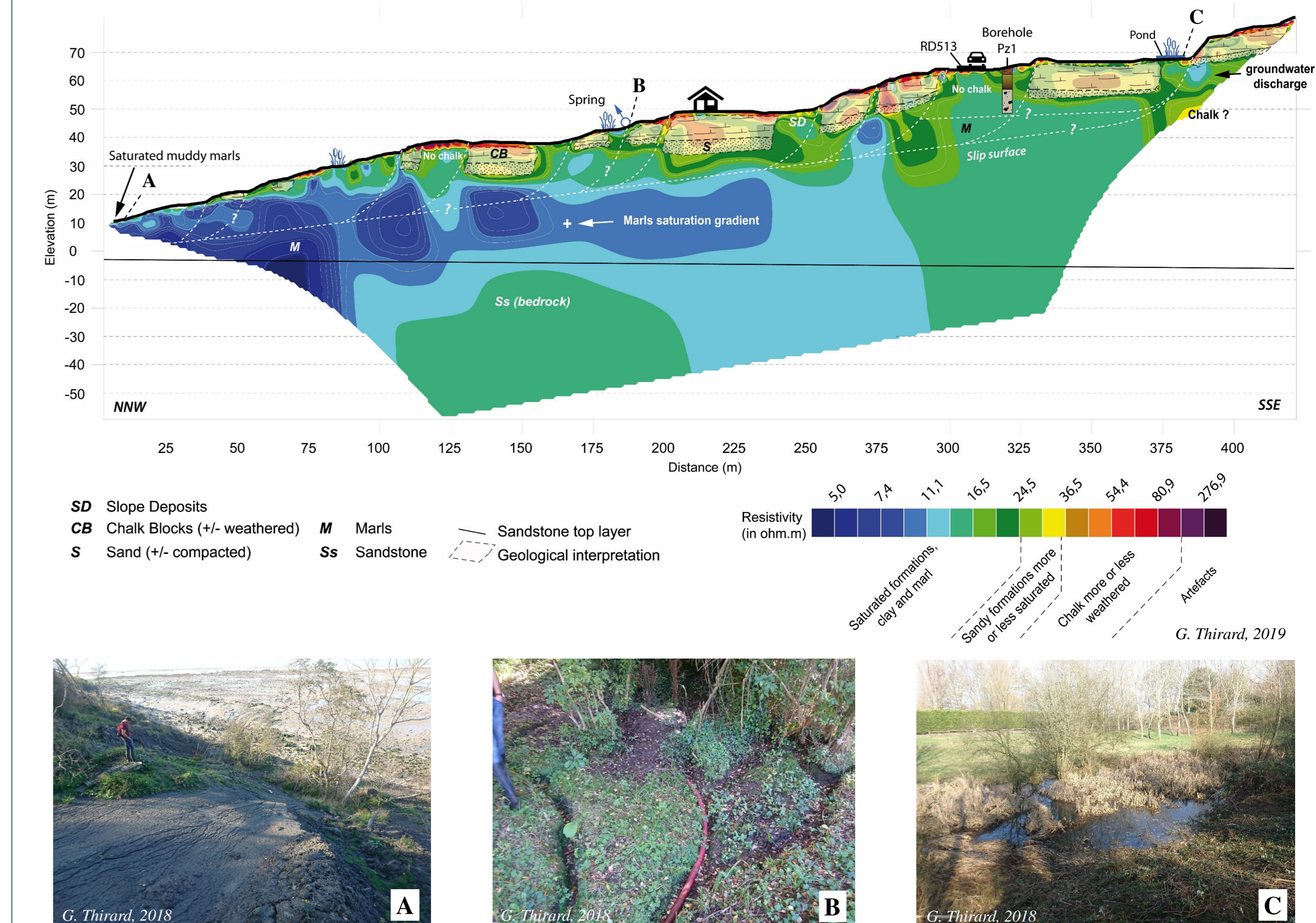


Figure 7. Interpretation with the help of ERT (Iteration 4 ; RMS error = 3.7%). The values ranges are adapted from Lissak (2012) (A) Marly mudflow at the foot of the landslide; (B) Springs nearby the seismic/ERT profile; (C) Pond at the bottom of the main scarp (water stagnation)

