

LANDSLIDES

in research, theory and practice

VOLUME 3

Edited by E. Bromhead, N. Dixon
and M-L. Ibsen

Proceedings of the 8th International Symposium on Landslides
held in Cardiff on 26–30 June 2000



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The Super-Sauze Landslide (Southern French Alps): Contribution of Geomorphology in the Understanding of Flowslides.

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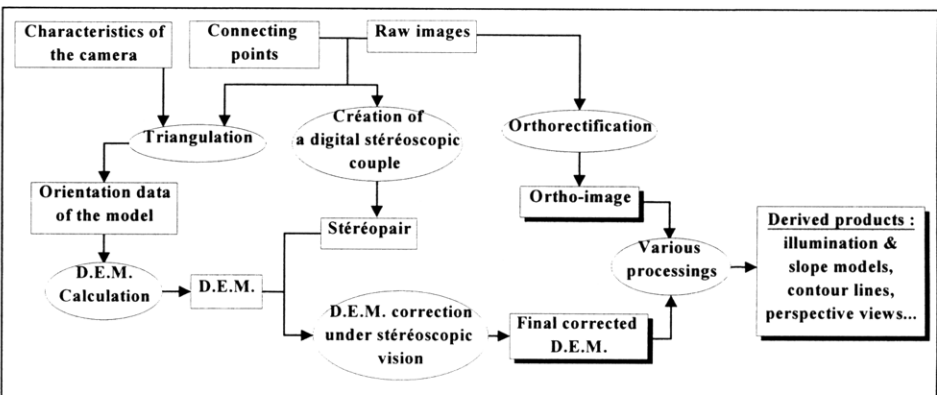
INTRODUCTION

Among all listed, classified and precisely defined landslides (Dikau et al., 1996), flow-slides constitute a particular type whose complexity still raise a certain number of interrogations for the geomorphologists that attempt to model their behaviour in order to foresee their evolutions. One of the main difficulties rests on the necessity to know these unstable masses from both the spatial and temporal point of view. In a specific lithologic context, but spread in all Southern French Alps, namely callovo-oxfordians "Terres Noires" covered by moraines, the Super-Sauze flowslide is under pluridisciplinary study since 1991 (Weber, 1994). The aim is to acquire a precise and detailed knowledge of its morphological evolution, its three-dimensional structure and its mechanical behaviour. The accent is especially put in this paper on the influence of lithological and morpo-structural characteristics of the site on the initial failure, the extension and the current dynamical behaviour of the landslide.

THE HISTORICAL APPROACH

A historical approach by digital photogrammetry allows to follow the geomorphological evolution of the whole Super-Sauze slope since the years 1950's -before the initial failure of the landslide- until our days. This original procedure illustrates perfectly the contribution of an increasingly effective and accessible digital photogrammetry method for the historical spatio-temporal knowledge of geomorphological phenomena.

Figure 1. The digital photogrammetric image processing



The digital photogrammetry method

Stereoscopic couples of aerial photography from 1956, 1971, 1978, 1982, 1988 and 1995 provided by the Geographical National Institute (IGN) were used (Authorisation No. 70 8006 © IGN France, 1998) to produce six Digital Elevation Models (D.E.M.) and complementary derived products in term of ortho-images and perspective-views (Fig. 2). This treatment was realised with the photogrammetric pack Orthomax® from the image processing software Imagine® - Erdas™ (Weber and Bolley, 1998). One of its originality is the "manual" correction of the unavoidable altimetric aberrations occurring in such produced D.E.M.; these errors directly linked to performances of the correlator according to the initial image quality are particularly frequent in homogeneous zones without sufficient textures or contrasts (i.e. with low contrasted radiometric values as for example shaded areas or snow-covered terrains); they involve anomalies (peaks or hollows) sometimes very local on one or several pixels in the restituted relief. The quantity of correlation errors is also linked to the resolution of the D.E.M.'s : a compromise has to be established between high resolution with strong correlation noise and low resolution lacking morphological details.

For corrections, the Orthomax® professional pack allows the visualization in relief (on computer screen) of a couple of images (the stereopair) with help of liquid crystals glasses. Each image of the couple is displayed on the screen by a frequency of 120 Hertz and each eye is alternatively masked by the same frequency. Thus, the left eye sees only the left image and the right only the right, and this 60 times par second. The instinctive fusion of the pictures realized by the brain allows the perception of the relief. Knots of the D.E.M. are then superposed to this topographical representation and a publishing utilitarian authorizes their manual displacement (in altitude only) in order to put them in coincidence with the visualized terrain. For the six D.E.M. generated in this study, the percentage of points thus manually readjusted varies between 3 and 11% of the 8881 points composing each model.

