

STUDIES ON LANDSLIDES IN NORMANDY (FRANCE), IN VIEW OF THEIR OCCURRENCE PROBABILITY

J.C. FLAGEOLLET*, P. GIGOT**, E.HELLUIN*
and O. MAQUAIRE*

*Centre de Recherches en Géographie Physique
de l'Environnement

**Laboratoire de Géologie structurale
Université de Caen - 14032 CAEN CEDEX (France)

SYNOPSIS

Two sections of the coast of Normandy are threatened by major landslides : the Bessin area, where steep cliffs, cut in Jurassic clays and limestones, recede by landsliding. The latest major landslide took place in August 5 1981. Using data derived from morphological, geological, geotechnical and geophysical studies, the type of displacement associated with the 1981 landslide has been defined, as a roughly, continuous and plane slip surface, with thrust-support. The high density of tension cracks in the limestone plateau, parallel to the coast, along the cliffs has been appreciated by small seismic refraction. This fissuration is related to the release of strength and to the creep of the underlying marls. A map of the most cracked coastal sections has been drawn up. The width of the decompressed area and the density of tension cracks, obtained by seismic values, give some indications relative to potential slides, in terms of location and, in a certain way, in terms of occurrence probability.

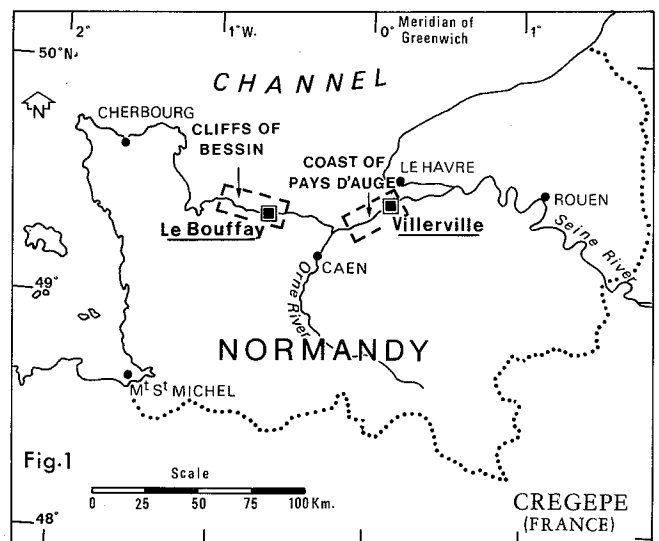
In the Pays d'Auge, on the coastal slope, underneath the Cenomanian chalky ledge, Albian green sands and Kimmeridgian marls are overlaid with thick quaternary periglacial debris cover in a low-angle slope : heads, loess and blocks of chalk. On each side of Villerville, this formation and its basement are periodically affected by landslides, and the last major one occurred late 1981 and early 1982. A combination of observations and measurements will be soon completed : superficial displacements measured by topometry, shape and depth of the rupture surface, displacements in depth by inclinometry, strength parameters and stability analysis, evolution of the saturation level, erosion by sea waves... Thus, the next stage of the study will be an attempt of occurrence probability model by statistical processing of meteorological, piezometric and marine hydrological data.

INTRODUCTION

The legislation recently passed in France on natural hazards obliges the civil Service, local communes and private individuals, to put projects and development operations with the Plans d'Exposition aux risques naturels majeurs prévisibles (P.Z.E.R.N. for short) that is a "major natural hazards" map, whose features and contents are standardized for the entire French territory. First PZERN are making in some threatened areas, where the knowledge of the phenomena was before in advance. It is the case of the Calvados coast, for landslides, where a former type of map, called ZERMOS, has been drawn. However, it appears that there are still a lot of necessary details to be monitored, specially with reference to some of the permanent conditions associated with landsliding, i.e. -location and type of rupture surface, changes in the saturation level etc... and, as frequently, the precise internal conditions at the moment of the breaking. In order to look into some of these problems, an important program has been implemented, and covers two separate sectors of the coast of Calvados, where two major landslides occurred four years ago, known respectively as the Le Bouffay and Villerville landslides. This program includes : measurements of surface displacements using a topometric network, measurements of internal displacements using inclinometers (in three deep bore holes at Villerville), vertical displacements of the saturation level in twenty piezometers, and, at Le Bouffay, seismic refraction measurements in view to mapping the width of the decompressed area along the cliffs.

MORPHOLOGY AND GEOLOGY

Studies on landslides in Normandy started again after 1982, thanks to two favourable circumstances, the entry into service of the "Commissariat aux Risques Naturels Majeurs", created in 1981 and responsible for mitigating natural hazards, and the occurrence of two major landslides, in two sectors of the coast of Normandy (fig. 1).



- The first sector (fig. 2) is located between Grandcamp and Arromanches, on both sides of Omaha Beach, the famous beach where the allied troops landed in June 6, 1944. 28 km of steep cliffs, known as "falaises du Bessin" are cut in a sedimentary suite of Bajocian and Bathonian age, from the bottom up : - Porifera limestones (C.S.) Bajocian, massive. - Marls of Port en Bessin (M.P.), lower and mid-Bathonian with a maximum thickness of 38 m. Some thin calcareous strata are interbedded in these marls. Carbonate amount varies from 35 to 60 %. The silt fraction ($<2\mu$) amounts to an average of 50 %, with smectites (80 %) and illites (15-20 %). Atterberg limits are : liquidity (Wl) 50 %, plasticity (Wp) 27 %. The plasticity Index (Ip) reaches 23. Thus, these marls have a fairly plastic behaviour. Oedometric tests have given the following approximately values : initial void ratio (Eo) : 0.76 ; preconsolidation stress (σ_c) : 120 kPa ; compression index (Cc) : 0.19. But alternative long-duration tests give residual shear $\varphi' = 16^\circ$ and cohesion $C' = 0$ kPa. The question arises as to why these residual values are zero in the marls, without their having an old rupture surface ? The proposed explanation reposes on some observations made in a small Quaternary valley cutting the marls. One can observe that the limestones have been strongly decompressed on each side

middle Bathonian, with a maximum thickness of 35 m, are made up of massive and thin calcareous beds separated by argillaceous layers. - Over the Bessin limestones exist, locally, clays and sandstones of Le Planet, probably Cretaceous in age, and, behind the cliff occur a few meters of flint clays and Quaternary table land loams.

