The Séchilienne Slope -Romanche Valley (ISERE), France

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1 INTRODUCTION

Séchilienne is located on the national road RN 91 Grenoble (Isère)-Briançon (Hautes-Alpes), in the alpine Romanche valley, approximately 30 km south-east of Grenoble (Isère).

Between Vizille and Séchilienne, in the " Ruins of Séchilienne " area, the valley is the theatre of a great slope movement, which affects the southern side of the Mont Sec.

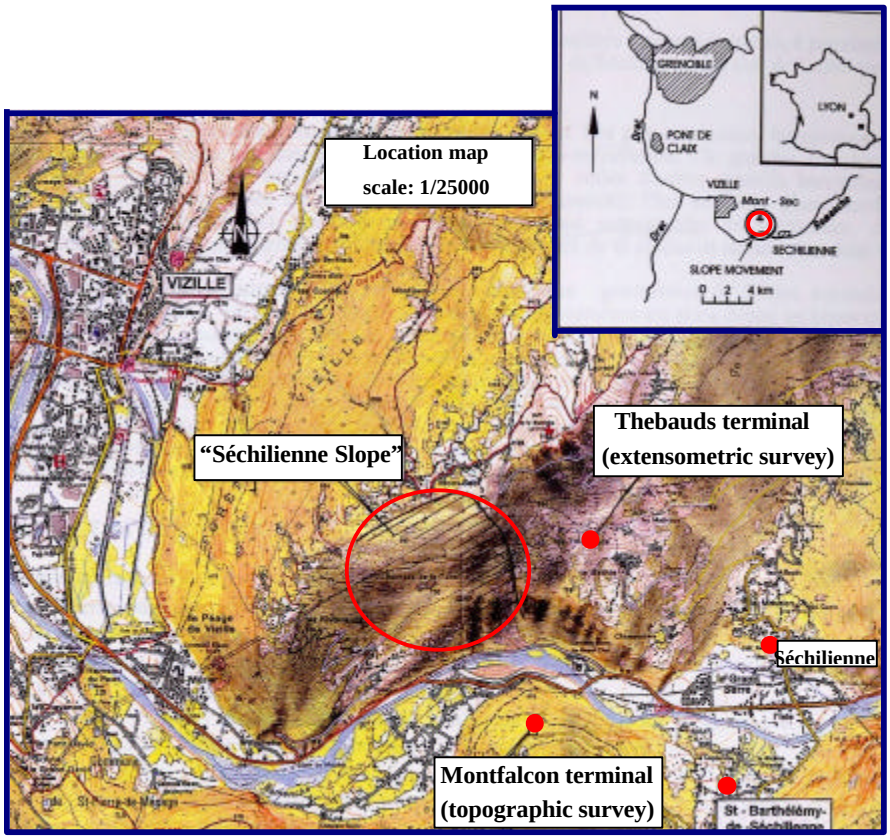

Fig. 1: Location map of the "Séchilienne Slope"

2 REGIONAL FRAMEWORK

2.1 *Climate*

The considered sector, characterised by a climate of mountainous type, has an altitude ranging between 600 and 1200 m, the top is 2500 m high. Strong precipitation occur generally in spring. They may reach an amount of 400 mm over two months (october-november 1992), and 280 mm in only one month (July 1973).

2.2 *Regional Morphology*

The slope of the Romanche valley was modelled by glacial erosion, the final ice melting being approximately 10 000 years old.

The morphologic indices show that the initial würmien II glacier reached 1400 m. The slope failure could correspond to the free face of the glacier würmien III (last glaciation). Some authors propose a lower altitude (600 m), that is to say fairly the base of the Séchilienne movement for the last glacier.

2.3 *Regional Geology and Structural Setting*

The " Séchilienne Slope " site belongs to the old basement (ante-Westphalian) of the Belledonne chain, one of the external crystalline masses of the French Alps. That geological formation is articulated in two great units, external and internal branches, separated by the " synclinal median ".

The external branch, the less developed, consists of a single lithological formation: the «série satinée » formed by micaschists with two micas.

The internal branch is wider**.** With the difference of the precedent, lithological facies are more diversified according to the abundance of materials of volcanic origin (green series). Granitoids are also represented.

The " synclinal median ", is a thrust fault for C.BORDET.

The “Séchilienne Slope” is located in the « Serie satinée », near the synclinal median, which determines the depression trending from Séchilienne to the Luitel Pass, towards the north.

Oldest hercynian phases are responsible of a huge isoclinal fold with a meridian axis.

Great structures lying, with southern vergency, were described, comparable to those of other French hercyniens masses where they are dated from early hercynian age (Devonian-Dinantian). Later an hercynian phase (posterior to carboniferous granitisations) is particularly responsible, of the " carboniferous syncline genesis ", known in various points of the chain and in particular in the " Ruins" sector.

The Alpine tectonic began at liasic age by distension generating normal faults (“distension téthysienne”). The lower part of the future external crystalline solid masses was cuted out in toppled blocks (generally tilting towards the west) which were responsible of important and rapid variations in thickness within liasic and Jurassic cover.

At the beginning of the Tertiary, an important deformation phase occurred (the antenummulitic phase) which features has been later taken again by the main alpine phase. The blocks, previously individualised, were then brought to overthrust, giving sometimes a western vergency at a large scales (geophysics shows that the whole Belledonne massif is currently overlapping towards the WNW). Finally a late movement with vertical uplift brought the chain at its current altitude.

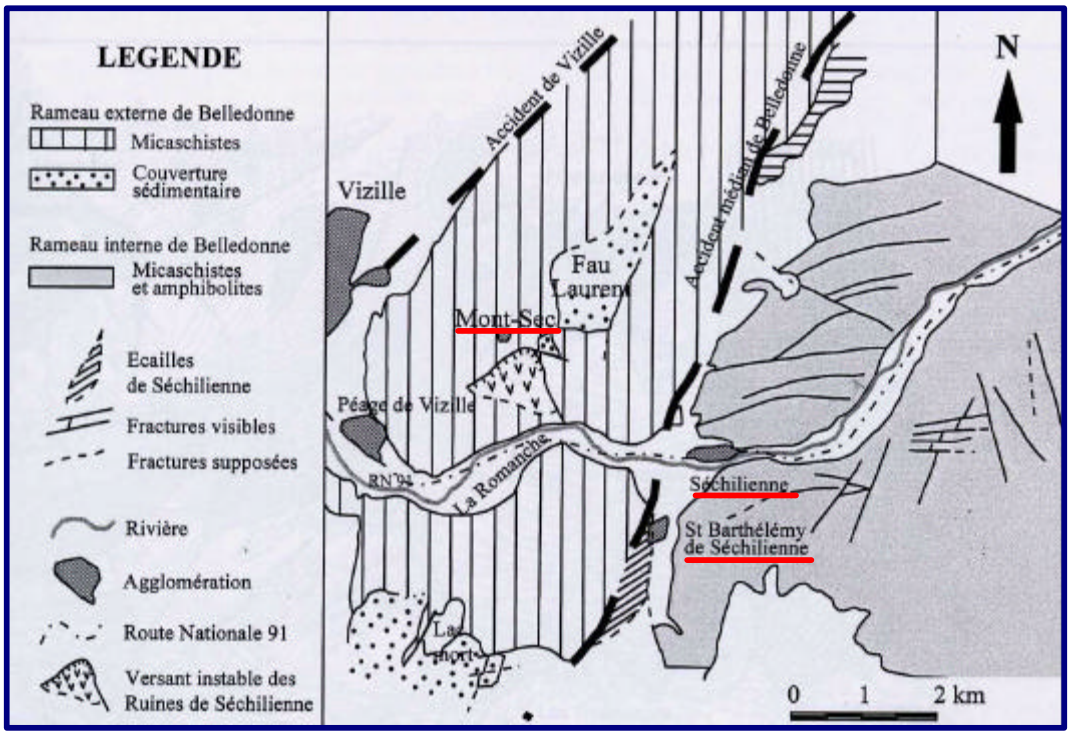

Fig. 2: Structural setting of the Belledonne mountain mass (after the Vizille geological map - 1:50.000).

