In-situ geophysical and hydrochemical monitoring of landslide dynamics (Pégairolles, Languedoc, France)

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Introduction

Landslides are caused by the combination of ground inherited conditions (geology or glacial history) and triggering factors (weather, earthquakes, human activities). A correlation between rainfalls, groundwater flows and slope movements has been demonstrated at a series of sites emphasizing the role of water circulations on slope instabilities. Because landslides are complex dynamic systems in time and space, many uncertainties exist about the internal hydro-physicochemical processes affecting the sliding mass and the associated deformation visible at surface.

In order to better study the hydraulic triggering mechanisms, much effort has been applied at different sites combining geological, geophysical and hydrogeological approaches in order to constrain the 3D geometry of the sliding (Jongmans & Garambois, 2007), the related deformation (Malet et al., 2002) and the groundwater flows within the landslide (De Montety et al. 2007). Despite considerable advances in landslide processes understanding and modelling (Tric et al., 2010), the dynamic of such systems remains poorly constrained, in particular the relationships between infiltrations, groundwater flows and fluid-rock interactions within the sliding while this coupled effect is recognised as a key factor for slope instabilities. Over the past few years, the time-lapse electrical resistivity tomography is also used to monitor the spatial and temporal distribution of water content through the landslide. This contributes to a better characterization of the dynamic nature of landslides providing images of both infiltrations and groundwater patterns at depth. Nevertheless, the rock-fluid interactions associated to water circulations has been so far little studied and referenced for landslide investigations, although those internal mechanisms may modify the hydro-mechanical behaviour of the unstable slope and may also contribute to the slope failure. Because the rock-fluid interactions occur at small scales within the sliding, near field observations are essential to better constrain the hydro-physicochemical processes conducing to slope instabilities.

The Lodève landslide aera is located in Languedoc (France), 60 km to the northeast of Montpellier (Figure 1). It corresponds to a series of deep-seated landslides (up to 100 m in depth) with slow slip displacements (4 to 6 mm/year). In this area, the landslide activity is associated with both intense short duration precipitations events (called "Cévenol events", 300-500 mm/day) and the related dissolution of Triassic evaporite layers at depth, which controls the quaternary evolution of the local valley. In this region, no seismic or other tectonic activity contribute to slope instabilities. Considering a relatively simple geological context and the presence of a unique triggering factor, this landslide offers a natural observatory to study the impact of heavy rainfalls on slope landsliding. As a consequence, this work focuses on the spatial and temporal dynamics of landslides, and especially on the relationships between rainfalls, ground water flow and deformation within the landslide.

Method

The project proposes an innovative approach consisting in coupling borehole instrumentation (geophysics, hydrodynamics and hydrochemistry of aquifers) and surface measurements (GPS, hydrodynamics and hydrochemistry of the sources). This approach allows an in-situ high-frequency monitoring of both internal processes and deformation. For this, two nearby boreholes were drilled in 2012 to 60 meter depth. One of the boreholes was fully cored and downhole geophysical measurements (Lofi et al., 2011) were recorded in both of the holes (Figure 2). An set of downhole monitoring sensors was installed to image both deformation and water flow within the landslide, both infiltrations and deep circulations, in order to study the role of fluids in slope instabilities. This work is then based on a complete and original instrumentation deployed in the two nearby boreholes since

2012. The landslide is investigated by in situ permanent observatories (Figure 3) for both geophysical (electrical resistivity and deformation, both with m-scale spacing and daily data acquisition) and hydro-geochemical monitoring (piezometric height, pH, temperature, fluid sampling at 4 depth intervals, with monthly data acquisition).

Figure 1 *Oversight of the Pégairolles experimental site installed within the vineyards visible in the center part of the picture. The down slided part of the hill located just above the vineyards is delimited at the top by a change in vegetation.*

These studies also include geological and geomorphological detailed mapping of the landslide, a detailed core descriptions and analyses in order to characterize the sedimentary succession and fabric of both the hanging wall and footwall, as well as geomechanical and petrophysical characterization of rocks. The data will provide constraints an efficient input to physical and numerical models describing the landslide hydrodynamic behavior in relation with climatic events. Moreover, this monitoring may lead to the identification of geophysical proxys of internal processes responsible that may be used as indicators for landslide precursor. This may contribute to a better management of natural hazards.