The cliffs are higher in the middle sector, close to Port en Bessin, as a result of an anticline bulge, striking N.S., and with NNE-SSW faults (fig. 2). Thus to the west side, between Grandcamp and Vierville, where the cliff is virtually calcareous everywhere, one can observe rockfalls from the overhanging cliff, in the Cap Manvieu area. West of Port en Bessin, the cliff is higher (60 m) ; some small circular slides occur in the two calcareous suites (C.S., C.B.) and relatively thick marls. East of Port en Bessin, the cliff is 70 meters high, the sedimentary series is complete, from the Bajocian to the Cretaceous and the Bessin limestones are thick. It was here, at Le Bouffay, that the major landslide of 1981 occurred. Further undermining of marls by the sea at Cap Manvieu causes falls along the whole length of the overhanging calcareous ledge. Elsewhere (ie Chaos), the profile of the slope is lower, with a hummocky topography, associated with the creep of marls.

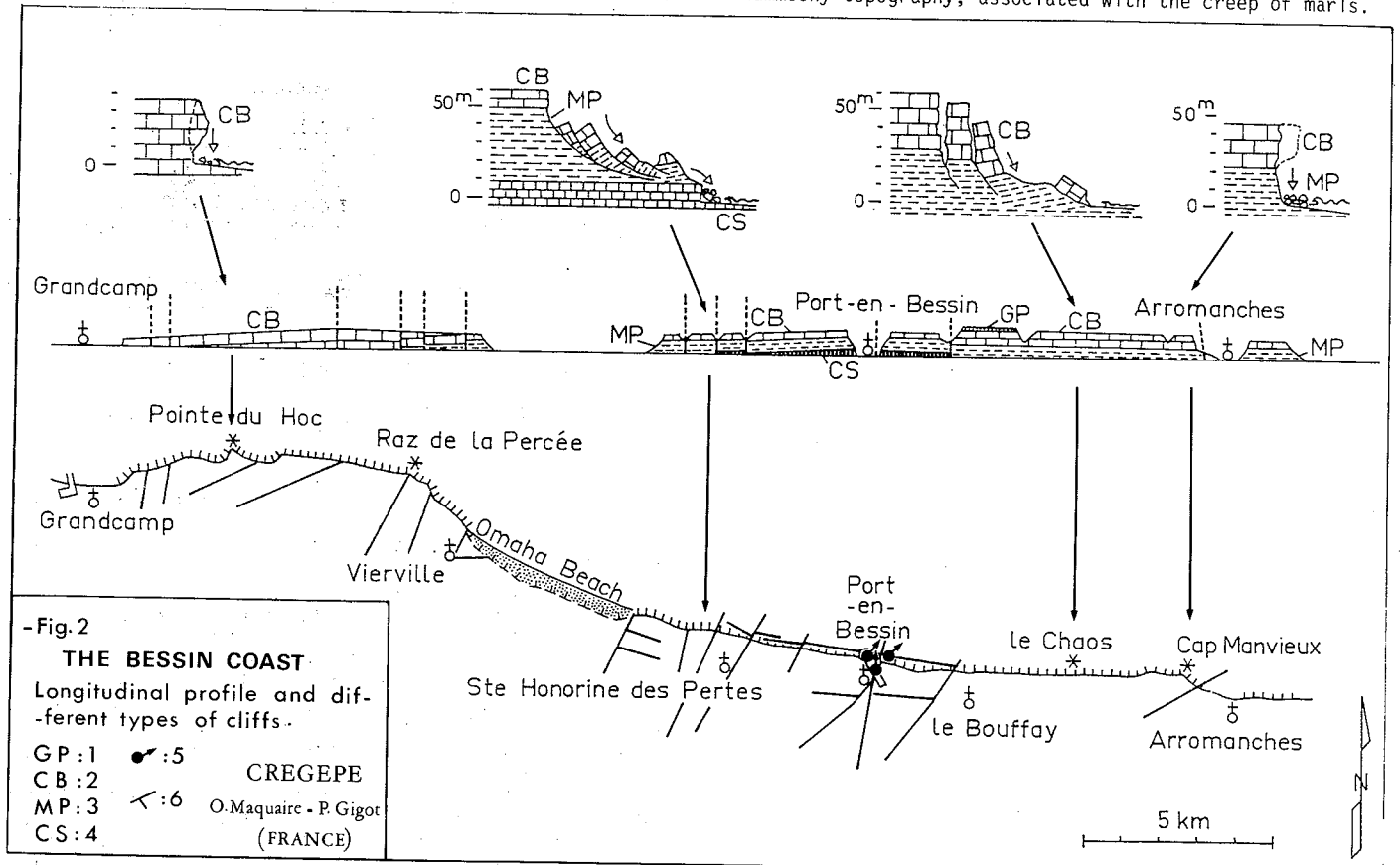


Fig. 2
 1. Le Planet sandstone (Cretaceous) ; 2. Bessin limestone (middle Bathonian) ; 3. Port-en-Bessin marls (middle and lower Bathonian) ; 4. Porifera limestone (Bajocien) ; 5. Uncatched spring (karst resurgence) ; 6. Major fault.

of the dale. This decompression is associated with creep of the underlying marls. As a result of this creep, the marls are finely sheared in their sedimentary layers, which strongly reduces their cohesion as if they had been broken by landsliding. - Limestones of Le Bessin (C.B.),

- The second sector (fig. 3), which is slightly shorter (10 km), is located to the East, beyond the well known seaside resort town of Deauville, between Trouville and Honfleur, known locally as the "bloom coast". Instead of steep and bare cliffs, the coastal slope profile presents

