# TEMPORAL ASPECTS OF THE LANDSLIDES LOCATED ALONG THE COAST OF CALVADOS (FRANCE).

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## INTRODUCTION

The coasts of Calvados have 50 km of cliffs, some sectors of which are periodically affected by numerous earth movements, sometimes very extensive.

Two sectors have been subject to spectacular landslides (Fig.1). To the west (Bessin) in a relatively unconstructed area stretching over 32 km from Grandchamp and St. Côme de Fresné whole stretch of cliff 350 m long by 50 m wide suddenly gave way in August 1981 at Le Bouffay. In January 1982 a landslide totally or partially destroyed several houses and damaged the departmental main road in several places in the east of the department, between Trouville and Honfleur at the Cirque des Graves and the Fosses du Macre at Villerville-Cricqueboeuf.

The cliffs at Bessin, from 10 m to 75 m high, are cut into chalky and marly formations. They are affected by tectonic deformations which consequently present a very variable lithological profile, giving rise to great diversity, both in form and volume, and to numerous earth movements (rock falls, collapse of overhanging sections of cliff, small rotational landslips, plane landslips with sinking behind, landslips by flowing of marls at the foot of the cliffs etc.).

In spite of this great diversity of movement, we were mainly interested in the coastal sector of the Pays d'Auge, on which most of the important research has been concentrated.

Historical research into various documents provided data which enabled us to define the spatial and temporal distribution of movements in relation to pluviometric episodes. This small-scale study was supplemented by extensive research into the coastal sector of the Pays d'Auge where the landslips at Villerville-Cricque have been equipped with monitoring networks. We have been able to give a more precise definition of the conditions giving rise to the onset and continuation of movements and their succession, depending on the year and the season, using records of movements and of the displacement of layers in relation to rainfall and models based on stability calculations.

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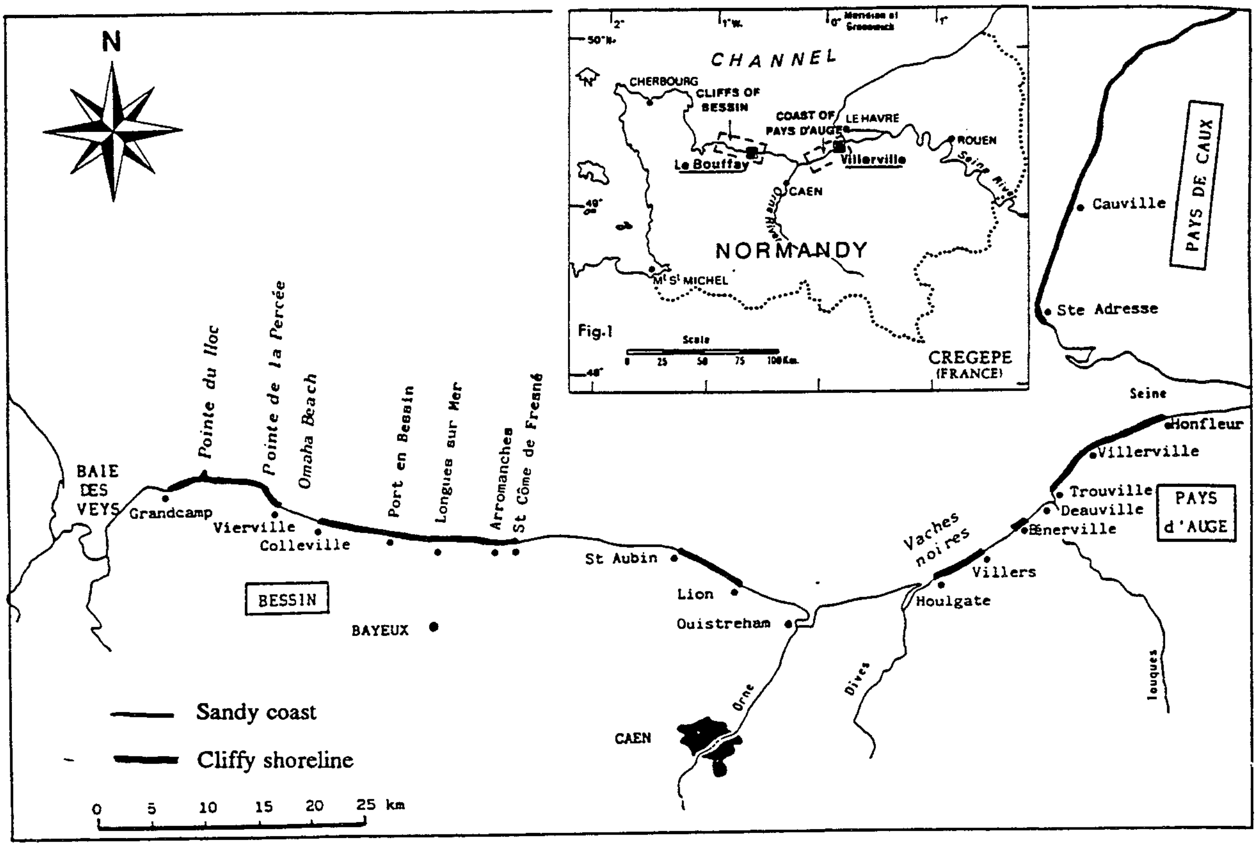


Fig. 1 : The littoral of Calvados : Location of the main coastal cliffs.

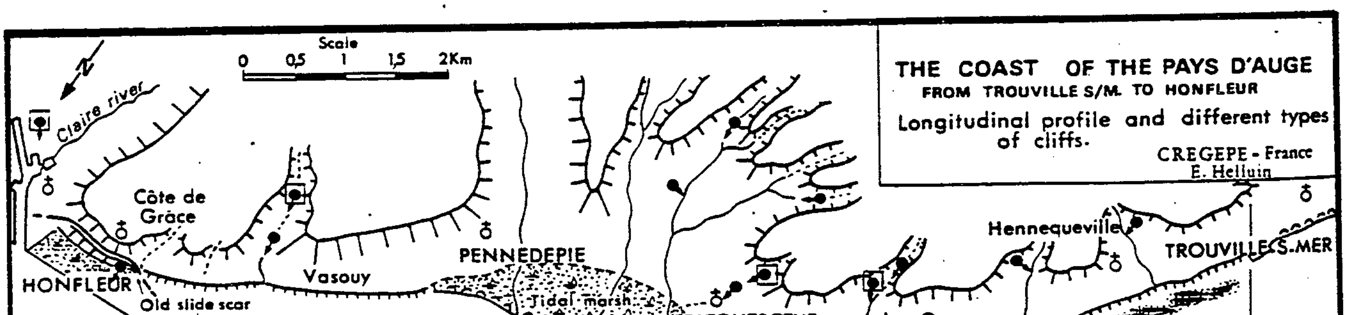


Fig. 2 : Geomorphology of the cliffs of Pays d'Auge (Calvados).

## MORPHOLOGICAL SITUATION

To the east of the department of Calvados over 12 km between Trouville-sur-Mer and Honfleur, the plateau of the Pays d'Auge is bordered by cliffs which are 140 m high at the highest point, composite in their topographic aspect and their geological structure. The variable profile from one extremity to the other (Fig.2) is comparable with the relative thickness of the sediment strata, with a low dip to the east. A main cliff face formed by chalk of the Cenomanian period rests on a bed of glauconitic sand. Above, a thick series of clay marl of the Kimmeridgian and Oxfordian periods overlays sandstones limestones of Hennequeville, which strengthens the base of the cliff and constitutes a rocky stretch of level ground between Trouville and the Heurt tip. At the foot of the chalky escarpment the slope is gentler and relatively rectilinear, except grooved valleys descending from the plateau to the sea. The relatively regular slope of thick superficial formations consists partly of panels and fallen chalk blocks and partly of "scree" (head), fragments of chalk, silex and loess which fill the spaces between the chalk blocks. These formations were finally established during the Upper Pleistocene period (Flageollet J.C. and Helluin E. 1984 and 1987).

The coastline is unstable at several points and disturbances appeared in previous centuries, particularly at the Graves amphitheatre at Villerville and at the "Fosses du Macre" at Cricqueboeuf, which have always been regarded as unstable. Small earth movements were usual and the inhabitants of the region gradually became accustomed to them.

