GEOPHYSICAL INVESTIGATION OF THE LARGE SÉCHILIENNE GRAVITATIONAL MOVEMENT, THE ALPS (FRANCE)

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INTRODUCTION

Major gravitational movements are common in the metamorphic formations of mountain ranges and show various types of failure, such toppling, sagging and translational or rotational sliding. The different failure processes are mainly governed by the characteristics of the discontinuities (foliation, schistosity, faults and fractures) affecting the mass (Antoine et al., 1990). In the Alps, most of the gravitational movements have probably been initiated or reactivated after the retreat of glaciers some 10,000 to 15,000 years ago, and have evolved at very different rates, depending on the initial geological and topographic characteristics, as well as on the other factors contributing to lower the stability (presence of water, earthquake ground motions, climatic cycles). The instability process progresses through periods of stabilisation and reactivation and leads to slope failure after decades or centuries. The Séchilienne movement, which is located in the French Alps near Grenoble, is affecting the right southfacing bank of the Romanche river (figure 1) The slope is homogeneously made of micaschists with subvertical foliation at right angle with the valley (except in the upper part of the slope where it is folded with an axis inclined of 30° in the north direction) and is affected by 3 sets of subvertical fractures. The main family runs ENE-WSW and delimits vertical slices in the rock mass. It is clearly distinguished by several hundred meters long depressions in the morphology associated with scarps of several meters high (Vengeon, 1998). Some of these depressions are 20 m wide, attesting the long duration of the gravity-induced processes. The slope angle is about 40° in the lower part of the hill (elevation between 330 m and 950 m) and decreases to 20° between 950 m to 1100 m (Mont Sec). Near the crest, a 20 m high scarp which is followed on a distance of several hundreds meters reveals an upper collapse. The non-freshness of the scarp and the absence of glacial erosion sign and deposits show that this movement is relatively old and occurred after the last ice age. The part of the slope which exhibits signs of current instability is located in the middle of the hill, at an elevation between 700 m and 850 m, and involves a rock volume estimated to about 3 million cubic meters (Giraud et al., 1990). This area was extensively instrumented since 1988 (Evrard et al., 1990) and the measured displacements are globally oriented in a SSE direction, perpendicular to the strike of the main fractures, and dip downhill between 10° and 20°. The movement rate varies from a few cm/year to a few dm/year. Besides geological surface observations and displacement measurements, a 240 m long gallery was excavated in 1993-94 at the elevation of 710 m. It showed a succession of blocks delimited by highly fractured and sheared zones parallel to the main fracture set. No sign suggesting the presence of a sliding surface has been observed (Vengeon, 1998). Numerical modelling with the discrete element method was able to retrieve the main field observations and suggest that the movement at Séchilienne is controlled by the main discontinuities cutting the mass into blocks and includes toppling and local sliding, evolving through progressive damaging to a potential large sliding of unknown characteristics (Vengeon, 1988).

The data available at Séchilienne have led some authors to propose that the hill could be affected by a massive movement, delineated to the East by the active zone and to the North by the Mount Sec scarp. No western limit is clearly visible in the topography and the thickness of this moving mass is unknown. Consequently, the volume estimations for a rock avalanche scenario are highly variable and poorly constrained, ranging from 3 to 20 hm^3 (Giraud et al., 1990 ; Antoine et al., 1994) with a global mass movement between 50 to 100 h m^3. The aim of this study is to try to get information at depth over the movement area by using geophysical techniques and to confront the results with existing geological data.