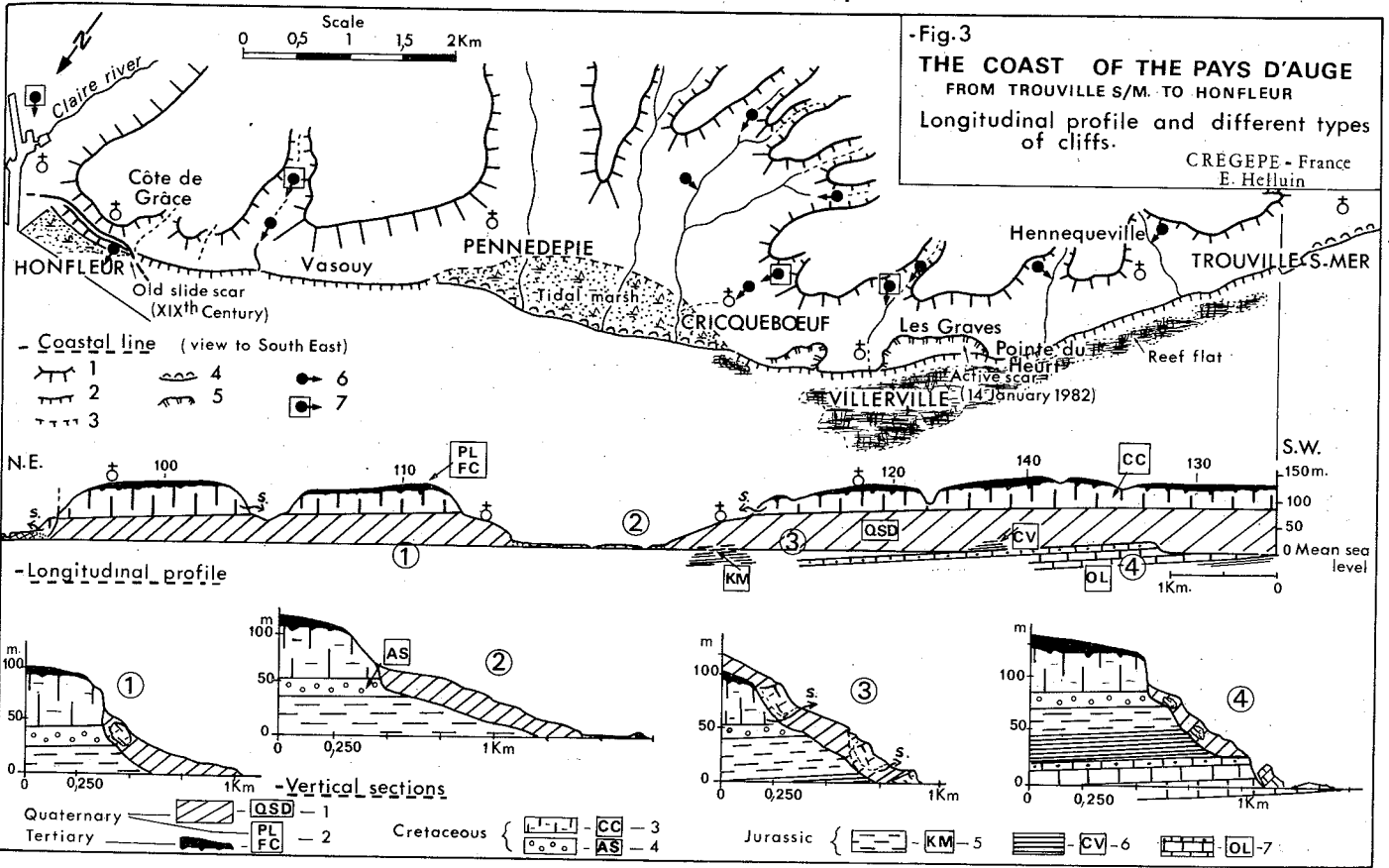


Fig. 3
 Coastal line : 1. Ledge ; 2. Active cliff ; 3. Old cliff ; 4. Sand bar ; 5. Crown scarp ; 6. Uncatched spring (emergence) ; 7. Caught spring.
 Longitudinal profile : 1. Quaternary superficial deposits ; 2. Plateau loam and flint clay ; 3. Cenomanian chalk ; 4. Albian sands ; 5. Kimmeridgian marls ; 6. Clays of Villerville (Oxfordian) ; 7. Oxfordian limestone.

two successive morphologies : at the top, a steep woody ledge about 50 m high and beneath, a regular slope, occupied by mansions built in the middle of the last century, except for a few amphitheatre-shaped sites, threatened by landsliding. The ledge at the top is the edge of the chalky Cenomanian plateau known as "Pays d'Auge". The chalk is sandy with layers of interbedded cherts diaclased and fissured and is thus, porous, with a water table over its highly argilleous and glauconitic bottom. The less steep slope is regularized by thick Quaternary deposits which cover the lower part of the Cretaceous and Jurassic sedimentary suite, under the chalk : glauconitic Albian clays and sands (10 m), Kimmeridgian and Oxfordian marls and clays, known as "Marnes de Villers" (M.V.) beneath which appears a 10 m thick, more resistant cornstone limestone, known as "Grès d'Hennequeville", which forms a low cliff or a calcareous platform in front of the sandy beach. This entire sedimentary group dips weakly to the NE. Chalk and Albian sands are two aquifers, each containing a nappe ; the chalk aquifer attains a thickness of about 50 m some kilometers inland, beneath the plateau, and thins out rapidly, being less than 10 meters thick at the ledge ; the water infiltrates into deposits and marls within the slope.

Slope deposits consist of three components : - chalky Cenomanian blocks, voluminous close to the ledge (more than 100 m long) and smaller close to shore ; heads made of frost-fractured flints and cherts, chalky chips in a more or less abundant sandy or silty gangue and, lastly,

sandy loess or loam. Accumulation of this debris cover took place during the Wurm ; first there occurred solifluction of glauconitic Albian sands, resulting in stripping off blocks of chalk and favouring their sliding down slope, then frost fissuring of the chalky ledge and blocks and deposition of heads and of loess, the latter derived from the foreshore by the wind during drier cycles at the end of the Weichselian period. One can observe the three head-loess sequences of Normandy : Weichsel I, II, III, the last two being characteristic of increasingly colder and drier weather conditions. Loess draped over the slope, gave it a regular shape.

At the end of the Holocene marine transgression which came close to present sea level, more and more extensive landslides occurred. The thickness of the slope deposits on the one hand, and the dip of the sedimentary suite on the other, resulted in progressive changes in the height and the profile of the slope from Trouville to Honfleur.

HISTORY OF THE LANDSLIDES IN NORMANDY

The studies relative to the old landslides have been carried out using postcards, aerial photographs, books and, particularly, the files of the departmental archives. These documents have enabled a map to be drawn up, showing locations of former landslides in Calvados. A second study based on local and regional newspapers relating landslides and other catastrophic mass movements enabled us to make a second, and more detailed, inventory.