## REMINDERS OF MAJOR INCIDENTS

On the night of the 13 - 14 January 1982 the shock was considerable because of the unexpected extent of the movement and the damage to dwellings. At the Graves amphitheatre and the "Fosses du Macre", after many warning signs such as fissures and heaping, a sudden acceleration in movements caused considerable damage, partially or totally destroying some thirty houses and cutting the CD 513 at two points by subsidence of some tens of centimetres.

The disturbances on the slope took the form of subsidence which were compartmented by subvertical scarps varying from some tens of centimetres to over 1 or 2 metres. At the summit the crown of the landslip, formed by a scarp departing from level by more than 3 metres in places, formed a rather winding arc the west face of which was at a tangent to the town of Villerville.

The most surprising, however, was the appearance of a fold of marl some 2.50 m high extending over 300 metres along the base of the slope to the right of the Graves camp site, which raised the height of the beach and the stone-built jetties . No such phenomenon was observed in front of the "Fosses du Macre" at Cricqueboeuf.

The disturbances at the Graves amphitheatre were much greater than at the "Fosses du Macre". The regressive extension of the disturbances outside the known zones moved a much wider strip of land which caused considerable damage to buildings and to the CD 513. At Cricqueboeuf the active landslip zone did not increase much as compared that which has been known for a long time (ZERMOS cartography), except, mainly, on the flanks. After the rapid acceleration phase the absorption of the movements lasted about two weeks.

## TEMPORAL DISTRIBUTION OF MOVEMENTS

### THE HISTORICAL INVENTORY OF EARTH MOVEMENTS

It was necessary to check past incidents, supposing that future developments can be linked with those in the past. We therefore carried out historical studies in order to count, locate and characterize the earth movements, placing them in their climatic context.

This indispensible phase of listing and analysing historical facts was accomplished by collecting data. We had to seek out and use various archives, but movements had only been recorded in them if they had occasioned significant damage, particularly in urban zones.

In Normandy, in particular on the coast, the first searches were undertaken in Bessin by O. Maquaire (1983 and 1984) and were continued and completed for the whole of Calvados by J.L. Ballais et al., (1984) and E. Helluin (1988).

Written information is to be found in national, departmental, district and parish records of varying interest and often difficult of access. Generally speaking, series are filed according to the origin of the flow of documents (Vogt. J., 1973; Humbert M. and Vogt J., 1983). In departmental records the files relating to disasters and earthquakes are in the Z series (which come from sub-prefectures) or the M series (prefectures); the S series contains the files of the Mines and Bridges and Footways services, etc.

The district or parish archives are disappointing; they are either inaccessible or simply non-existent, having been destroyed during the Second World War.

If records in the strictest sense contain little mention of earth movements, the local daily or weekly papers are a rich source of information. Thus E Helluin (1988) listed 320 cases of earth movement when she made a systematic search through 25 complete collections of newspapers issued between 1885 and 1985 in and around the Pays d'Auge.

If the data collected are numerous, they do not cover all the movements which really occurred. Research into records is really only fruitful for urban sectors. With rare exceptions local people in under-populated areas ignore natural phenomena or treat them as an everyday occurrence. This is apparent in the file of over 300 incidents, 90% of which related to the populated coastline of the Pays d'Auge.

## CLIMATIC CONDITIONS AND HISTORICAL INCIDENTS

The qualitative analysis of the simultaneous representation of rain and incidents led us to choose climatic parameters close to, preceding or accompanying the incident and **distant** parameters representing the effect of memory of the accumulation of previous rainfall.

We were able to undertake this analysis thanks to the data base set up by E. Helluin after exhaustive research into the regional press and departmental records (Helluin E., 1988).

### MOVEMENTS OBSERVED AND ANNUAL RAINFALL

The juxtaposition of annual rainfall diagrams and the annual number of cases recorded (Fig. 3) shows a close relationship between years of heavy rainfall and the number of movements, as, for example, in the years 1935, 1937, 1960, 1965, 1966, 1974, and 1981 to 1983. Other situations are also revealed; there are quite dry years during which cases are noted, such as 1879, 1945 and 1946, which were preceded by a period of high rainfall. At the extreme, incidents occurred during or following several dry years (with rainfall below average).

The affect of preceding rainfall on the onset of disturbances is shown by the calculation of movement averages which take account of the "memory" effect (DUTI, 1985). Generally speaking, and for this chronological series, the best adjustment is provided by a mobile average calculated over three years (Fig. 3).

Extreme conditions even combined for the particularly excessive period between 1978 and 1983, during which a large number of incidents were recorded. This analysis demonstrates the determining role of heavy rainfall and their succession in the onset of disturbances and stresses the weight of preceding rainy incidents.

However, some observations should not be compared with rainfall or be confused with it. Other natural factors, such as storms and periods of freezing are superimposed on rainfall in the series data and they can aggravate an already critical situation and accelerate earth movements. The various possible combinations must be examined in accordance with different time periods in order to pinpoint the periods which were effective in moving the slope.

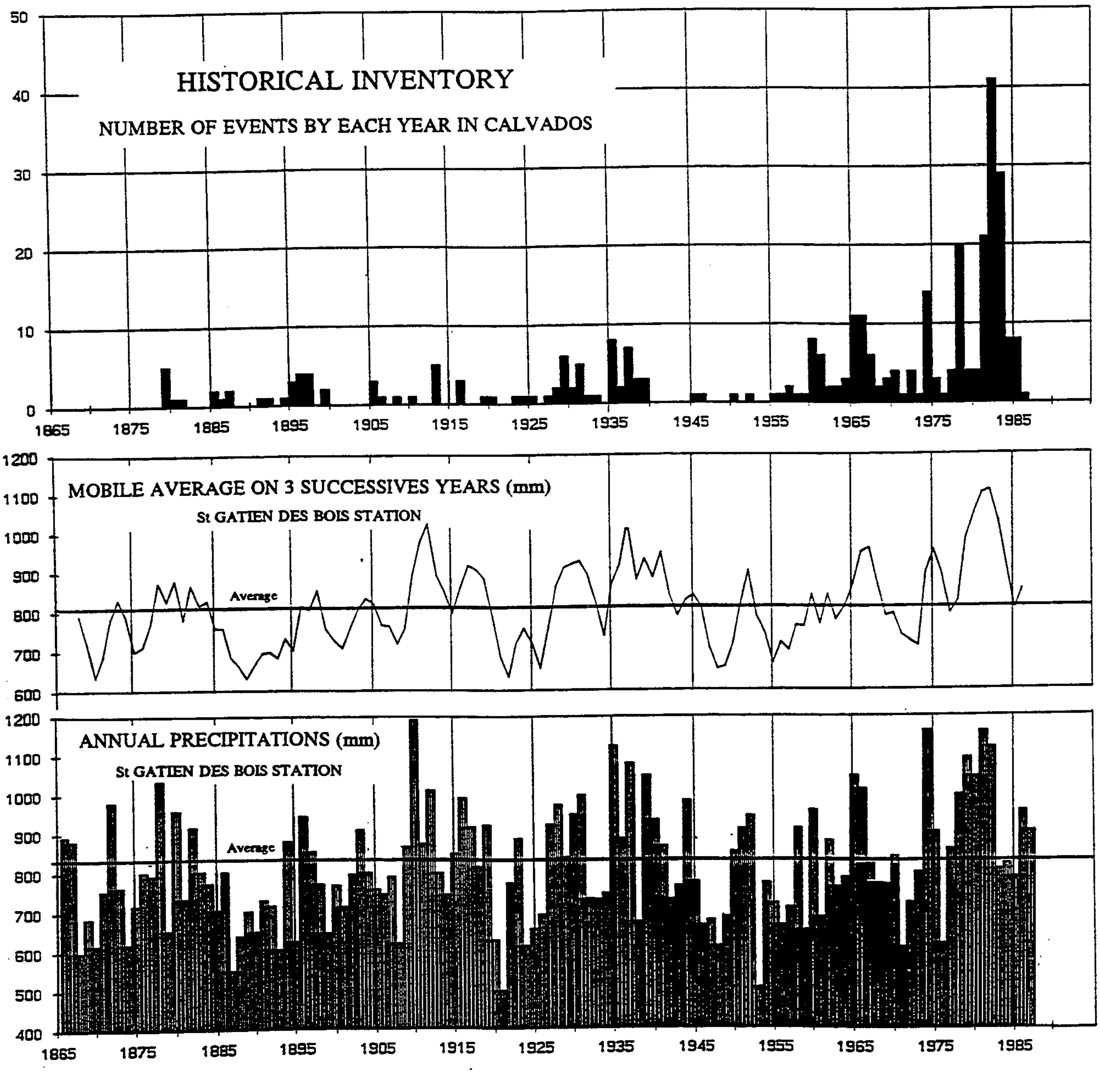


Fig. 3 : Annual precipitations in relation with historical inventory between 1865 and 1986.