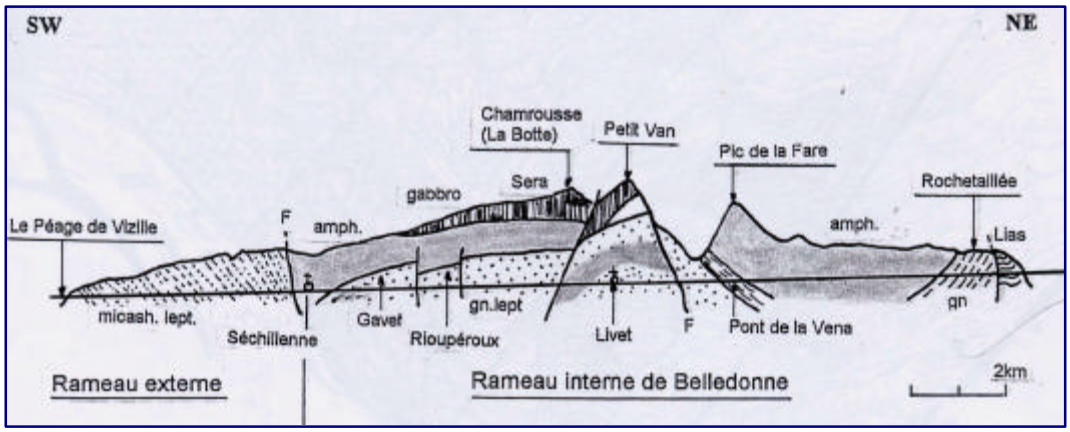

Fig. 3: E-W section of the Belledonne Belledonne mountain mass along the Romanche valley between Vizille and Rochetaillée (after J.P. Menot)

2.4 *Local Geology and structural setting*

The external branch, to which belongs the unstable Mont Sec area, is mainly made up of micaschists (série satinée), with some carboniferous formations pinched in the tectonic contact and covered with triassic and liasic sediments (plateau de Fau – Laurent).

The "série satinée" is a lithological unit formed by chlorito and sericitoschists, derived from a flyschoïd material, essentially pelitic, with some arenitic layers. Its age is uncertain (Protérozoïque, early Paleozoïc, late Paleozoïc).

That formation is characterised by distinct metamorphic episodes, both of hercynian age. The oldest would be of devono-dinantien age, and the youngest of carboniferous age. The alpine metamorphism is especially a retrograde one.

The reconstitution of the tectonic setting of the Séchilienne slope was based on aerial photographs interpretation and on field surveys.

Early phases of distortion (D_0, D_1)

The first deformation stage (D_0), responsible of the foliation is accompanied by the genesis of small quartz veins.

We don't know any fold associated to that episode. The "serie" is then folded by another phase of deformation (D_1), characterised by the apparition of the oldest known fold (P1) which affected the quartz veins system.

Small isoclinal folds with vertical axis, are observed in several points of the slope, in particularly along the way which leads from les Thiébauds to the highest gallery (level 900m) and to the north of this same one. Some folds, with vertical axis and of decametre amplitude, visible on the RN91, are probably linked to the same phase of deformation.

S_1 schistosity is confused with S_0.

The D_0 deformation phase would be of antecarboniferous age while the D_1 phase would correspond to the beginning of the hercynian orogenesis.

Hercynian deformation phases (D2)

The hercynian stage (of Westphalian age?) at the origin of the superimposition of the layers of the Belledonne complex causes the overlapping with southern vergency, of the basic Chamrousse basic formation upon the Taillefer unit and the genesis of P2 folds.

The P2 folds are asymmetrical ones with subhorizontal short side and subvertical long side, slightly dipping to the north (reverse side of a large fold with southern vergency?).

The horizontal axis has N.50 to N.80° E direction. We have observed these folds in Mont Sec subsidence but also at the entry of the mining gallery (level 900).

Some N60-70° E faults with a left lateral displacement are contemporary of that deformation stage.

These conjugated N20-50° E and N120-140° E faults have respectively left lateral and right lateral strike slips.

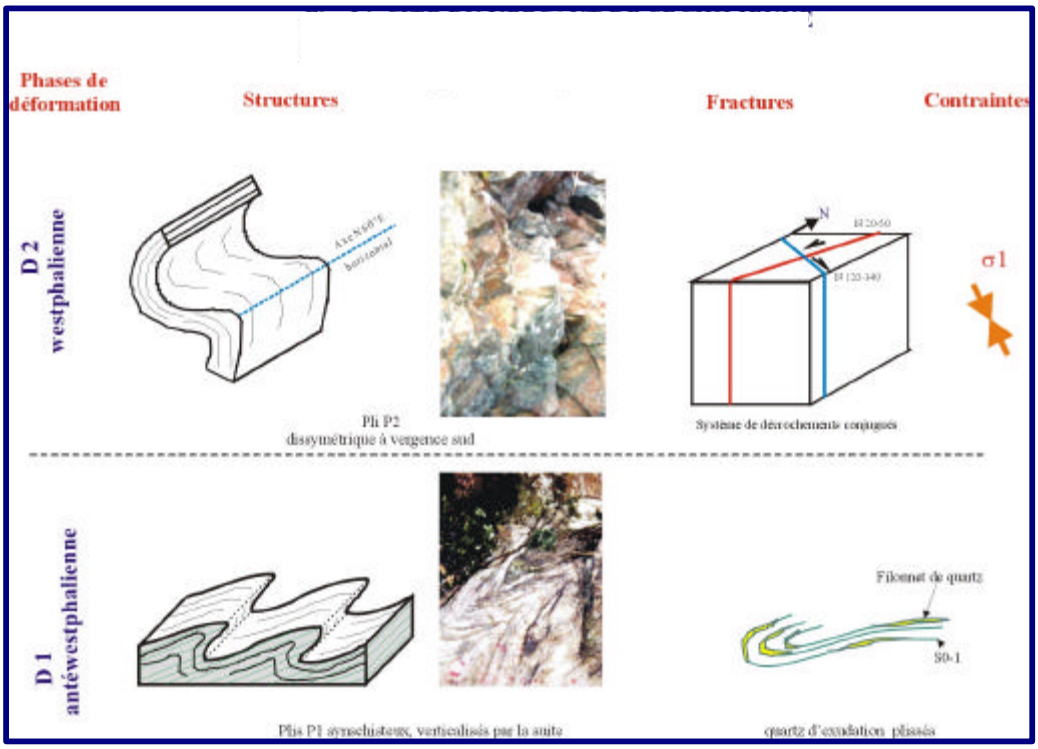

Fig. 4: The D1 and D2 structural stages

The D3 phase

The D3 deformation stage, probably of permian age, played a great role in the morphology of the slope and probably continues to have a major one in the genesis of the disorders observed at the present time.

This deformation phase, which is a strike slip phase, is responsible of the actual structural state of the Séchilienne slope. It is characterised by tectonic structures usually observed in transcurrent condition (associated folds and shear zone) to which the setting up of a lead-zinc and quartz veins field, exploited at the last century, was surimposed.

Folds and associated discontinuities

In the exploration gallery (level 900), a large fold was identified by structural measurements. That fold is also visible on oblique photographs taken from helicopter and constitutes the major structural feature of the Séchilienne slope.

The study of the foliation plans shows that all the upper part Mont Sec is affected by this broad fold.

Secondary P3 folds, with horizontal N.170° E to NS axis, affected again the P2 folds.
Some of them are associated with reverse faults along accidents dipping to the west.

The N 20-50° E and N 120-140° E conjugated faults, moved into opposite direction of the previous lateral movement, therefore they have respectively a right and left lateral displacement. Two of them have a leading role in the division of the mass:
The N. 20° fault trending from the “Rivoirands” to the N-NE edge of the upper subsidence
The N. 140° fault E forming the higher limit of the Ruins corridor.