The map shows the main locations on the coast, their aperiodic occurrence and the age of the phenomena. The first called "éboulement" close to Honfleur, dates back to September 1, 1538. A second occurred in 1615. Between Port en Bessin and Arramanches, in the Fontenailles area, the first mentioned landslide happened around 1750-1760. Three voluminous blocks of limestone had been stabilized in a vertical position, in front of the cliff, and were accordingly called the "three young ladies of Fontenailles". The third, the largest, 25 m high, was destroyed by the sea-storm of April 26, 1902. At this time, it was located 63 m seaward of the cliff, which shows that the cliff had receded a lot from 1750 to 1900. The average rate of retreat of the cliff in the Le Bouffay sector is estimated at a minimum of ten of meters per century. A comparison of the land-use maps of the period (1809-1975) reveals that the average rate of retreat of the cliff foot in the Bessin area attains 20 m in the immediate vicinity of Le Bouffay.

The Le Bouffay landslide occurred on August 5, 1981, following continuous strain, the first signs of which were observed on the plateau in April 1981, particularly a visible crack in June 1981, showing the location of the crown. Various other cracks appeared and grew in July. The main motion occurred at 8.05 p.m. Eye-witness accounts are contradictory and changing. Some witnesses saw the ground sink in one piece, almost quietly, without a shock-wave; according to other witnesses, the noise was dreadful. The crew of a fishing boat saw the cliff move forward: "the sea was rough and sprays of water higher than the cliff spouted up". At the same time the foreshore buckled, forming a ridge several meters high. Whatever the case, the plateau has been cut to a length of 350 meters and a width of 50 meters, with the boundary displaying the "classic" crescentic shape. This landslide is made up of three main morphological units, from the sea to the plateau (fig. 4a).

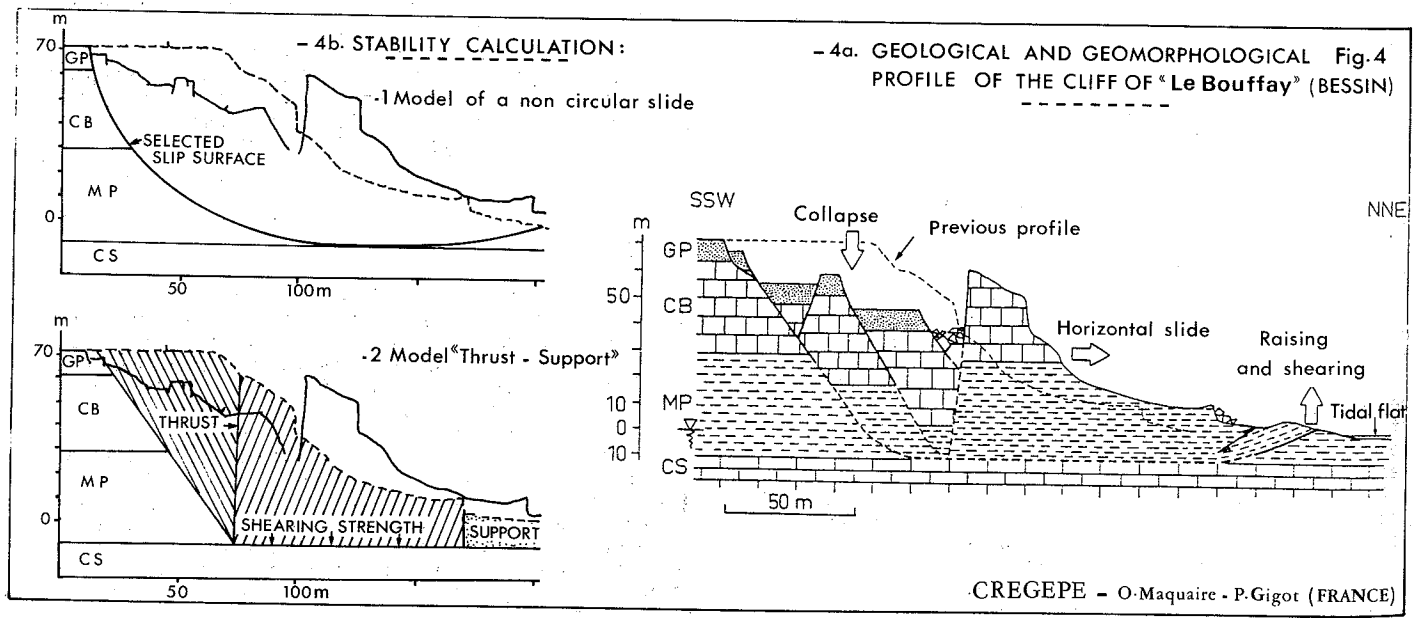
- An approximately 50 meter-wide strip, displaced horizontally for about 25 meters to the north, bordered on the south by an almost rectilinear scarp, oriented E-W. This piece of plateau is not much disturbed.

- Beyond this first unit, a collapsed belt shows some large blocks, some in horizontal position, others in a reversedip position of about 20 degrees.

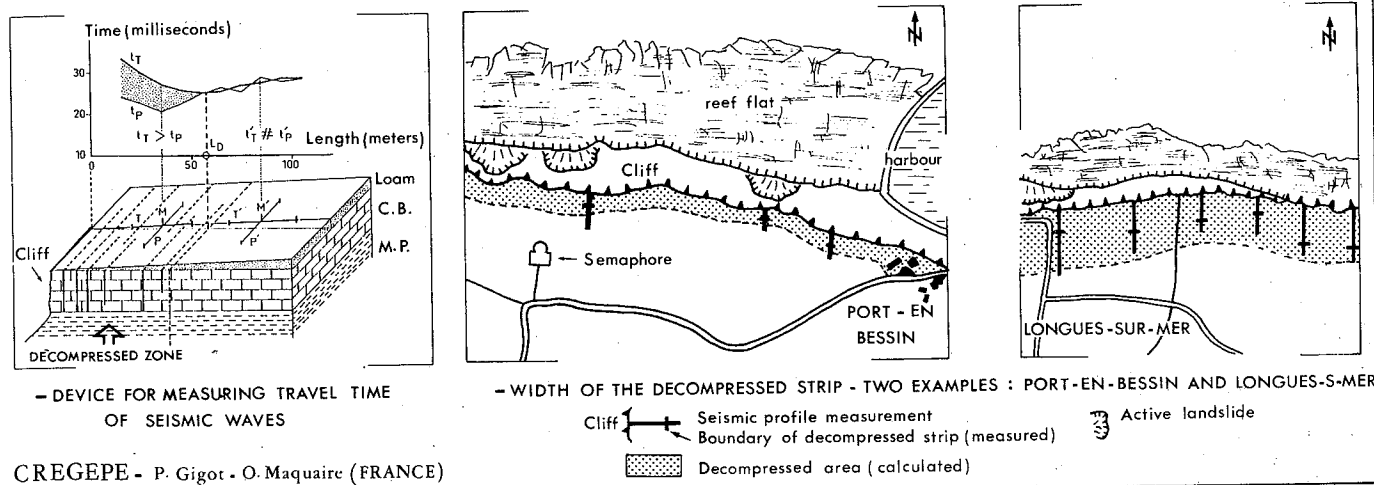
- An uplifted and sheared zone, in front of the horizontally displaced strip. The foreshore buckled up forming ridges of limestones and marls ranging from about 2 to 4 meters which were rapidly dismantled by sea erosion. The slip didn't surprise the officials. Several days before the event, summer visitors had been warned off, illegal camping forbidden, and there was no victim probably because the slip occurred in the evening.