## DISTRIBUTION OF INCIDENTS AND CLIMATIC CONDITIONS

Seventy-six per cent of incidents occurred between October and March, 19% of them in January, which shows the maximum of activity. Landslides were the most frequent type of movement, being 63% of the total. In 85% of cases they started on the coastline of the Pays d'Auge, where three quarters of movements occur, as opposed to only one quarter inland. Sixty per cent of movements occurred during a rainy period and in 75% of cases the pluviometry for the previous month was above average, 20% being over 140 cm.

Pluviometry during the three previous months was higher than the average for the three autumn months in 61% of cases and in 9% of cases it exceeded the average rainfall for the six months of autumn and winter. However, these figures must be moderated, as some 40% of incidents occurred at an average quarterly rainfall which was lower than the average of 260 mm and even for levels of 90 mm. Some 90% of incidents occurred following years in which rainfall was higher than average. Twenty-five per cent of cases followed a single year and 55% occurred after three years of heavy rainfall. If we now examine the part played by storms in 139 incidents on the coastline, 57% occurred during a period of strong agitation, 40% of them immediately after or during the onset. The simultaneity of low temperatures and the appearance of disturbances is low, only 29% of cases. In 10% of them, the movements occurred during a thaw and 10% during intense frost over several days.

This initial analysis of the relationship between pluviometry and historic incidents enabled us to pinpoint a type of movement, its location and the relative weight of the various onset factors. Thus, the pluviometric structures and their combinations are determinant; heavy or very heavy rainfall in the preceding month or years. Landslips predominate over other types of movement and occur for the most part on the coastline of the Pays d'Auge, with a higher frequency during the autumn and winter months.

A second analysis (a factorial analysis of multiple correspondences) shows that if the pluviometric conditions preceding earth movements are various, there is nevertheless a general tendency associating a distant pluriannual factor to a close parameter, the one superimposing on the other. However, their respective influence on the onset is difficult to estimate. Thus the succession of several years of heavy rainfall is expressed, for the layers, by a cycle of heavy rainfall, and results in the lowering of the slope's safety factor, in this case it takes only a minimal climatic risk to cause a rupture. From the forecasting standpoint, this analysis shows the advantage of monitoring climatic conditions closely over a long period, but it also demonstrates the difficulty in defining a rupture threshold which could form the basis of an alert system.

## CONCLUSION

The parallel analysis of various types of incidents occurring in a given region and their climatic conditions shows the considerable diversity of situations met with and the complexity of the combinations of immediate and distant factors. The various associations between close pluviometry and the annual or pluriannual rainfall preceding the incident indicates that disturbances can occur even after relatively dry months if they were preceded by abundant annual rainfall. On the other hand, heavy rainfall in the preceding month (or two or three months) may suffice to trigger disturbances even after relatively dry years.

In Calvados, and for earth movements of variable extent and nature, the analysis has nevertheless provided the extent and quantity of rainfall for various time phases. This analysis has therefore been very precise, thanks to the installation of monitoring networks giving exact figures for movement and climatic conditions for a given landslip.

## MONITORING NETWORKS

Several reference points and an alert system were installed at two points on the CD 513 to the right of the Graves amphitheatre (Fig. 4) after major incidents in 1982, but it was only in December 1984 that a real monitoring network was installed at the Graves amphitheatre itself. It was supplemented by the installation of several other measurement points at the Macre rift at Cricqueboeuf in the autumn of 1992.

The choice of methods and instruments was guided by the numerous recent examples of monitoring several large landslides in France and abroad; such as that at La Clapière near Saint-Etienne-de-Tinée (Follaci J.P., 1984; Vibert C., 1987), or the monitoring of test filling on the unstable slope at Sallèdes in the Puy-de-Dôme (Pouget P. et al., 1984), the monitoring of stability on the Frejus road on the flank of an unstable slope (Giraudin P., 1984) or the Hérémence sites in Switzerland (Misérez A., 1985), Villarbeney, la Chenaula, Cossonay and Frasse (DUTI, 1985).

The networks consist of:

- **about a hundred marks** in concrete or steel sealed into the ground , the spatial location of which have been determined by triangulateration by a Wild T2 or T 1000 theodolite fitted with a DI4L electro-optic distancemeter;

- **three drilling cores** fitted with inclinometric tubes;

- **twenty one wells and piezometers** one of which is fitted with a limnigraph to follow the pulsation of the flows continuously;

- **the climatic data** are supplied by the Saint-Gatien-des-Bois meteorological station

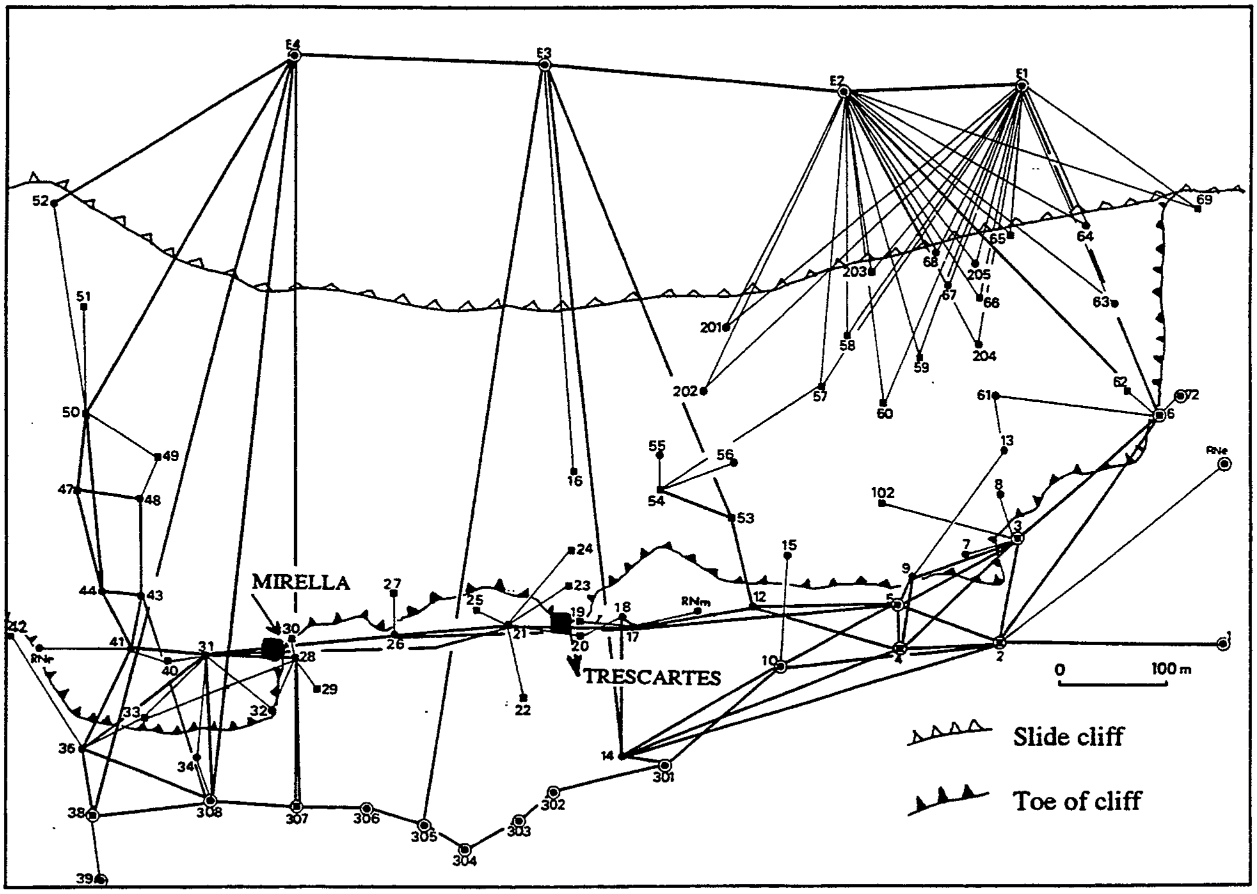


Fig. 4 : Diagram of recorded views during a topometric survey at Villerville.