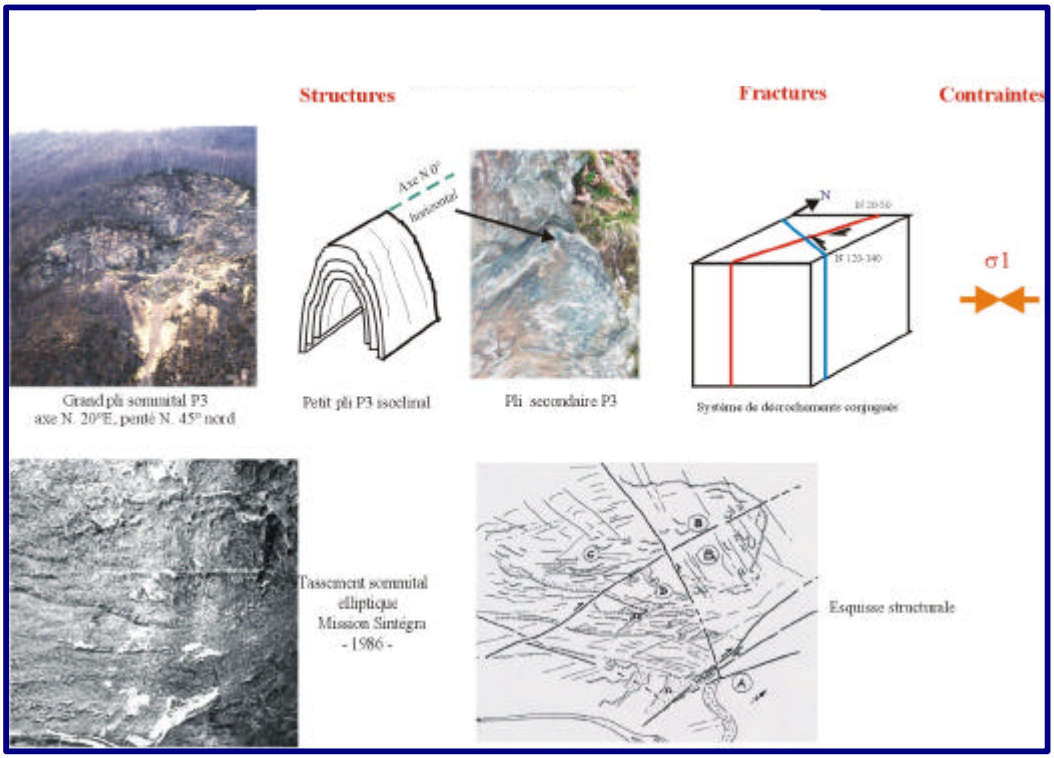

Fig. 5: The D3 structural stage

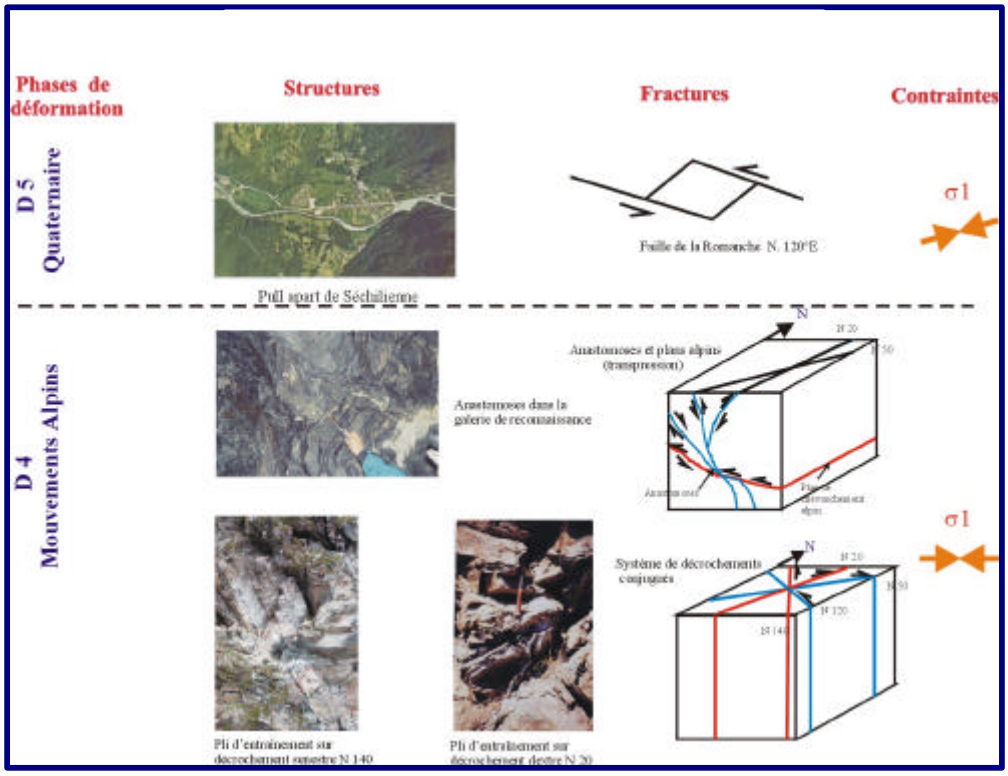

Fig. 6: The D4 and D5 structural stages

Late alpine deformation phase (D4)

The P4 folds, with NS to N. 20-30° E axis dipping to the north, are present at several scales in the Séchilienne slope. Of metric size, they were observed in the higher part of the slope, in particular along the way which lead from the “Thiébauds” to the “Grand Combe” mine.

The main discontinuities are the following:

- N20° to N30°(K) faults more or less parallel to the synclinal median direction, which represents the overlapping of the Belledonne Internal branch upon the External one (Série Satinée). They are characterised by a right lateral strike slip (alpine age) which can be seen in the depression located south side of the Mount Sec (Grand Combe) to the passage of the main N20° fault across the Mont Sec subsidence.

- N 120° to N 140° (K') faults are conjugated with the previous ones. They are left right lateral strike slip faults (of alpine age), shown by the displacement towards the NW of the "Ruins" top and of the NE part of the subsidence summit. This movement is also apparent in the brutal interruption of the "Grande Combe", which appears to be displaced of approximately 80m towards the left.

The K fractures family is well expressed in the S-W side of the Mont Sec depression and in the slope, while the K' family, with a looser network, is visible in the northern side of the landslide.

- The fractures behind the Mont Sec (F) with a 40 meters high scarp, and a N.60°-E direction, are dipping 70° to the south;

- The "Grande Combe" (F'), is a ten meters deep graben, delimiting the upper elliptic depression to its southern side (N60-70°E direction, dip 65°N) ;

- The N60-70°E (F' ' -F' ' ') fractures dipping 65° to the north, form a dense network in the moving zone (« Ruins » corridor), where they are largely opened, under the double action of the Mount Sec releasing stress and the neotectonic. Many fractures of this type were located in the exploration gallery at the 710m level. The observed toppling shows their predominant action in the slope evolution.

A fifth family of discontinuities, not visible on the structural diagram, consists of a diaclases network. These diaclases of dominant N 110-120°E direction present a steep dipping (about 75°) to the south.

The quaternary phase (D5)

The study of the cartographic documents and of the aerial photos of the Séchilienne sector, revealed in the Romanche valley, at the site of the Séchilienne village, the existence of a small losangic basin evoking a pull-apart type one.

Interpretation

Three important faults share the Séchilienne slope into four compartments differently structured.
Compartment A: to the east of the " Ruins " corridor the fractures are less dense and we don't find there the N70° in N80° directions;
Compartment B: (B1+B2): to the NE of the main N140° fault, this compartment is divided in to thin straps by accidents of comparable nature and direction;
Compartment C: the N20° and N70° discontinuities are better represented than N140° ones, almost absent;
Compartment D: delimited by the main N20° and N140° faults, the N20° and N70° accidents to N90° accidentsare numerous whereas the accidents N 140° ones do not appear any more.

The Mont Sec division is compatible with the delimitation of panels with different kinematics, according to the trajectory analysis.

Moreover one notes that the Mont Sec depression, of a fairly elliptic shape, is bordered by concentric discontinuities and is shared by some radial fractures which converge towards the centre of the ellipse. This pattern, in space relation with the upper large fold and with the Séchilienne quart veins field. That pattern evokes the "cone sheet" structures.

The mentioned studies carry us to attribute the slope releasing stress, to the Romanche glacier melting. The decompression is considered to be responsible for the opening of the various discontinuities families, for the movement of panels with variable kinematics, and for the subsidence of the upper Mont Sec area.