The other inventory of landslides in the Pays d'Auge, has been made up thanks to an exhaustive study of a series of 25 regional and local newspapers from 1875 to 1975. 235 ground movements, i.e., landslides on slopes and subsidence on plateaux, have been monitored since 1875 in Calvados and part of the Lower Seine Department. These movements occurred on 135 different sites, 98 of which had moved only once during more than a century. One can observe a migration of the instability zone with time: at the end of the 19th century, it was especially located along the Pays de Caux cliffs; from 1900 to 1960, it appeared and grew between Villerville and Hennequeville, at "les Vaches noires", and in the Pays d'Auge. Since 1960 the movements have been mainly landslides, more voluminous and more numerous, both in the interior and on the coast of the Pays d'Auge. The meteorological data indicated in the newspapers show a good relationship between the number of landslides and precipitation. Precipitation has been on the increase notably since 1960. In the days preceding the 1982 landslide, the inhabitants had been fore-warned by cracking sounds and distortions of housewalls so that when the landslide started, in the night of January 13, 1982, and went on for several days, the inhabitants had had time to leave their homes and seek cover elsewhere. Nevertheless, the size of the phenomenon and the widespread damage caused surprise and emotion: a lot of small houses and two mansions were completely destroyed; the cornice road sank and became dangerous.

As in Le Bouffay, a spectacular ridge, 2 m high and about 100 m long, which buckled up the beach, re-formed at each low tide, several days after January 13th.



-Fig. 5 AN EXPLORATION SEISMIC REFRACTION STUDY OF DECOMPRESSION BEHIND THE BESSIN CLIFFS



The major concern was for Villerville, a village of nearly 70 houses, caught in a pincer movement. There were, actually, two landsliding areas, on each side of Villerville, respectively the "Fosses du Macre" on the east side, and the "Cirque des Graves", on the west, and these landslides had moved dangerously closer to this seaside resort.

INTERPRETATION, PROBABILITIES OF OCCURRENCE

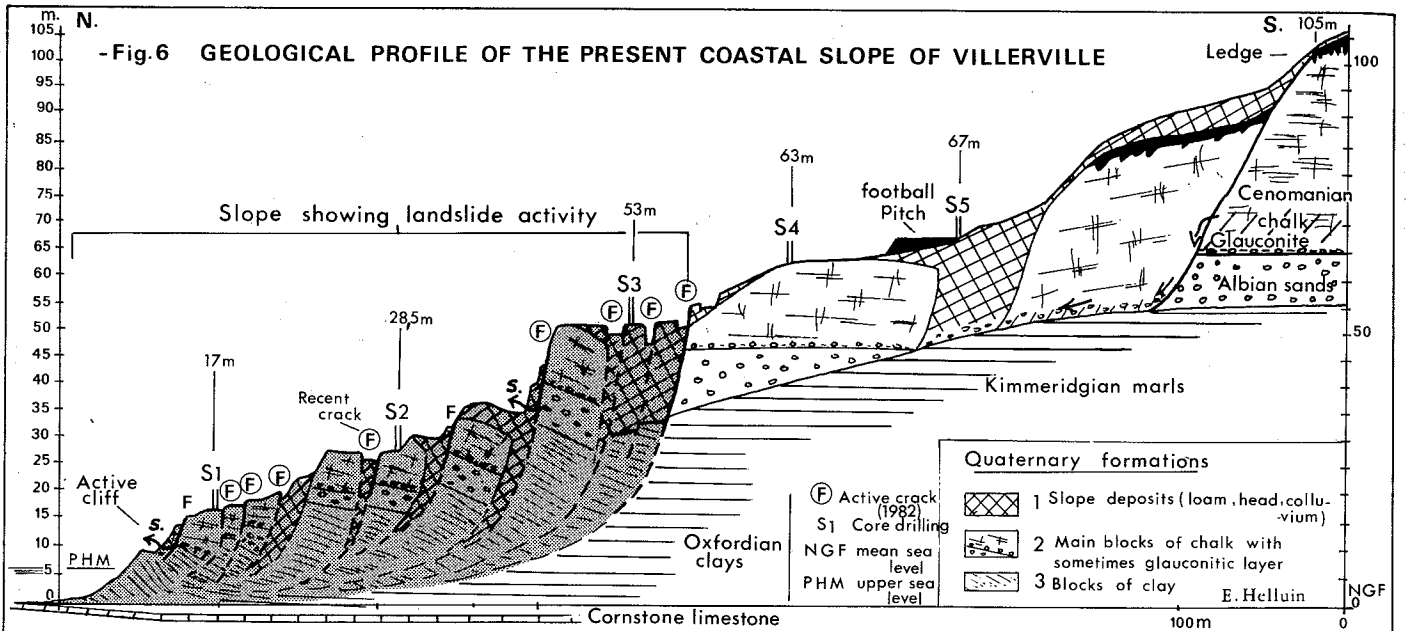
- At Le Bouffay, morphological features and geological and geomechanical data indicate a rupture along a nearly horizontal surface, at the bottom of the marls. To confirm this kinematic hypothesis, we have calculated the safety factor, using two different models (fig. 4b) :
 - A model of non circular slide, whose stability is computed using the iterative method with $\phi = 18^\circ$ and $C' = 10$ kPa, one obtains $F = 0.976$. A rise of two meters of the water table level induces a change of F of $\approx 2\%$.
 - The second model, "thrust-support" and planar slide is less realistic than the first concerning the rupture surface and enables us to integrate the observed disturbance in the calculation. With $\phi = 18^\circ$ and $C' = 10$ kPa, one obtains $F = 1.06$. A rise of two meters of the water table level induces a change of F of -3% . It is thus concluded that the landslide kinematics is a planar slide, by rear thrust rupture, and support strength in the front, the sliding limit surface being probably continuous. A ten meter retreat of the foot of the cliff, in less than a century, and a rise of 2 meters of the watertable level, could explain the triggering of the 1981 landslide.
- The most recent studies have tried to locate, along the coast, the cliffs which are likely to be the most threatened by landslides in the future. They have taken into account the degree of fissuration in the plateau, beyond the cliff. This cracking is related to the release of strength and creep of marls, and measured by seismic refraction. Thus, a map of the most fissured coastal sectors has been drawn up (fig. 5).
- At Villerville, the interpretations are less advanced, because the 1982 landslides had come after several past landslides, whose number is still unknown.
- Villerville is built on a periglacial alluvial fan, in the axis of a dale perpendicular to the coast ; its basement seems to be stable, because the Quaternary