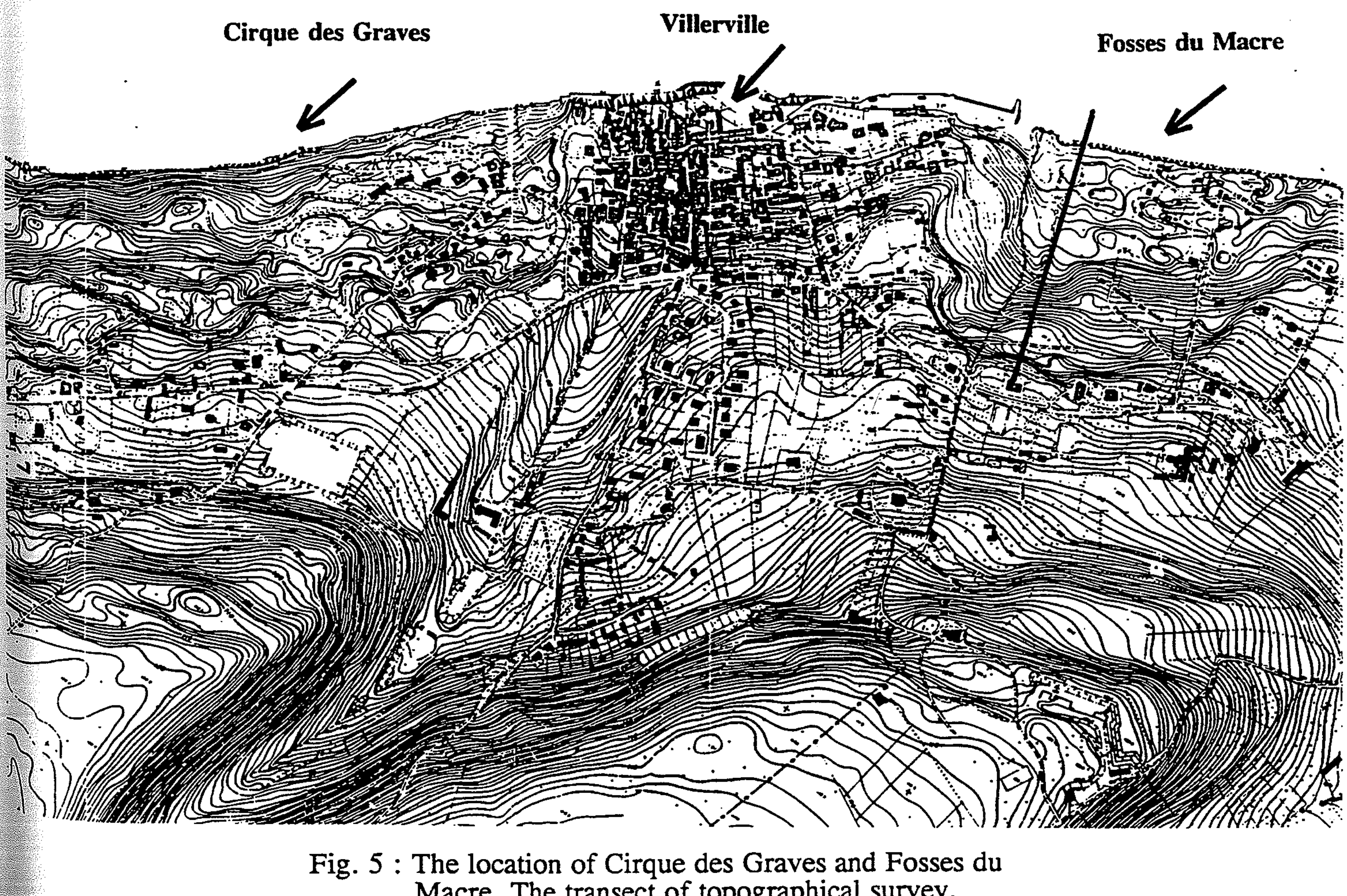


Fig. 5 : The location of Cirque des Graves and Fosses du Macre. The transect of topographical survey.

set up on the plateau less than 2 km. from the flow.

## SURFACE MOVEMENT MEASUREMENTS

Given the constraints (very twisted morphology, with differences in level of approx. 120 m., dense bushy vegetation, numerous constructions, etc), it has only been possible to install a simple sighting system based solely on the two stations opposite the flow, as was the case, for example, for the monitoring of the Clapiére site (Follaci J.P., 1984).

### AT THE GRAVES CIRQUE AT VILLERVILLE

**Eighty seven points** were set up over a length of 1 km. between the western edge of Villerville and the Heurt tip, over a breadth of approximately 600 m, between the rocky level stretch and the edge of the plateau, a surface of approximately 60 ha since it was essential to have many intermediate points. Some of them had a levelling trunnion; others, with no trunnion, were fitted with a "geometer's" nail-type centring point; others are steel drill points firmly embedded on the rocky strand and the footpath. Twenty two of them form the outline of fixed points (basically polygonal) outside the zone which is moving at present or which may do so in the near future. The stability of these points is monitored by topometry and by reading with the precision level with a micrometric screw (Pincent B., 1977).

We have noticed that there is an extensive area which has no point because of its inaccessibility.

### THE FOSSES DU MACRE AT CRICQUEBOEUF

This is an extensively wooded slope, but it happens that there is a clearing of some fifty metres throughout its length from the crown of the landslip to the coastline. It was possible, therefore, to install a measurement line in the autumn of 1992 (Fig. 5). It is perpendicular to the slope (the line of the steepest slope) (Fig. 6) and consists of fifteen points of the "landmark" type embedded in the ground over a length of some 50 cm. (Bloetjes O., 1992).

### SURVEYS AND DATA PROCESSING

It is essential to have a large number of monitoring stations (39 at Villerville and 3 at Cricqueboeuf); furthermore, for most of the equipment the measurement time is of the order of three to four days, depending on the weather, and three or four people are needed. Some two hundred measurements are taken at Villerville