The geomorphological evolution

The multi-temporal comparisons of the models and other derived products are not only visual and qualitative, but also quantitative: planimetric and altimetric interpretations can respectively be made on the ortho-photographs and the D.E.M. (Fig. 2). The morphological evolution of the slope is particularly nice and easy to follow on the perspective-views; those permit a real "flying over" in space and in time of the unstable slope and constitute thus precious communication tools in relation to non-experts in landslides.

In 1956, an important part of the Super-Sauze slope is eroded over 90 hectares in badlands affecting the very sensitive callovo-oxfordians black marls; in the Southeastern part of these badlands locally called the "roubines", a main gully, rather more developed than the others, began to destabilize the morainic material covering the marls. This progressive baring of the substratum leads to first ruptures in the marls in the course of the 1970's. From there, two main morphological processes are noticeable in the quick development of the flowslide : the recession of a main scarp by mass movements (rockfalls and slippings) to the uphill, and the spatial extension of a composite flow downward. Both aspects are clearly visible on the different images produced : in the ablation zone, the main movements occurred between 1971 and 1978 and mainly between 1978 and 1982. Below, the extension of the accumulated material in the form of a large debris flow can be followed from 1978 on. Considering that more than 50% of the solid fraction is smaller than soil size, the common term of mudflow can also be used (Dikau et al., 1996). Between 1982 and 1988 for example, the foot of the

