Conters-Gotschnahang Landslide - Eastern Switzerland

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1 INTRODUCTION

The landslide of Conters-Gotschnahang is located in Eastern Switzerland, in the Canton of Graubünden (see figure 1). The area is called Prättigau Valley and the river flowing at the toe of this landslide is named the Landquart. The landslide composed of two main parts is situated between two important villages, Küblis and Klosters, on the right side of the valley. The whole unstable zone is up to 5 km long and up to 11 km wide. It is necessary to consider separately two main sliding zones : the landslide of Conters and the landslide of Gotschnahang which are connected by a less important complex slide zone extending below the Casanna peak(see figure 2).

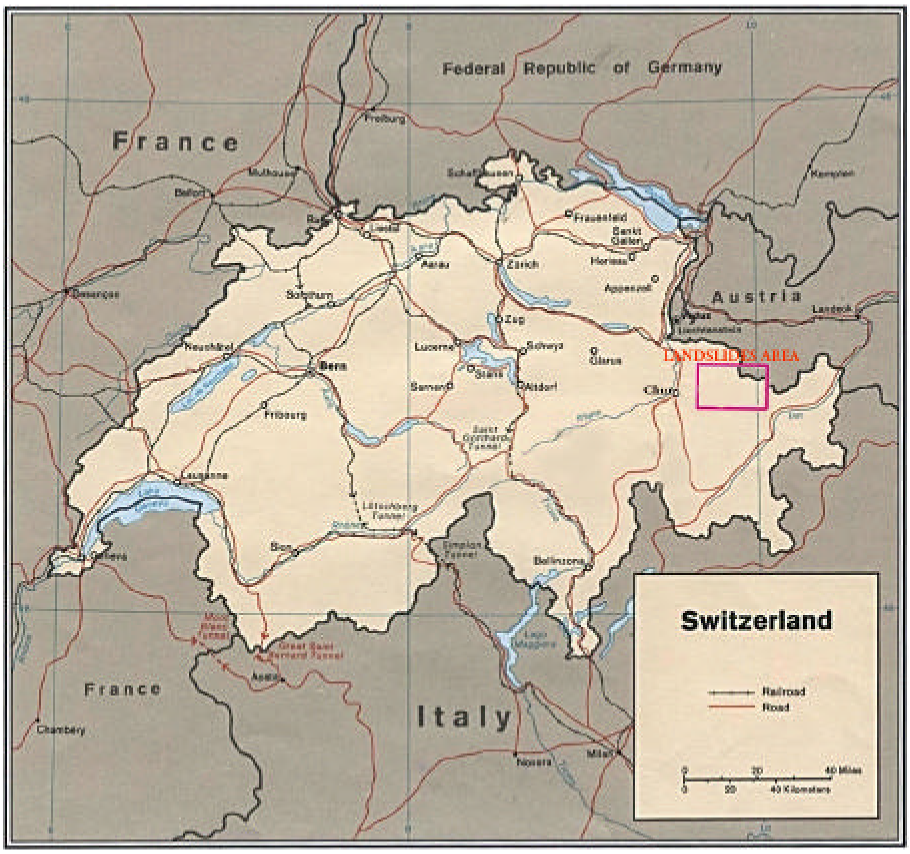

Figure 1. Location of Conters-Gotschnahang Landslide in Switzerland.

Figure 2. Limits of Conters-Gotschnahang Landslide on topographic map at 1 : 25 000. Reproduction authorized by the Swiss Federal Office of Topography.

Landslide of Conters:

Its area extends from Drimarchenspitz and Seehorn to the Landquart river, east from Conters. The gradient is almost constant. The slide of Conters is 4,5 km long, 5,5 km wide at its toe and its surface covers 20 km2. The top of Conters landslide is hard to define, as the main slide is prolonged by secondary slides (see figure 3).

Figure 3. Lateral view of Conters Landslide extending down to the Landquart river (to the right) and displaying a typical morphology.