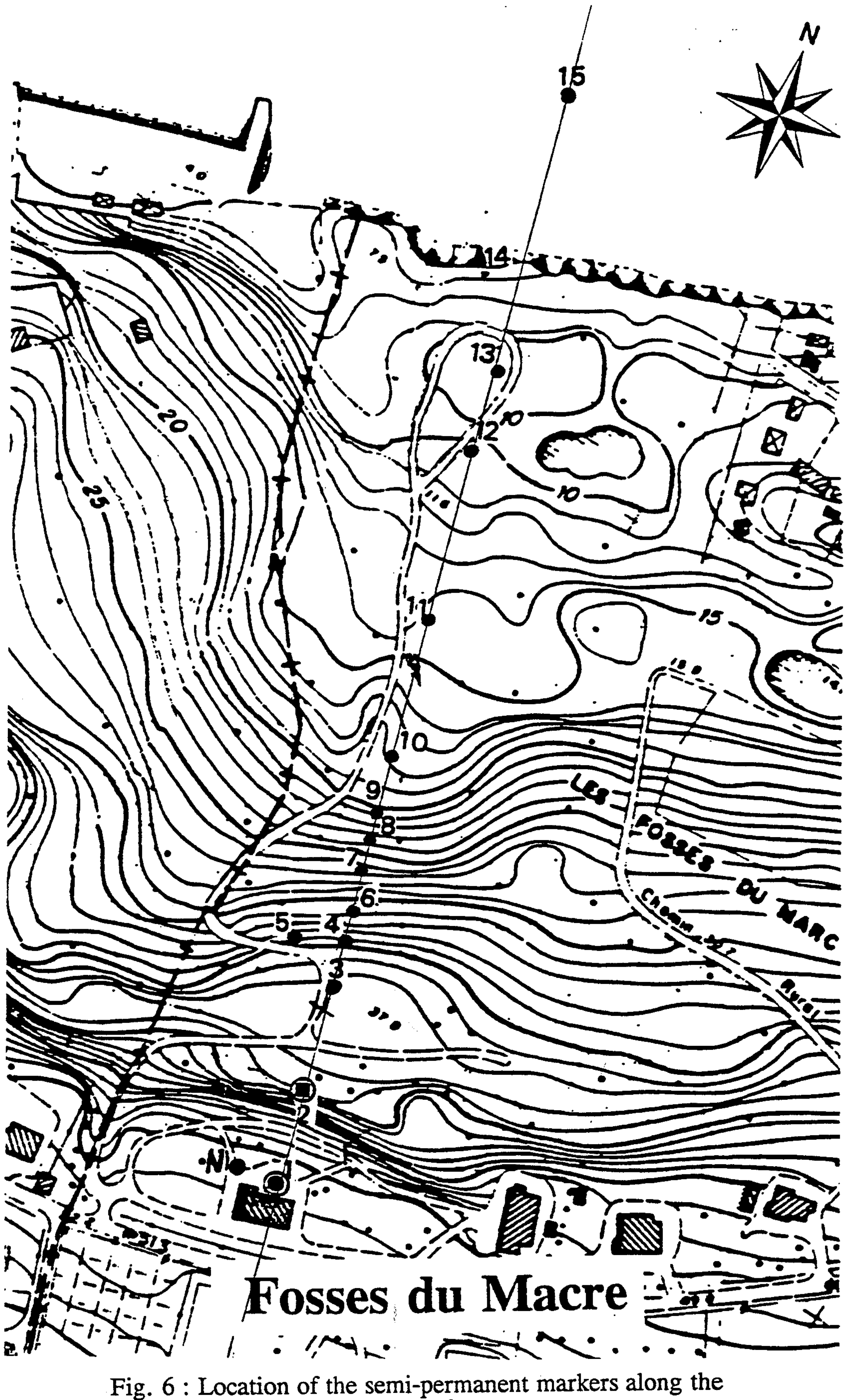


Fig. 6 : Location of the semi-permanent markers along the transect at Cricqueboeuf.

(Fig. 4) and sixty are taken at Cricqueboeuf (Fig. 7), but it should be stressed that the stations on the rocky level stretch are difficult, as they can only be reached at low tide.

Given the large quantity of data to be processed (about a thousand for each full survey at Villerville and Cricqueboeuf) it has been possible to determine the location of a point in space by triangulateration owing to the development of specific measurement programmes using the classic least square method (Maquaire O., 1990). In Planimetry the precision of the point's location is from 5 to 10 mm. In altimetry it is less precise because of the indirect levelling, so the altitude is then determined by direct automatic levelling.

### RESULTS

Ten surveys were carried out at Villerville between December 1984 and February 1988. Forty six points moved, depending on values which varied considerably from one point to another on the slope; for example, in planimetry the movements varied from 4 cm to 5.20 m. The general direction of the movements observed within the landslip corresponds with the line of the largest slope which is perpendicular to the coastline.

The average annual speed takes full account of the spatial distribution of these movements (Fig.8). The increasing speeds in the upstream-downstream direction is organised in more or less concentric strips starting from a median core centred at points 201 and 202. If the readings were predictable in the Graves camping zone at the Heurt tip level they have been must greater than was previously suspected.

Between February 1988 and September 1993 the distribution of speeds for the Graves camp site is the same. However, as we shall see further on, they are much lower (from 2 to 8 cm per year in close relationship) with rainfall conditions.

Only two surveys have been carried out at Cricqueboeuf up to now. If this is insufficient to give us an overall view of its development, we may nevertheless note that over a year, between November 1992 and September 1993, the movements have been trivial - only of the order of 1 to 3 cm.

## RELATIONS BETWEEN PIEZOMETRY AND CLIMATIC CONDITIONS

### PIEZOMETRY AND RAINFALL

If the piezometric curves indicate that refilling and drainage phenomena occur almost simultaneously at all points of the slope, the altimetric variations differ considerably from one point to another. Whether they are less than a metre or more

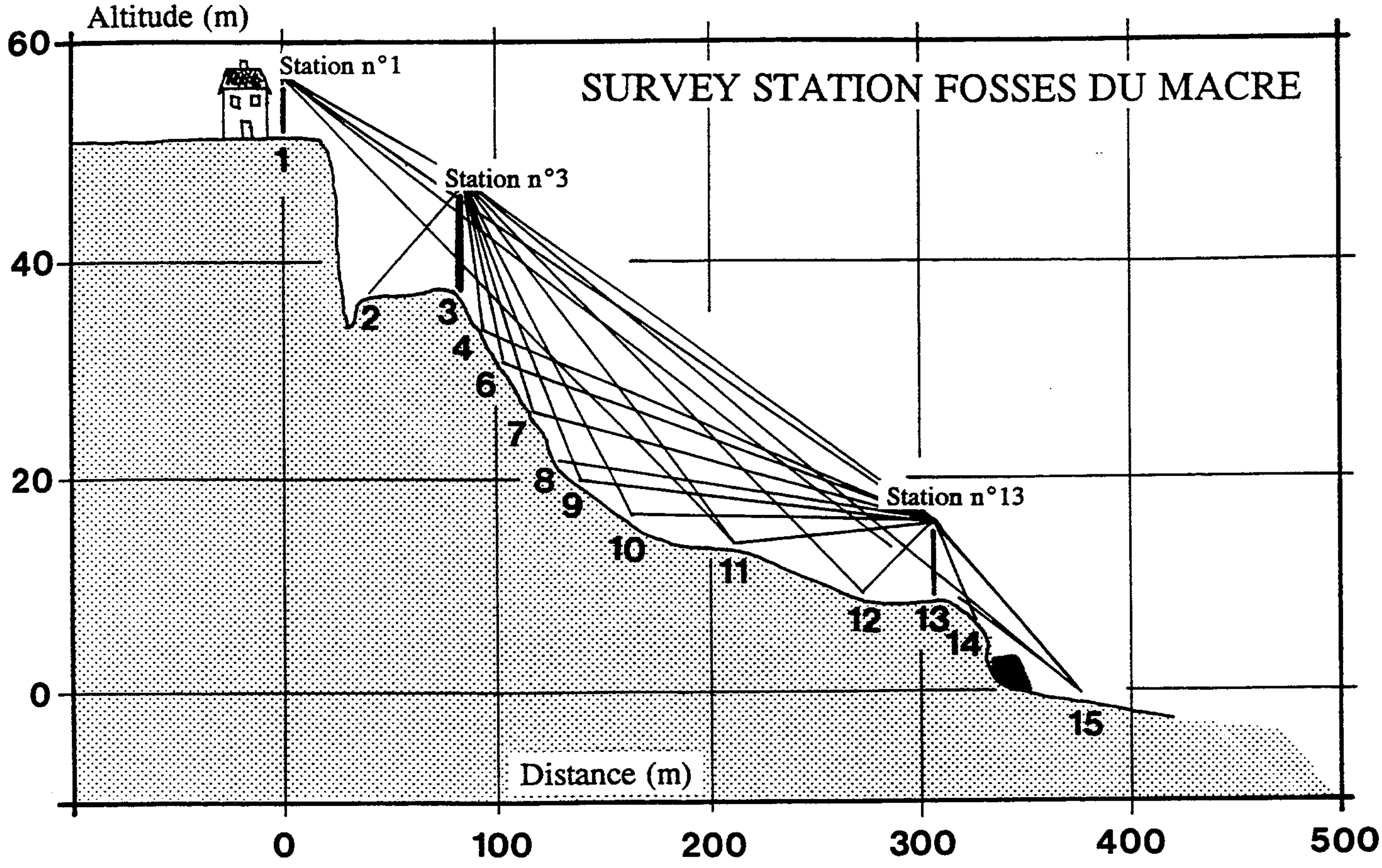


Fig. 7 : Diagram of sightings recorded during a topometric survey at Cricqueboeuf.