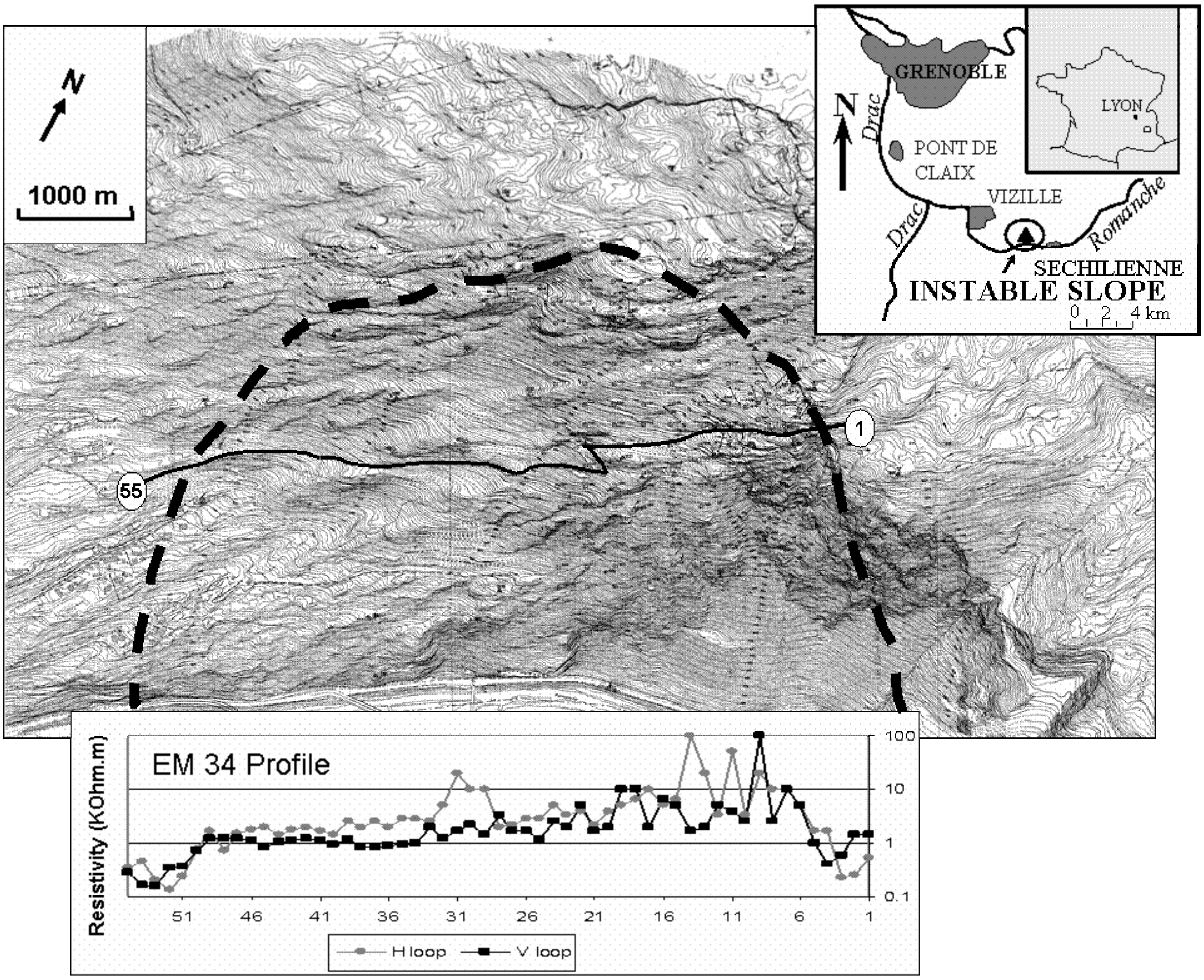

Figure 1: (a) Location of the Séchilienne movement. (b) Topographical map of the movement with the location of the geophysical profiles and the results of one EM34 profile apparent resistivity in log scale)..

GEOPHYSICAL INVESTIGATION

Geophysical methods have been rarely applied to large gravitational mass movements, particularly in rocky conditions (Havenith et al., 2002) This probably lies in the field difficulty and the effort required for making measurements on high slopes. However, geophysical methods are relatively flexible and are the only techniques able to give information on the inside of the mass. Besides, they investigate a large volume of rock and some of the measured parameters (seismic velocity, for instance) can be correlated to mechanical properties (fracturing degree). Due to the difficulty of performing measurements, only two types of measurements were made: electromagnetic profiling (EM 34) and seismic tomography. Five EM profiles with two loops, 20 m apart, were carried out across the movement in order to find a possible relation between the electrical resistivity and the degree of fracturing within the micaschists. The penetration depth is between 4 m to 30 m with vertical loops and very shallow with horizontal loops. One EW profile passing just above the active zone is presented in figure 1 for the two loop position. To the East, the profile starts in the undisturbed rock and the apparent resistivity is lower than 1 KΩm. At the limit with the active zone, the resistivity strongly increases to more than 20 KΩm. Passing the active zone, the resistivity regularly decrease to the western end of the profile where values below 1 KΩm are obtained. The evolution of apparent resistivity with distance is approximately the same for the two loop positions. These results, corroborated by the other profiles, suggest that the highly fractured zones are well correlated with high resisitivity values and distinguish from the undisturbed mass which are characterised by resistivity values lower than 1 KΩm. Measurements all over the slope also suggest that the intensity of the gravitational process is spatially variable, as resistivity values regularly vary between unaffected and affected zones. On another hand, we benefit from the presence of the 240 m long gallery to perform a seismic tomography between the side and the gallery. Forty-height geophones, 10 m apart, were deployed and registered the signals generated by 20 explosions (figure 2). The seismic image obtained after inversion of the travel-time values with a RMS of 1% is presented in figure 2. The robustness of the image has been tested by starting with different initial models. The major features are the large range of P-wave seismic velocities whose values are between 800 m/s and 5000 m/s, and the presence of strong lateral velocity gradients. Considering that the volume investigated is almost homogenous rock, these two features highlight the strong fracturing and weathering degree whose intensity is not only depth dependent but also varies laterally. No systematic superficial damaged zone overlying a sound bedrock has been evinced at least down to 100 m depth. These results, showing the juxtaposition of highly fractured and undamaged zones are consistent with field observations and motion measurements at the surface and in the gallery, as well as with the geological model used for discrete numerical simulations. These simulations seem to exclude the scenario of a large and deep seated rock slide at the present time, as long as the characteristic discrete block motion will be observed. The hill is characterised by a heterogeneous fracture degree resulting from old tectonic structures and the action of current gravity forces. The distribution of the apparent resistivity values however suggests that the damaging process has affected a zone much wider than the most active area showing instability, which is consistent with the latest movement measurements.