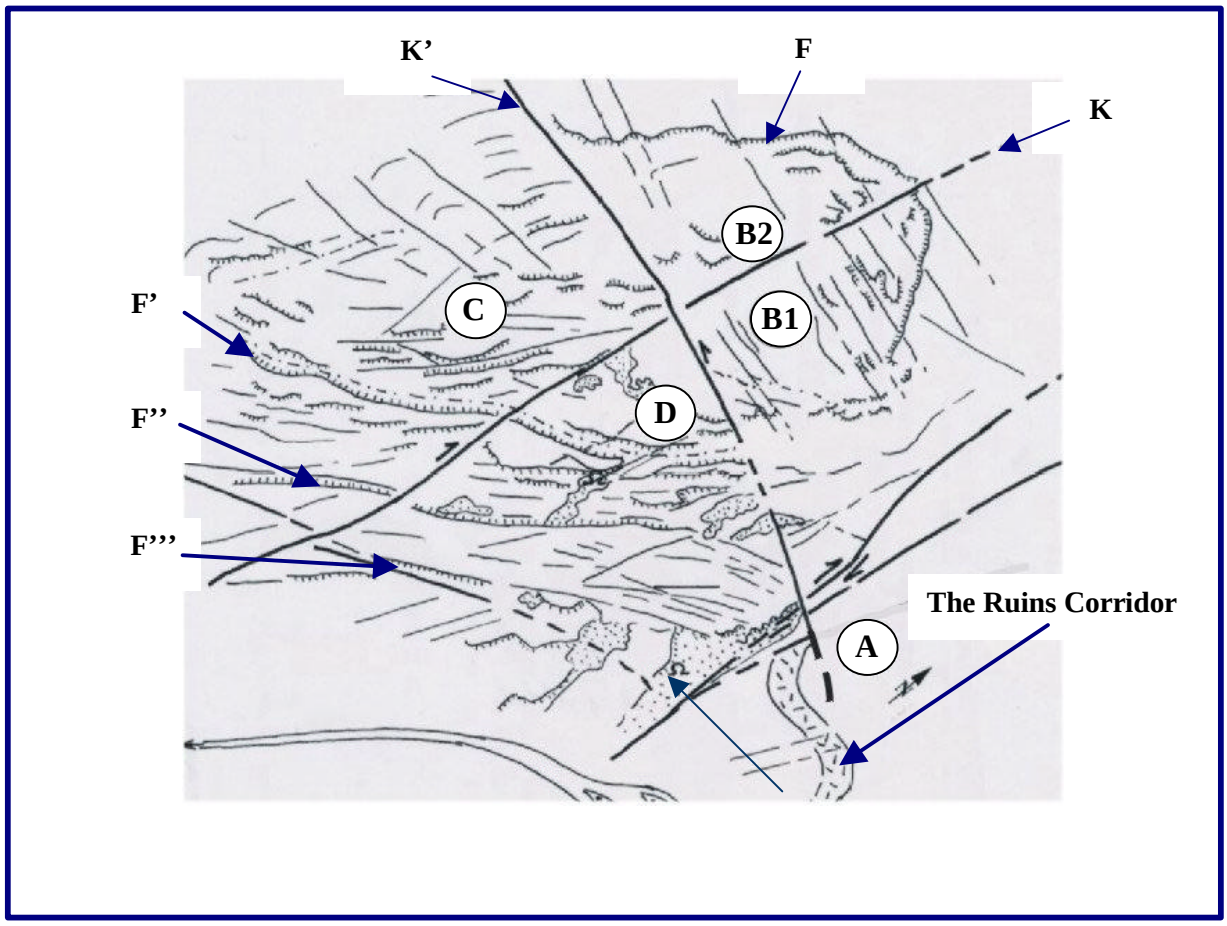

Fig. 7: Structural setting of the Sèchilienne Slope
(the surrounded letters show different moving areas).

2.5 *Water Conditions*

The Mount Sec hydrogeology depends on two distinct and complementary mechanisms. The feed is related to the direct infiltration of meteoric water (rain and snow) in the basin slope. It determines mainly the flows in the higher zone of the Mount Sec, but also with the existence of deep circulation, along privileged fractures, depending on the internal hydrogeology of the mass.

In the unstable zone there aren't spring. One also notes the absence of water in the vicinity of the base of the active zone.

The only certainty is brought by the results of the monitoring since 1985. The measurements underline a cyclic variation of the speed of displacement which can classically be attributed to seasonal water levels fluctuations in the fractures system.

These results which bring to us to conclude that there is in the lower part of the slope a sufficient low fractures permeability to allow, a temporary rise in the piezometric level in the wet period.

Recent observations in the exploration-mining gallery (level 590m), show important flow of water, well distributed between 50 and 200 m, from the entry. This undoubtedly gives the order of magnitude of the average of saturation in certain parts of the rock-mass.

The observations, made during the EDF gallery draining, established at the slope base (level 430m) the existence of a major flow level corresponding appreciably to the level of the mining exploration tunnel.

3 LANDSLIDE

The SECHILIENNE Ruines sector has always been considered as the dangerous passage between "Vizille" and "Bourg d'Oisans". The testimony collected over the last five centuries related minor events, which were considered as natural erosion.

3.1 *Landslide Identification*

The "Séchilienne Ruins" sector is in the right side of the Romanche river, in the Alps of Dauphiné, 2,5 km downstream to the Séchilienne village, and 15 km SE to Grenoble town.

3.2 *Landslide Morphology*

The Séchilienne Ruins sector is the theatre of a great slope movement, which affects the southern part of the Mount Sec area. It shows a homogeneous slope dipping 45° to the south between the bottom of the valley (level 325m) and the southern limit of the Mont Sec subsidence. Then comes a gentle dipping 20° slope up to the top.

This slope deformation is probably dependent on the mechanism of the internal mass rupture subjected to the erosion of the glacier. This remark is confirmed by the presence in an unstable slope to the East, where a typical glacial platform shows a counter dipping (10°).A similar platform is visible close to the "Rivoirands", western part of the moving zone.

The glacial history left some marks in the Romanche valley where a significant over caving could be highlighted geophysical prospection. This survey carried out in the bottom of the valley, shows in the right sector of the Séchilienne Ruins, alluvial deposits of about 80-100 meters thick. Downstream, at the "Croix du Moutet", the basement is at a lower depth.

The recent geophysical studies have highlighted the following main features:

- ✓ The upper part of the Mont Sec area is characterised by the presence of an old subsidence due to an elliptic collapse, this zone being limited to the north by a 40m high scarp (F) and to the south by a few meters deep graben: the "Grande Combe" (F').
- ✓ the slope is cut out by fractures with N60° - N70°E direction, (F''– F'''), bordered by scarp facing to the north, which are similar to the "Grande Combe" graben.

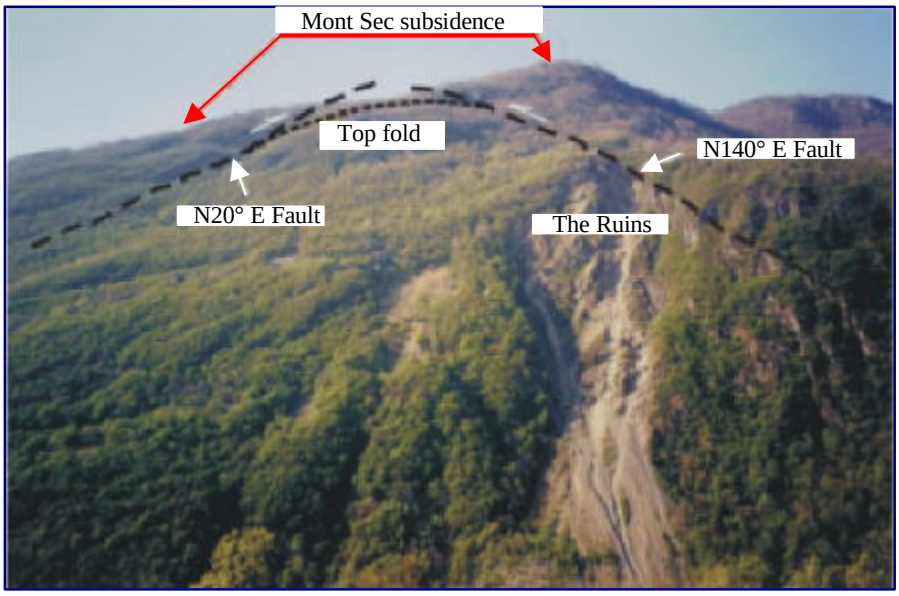

Fig. 8: View of the "Ruins" corridor and Mont Sec subsidence.

3.3 *Landslide History*

Old events

- Some rockfalls during the 18th and 19th centuries.

- 1906, the last rockfall recorded in this investigation occurred during the 23 to 24 February night. Some blocks were detached 20 m above the road at the kilometric point 22,740. The global mass was about 80 m^3 whereas other blocks threatened to collapse. The road was blocked and the Grenoble power line feeding destroyed. March 20, the threatening rocks, approximately of a 80 m^3 volume, were dynamited.

In the 19th century, blocks and landslides regularly damage the old way, which crossed the Ruins sector. Difficulties in the road maintenance and the decline of the ground human activity led to choose other transportation ways.

This slope was also a mining district. The zinc extraction began in the medium of XIXth century and end in 1914.

Recent events

It has been possible to define a space temporal evolution of the site, thanks to five series of aerial photographs from IGN (1937, 1948, 1956, 1982 et 1987). A clear modification of the site activity has been observed.

On the photos of 1937, several ravines mark the «Ruins» corridor area (which limits to the east the lower frontal zone).

Between 1937 and 1948, an evolution of this sector is perceptible in the higher part.