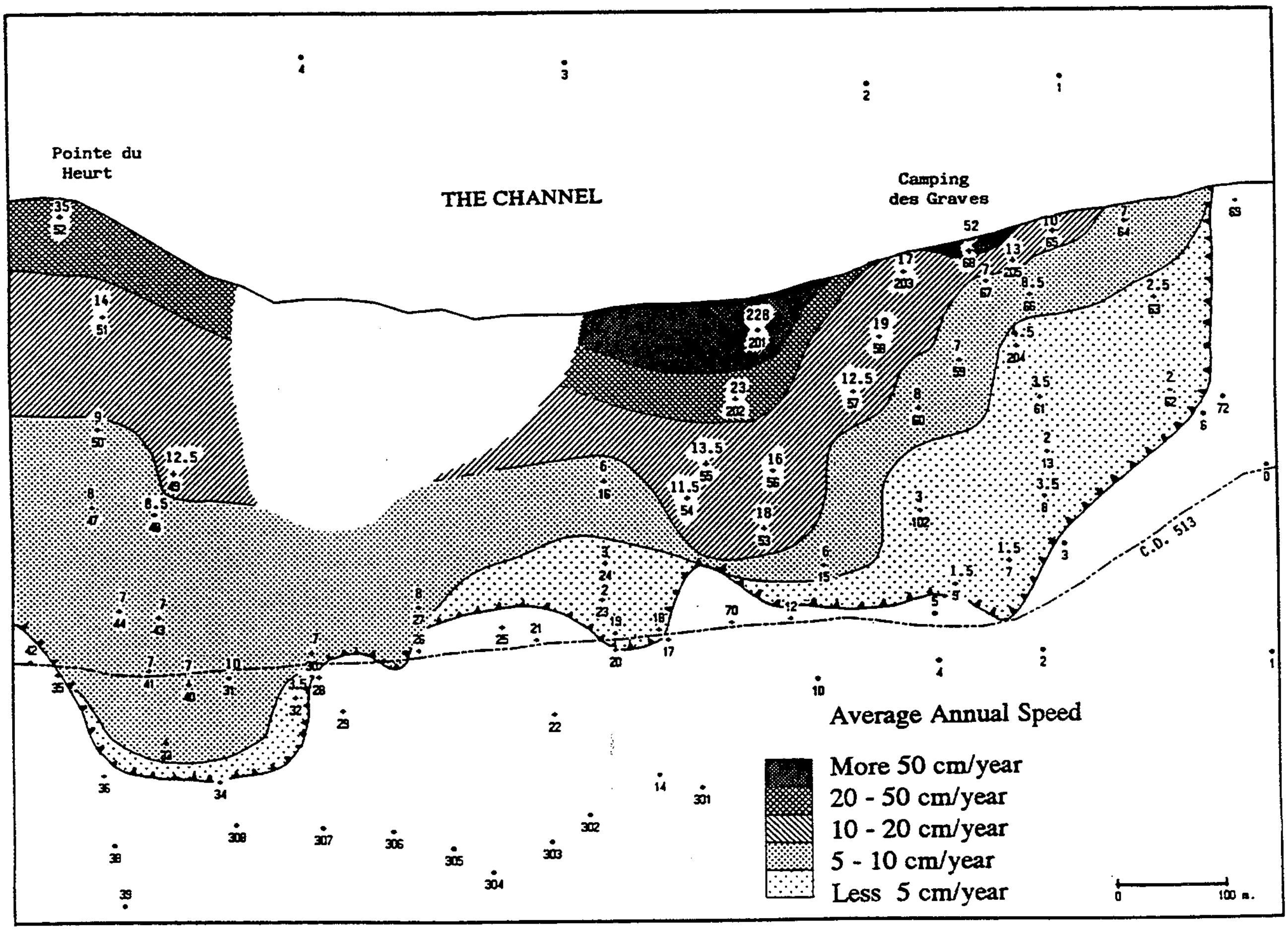


Fig. 8 : Average annual speed in planimetry between january 1985 and february 1988.

than three metres they are directly related to structural conditions - the type of material, fracturation, transmissibility - and with the power of the aquifer. Thus the layers near the surface or those which are deeper but which flow in a fissured milieu are subject to wide altimetric fluctuations of short duration.

The relationship between piezometry and rainfall is established from rainfall or effective rainfall, as has been established in studies carried out elsewhere (DUTI, 1985; Delmas Ph. et al., 1987; Cartier G and Pouget P., 1987; Matichard P and Pouget P., 1988).

Effective rainfall corresponds to total rainfall, diminished by evapotranspiration (E.T.P.), calculated by the TURC formula, which is very suitable for the climate of Normandy.

The piezometric curves show sudden refilling following very rainy periods (Fig. 9) Conversely, drainage commences and continues even in short deficit or unwatered periods. Another frequently observed phenomenon is the brevity of high ground water episodes.

The ground water refills in October or November for five to six months, depending on the year and the rainfall distribution, i.e. until the end of March or the beginning of April. This high water period corresponds roughly to that of effective rainfall or pluviometric excess. However, this rising phase for subterranean water is not sustained: a few dry or unirrigated days slows down the rise or starts the drainage of the ground water.

The response time between the rise and the start of effective rainfall is from four to five days (Fig. 9). For example, at the beginning of the hydrological year, set at 1 November in 1985 and 10 October 1986, it took some twenty days (twenty five in 1985 and eighteen in 1986) for the waters to rise. This time lapse corresponds to the saturation phase of the slope basin after the lowest water level, to the reconstitution of the necessary reserves in the ground and to the infiltration time.

The quantity and measurement of rain causing each rise has been calculated, as was the case on the Sallèdes site (Delmas Ph. et am., 1987); Matichard Y and Pouget P., 1988). The results obtained are very broad and only take account of the total amount of rainfall; however, the correlation is better with effective rainfall (Fig.10).

## PIEZOMETRY AND ICE

Following the landslip of 1982 ice was responsible for blocking the surface flows and consequently for a rise in interstitial suppressions disastrous to the stability of the slope.

Rigorous and persistent freezing between 1984 and 1987 gave rise to some interesting observations. To the main outlets at the foot of the slope, we can see the continuation of a very weak flow, slowed down but not blocked. At the same time,

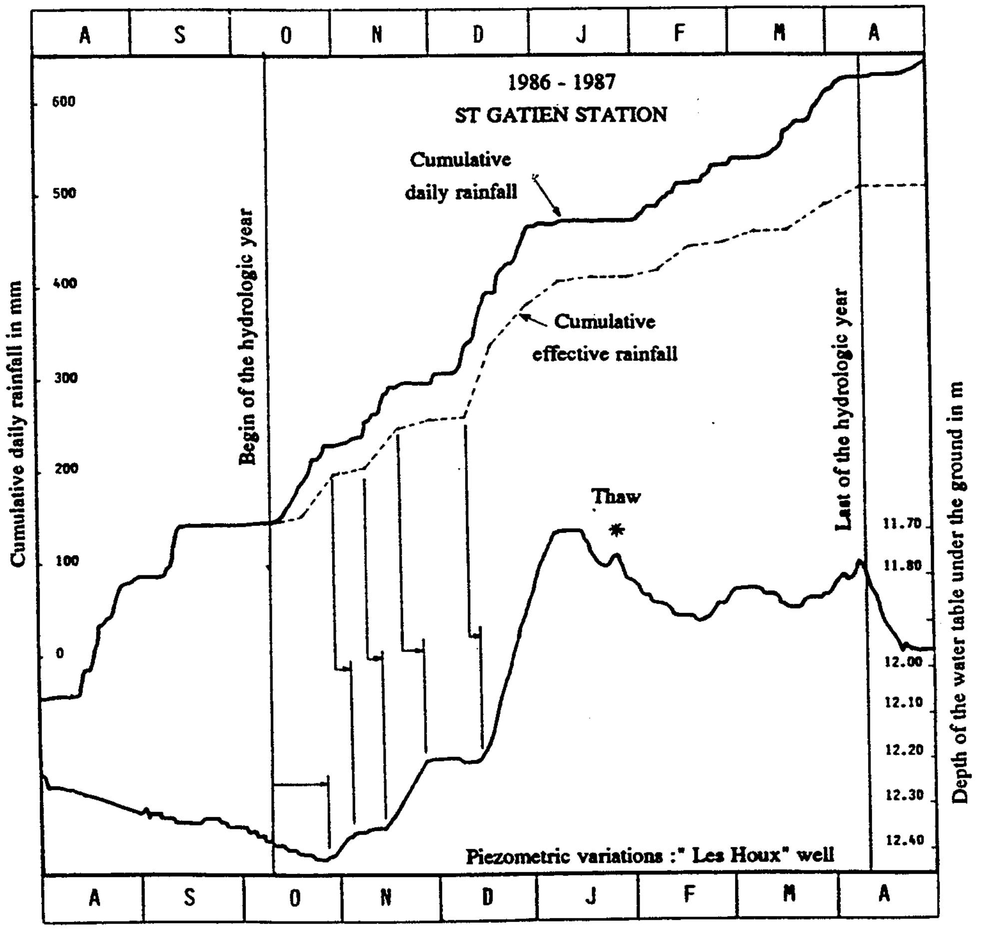


Fig. 9 : Cumulative daily rainfall and cumulative effective rainfall of the St gatien des Bois Station and piezometric variations of the "Les Houx" well from August 1986 to April 1987.