6 RESULT OF THE CROSS-INTERPRETATION

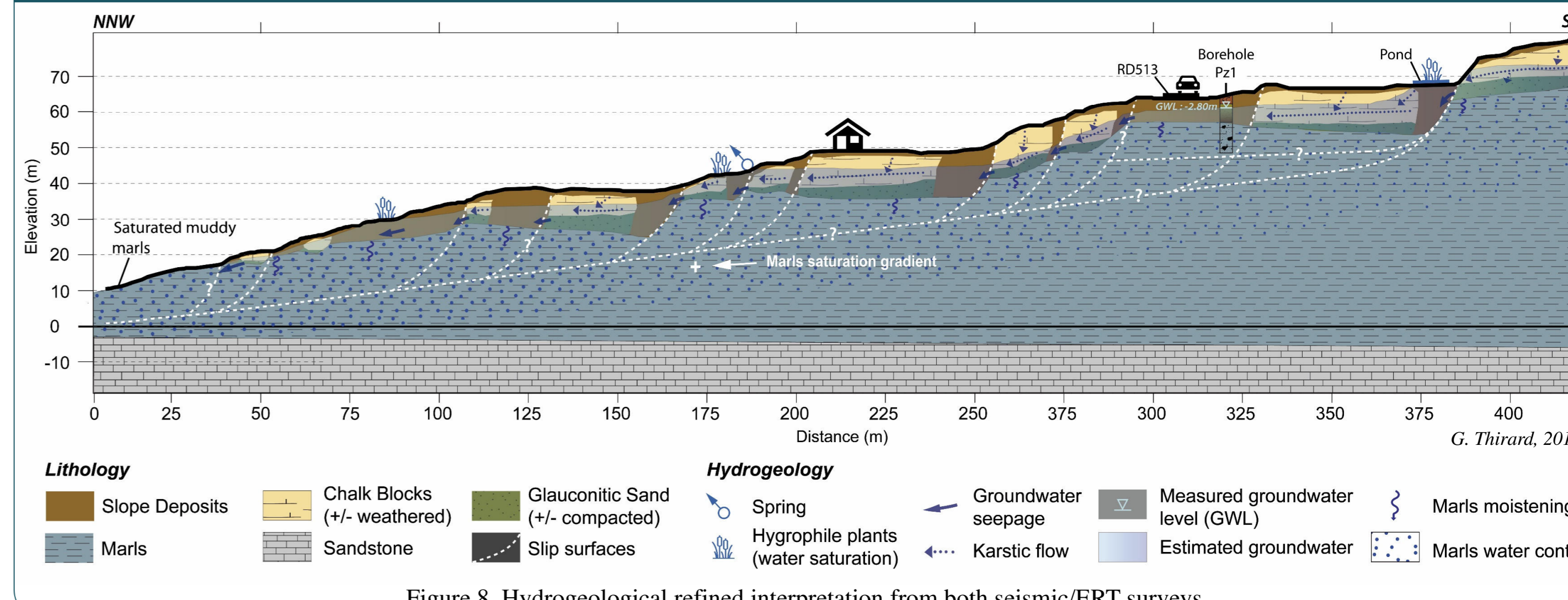


Figure 8. Hydrogeological refined interpretation from both seismic/ERT surveys

7 CONCLUSION & RESEARCH PERSPECTIVE

The three different geophysical methods **complement one another**:

- SP & ERT are completing each other on the hydrogeology knowledge (water flows, internal saturation);
- Coupling seismic and ERT surveys allows refining the structural model for depth and lateral bounds.

Through that work, the knowledge was clearly improved in many ways:

- ✓ **Robust assumptions** have been issued from the SP mapping **about the groundwater preferential circulation** at the landslide scale;
- ✓ **SP & ERT results are linked**, in particular on the upstream-downstream saturation gradient;
- ✓ **The limits and thicknesses** of chalk panels, sands and marls are now **better-constrained** in the middle of the Cirque des Graves thanks to both ERT/seismic surveys.

From these cross-geophysical data, numerical models will soon be conducted thanks to the **hydromechanical software FLAC®**, in order to confirm the hypothesis of functioning and define the **boundary conditions of reactivation** of this landslide.