On the photos of 1982 (34 years later), one notes a strong evolution of the corridor branch, nowadays well individualised.

A very clear aggravation during the winter 1984/1985 was observed.

In 1987, the ravines zone is active and disorganised, emphasising a clear acceleration of the sector degradation.

4 INVESTIGATION AND MONITORING

4.1 *Survey and monitoring of landslide activity*

The design of a monitoring system has to meet two different objectives:
- movements analysis and mechanisms identification for the understanding of the phenomenon ;
- the installation of the monitoring infrastructure in the site allows to manage the safety of people (emergency plan), in the zones exposed to a mass movement.

A first monitoring device was set up in 1985 and then was completed in 1988 and in 1993.

It now includes the following devices:
1. surface monitoring (geodetic measurements, GPS and manual extensometry) ;
2. gallery monitoring (topography , manual extensometer and tiltmeter) ;
3. tele-monitoring (automatic extensometry, automatic geodesy et radar micro-wave)

Surface monitoring – Conventional topography survey -

A groundwork reference was defined since 1988, and even in 1985 for some reference marks. 46 points are observed by **geodetic measurements**, 16 points observed by **GPS**, and four additional points compose it. They evaluate respectively the angular and the distance measurements necessary to the reconstruction of the vectors displacement evolution. The device of the conventional topographic survey is based on the utilisation of the Theodolites electronics-Wild T2002 et T2000 whit electronic notebook Wild CRE and the distancemeter WILD DI 2000

The measurement frequency is carried out one time for year.

Principal results of the previous years are:

1) the vectors displacement are perpendicular to the Romanche river, towards the «Ile de Falcon» in the south east direction .
2) the frontal part of the mass, the most active, which extends in 1999 from 44 to 65 cm with subsidence of 11 to 36 cm. These values are fairly twice higher than those recorded in 1998. The annual average rate of displacements since the origin of the measurements is included between 23 and 44 cm/year and between 6 and 25 cm/year in the higher part.
3) the zone located above the active frontal part evolves at a speed included between 1.5 and 7 cm/year. While the one localised in the western proximity, (towards the exploration gallery), progress from 1 to 3.1 cm/year.
4) the unstable solid mass on the West side, moves at a speed lower than 2 cm/year.

The lower limit of the moving zone is in correspondence of the scar that marks the site towards the level 540/580 and goes up to the west direction (over Rivoirands).

Since the origin of the measurements and for the majority of the monitoring points, the analysis of the displacements evolution underlines an acceleration of the movements that is more accentuate in planimetry than in altimetry.

Since 1988, a network of 49 points is equipped by **extensometers** (Invar wire) LCPC on the site, in order to check the evolution of the fractures or of the cracks opening (relative movement).

These double devices, in particular the twenty-seven points that are **extensometric remotesurvey**, are used in order to have the control and an absolute reference, they allow to readjust the sensors in case of maintenance.

The frequency of the measurements is at least four time a year (and upon request).

Gallery monitoring

The **Geodetic survey** is realised with a precision of about 0.25 mm. Such network is characterised by the installation of 24 points in the gallery 710 a.s.l. and by 24 points in the gallery 595 a.s.l.. The frequency of the measurements is 3 times per year (and upon request).

The main results indicate that the mass becomes deformed according to tilting and rotational movements of several panels delimited by discontinuities located at 20, 90, 190 and 230m from the entry of the gallery (point 624). These discontinuities generally correspond to faults.

Taking into account the difficulty to access to the gallery 595 a.s.l. during wet period, measurements are taken only one time per year, rather dry period. The measurements carried out in June 1999 make it possible to visualise a 1 cm opening fracture and a 1 mm subsidence (2 mm) at the head of the gallery since August 1994.

The measurements carried out in the gallery 710 (24 bases), 595 (24 bases) and 875 (8 bases) emphasised the tilting of different compartments (the ones compared to the others).
The discontinuities, observed during levelling measurements, are well confirmed by extensometric measurements: some phases of opening and tightening of the fracture are observed.

The main results:

1) the amplitude of the movements is about 1 cm/year;
2) the graphs are provided considering that the gallery surface is stable, but it is probably not the case;
3) the relations between the extensometer and the levelling measurements are clear and confirm the existence of compartments more or less individualized with distinct behaviors,
4) these measurements confirm a deformation according to a displacement vector slightly tilted compared to the horizontal level (traditional geodesy).

Taking into account the extensometric and altimetric movements, located in the moving zone, it appeared necessary to implement two **tiltmeters** to visualize tilting measurements. They were set up in March 1998.

These tiltmeters made with silica, provided a high degree of accuracy and were connected to a centralized system of data acquisition.

We can say that in this zone, at 100 meters from the entry, mass movements with a component approximately 20 mm towards the south, over a period of 18 months and with a component close to 8 mm towards the east over a period of 8 months, were recorded.

Automatic monitoring

The Probe extensometer consists of 27 sensors with pulley and Invar wire set in a sector of approximately 100m x 60 m, adjusted at the base of the frontal zone, the most active one.

Since 1985, measurements data are transmitted to the “Thiebauds” terminal site by radio wave and then at LRPC exploitation center of Lyon by phone network.

This terminal provides the following functions:
- piloting and control of the sensors network distributed on the site;
- data pretreatment and alarms (1^{st} level);
- data transfer.

Since 1985 some fractures have widened from 1 to 6 meters, others equipped in 1992, 1994 and 1996 opened from 1.5 to more than 3 meters. On the ground, these movements cause significant morphology disorganization. Since October 1999 the rate of the fractures opening show a continuous increase, this until the beginning of March 2000.

Since July 1996, a topographic survey (**automatic geodesy station**), type LEICA TM 3000D, has been established on the opposite side of the unstable slope in the Montfalcon terminal. It is connected by the commutated telephone network to the Lyon Exploitation Center.

The motorized theodolite, in which is incorporated, since December 1999, an optical distancemeter (laser telemeter infra-red-ONERA) allows measurements of distances by means of 41 targets reflectors of a prism type) distributed on the unstable slope.

This device presents the disadvantage to become inoperative by a rain or foggy weather. In this configuration, the extensometric sensors ensure alone the continuity of monitoring.

Measurements are taken each 2-hours one can summarize the results as follows:

- in the frontal zone, movement reached 32 to 68 cm during the year 1999. On the level 710 and 585 the movements are lower and gradually attenuate (11 cm on level 717 and 0.5 cm on level 585).
- independently of the season fluctuations the average slope movement increases gradually (40 cm/year until march 1999, about 60 cm/year after this date). This last tendency is correlated with a clear rainfall increase;
- in the higher zone (above the frontal active zone) the progression of the movement are 1 to 3 cm/year;
- in the western zone (the Rivoirands level) the movement does not exceed 1 cm/year.

In the lower part, the defined limit is in agreement with the limit given by the traditional geodesy.

4.2 *Monitoring of meteorological and hydraulic conditions*

The meteorological station is located at the Mont Sec top, near the NGF 1120 point. It belongs to EDF and provides data each day to estimate:

1) the precipitation height
2) the snow height and the equivalents water quantity.

According to the site characteristic, EDF and METEO France provide data corresponding to the evapotranspiration, melted snow and water infiltrated in the soil.

Since the station startup, strong quantity of water infiltrated in the ground were recorded in 1999 (141 cm) and 1995 (133 cm) comparatively to low rain quantity of 1997 and 1998 yars (respectively 80 cm and 87 cm).

5 MODELLING

A two-dimensional model of the Mont Sec slope was set up, with the computer code UDEC (distinct element method), along a cross section perpendicular to the large axis of the elliptic subsidence, intended to simulate the wedge effect.

Taking into account of the main systems of fractures (F, F’, F’’, F’’’), it was be possible to simulate the slope evolution due to glacier withdrawal, in comparison with the morphological observations
(Fig. 9–10).

The calculation parameters showed that the deformation amplitude variations depend primarily of the mechanical characteristics and of the dips of the discontinuity plans.

The conclusions obtained with this modeling are summarized in the following way.