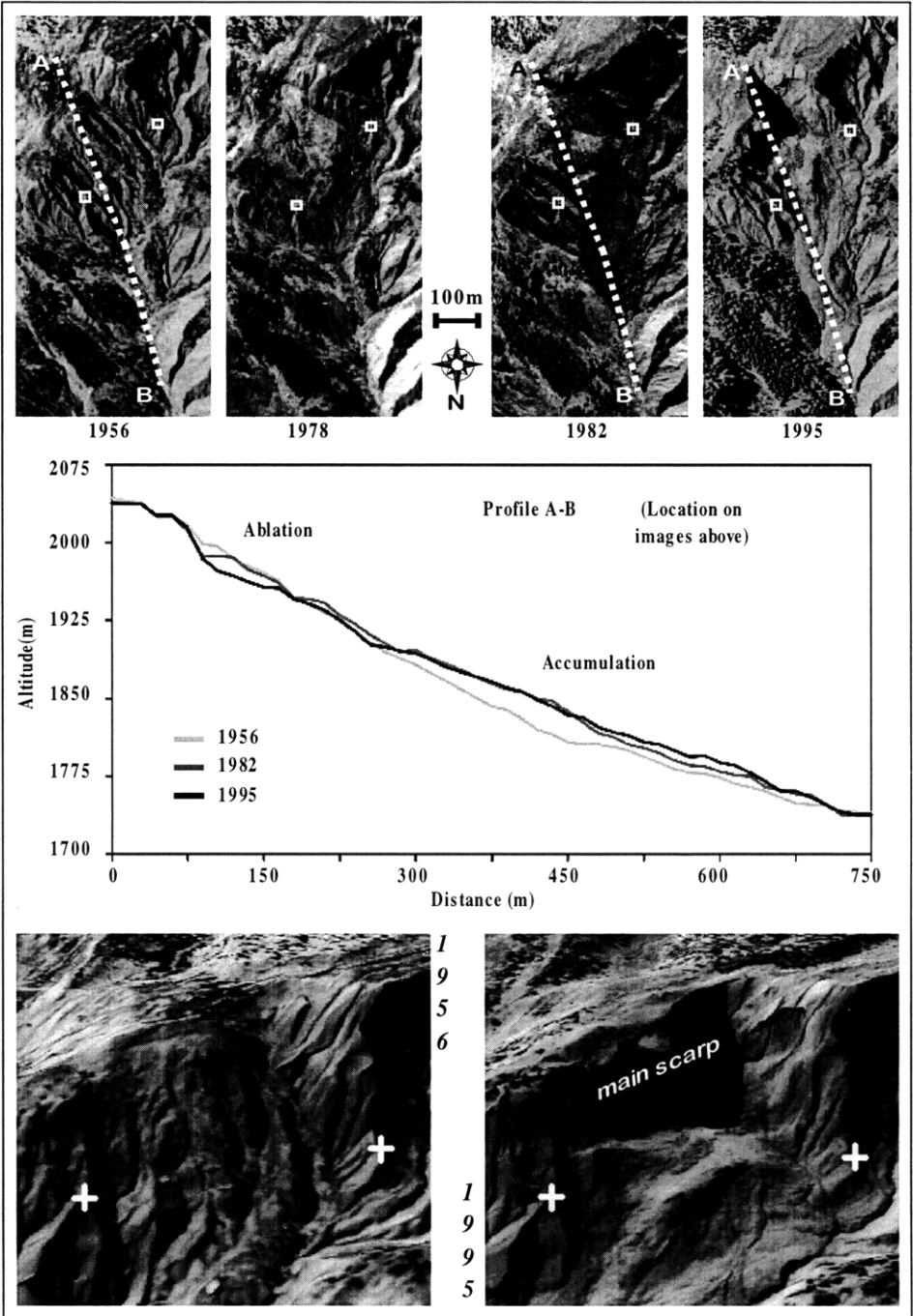


Figure 2 : Examples of ortho-images (top), D.E.M. extracted profiles (center) and perspectives-views (bottom) obtained by digital photogrammetric processing.

flow moved 180 meters forward in the thalweg, i.e. with an average speed value of 30m/year. In 1995, the total length of the landslide from the crown to the foot of the flow is more than 800m.

THE CURRENT MORPHOLOGICAL AND DYNAMICAL CHARACTERISTICS

Numerous pluridisciplinary in situ investigation techniques and methods have been realised in the Super-Sauze test site during the last ten years. First of all, detailed morphological observations permit to identify several fundamental processes explaining the evolution of this slope and the occurrence of this type of landslide on it. A topometrical survey registrates also the kinematics of the unstable mass since 1991 and different geotechnical, geophysical and hydrogeological investigations define more precisely its internal structure and its hydrogeological and rheological functioning. Completing the photogrammetrical results, these works give us a good knowledge about the three-dimensional morphology of the landslide and its behaviour in relation with climatological conditions especially, but also about the geomorphological reasons why it occurred at this place. Some aspects of these knowledge are briefly exposed.

The structural predispositions of the "Terres Noires"

One of the main question arising from the observation of the pictures of 1956-71 and the following of 1978-82-88-95 is what kind of phenomena happened in the upper part of the badlands to lead to the ablation of such a volume of the slope? From a mechanical point of view, the hypothesis of one big deep slide whose surface of rupture would pass under the gullies appeared difficult to conceive. The observation in the course of the spring 1997 of a phenomenon never observed before has brought a satisfying reply to this interrogation: it concerns the rupture of a crest of a gully situated in the same badlands basin, westward of the current studied flow. One observes clearly the rupture of the crest in its length giving birth to a several meters high subvertical escarpment. Once such a wall fails, marls exfoliate in whole panels following the schistous structure and the scarp retreats parallel to itself taking progressively more material. The orientation and the form of these ruptures are therefore totally conditioned by the structural arrangement of the "Terres Noires" and one suppose that similar phenomena have been able to happen some decades earlier on the eastern flank of the roubines. The current configuration of the main escarpment replies indeed perfectly to this hypothesis. Because of the ulterior recoveries that have totally masked the ancient slope, the major difficulty rest to know the exact position of these initial ruptures, i.e. to fix the real limit between ablation zone and accumulation zone.

The main scarp presents along its roughly circular lay-out two opposite faces exposing the black marls in two very different positions : on one side (the eastern part), the marl layers are rigorously parallel to the wall that retreats by regular detachments of rocks according to the bedding planes. On the other side, the reverse slope induces a far more irregular recession, by rarer rocky collapses but often of large cubage. This typical structure in "bord and wall" so defined in another context by the British mining ingeniors Adler et al. (1951) explains totally the current shape of the main scarp and its location in the upper part of main gully previously observed at the same place in 1956.

The morphostructural and hydrogeological characteristics of the landslide body

The body of displaced and accumulated materials (mainly composed of reworked marls but including also heterometric morainic blocks and boulders) shows different morphological