Landslide of Gotschahang:

Extending from Gotschnagrat to Klosters, the slide of Gotschnahang is 2,7 km long, 3,5 km wide at toe and its surface is 5 km2. The landslide of Gotschnahang overhangs Klosters's touristic resort. On this large rockslide very active cones of fallen rocks cover its upper part (see figure 4).

Figure 4. General view of Gotschnagrat landslide seen from the outskirst of Klosters.

The railway line Landquart-Davos owned by a regional private company (Rhätische Bahnen) as well as an aerial cablecar line cross the landslide. Furthermore, intensively inhabited zones, particulary the touristic resort of Klosters, and the main A28 road Landquart-Davos, are to some extent threatened by the zone in movement.

A project of Klosters bypass for the main road was first designed at the toe of landslide, then had to be changed to a very long tunnel developing below the landslide mass, but emerging just in the right side limit of the slide.

Between these two landslide zones, a complex landslide area initiating by toppling and rockfall at the top of the slope extends below the Casanna peak down to Serneus allowing thus a stable site for the downstream entrance of the Klosters bypass tunnel.

2 REGIONAL FRAMEWORK

2.1 Climate

Pluviosity

The average annual rainfall amount measured in the area of Conters-Gotschnahang landslide reaches a value of some 1.600 mm, dropping to aprox. 1200 mm or 1400 mm at the base of the slope, in particular in Klosters village. This moderate spatial variation is due to a limited orographic effect as well as to the NW-SE orientation of the Prättigau valley.

The monthly distribution is fairly similar to what is observed in the region of Sedrun (see fig. 3 of chapter corresponding to the Sedrun landslide).

Due to the altitude of the upper parts of the slide, which develop between 1.800 m and 2.200 m and to a specific meteorological context, a large amount of precipitation falls in the form of snow.

Finally, it can be observed that in the valleys oriented E-W of Eastern Switzerland the trend of increase of annual rainfall during the XX th century is quite marked as shown by the Klosters data (see figure 4 of chapter on Sedrun landslide). This evolution is clear since 1960 and especially in the period 1973-1985.

Temperature

At the top of the slide area (aprox. 2.200 m.), average temperatures range from –8°C in January to +8°C in July, with important variations throughout the year. As the slope faces North and receives high amounts of snow, the snowmelt process can be quite delayed and snow patches may still appear in the fields in the month of June.

Evapotranspiration

The expected values are on an average of 400 mm, similar to those estimated for Sedrun landslide (see figure 6 of the chapter on Sedrun landslide), but slightly higher due to the presence of a dense forest lower on most of the slide.

Snow

A complete information concerning snow depth exists in the area as one of the most famous meteorological stations at high altitude, namely Weissfluhjoch above Davos, lies in the vicinity of the top of Conters-Gotschnahang landslide. Thus it can be stated that, in the upper part of the slide, the depth of snow with a return period of 100 years reaches some 500 cm (see snow data on figure 7 of the chapter corresponding to Sedrun landslide).

Measurement data description

In the studied area an automatic station measures rainfall continuously, namely at Klosters (ANETZ net), but very few other significant stations are available in the area, namely one on top of a nearby mountain (Weissfluhjoch at an altitude of nearly 2.800 m), and one in Schiers, in the lower part of the Prättigau valley, at an altitude of 650 m, being thus less significant. The data available in Klosters date back from 1901.

A large amount of information exists on snow cover in the area, as it is one of the most snowy regions in Switzerland.

As far as evapotranspiration measurement is concerned, it is difficult to produce reliable estimations, but simulation models have been used to establish relevant information all over the country.

Climate at local level : Pluviosity

The ISM[1] station of Klosters, on duty since the beginning of the XXth century, displays a long term average annual rainfall of some 1.300 mm (1.295 mm for the reference period of 1901-1960, but 1.484 mm for the new reference period of 1951-1980) ; two extreme annual values of nearly 1.800 mm have been recorded in 1954 and 1970 ; moreover 10 other annual values exceed 1.600 mm. As far as the dry years are concerned, 6 values are below 1.000 mm, the minimum value reaching 920 mm in 1992. The clear increase of rainfall of the period 1973-1988 reaches 7,3% of the long term annual average value over the period 1934-1995 ; it is thus somehow surprising that the movements do not reflect such an evolution.