The slope decompression, consecutive at the withdrawal of the Romanche glacier, generated:

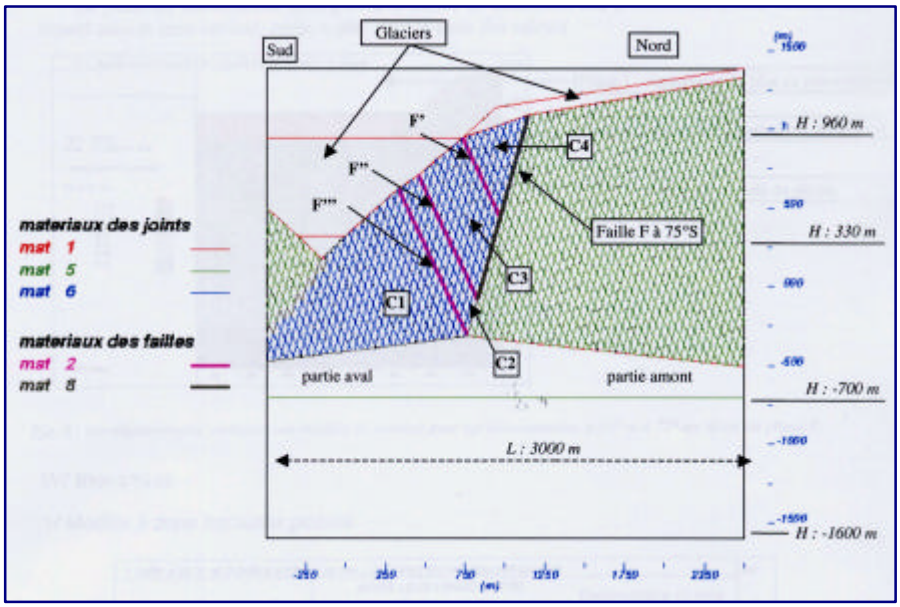

Fig. 9: Materials constitutive of the slope model with discontinuities F', F'' and F''' (65°N) and F (75°S)

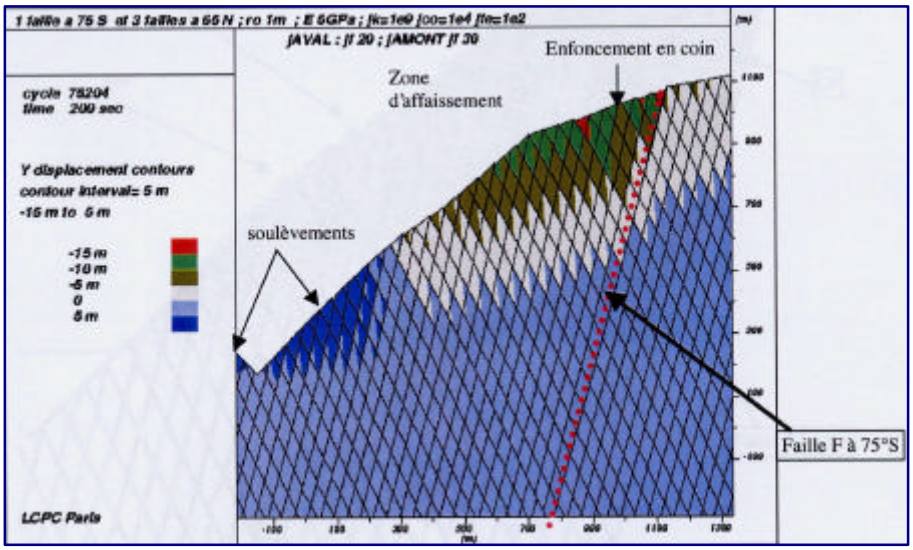

Fig. 10: Vertical displacement contours.

1) the opening of various families of discontinuities in the upper part of the landslide;
2) the delimitation of panels with variable kinematics;
3) the upper subsidence related to the wedge effect.

The structures and the main discontinuities implied in the slope movement are respectively:

- N60° in N70° bands and associated fracturing;
- the large fold with a N20° axis, dipping 45° towards the North , localized at the top the Mont Sec;
- the shear zone to which belong NS, N20° and N140° faults.

The combination of these structures is responsible of the following types of disorders:

- the active "Ruins corridor"
- the subsidence of the Mont Sec related to a wedge effect;
- the gentle rising of the lower part of the slope

Neotectonic indices observed in the Romanche valley and at the lower part of the slope indicate a recent seismic activity, which may be involved in the accentuation of the instabilities.

6 STABILISATION/PROTECTION WORKS AND REGULATION

The slope “Ruins of Séchilienne” is interested by an instability, reactivated during the winter and spring 1985, where was revealed the existence of a landslide short-term risk of a volume from two to three million cubic meters, which could cause the partial destruction of the Romanche bed and of the R.N. 91.

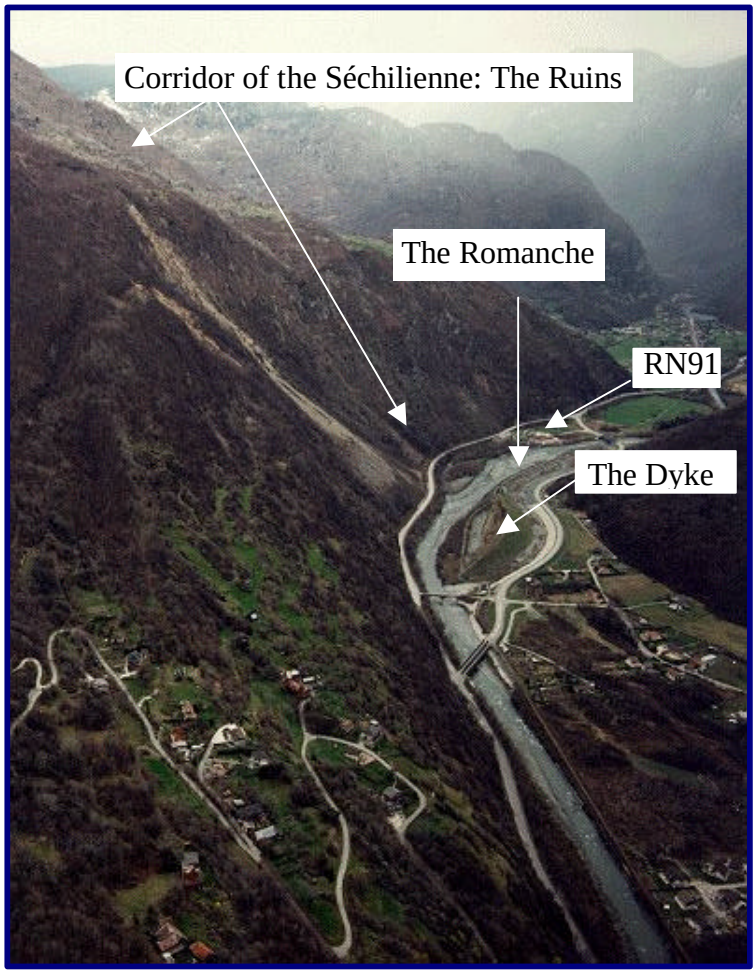

Fig. 11: View of the Romanche valley

The continuation of the geological investigations and geomechanics showed that this instability develops on the major part of the rock slope and mobilises a volume of several tens of million cubic meters, with the risk of causing the complete obstruction of the valley bottom.

A major slide could involve multiple consequences: burial of the allotment of the Ile of Falcon which represents a hundred of dwellings, prolonged interruption of the road communications, creation of a dam and the flood risk downstream.

Two communities are very directly threatened:
- Séchilienne
- St. Barthélémy de Séchilienne

No stabilisation means of the moving masses is possible, but the following safety measures were carried out:
- expropriation procedure, already started, of the Ile of Falcon (99 house and approximately 280 inhabitants)and of a factory;
- a dyke, elevated at RN91 upstream and at the foot of Séchilienne Ruins, with which it is possible to stop the blocks of large dimension propagated in the slope.

In this emergency the decisional authority, with the support of a scientific team, preferred to take in consideration the possibility to turn the Romanche waters and the RN91 to outside from the risk zone with a gallery.

This gallery has a length of 1934 m, and a diameter of approximately 15 meters and a slope of 1% . The foundation raft will be left gross, simply regulated for the passage of a 4x4 vehicle (Fig. 12).

The general design of this project is based on the following principles:
- the work makes it possible to evacuate the Romanche flow to avoid an accumulation of an important quantity of water behind the collapse mass (flood upstream risks and immersion risk of a fragile stopping).

- the residual water level, upstream of a first collapse, must be limited to prevent that a second one would create a wave likely to still threaten the infrastructure.

- the gallery head is protected from the collapse, considered in its maximum extension, and from the effect caused from the air blast generated by the same event.

Risk management finalise to ensure the public safety, in the regional planning interested directly and not of the “Ruins of Séchilienne " slope movement is governed by:

- ✓ The **law of 22 February 1987**, which imposes to take into account the natural risks in the town planning documents.
- ✓ The **law 2 February 1995** related to the environmental protection (Prevention of the natural risk foreseeable or PPR and expropriation procedure for natural risk that threaten seriously of the human lives).

