Understanding the controls on solifluction movements in different environments: a methodology and its application in the French Alps

Albert Pissart

Summary

A study made in the Alps has demonstrated that statistical analysis of the correlation between the rate of displacements of blocks on slopes and the factors that control solifluction (gradient of slope, humidity, granulometry, vegetation, etc.) enables classification of the relative importance of these factors. To obtain good results, it is necessary to avoid the mixing of different processes, such as solifluction and scree movements of free pebbles. It should be possible to investigate climatic controls in the same way if solifluction movements are measured near meteorological stations and if the different factors involved are measured in an identical way in the different places.

Résumé

Une étude réalisée dans les Alpes a montré qu'une analyse statistique de la corrélation entre la vitesse de déplacement des blocs sur des pentes diverses et les différents facteurs qui influencent la solifluxion (valeur de la pente, granulométrie, humidité...) permet de classer par ordre d'importance les différents facteurs. Il convient cependant de ne pas considérer ensemble des déplacements dus à des processus différents, comme par exemple la solifluxion et le roulement de blocs sur des éboulis. Il paraît possible d'étudier de cette manière les paramètres climatologiques qui contrôlent la vitesse de la solifluxion, à condition que des mesures soient effectuées près des stations météorologiques et que les différents facteurs étudiés soient mesurés de manière identique.

1. Introduction

We have known for many years that the rate of movement of blocks by solifluction processes is controlled by several factors. These include not only the steepness of the slope but also the humidity of the soil during thawing, the size of the blocks, how deep they have sunk in the ground and the importance of the vegetation cover (HARRIS, 1981). As a result, measured rates of solifluction displacements have generally an anecdotal character. Usually, we only bear in mind the maximum, the minimum and the mean of the values which have been reported.

One possibility to further our knowledge of these present-day periglacial processes is to look for mathematical equations which give the weight of the different factors controlling solifluction such as slope, vegetation, humidity, granulometry, etc. and the different parameters of the climate. This methodology may help to predict the consequences of climatic changes on solifluction processes. For instance, we do not know if, in a specific place, a warming of the climate will limit solifluction processes through a greater vegetation cover, or if the same warming will accelerate solifluction because freezing and thawing cycles will be more frequent. The prediction of the effects of climatic changes, and a better estimation of the modifications which have occurred in the past, will be possible if scientists who are interested in these processes utilize exactly the same methodology. It is necessary that everybody conducts measurements of the different factors in the same way in order to be able to process all the results together using a computer. The proposed methodology has been used by WISHMEIER et al. (1978) to produce the universal soil loss equation (USLE). I believe, however, that it is easier to find a solution for solifluction than for soil erosion due to the inherently more complex nature of the latter.

This approach is demonstrated here using measurements of stone displacements in the Alps at 1850 m a.s.l. (PISSART et al., 1981). This study made use of painted stones on differing angles of slope and exemplifies the necessary precautions required to obtain valuable and comparable results.

2. Factors controlling the rate of the displacements of stones on the slopes of the Chambeyron

2.1 Field data

Measurements were collected of the displacements of 297 blocks on slopes inclined between 2° and 34° for different time periods from 2 to 32 years (Table 1). The observations for 32 years result from the lines painted by MICHAUD and CAILLEUX in 1947 (MICHAUD et al., 1950). The original marks are still well preserved and remain usable to this day even after 45 years. Other lines have since been painted in 1963 and more recently.

For each block the following measurements were recorded:

(1) The gradient of the slope measured in degrees near the block;
(2) The length of the block measured in centimetres;
(3) The depth to which the block has sunk into the ground in centimetres (this value was

estimated when the block was too large to be lifted);

(4) The granulometry estimated in the field. A value of "0" was given for fine material without pebbles greater than 1 mm; values of 1, 2, 3, 4 and 5 were respectively attributed when, in addition to the fine material, the pebbles were not larger than 1, 5, 10, 20 and 100 cm; values of 6 and 7 were given when no material finer than 1 mm and 1 cm respectively was observed near the block;

(5) The humidity estimated in the field as high, medium, low and nil, for which values from 0 to 3 were assigned. The last value was given when no fine material existed between the blocks;

(6) The potential humidity estimated in the field related mainly to the location of the block with respect to snow patches;

(7) The vegetation, assigning a value of 0 when no vegetation exists and 4 when a complete cover of vegetation was developed near the block.

I am aware of the limitations of the ordinal-scale estimates which have been used and appreciate how interesting it would be to have true granulometric data (especially as thin material controls the formation of segregation ice), measured values of the humidity during freezing and thawing, and also a classification of the vegetation related to the root development.

Table 1 Characteristics of the stone lines

Gradient of slope	Number of stones	Sites	Size of the blocks		Maximum mean annual displacement	Time period of observations
			Minimum	Maximum		
27-34°	107	Scree deposits	3 cm	350 cm	16 cm/year	32 years
8-24°	23	Slope solifluction	30 cm	175 cm	2 cm/year	32 years
5-28°	9	Slope solifluction	70 cm	200 cm	6 cm/year	16 years
16°	8	Thalweg blocks accumulation	24 cm	90 cm	0.5 cm/year	32 years
7-12°	45	Thalweg solifluction	3 cm	180 cm	1 cm/year	32 years
11.5°	24	Striated soil	1 cm	4 cm	13 cm/year	2 years
5-6°	17	Striated soil	2 cm	5 cm	10 cm/year	2 years
2-4°	65	Thalweg solifluction	5 cm	220 cm	1 cm/year	16 years