2.2 Regional Morphology

The deep valley of Prättigau is oriented S-E to N-W from Conters to Klosters and N-S from Klosters to Davos. The central and northern parts of Klosters village extend on a large ancient rockfall deposit coming from the North which dams the valley. Just downstream, a large debris flow scree is an extension of the former deposit and occupies a wider part of the valley floor caused by the confluence of a lateral glacier valley (see figure 4).

In the zone of Serneus-Mezzaselva, downstream of this scree, the valley floor is fairly wide, partially occupied by alluvial deposits of the Landquart river, but the eastern part of Conters slide causes then a reduction of the width of the riverbed over a length of 5 km.

2.3 Regional Geology and Structural Setting

The main part of the left versant of the valley is composed of Prättigau-Flysch. The landslide of Conters is situated in this zone. To the East, the Flysch disappears and we find the Falknis-Sulzfluh Nappe and the complex « Aroser Schuppenzone » (Arosa flake zone). The landslide of Gotschnahang is situated in this second zone (see figure 5).

Lithostratigraphic unit (Conters landslide):

Prättigau-Flysch (upper Cretaceous and Eocene) with different units, stratigraphically from top to bottom: Ruchberg Serie, Oberälpli Serie, Eggberg Serie, Gyrenspitz Serie, Fadura Serie.

Lythotype :

Prättigau-Flysch (Upper Cretaceous): sandstones, sandy limestones, limestones, clayey schists, marly schists, marly limestones, quartzites and calcareous brecchias.

Second lithostratigraphic unit (Gotschnahang landslide) :

« Aroser Schuppenzone » (Arosa flake zone) (mainly Trias and Malm limestones and cristalline rocks) and Sulzfluh Nappe (mainly Malm limestones and Gyrenspitz Flysch). Uphill zone: Silvretta Nappe.