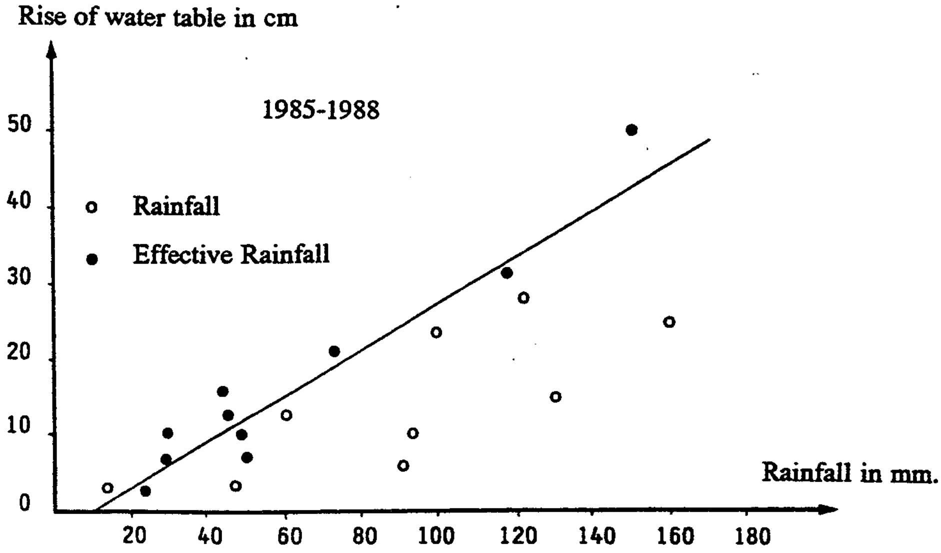


Fig. 10 : Relation between rainfall and rise of water table.

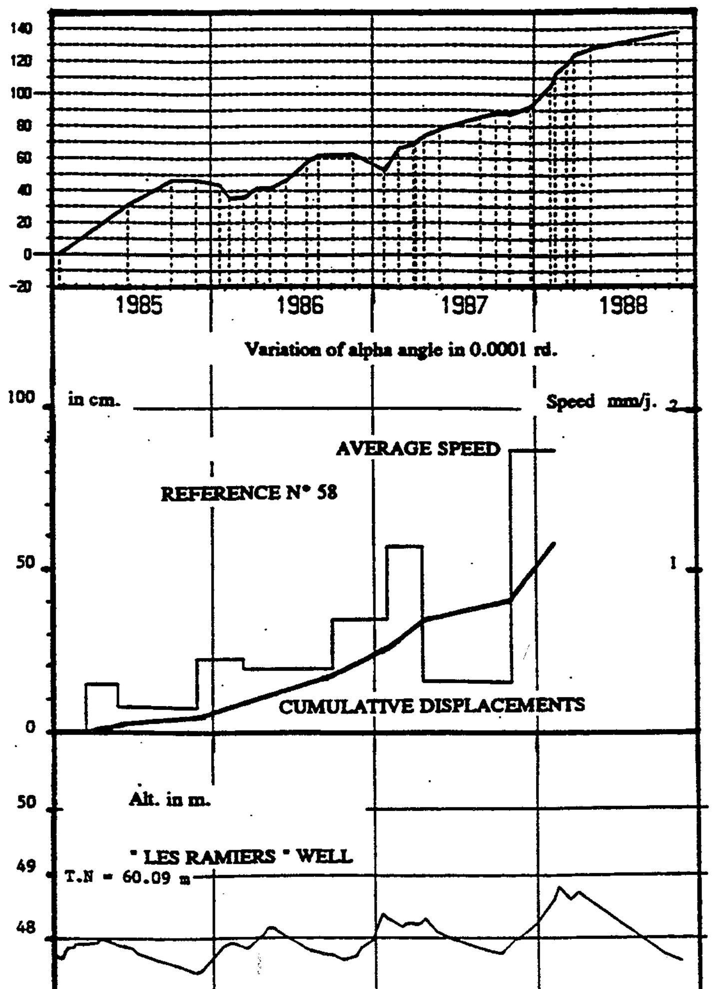


Fig. 11 : Seasonal variability of movements of reference 58 and variations in piezometric levels.

piezometric measurements indicate that a phase when the water plane surface was maintained is followed by a drying-up phase due to the absence of vertical alimentation, except after thaws and melting slows. For example, in January 1987 there was almost no rain for some twenty days but there were heavy snowfalls and intense freezing for about a fortnight.. The snow, on average 6 cm. thick, started to melt on the 21 January until the 25th and 26th January and a slight rise of 2 to 3 cm. was recorded. This temporary rise was maintained for two days; then the drainage phase recommenced, in the absence of vertical alimentation (Fig.9). Thus it took some four or five days for the melting waters to feed the water level, which corresponds more or less to the level given previously for the response time between alimentation and the rise in the piezometric level.

These observations in icy periods are interesting, but they are nevertheless insufficient to estimate the influence of ice on the onset of instability such as that in January 1982, for example. In fact the observation relates to the free layer levels. It would have been necessary to install interstitial pressure measurement cells in the vicinity of the rupture surface.

## MOVEMENT FREQUENCY: RELATIONSHIP BETWEEN RAIN, FLOW AND MOVEMENT

### SEASONAL VARIABILITY

Movements vary with the season, and their amplitude relates closely to the climatic conditions: heavy rainfall, melting snows etc. This variation is visible on graphs of base plate levels or cumulative movement curves (Fig. 11). The latter are obtained from the successive movement values measured between two consecutive topographical surveys, supposing a constant speed between the measurement interval; this is inaccurate, as movements occur in sudden accelerations of unequal magnitude, followed by calm periods. The exact shape of the movements and the time at which they commenced could only have been reconstituted with a continuous measuring device (Invar wire, inverse clock). In spite of this lissage, we observed similar behaviour in all the points on the slope, with considerable speeds in wintry periods which corresponded to high piezometric levels. In summer periods the speeds decreased considerably in relation to the drainage of the flow.

It is difficult to determine a critical level n the flow or of an effective rainfall quantity corresponding to the commencement or dangerous and sudden acceleration of movements. The major difficult arises from the fact that movements are not measured continually. Attempts to establish a relationship between movements and cumulative rainfall (Meneroud J.P., 1983; Canuti P et al., 1985), or between cumulative movements and cumulative effective rainfall to take account of the pluviometric history, such as that attempted at the Champ-la-Croix site (Matichard Y and Pouget P., 1988) have not given the results expected because of the imprecision in the commencement and acceleration of movements. However, we can state that sudden accelerations generally occur during the three winter months of state that sudden accelerations generally occur during the three winter months of December, up to the end of February.

## PLURIANNUAL DEVELOPMENT.

At present we have the good fortune to have a series of more or less regular measurements over eleven years between the end of 1982 and the end of 1993. These measurements enable us to see the various phases in the development of the Villerville landslip in relation to the climatic and piezometric data (Maquaire O., 1993).

Between December 1984 and February 1988 we observe that the high water levels, and to a lesser extent the low water levels, are higher from one year to another. This pluriannual rise of the flow's average level arises from the rainfall "memory" effect from previous years. This development is observed in wells on the plateau for which there are records over a long period from 1976. The pluriannual rise which began in 1978 continued until March 1982 and April 1983 (Fig. 12c). Then there was a period of several years in which the average levels decreased. This increase from 1978 coincides perfectly with the non-cyclical annual pluviometry fluctuations at the Saint-Gatien station (Fig. 3), which corresponds to a period when rainfall was considerably higher than average, with a mobile average mobility calculated over five years which was 20% higher than the interannual average and which was even as much as 30% higher in 1982 (Maquaire O., 1990 and 1994).