deposits are porous, coarse grained, resistant to sliding ; the waters running in the dale are diverted upstream of the village, and a stone wall protects it against seastorms. The danger comes from a possible widening of the landslides in their lower part.

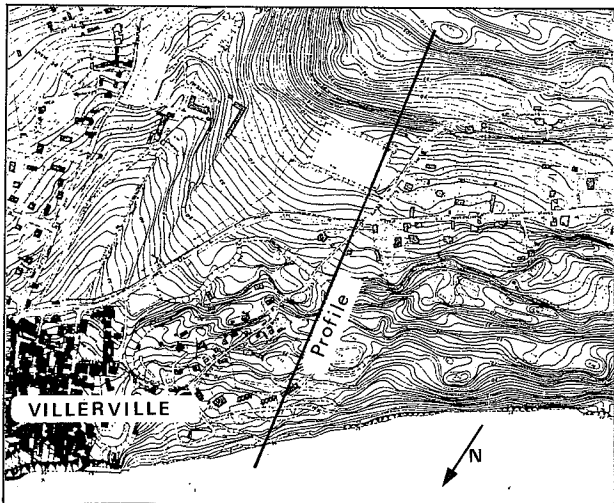
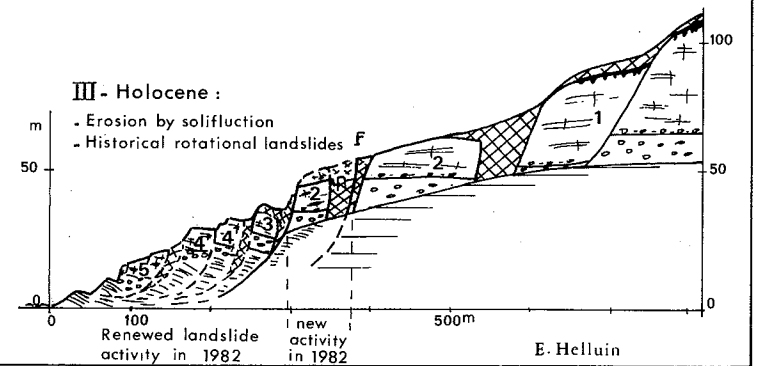
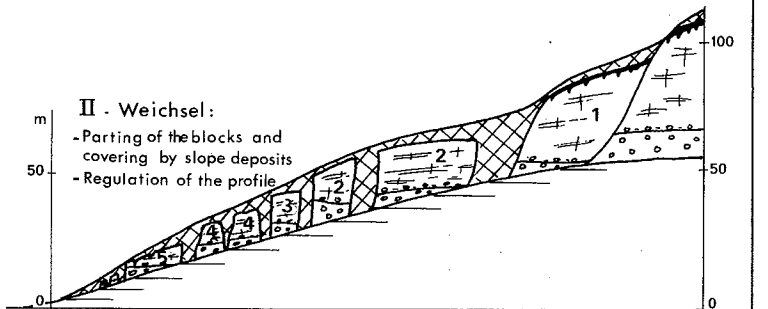
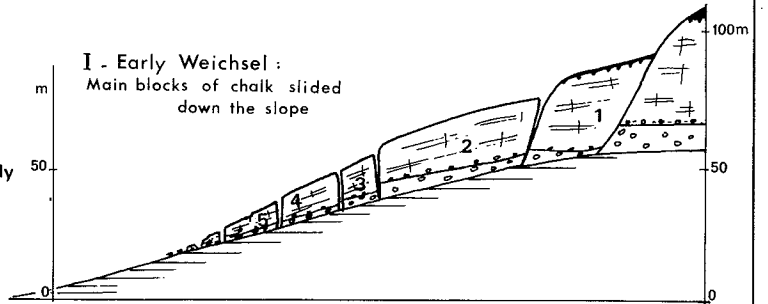
- The morphology of both landsliding areas suggests that, according to the terminology of Varnes or Crozier, there exist only the concave upper part and the head of the landslide, the greater part of the foot and toe is missing, having been gradually dispersed by the sea. The morphological features of these landslides allowed us to interpret them in 1984 as multiple rotational retrogressive landslides (fig. 6). More recent investigations give a better idea of the location of the rupture surfaces, on the one hand, by examination of the drilling cores, coming from 3 recent drill holes, and on the other hand, by the use of inclinometers and measurements of the most recent displacements in depth, since december 1986 (fig. 7). Measurements of displacements on the surface using topometric instruments, have been made during the last two years (fig. 8). The rate of dispersion by sea of the sands and debris on the beach, is also being measured. It remains to calculate the safety factor for different models, with a circular or planar rupture surface, and to integrate parameters such as displacement rate, rainfall, piezometrical oscillations, etc... in a model, so as to allow for a better approximation of the probability of dangerous accelerations.

CONCLUSION

The 1982 landslide at Villerville was given much publicity, but the reports of the popular press and television reports were less concerned by the fate of the inhabitants of the resort than by the presence, close to the boundary of the landslide, of a mansion belonging to a well-known cinema actor. Under the pressure of events and of public opinion, the local politicians allocated some funds, to enable the monitoring, during two years and using cheap instruments, of superficial movements. The main difficulty of the research program that we have worked out, has been to bring different public services to work together and to find the funds essential for expensive operations such as relatively deep drillings and setting up of inclinometers.