[1] Swiss Meteorological Institute

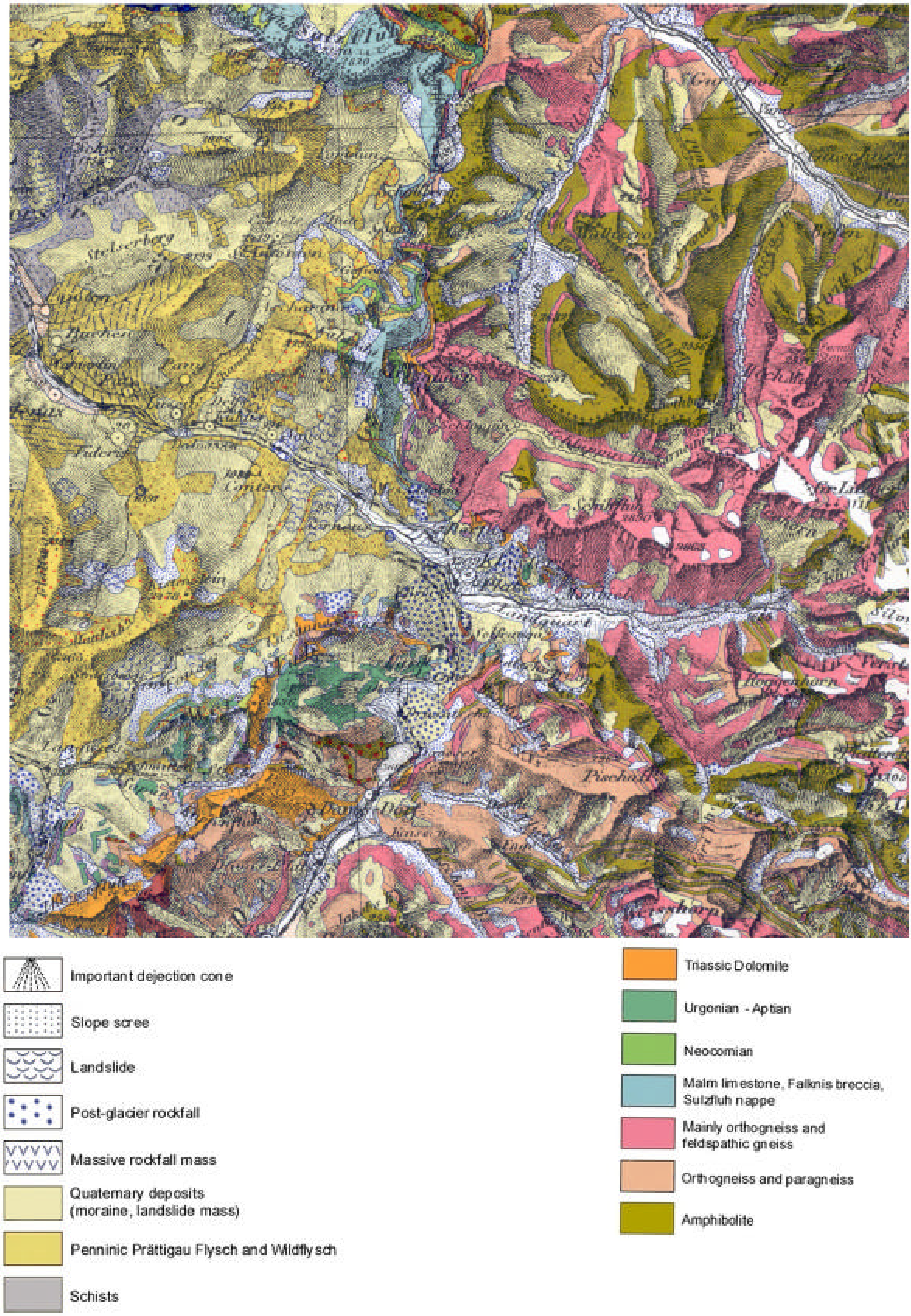

Figure 5. Geological map in the area of Prättigau Valley (1 :200 000)

Second lythotype :

Aroser Schuppenzone:
- Cristalline rocks (diabases and ophiolites)
- Dolomites, quartzites, gypsum, "cornieule"(vacular dolomitic rocks) (Trias)
- Limestones, radiolarites (Malm)
- Limestones, marls (Cretaceous)
- Marly limestones, marly schists, sandy limestones, limestones and brecchias (Prättigau Flysch)
- Gneiss, amphibolite and micaschists (Silvretta Nappe, uphill zone)

The structural features are strongly folded layers with axial and foliation orientation mainly transversal to the valley (N-E). However large variations are often observed.

3 LOCAL FRAMEWORK

3.1 Local Geology and structural setting

The local geology shows the same units mentioned in the regional framework ; the lythotypes are detailed by series :

Lithostratigraphic unit (Conters Landslide, see figure 6) :

Prättigau-Flysch (upper Cretaceous and Eocene) with different units, stratigraphically from top to bottom:
- Ruchberg Serie
- Oberälpli Serie
- Eggberg Serie
- Gyrenspitz Serie
- Fadura Serie

Lythotype :

Prättigau-Flysch (Upper Cretaceous):
- Ruchberg Serie: Sandstones in thick beds with clayey schists in thin layers
- Oberälpli Serie: Clayey schists, marly schists strongly sheeted and sometimes folded, with thin layers of sandstones and quartzites.
- Eggberg Serie: Marly limestones, thick layers sometimes foliated, interbedded with thin brecchias layers.
- Gyrenspitz: Marly limestones and marly schists, sandy limestones, limestones and fine layers of brecchias.
- Fadura Serie: Calcareous brecchias changing to marly schists with limestone and sandy limestone beds near the base of the serie.

As the landslide is very deep and formed by disaggregated rock, the state of the bedrock does not affect directly the behaviour of the slide.

Second lithostratigraphic unit (Gotschnahang Landslide) :

« Aroser Schuppenzone » (Arosa flake zone) (mainly Trias and Malm limestones and cristalline rocks) and Sulzfluh Nappe (mainly Malm limestones and Gyrenspitz Flysch).