CONCLUSIONS

Two geophysical techniques – electromagnetic profiling and seismic tomography – were applied on the large gravitational movement of Séchilienne (northern Alps, France) which affects a slope made of metamorphic rocks (micaschists). All the zones exhibiting signs of movement (collapse, toppling, sliding) are characterised by extremely high apparent resisitivity values (over 20 KΩm), probably resulting for the presence of voids, while undisturbed zones are systematically lower than 1 KΩm. Seismic tomography shows high contrasts in seismic velocity (from 800 m/s to 5000 m/s), both vertically and horizontally, with the juxtaposition of strongly fractured blocks and undisturbed ones. This picture of a spatially and heterogeneously fractured mass is consistent with the geological observations made at the surface and in the gallery. In the future, it is planned to perform electrical tomography profiles at specific places in order to confirm the lateral extent of the mass affected by the movement.

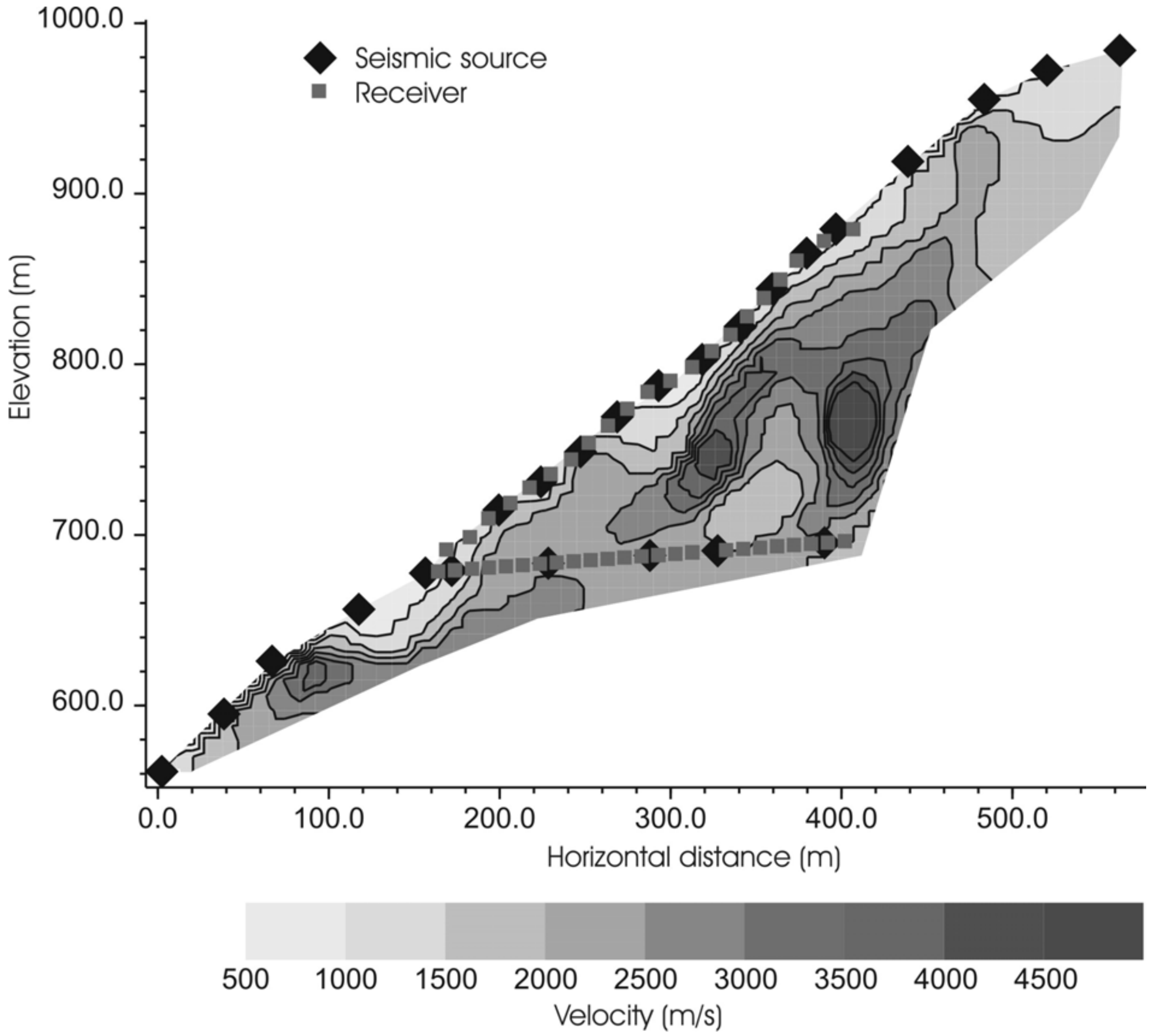

Figure 2: Seismic tomography through the Séchilienne movement (see location in figure1)

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