- INTERPRETATION - According to the study of the Quaternary geological formations.

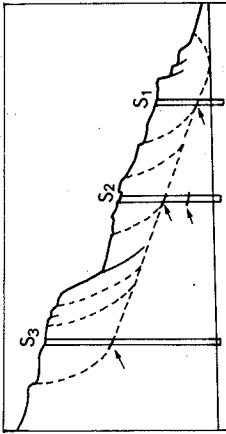


CREGEPE - (FRANCE)

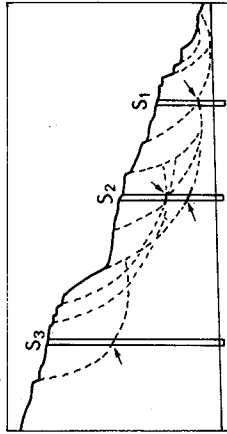
LOCATION OF DRILLING HOLES AT VILLERVILLE
GEOLOGICAL INFORMATION

INTERPRETATION O. Maquaire

1st Hypothesis: Planar sliding



2nd Hypothesis: Successive rotational landslide



Supposed landslide surface
Surface given by inclinometry

- 0m. = Mean sea level
 - (S_i) Drilling hole
 - P_i Well
 - n°67 Landmark
 - ▽ Piezometric level
 - ▬ Confined water
- In the drilling hole:
 - ▬ Rupture zone
 - ▬ QSD: Quaternary slope deposits
 - ▬ M. Marls in place
 - ▬ M. Marls (probably disturbed)

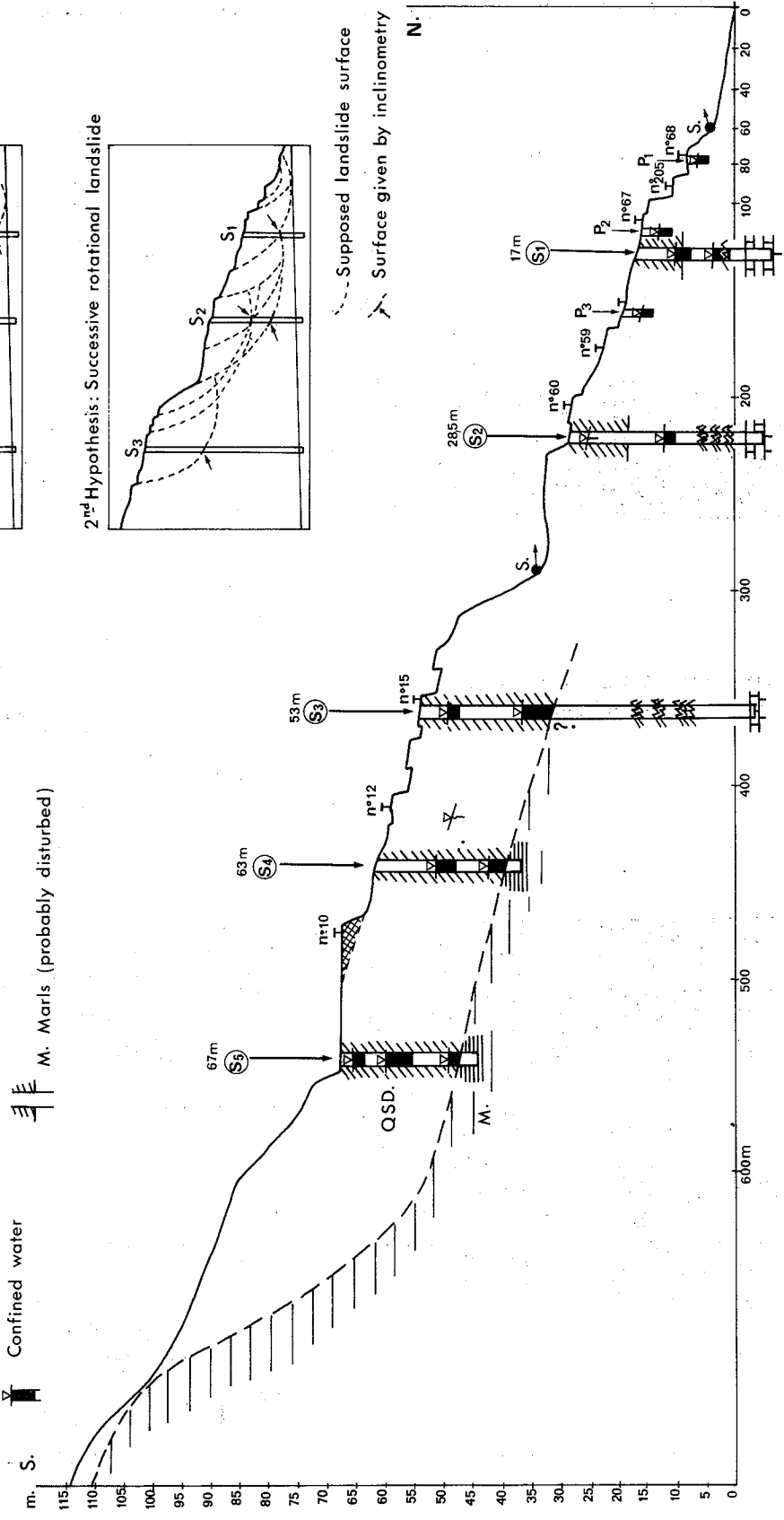
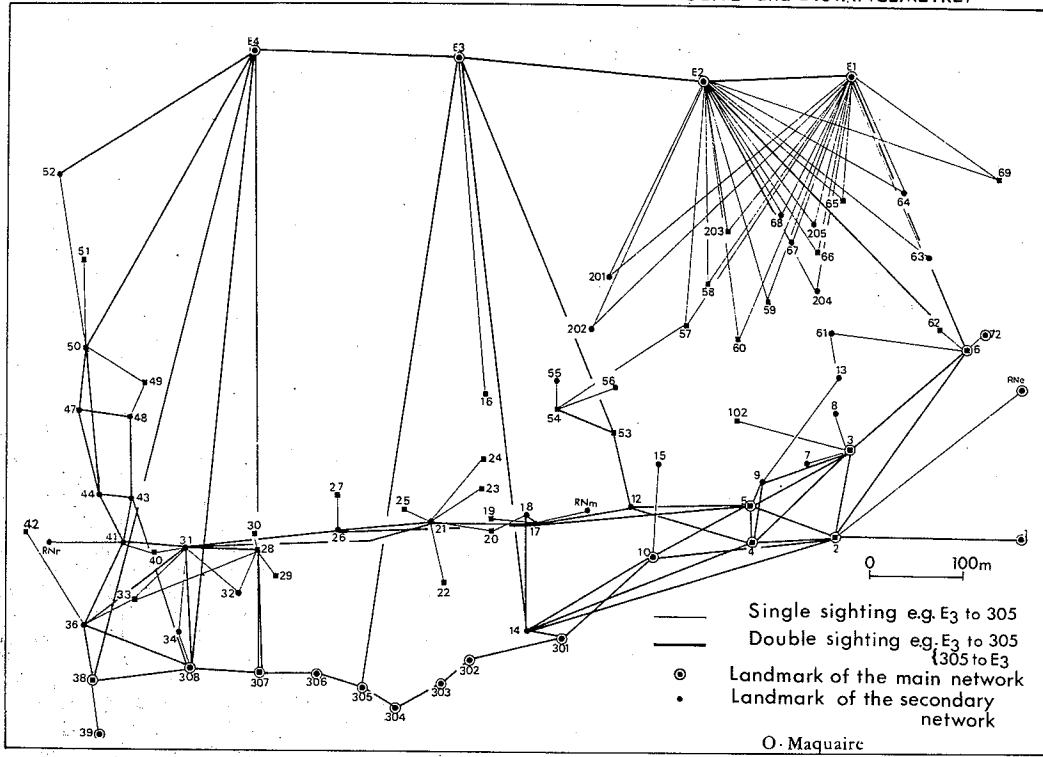