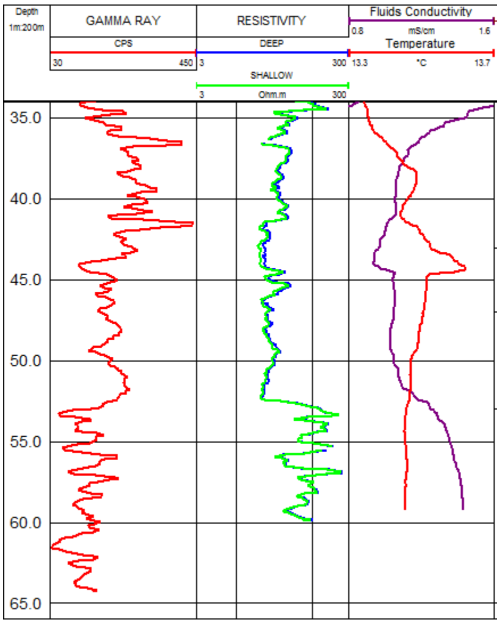
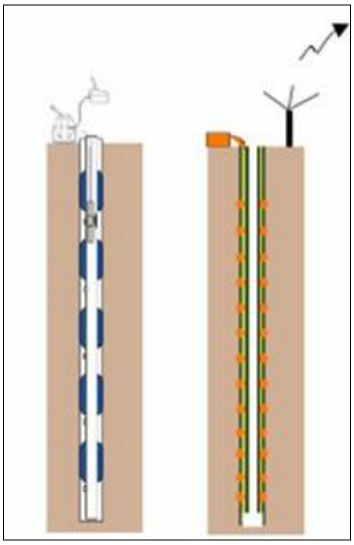


Figure 2 *Downhole geophysical measurements recorded in one of the instrumented boreholes. Alternating clays and anhydrite layers are identified easily from electrical measurement and natural gamma data. While anhydrite is characterized by high electrical resistivity and low gamma ray values (below 53 m depth), clays have an opposite behaviour.*

(A) 

(B) **Required parameters are missing or incorrect.**

Figure 3 *(A) Downhole observatorie installed at Pégairolles in two nearby boreholes. The first hole is equiped with a Westbay completion featuring 4 distinct sampling intervals (centered on 30, 45, 52 and 60 m). The second hole is equiped with an electrical monitoring array along which a optical fiber has been fitted. Tee optical fiber is fitted with 10 bragg sensors set to measure vertical strain.*

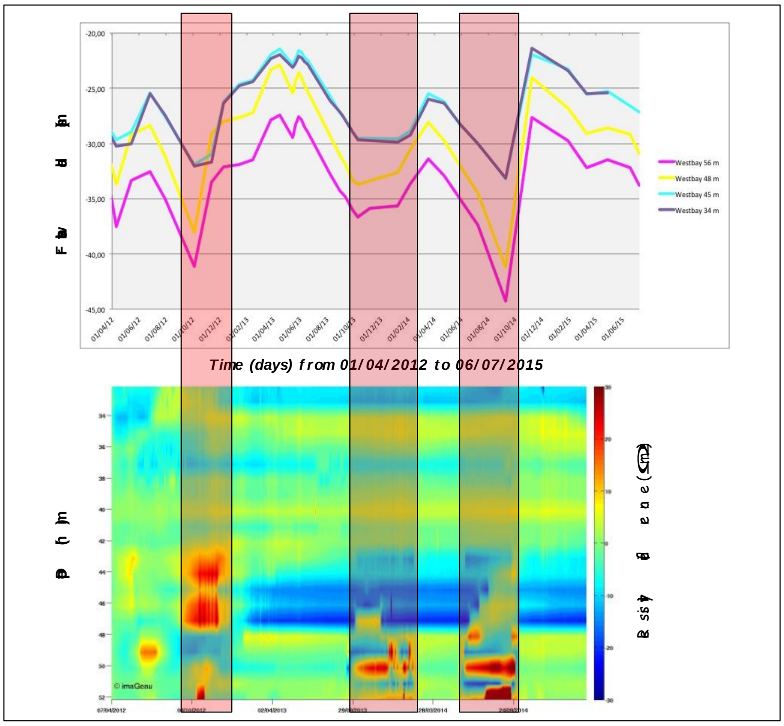


Figure 4 *To the top, subsurface fresh water heads from the 4 westbay sampling intervals and over a period of 3 years (April 1, 2014 to July 6, 2015). At bottom, electrical resistivity difference image obtained over the same period and down to 62 meter depth. The electrical resistivity is sensitive to the ionic charge of the pore fluid which changes in relation to evaporite layers dissolution. Changes in electrical resistivity appear to mostly coincide with fall periods and low water levels after summer.*

Conclusions

The data recorded so far during five years of investigations (Figure 4) show mainly seasonal changes within the slope, in relation to recharge and discharge processes of the penetrated aquifers. We also observe particular events correlated to heavy rainfall events and characterized by both electrical resistivity and geochemical variations at depth. These first results point out the revelance of the downhole monitoring to progress towards a better understanding of internal landslide processes in relation with climate forcing.

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