Second lythotype :

Aroser Schuppenzone:
- Cristalline rocks: Essentially diabases and ophiolitic rocks with serpentinites
- Trias: Dolomites, quartzites, gypsum, "cornieule"(vacuolar dolomite)
- Malm: Essentially limestones and radiolarites
- Cretaceous: limestones, marls

Sulzfluh Nappe:

- Malm : limestones

Gyrenspitz:
- Flysch (Upper Cretaceous):
  Marly limestones and marly schists, sandy limestones, limestones and fine layers of brecchias.

3.2 Water Conditions

Landquart river has eroded the toe of both Gotschnahang and Conters slides, but the present erosion is limited (see figure 7). On Conters slide, four main torrents some 3 km long drain the whole sliding area; three of them incise the slope inducing a high bedload transport.

4 LANDSLIDE

4.1 Landslide Identification

The active sliding zone called Conters-Gotschnahang can be divided into two important landslides: Conters Landslide and Gotschnahang Landslide, with an intermediate zone between Casanna peak and Serneus also affected by movements (see figure 2).There are some other active rockfall or topple in this area.
In this project the two major landslide zones will be considered:

Landslide of Conters:
It extends from Drimarchenspitz and Seehorn down to the Landquart river, below Conters village, and displays an almost constant gradient of some 30% (see figure 8). The slide of Conters is 4,5 km long, 5,5 km wide at the toe and its surface covers 20 km2, mainly occupied by forests and meadows. The assumed depth may reach 200 to 300 m. The top of Conters landslide is hidden by several rockfall zones and secondary slides.

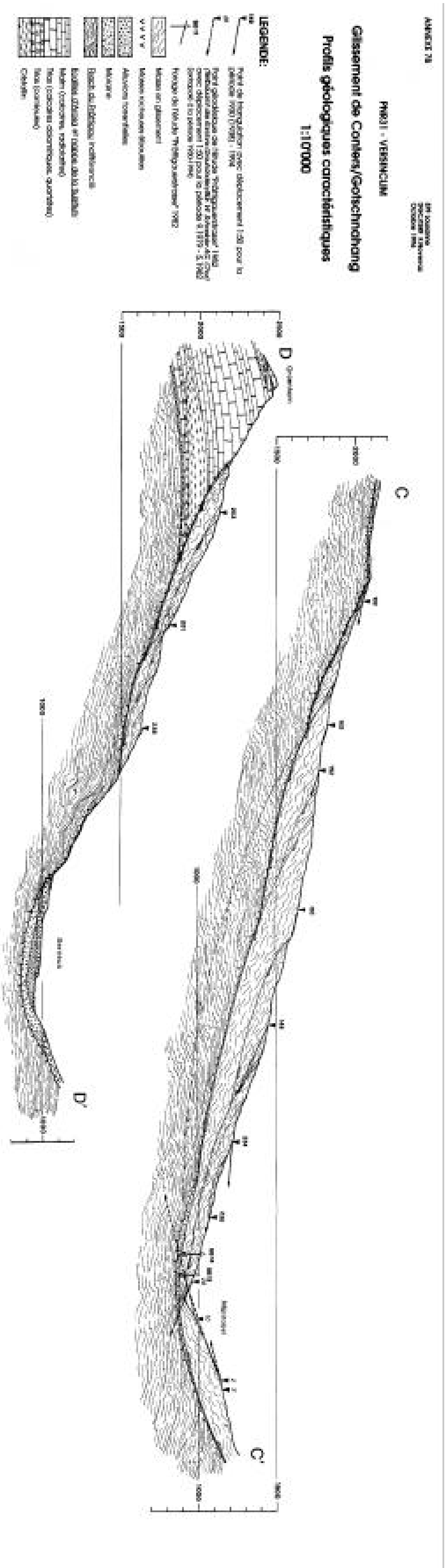

Figure 6 : Cross section AA' and BB' of Conters landslide showing the dip of the main lythostratigraphic units of the Prättigau-Flysch.

Figure 7 : Toe of Conters slide showing the past erosion caused by the Landquart river.