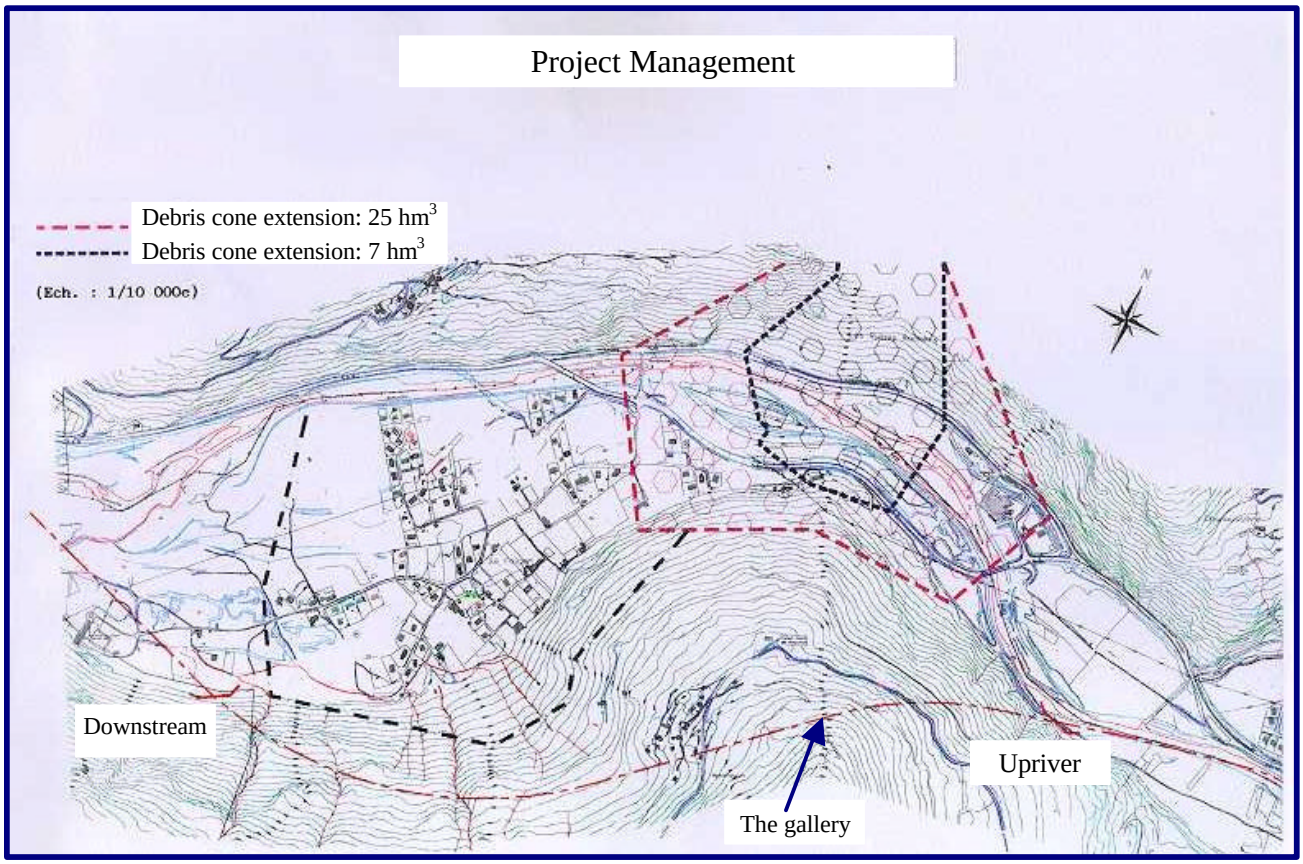

Fig. 12: Romanche underground derivation

7 LAND USE AND RISK ASSESSMENT/MANAGEMENT

For a correct risk management of the "Séchilienne" landslide, it is necessary to identify and evaluate the losses of a human, socio-economic and environmental nature, and later on to understand their degree of exposure to the natural event. These losses correspond to urbanized areas, with the infrastructures and the service equipment and the emergency and the spaces not directly exposed to the risks.

7.1 *Land Use*

The commune of **Séchilienne** is characterized by a surface of 2.417 hectares, including 33 urbanized hectares.

The urbanization, considering the historical data of Romanche flood, has been realized in the rural hamlet, in the flat alluvial along the R.N. 91 and in “Grand Serre”. There are other hamlets on

Mont Sec (Mouniers, Chamoussiere, Bathie, Aillauds, Thiebauds, Rivals) and on the west side of the "Ruins" (Rivoirands : 18 houses, approximately 40 inhabitants)

672 inhabitants were listed in 1990 and nearly 550 live in the agglomerated part.

The commune of **Saint Barthelemy de Séchilienne** has a surface of 1.210 ha (27 ha urbanized). Its develops on Romanche left side around the three principal sites:

1) the historical hamlet (altitude 460 m);
2) the Sapey village (altitude 1 000 m);
3) Ile of Falcon (altitude 300 m).

635 inhabitants (data of 1990) live in the commune, including 300 on the "Ile Falcon" (before re-location of some houses).

The inhabitants of Saint Barthelemy de Séchilienne work in the Grenoble economic basin.

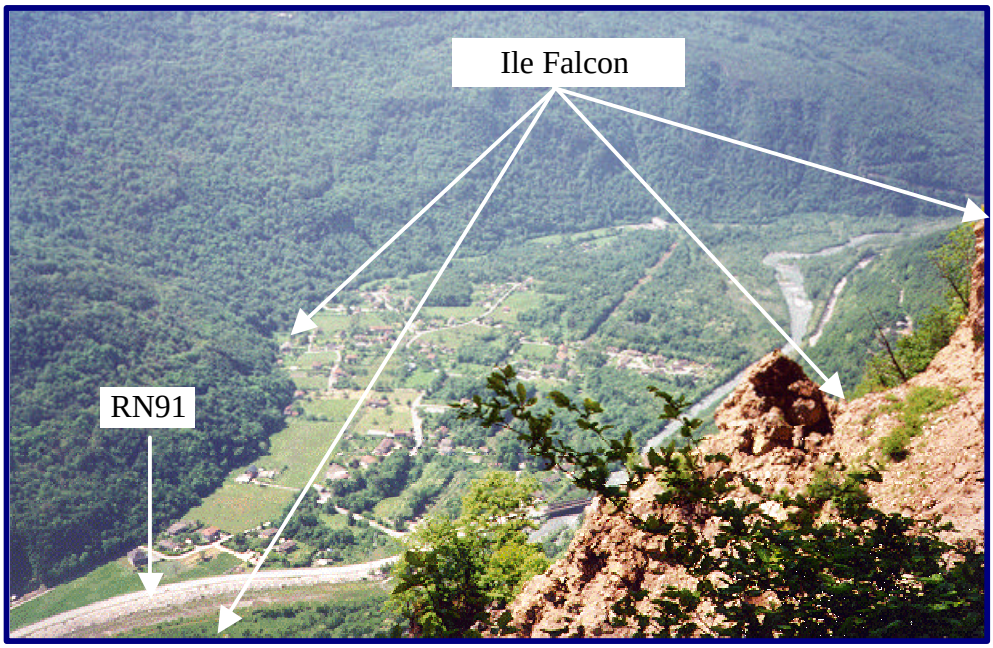

Fig. 13: View from the top of the "Ruins".

The commune has two schools, one in the hamlet, and the other in the "Ile Falcon".

The only significant economic activity is EDF station, but there exist also a joinery and 3 trade activity (bar, tobacco and restaurant).

R.N. 91 supports traffic of 2.000 vehicles per day with peaks of 20.000 vehicles in some day (service road of the ski resorts: the Alps D'Huez for instance).

There is along the R.N.91 a grid of water networks, electric lines, telephone lines.

7.2 *Elements at Risk*

Concerning the people life, the monitoring system should allow a sufficient alarm time to put in work the evacuation plan except in the case of unforeseeable event (earthquake, extreme rainfall episode, very localized). An emergency plan exists and functions within the same limits to protect of the people 635 inhabitants in the commune of Saint Barthelemy de Séchilienne and 672 inhabitants in Séchilienne.

The habitants directly in danger are 180 which 80% evacuated (Ile Falcon).

The superstructures in danger are:
- the Rhodia factory (50 employment).
- EDF gasworks (500 inhabitants) in the commune of Séchilienne (center borough and the allotment of Grand Serre)
- all the public equipment, the companies, the two village trade are in danger and moreover there, networks postal and telecommunications authorities, water, the cleansing, the E.D.F.
- the infrastructures threatened are the R.N. 91, all the north-south and east/west roadway systems.