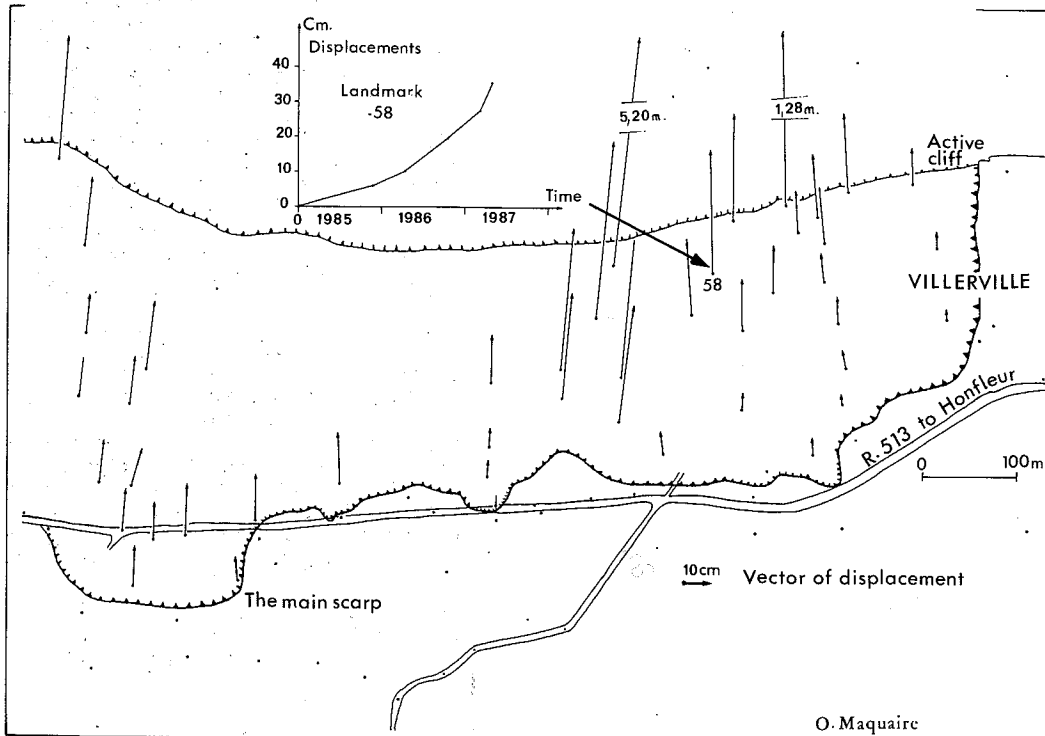
Fig. 7

Fig.8

DIAGRAM OF SIGHTINGS RECORDED DURING A "TOPOMETRIC" SURVEY
(THEODOLITE and DISTANCEMETRE)

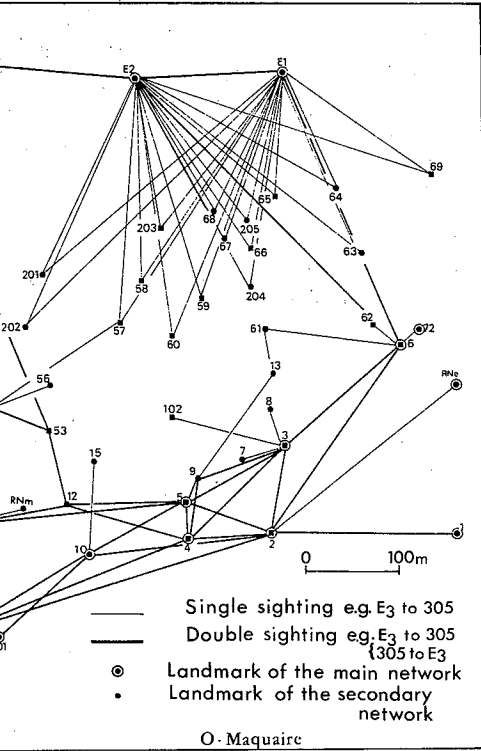


TOTAL DISPLACEMENTS RECORDED FROM JANUARY 1985 TO APRIL 1987



CREGEPE (France)

**URING A "TOPOMETRIC" SURVEY
(THEODOLITE and DISTANCEMETRE)**



Prior to the results of our present studies, a Departmental Service has had enrockments reinforced in front of the resort and has also reinforced supporting blocks at the foot of the landslide. The former will certainly prove to be effective. However, these enrockments disfigure the scenery and given the fact that they were constructed without prior appropriate landslide studies, it is practically impossible to tell whether they will resist seastorms and, especially, landsliding reactivation. The comportment of scientists, civil servants and politicians in matters of environmental hazards remains difficult to harmonize.

Thanks to Edward Anthony for correcting the original English version of the manuscript.

ANUARY 1985 TO APRIL 1987