Landslide of Gotschahang:

The slide of Gotschnahang, which begins just below the Gotschnagrat (altitude 2.300m) and extends to the village of Klosters in the Landquart riverbed, is 2,7 km long, 3,5 km wide at its toe and its surface is 5 km2. As its depth is very large, of the order of 250 m, its volume may reach 1 billion m^3. Its average slope reaches also 30%, but the slope increases from the top to the bottom. Its mechanism is probably a rockslide, but it is difficult to charaterize its scarp as it is covered by active screes of fallen rocks.

The UTM coordinates and longitude and latitude of the centroid of the landslide area are approximately:

X-UTM 780,000
Y-UTM 195,000

Latitude : 46°53'

Longitude: 9°48'

Figure 8: Oblique view of Conters landslide showing clearly its almost constant gradient.

4.2 Landslide Detail

- Movements and causes :

Conters landslide is the largest slide in Flysch context in the Swiss Alps (about 20 km^2) and displays a complex mechanism, although it is basically a dip slope slide. The Flysch is very prone to landslides, because of the low strength of this bedded and partly clayey rock formation and due to its fragile tectonic. The top of the landslide above Conters is not easy to define, because the main landslide scarp is hidden by rockfall and by secondary slides. Observed long-term movements have allowed to determine that the main mechanism is a slide of sedimentary rock on a similar bedrock, with a velocity varying in general between 10 and 30 mm/year; the rate movement can be qualified as "very slow".

Facing the central part of Conters landslide, on the other versant of Prättigau valley, the very active Heimwald slide induces a closure of the valley, causing thus an increase of movements in the central lower part of Conters Landslide.

Gotschnahang landslide is not so wide as Conters; its surface is much smaller (about 5 km^2), but its rupture surface is very deep (about 250 m in middle of landslide). The volume thus reaches about one billion cubic meters. The movement can be approximated by a rotational model (see figure 9 below). Observed longterm movements are characteristic of a slide over a sedimentary bedrock, with a velocity between 10 and 75 mm/year; the rate movement can also be qualified as "very slow".

In the upper part of Gotschnahang landslide, a superficial rockslide extends over the central part of the scarp. Similar superficial but deeper slides extend in the upper portion of Conters slide area, obliterating most of the initial main scarp.

Rockfall and rock topple affecting the sedimentary bedrock are also observed in the upper part of Gotschnahang Landslide, below Grünhorn and Gotschnagrat. There are very active zones of fallen rocks. All these movements appeared after the glacier retreat due to glacier erosion, but they do not affect the characteristics of the main slide.

On the other hand, a very active tertiary slide in the middle of Conters slide extends to the Landquart river, facing Heimwald slide. The observed movements of this slide, although they are much faster than the main phenomenon, are still classified as “very slow”, but they may be prone to a sudden acceleration.

The meteorological conditions seem to have a very small importance on the evolution of the movement. Conters landslide seems not to be strongly influenced by rainfall. Gotschnahang landslide seems to be somehow influenced by rainfall, but without a major trend of evolution.