Table 2 Correlations beween the different environmental factors

	Gradient of slope	Length	Depth	Vegetation	Granulo-metry	Present humidity	Potential humidity
Gradient of slope	1.00						
Length	0.10	1.00					
Depth	0.12	0.75	1.00				
Vegetation	0.15	0.31	0.18	1.00			
Granulometry	-0.02	-0.32	-0.11	-0.67	1.00		
Present humidity	0.68	-0.02	0.05	-0.13	0.14	1.00	
Potential humidity	0.83	-0.11	-0.08	0.03	0.08	0.73	1.00

2.2 Multiple-regression analysis

These values were processed by computer using a programme from the Department of Biomathematics at the University of California, Los Angeles (1979). The programme (BMDP 2R) estimates step by step parameters of a multiple regression equation and other statistical elements, such as mean, skewness, standard deviation, etc. Six of the blocks were not considered in the statistical treatment because the mean annual displacement was greater than three times the standard deviation. These exceptional displacements were probably related to accidental phenomena. If they were included in the statistical treatment the results would not have been very different.

Analyses were first made with the mean annual displacement in centimetres; secondly we have calculated the equation with $\log_{10}$ of the annual displacement. The correlation values were always higher when utilising $\log_{10}$ and therefore we shall only discuss results obtained with the transformed data.

When the displacement measurements were calculated for all the 197 blocks on all the slopes, only 39.5% of the variability in mean annual displacement was explained by the variables examined. The factors were included in the multiple regression equation in the following order (Table 3):

(1) the potential humidity;
(2) the depth to which the blocks have sunk into the ground;
(3) the granulometry;
(4) the gradient of the slope.

However examination of the algebraical signs which are placed in the equation proved surprising. The rate of displacement was greater where the soil was drier and where the granulometry was coarser.

Other data analyses (correspondence analysis and hierarchical ascending classification) have shown that these results are due to the mixing of different slope processes (MANTE et al., 1988). We should not consider together stone displacements on moderate slopes which are due to frost creep and solifluction, with stone displacements on steep scree deposits which occur due to stones rolling together or result from mass displacement of dry pebbles. It is clear that in such a statistical study each process has to be considered separately.

What is of greatest interest is that the percentage explanation achieved is as high as 77% for the 45 blocks on a slope between 7 and 12°. The sizes of the blocks vary between 3 and 180 cm and the time of observation is 32 years. In the equation only 3 factors are of importance: (1) the humidity, (2) the cover of vegetation, and (3) the depth to which the blocks have sunk into the ground (Table 3).

The results are in agreement with our knowledge of solifluction: namely that the displacement increases with moisture availability.

The effectiveness of the analytical technique in relation to these final results is further emphasized if it is remembered that there was no granulometric analysis, that humidity was assessed on an ordinal scale, and that several other terms included in the equation were only crude estimates.

3. Conclusion

The main aim of this paper is to demonstrate a method through which our knowledge of solifluction may be improved. As we have shown here, it is possible to classify, for each site, the importance of the different factors which may explain solifluction. I believe it is possible to extend this approach by pursuing the same type of statistical analysis in different environments and hence to classify the importance of different climatic parameters (e.g. number of cycles of freezing/thawing, mean annual temperature, freezing index, precipitations).

Such research is only possible if the solifluction movements are measured near meteorological stations, which is rarely the case. However, comparisons between sites will only be possible if the different factors are measured in an identical way everywhere. Such an approach will only be possible if several scientists decide on a co-operative programme.

Table 3 Results of the multiple regression analyses (BMDP 2R programme)

	Gradient of slope	2 to 34°	7 to 12°
	Number of blocks	297	46
	Presentation of the MAD	Logar.	Logar.
Correlation between the MAD (1) and ...	Humidity	0,30	-0,83
	Potential humidity	0,52	-
	Length of the blocks	-0,31	-0,43
	How deep they are sunk	-0,31	-0,50
	Granulometry	0,26	-0,79
	Vegetation	-0,17	0,79
	Gradient of slope	0,32	-0,52
Order in the regression equation (2)	1	Pot. hum. 26%	Humidity 68,7%
	2	Depth 34%	Vegetation 73,7%
	3	Granulometry 38%	Depth 76,7%
	4	Gradient 39,5%	
Coefficient in the regression equation (2)	1	0,30	-0,790
	2	-0,01	-0,500
	3	0,10	-0,005
	4	-0,01	
	(3)	-0,60	1,375

(1) MAD = Mean Annual Displacement
(2) The numbers give the order in the equation
(3) Independent in the regression equation

References

BMDP (1979): BMDP Statistical Software. Department of Biomathematics, Univ. of California, Los Angeles

HARRIS, C. (1981): Periglacial mass-wasting: a review of research - B.G.R.G. Research Monogr., Geo-Abstracts (Geobooks), Norwich, 204 p.

MANTE, C.; PISSART, A.; OZOUF, J. C. & COUTARD, J. P. (1988): Traitement par analyse des données de mesures de déplacement en milieu périglaciaire d'altitude (haute vallée du Chambeyron, Alpes de Haute Provence, France). Bull. Cent. Géomorph. C.N.R.S. (Caen) 34, 87-117

PISSART, A.; SCHEPERS, J. L. & LAURANT, A. (1981): Etude statistique des déplacements de cailloux superficiels dans un milieu périglaciaire de haute montagne, la haute vallée du Chambeyron (Basses Alpes). Recherches Géographiques à Strasbourg 16-17, 173-142

WISHMEIER, W. H. & SMITH, D. D. (1978): Predicting rainfall erosion losses. A guide to conservation planning. Dept. of Agriculture, Agriculture Handbook N° 537

Address of the author:

Prof. Dr. A. Pissart, Géomorphologie et Géologie du Quaternaire, University of Liège, 7, place du 20-août, B-4000 Liège, Belgium