7.3 *Socio-economics aspect*

The development possibilities the Saint Barthelemy commune were stopped as soon as the risk was known. The Plan of Occupation of the land (Land Use), in progress at the time of the diagnosis (1984/85), had envisaged the main urbanization on the territory of the Island Falcon. Area where the construction, profiting from flat grounds and the proximity of the transportation communication channels had developed since the middle of the year's seventies.

The effects were also frightening for the private individuals: the private transactions becoming impossible, the inhabitants of the Island Falcon were in the alternative, either to leave or to remain exposed to the threat.

In case of large landslide, the economic loss would be at two geographical levels: local and regional levels.

Local level (Séchilienne communes, Saint Barthelemy de Séchilienne).

The economic losses are the following:
- deviation over-cost for the population (1300 inhabitants) on work displacements, purchases and services;
- interruption of the EDF production with Peage-de-Vizille in the event of damage to the supply gallery;
- total immersion of the Séchilienne hamlet in the major failure event;
- for the communal budgets: loss of professional, land taxes and of dwellings, 30 to 60 %, including 1,4 MF coming from EDF (in addition to 4,8 MF for the other public budgets).

It will be added to it the cost at a national level:
- 85 houses expropriation and 1 paper mill transfer;
- compensation for outage of 2 power stations EDF (30 MF);
- energy loss on "Grand Maison" power plant;
- energy loss on "Grand Maison" or St-Guillerme by impossibility of conveying a transformer in the event of damage.

Regional level (Oisans, 22 communes)

The RN 91 controls the access to the OISANS: 10 000 inhabitants, mainly tertiary employment derived from tourism (70 000 beds, including 25 000 in second home), with spectacular inter-commune disparities.

The study and the analysis of the traffic and its variations (weekly, seasonal and annual data) reveal an economy strongly dependent on the road access continuity from downstream.

8 FIRST SCENARIOS

Scenarios were elaborated from four events families were selected (apart from a “null” scenario, with progressive showdown of the slide :

1. "No event" (after alert)
2. landslide of 5 hm³.
3. landslide of 7 hm³.
4. landslide of 25 hm³

7.1 *"No event"(after alert)*

The monitoring sensors of the site announce a very important acceleration of the movements leading the prefect authority to start the Emergency Plan (PSS) and within this framework to order the evacuation of the threatened population.

The movement stabilises then without major failure, excepted same rockfalls. The decision of allowing people to come back to then houses will be a difficult one.

7.2 “Landslide of 5 hm³”

The dam caused by the landslide does not seal the valley completely.

The landslide destroys a small part of the “Ile Falcon”.

The Romanche does not have any bed, flooding the remainder of the “Ile Falcon” and the RN 91.

7.3 *"Fragile dam" landslide (7 hm³)”*

The landslide will build a" fragile " dam with a crest at the level 350 m (bottom of valley 330m).

A water reserve of 2,1 hm³ is constituted in a time that goes from 4h to 7h in period of flood.

The landslide destroys some dwellings of the “Ile Falcon” and R.N.91.

Water covers the factory Rhodia and factory EDF and half of the dwellings of “Grand Serre”.

The east/west connections to the R.N. 91 are impossible. The north-south connections, Séchilienne/Saint Barthelemy de Séchilienne remain possible, the connection with Grenoble could be deviated locally with means of snow clearance in winter period but the service road of transit is blocked.

The water height to the right of the destroyed, formed stopping in a final way the Rhodia factory and the houses of the “Grand Serre” affected by the flood can be saved.

It is difficult to imagine the collapse impact on the preserved dwellings of the Ile de Falcon, but the life will be really difficult, even impossible during several days, even weeks (effect of breath, residual collapse, effect of fear, etc.). The school life will be stopped, like the trade activity of the “Ile de Falcon”.

The Séchilienne trade and companies will see their activity decreasing appreciably.

The experts will have, within sight of the stability of the residual solid masses, statement the fate of “Rivoirands”, the “Ile Falcon”. The area, which will be covered with debris materials, is of approximately 12 hm^2.

	By direct impact	**By effect of air shock wave and in the field of the possible blocks falls**	**By flood**
Concerned infrastructures and structures	The Rhodia factory *50 employment* The E.D.F. factory The "Ile Falcon" *2 houses de* *5 inhabitants*	The remainder of the Ile Falcon.	Grand Serre *15 houses*
	R.N. 91		Grand Serre and Fontagnon *communal access roads*
	Networks postal and telecommunications network Water distribution E.D.F		

Table 1: summary of the possible impact in case of a landslide of 7 hm³.

7.4 *"Landslide of 25 hm³"*

Scenario: sudden slide of 25 hm³, which is the totality of the strongly active part of the mass.

It is formed a solid dam whose peak is at a level of 380m (elevation of ground 330m). A water reservoir, also about 25 hm³ is constituted in a time that goes from 22h to 28h in flood period.

The landslide destroys the Rhodia factory, the factory EDF and the RN 91, and a part of the "Ile Falcon". The Séchilienne plain is totality covered.

The possible rupture of the dam causes a water surge downstream to "Pont de Claix" with incalculable consequences on the whole of the residential areas and the industrial areas (chemical factories of Jarrie, Pont de Claix, etc...).

All north-south and east/west connections are destroyed or unusable.

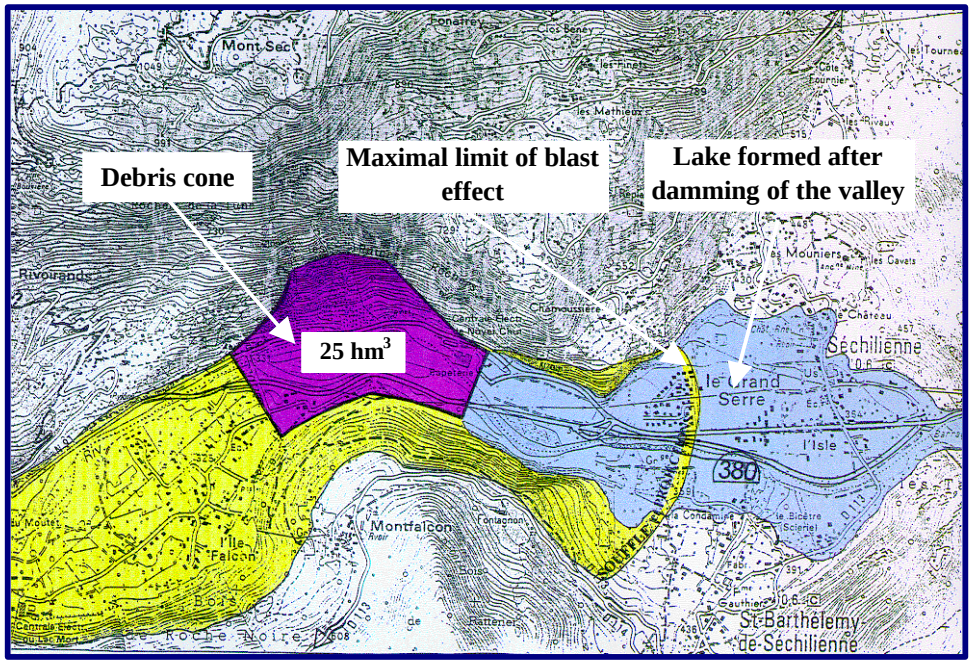

Fig. 14: Possible scenario after the landslide of 25 hm³

	By direct impact	**By effect of air shock wave and in the field of the possible blocks falls**	**By flood**
Concerned infrastructures and structures	The Rhodia factory *50 employees* The E.D.F. factory The "Ile Falcon" *15 houses* *35 inhabitants*	The remainder of the "Ile Falcon"	Séchilienne – All the Grand Serre allotment, the centre of the village *about 300 houses 500 inhabitants, all the public equipment, companies, trade.* Saint Barthelemy de Séchilienne *30 houses* *50 inhabitants.*
	R.N. 91		R.N. 91
	Networks postal and telecommunications network, water distribution, E.D.F		
	All various service networks driveways, all north-south and east/west roadway		

Table 2: summary of the possible impact in case of a landslide of 25 hm³.

It is impossible to envisage the state of the buildings after the possible water withdrawal.

In this case, one can consider that the direct effect of slide and the rise of water behind the dam cancel any social and trading life on the two communes.

It seems illusory in this case to be able to preserve the "Ile Falcon", which in any case would be cut physically of Saint Barthelemy de Séchilienne and Séchilienne. The only link would be the tunnel, which would not support the already difficult relations.

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10 PICTURES AND TABLES