The high level of the ground water which was observed in 1982 is in phase with the onset of the major movement of 10 - 11 January 1982. The extreme nature of the rain preceding this landslip is also fully demonstrated by the return periods; the annual effective rainfall (hydrological year), which are higher than ten years/ For the two or four preceding years this return period even corresponds to the maximum of the 39 years of pluviometric observation.
Thus, since the end of 1982 the subsidence measurements of the two points of the warning system along the CD 513 (Fig. 12a) and the movement of points, for example point 58 (Fig. 12b) in relation to the piezometric variations shows us the following;

- **a movement softent phase** following the major movement of January 1982.

- **a movement acceleration phase** since the beginning of 1985 which is demonstrated by a more or less sloping curve with the general appearance of an exponential curve on the cumulative movement curves;

- **a sudden onset** of movements in February 1988, leading to a sizeable landslip on the night of the 12/13 February 1988, mainly at Cricqueboeuf, which caused a good deal of damage, an extension upstream and laterally of the mobilised zone and a rise in the strand which dislodged the jetties and the breakwaters (Maquaire O., 1988);

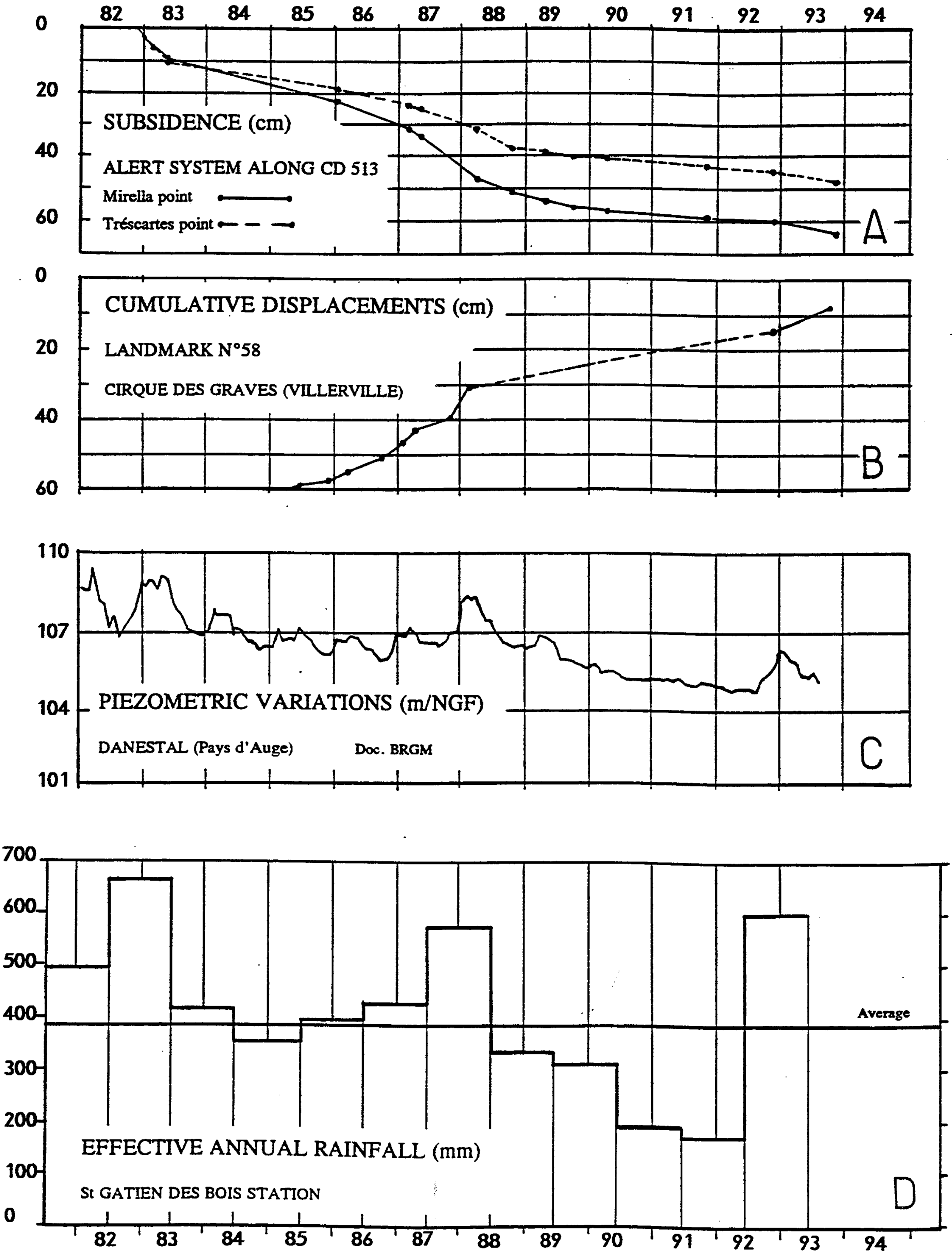


Fig. 12 : Evolution of displacements of landslide of Villerville in relation with piezometric variations between 1982 and 1993.

- **then a soften phase** for movements not wholly stable over approximately five years until the autumn of 1992 when a development commencement was recorded during 1993 in relation to the rise in the flow (Fig.12c).

These measurements indicate that this section of the coast is subject to **almost permanent** activity in which landslips are amongst the active movements.

If these movement measurements fully confirm the major role of water in the onset of movements, as has already been demonstrated previously by the historic investigation, we should not forget the role of the sea, which prevents the installation of a balance slope such as can be found inland in the Auge because of its erosive action at the foot of the slope. The part played by the sea is evidenced by stability calculation models.

## MODELS: STABILITY CALCULATIONS

Models made using topographic profiles, the geomechanical nature of the material, the shape and the position of rupture surfaces given by inclinometric data provide figures and conclusions regarding the respective parts played by the various instability factors.

The stability calculations have been reached by overall determinist methods (LCPC perturbation method) and by probabilist methods (random variations of mechanical characteristics). According to several working hypotheses, we show that a rise or fall of 1 metre in the height of the flow modifies the overall safety coefficient by approximately 5 to 6%. A 10-metre recession from the foot of the cliff only accounts for 1 or 2%. As a reminder the average recession determined by comparison with the Land Registry plans of the face of the Graves Cirque is of the order of 60 to 70 m. between 1829 and 1987, i.e. an average annual recession of 40 cm (Maquaire O. 1990). Over and above the weakness of mechanical characteristics (no cohesion and internal friction angle an average of 13°), the decisive part played by water as a factor provoking the onset is demonstrated once more. If the incidence of a suppression of thrust seems low on the overall safety coefficient, its role is nevertheless vital in the maintenance of the instability, as the probability of the onset of a landslip at the foot of the slope is appreciably higher.

## CONCLUSION

The coastal cliff in Calvados is subject to numerous earth movements which vary greatly in type and extent. They occur in certain sectors and at different time rates which it is important to recognize.

The temporal aspect of the onset and continuation of these movements has been approached on two time scales, the first historic and the second in the short term.

The first is based on a census of historic events, taken from various records which have been compared with meteorological conditions in order to establish the various situations which lead to the onset of phenomena.

The second was a large-scale study of the Villerville and Cricqueboeuf Cirques where monitoring networks enabled us to take precise and more or less regular measurements of movements, both on the surface and in depth, of the pulsation of the phreatic flow in relation to rainfall or icing and thawing.

It emerges very clearly that the mechanisms are governed by rainfall. They play a decisive part in the temporal variability of movements.

They have been studied at different time rates, as their role in triggering movements occurs in the rise of ground water which itself follows an annual or pluriannual cycle, spread through the season in relation to rainfall.

Nevertheless we still face many difficulties in connecting the two, because of the lack of data over long periods and in particular because earth movements and variations in the flow were not recorded continually.

If stability calculation models show the decisive part played by water as a triggering factor they also stress that of erosion by the sea (suppression of thrust) in the maintenance of the instability and the impossibility of reaching a profile of the balance of the slope.

A simple warning system can be applied over part of the present monitoring network, with topometric measurements at a few representative points and a follow-up of the flow level in one or two wells to detect rapid rises in winter. The maximum level recorded in February 1988 can be regarded henceforward as a "red alert" threshold.

But as inaccuracies regarding the relationship between piezometry and movements remain, and the knowledge acquired on site does not yet enable us altogether to establish the climatology/movement relationship exactly; a permanent system to measure movements and the phreatic level of the mass in movement should be put in place for several years.

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