compartments resulting from more or less juxtapositions and superimpositions of several "flows". Most of the time these units are determined by the buried paleotopography organised in a serie of crests and gullies. In the vertical dimension also, two main layers (sometimes three depending on the area) can be invividualised from a geotechnical point of view (resistance and nature of the formations, shearing of some inclinometric and piezometric tubes). In short, the body of the flow is organised as following : just under the main scarp, an important accumulation zone reaching 20m depth shapes the so-called "upper shelf"; the latest released materials are all accumulated here. Below, the flow consists either in older and more consolidated accumulations, or in more recent very wet mudflows resulting from the erosion of the upper shelf. The "lower shelf" visible since 1988 in the inferior part the flow is only the consequence of the paleorelief recovering, it is not an accumulation resulting from a particular flow. Downstream, the foot of the unstable landslide is deeply embanked in a narrow thalweg between two steep slopes, its width is minimal around 10m. The total length of the flow is 700m, its maximal width goes to 200m and the average slope is 32% (with an intermediary 45% slope between the upper and the lowest shelves). For the whole flow covering a surface of around 80000m², the confrontation of the ponctual geotechnical results with the photogrammetrical analysis permit to calculate a current total volume of accumulated material in the range of 650000 to 700000m³.

Progressive exhumations of crests observed in the last years prove a reducing in thickness of the flow in its upper part while topometrical measurements show rather an opposite tendency of swelling in its inferior part. Running water that export at the lesser shower or snow melt a not negligible mass of "Terres Noires" dig several gullies at the surface of the flow; the perfect superimposition of these current drainage channels with ancients 1950's fossilized gullies illustrates the prominent part taken by the paleotopography in the hydrological functioning of the flow (Fig. 2).

The dynamical behaviour of the unstable mass

28 topometrical measurement campaigns realised between August 1991 and May 1998 give us a very good spatio-temporal knowledge of the unstable terrains kinematical behaviour. This differential dynamical comportment of several morphological units is largely dictated, there also, by the buried paleorelief. Its influence appears particularly evident when one compares the current surficial displacements vectors with the disposition of the old gullies. Advancing speeds of the flow are also directly related to the thickness of the mobilized layer and to the humectation rate of the material.

Several morpho-dynamic sectors can thus be distinguished after these first seven years of investigation: average speed values are comprised between 1 and 2m/year for the less active units and reach 10 to 12m/year for the most unstable. Far more rapid movements could be measured on shorter periods, notably around the upper shelf where a surveying point moved by 18m between 02 and 26 May 1997 (snowmelt period), that means an average speed of 0.75m/day during these 24 days. Still from a temporal point of view, several acceleration periods could be identified, particularly from spring 1992 to spring 1993 in relation with heavy rainfall in 1992 (the wettest year since 1979), and in autumn 1994 following an exceptionally showery September (Fig. 3)

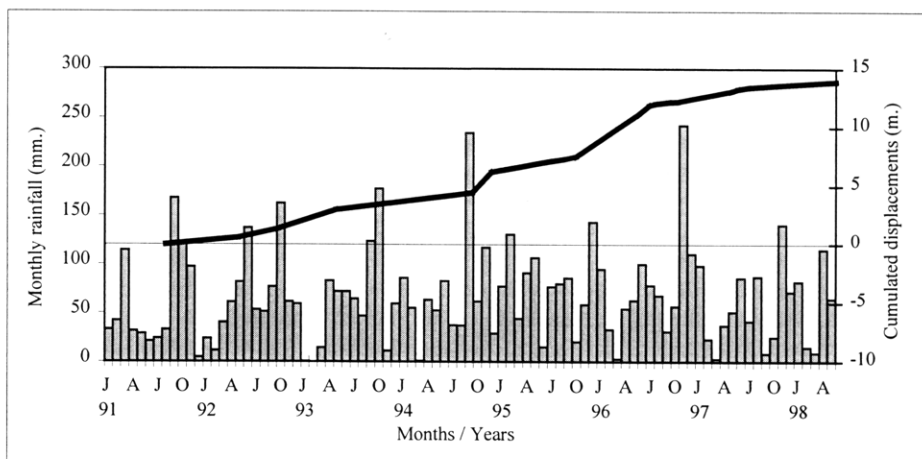


Figure 3 : Monthly rainfall in Barcelonnette and cumulated surficial displacements of survey point n°9 (lower shelf of the flow) between 1991 and 1998.

CONCLUSIONS

Observations made on the Super-Sauze flowslide give some fundamental information about the triggering and the functioning of such a complex landslide. The structural influence in the triggering of the initial ruptures is undeniable, as well as in the further extension of the ablation zones. From a geomorphological point of view, the behaviour of the released material is entirely determined by the buried paleotopography. The accumulation zone as a whole is organised in several units or compartments forming together a complex heterogeneous debris flow. The three-dimensional structure of this flow, its geomechanical, rheological and hydrodynamical characteristics represent many parameters explaining the dynamical functioning of such a landslide. This global geomorphological research undertaken on the Super-Sauze site brings the necessary knowledge before behaviour modelling applications.

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