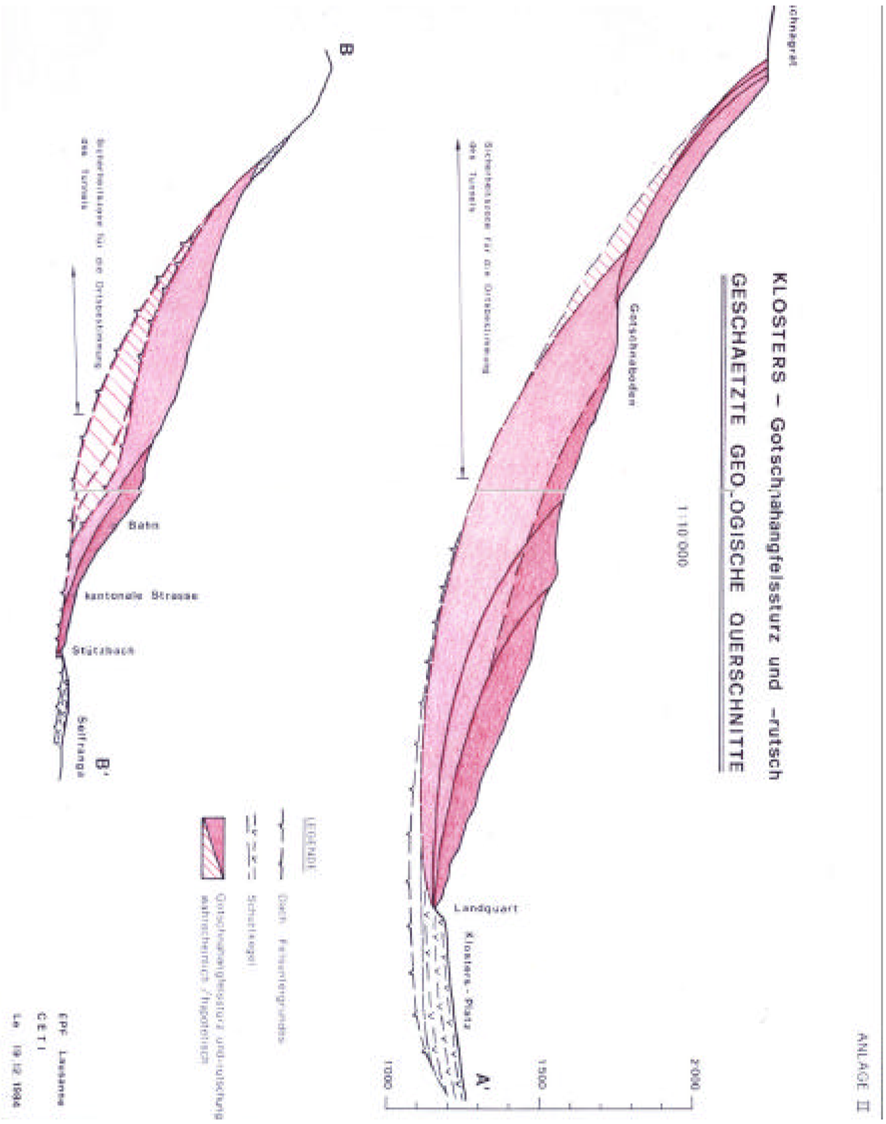

Figure 9. Rotational landslide of Gotschnahang.

4.3 Landslide Morphology

- Morphologic description :

Landslide of Conters :

The main scarp is not continuous and not always identifiable. A large number of secondary and tertiary scarps are present on its entire surface. The typical profile of the slide displays a fairly gentle slope in the upper part and a slightly steeper slope near the toe, due to the large scale sliding mechanism (see figure 6, in particular cross-section BB'). No clear morphology of present river erosion at the toe is observed (see figure 7), which induces to think that the change of morphology of the toe of the slide due to its own activity is more marked than the effect of the river erosion, even in the area where the very active Heimwald slide below Saas in Prättigau, in the opposite versant, tends to displace the river towards Conters slide.

Landslide of Gotschnahang :

Gotschnahang slide main scarp displays a triangular shape with a maximum drop of some 400 m. The sliding mass is slightly inclined in its upper part and displays an increasing slope down to its toe. The progressive lateral spread of the sliding mass induces a circular shape of the toe. Several secondary slides have somehow changed its initial morphology, confirming the fact that the central part of the slide is more active (see survey data).

- Slope profile and characteristics :

The whole unstable zone is up to 5 km long and up to 11 km wide.

The slide of Conters is 4,5 km long and 5,5 km wide at toe. The slope gradient is almost constant : 28% in profile BB' (see figure 6).

The slide of Gotschnahang is 2,7 km long and 3,5 km wide at toe. The slope gradient in the upper scarp reaches a value of 80%, in the central part, 32%, and an increasing slope down to its toe with a gradient which can reach as much as 70%.

Elevation of highest point above scarp: 2557 m. (Peak of Casanna-Grünenhorn). Lowest point: 800 m (in Dalvazza, west of Küblis).Average slope gradient: 30%. Slope exposure/orientation: N to NE.

Drop of Conters slide: from top of slope 1660 m; from top of sliding mass 1200 m. Length of slide: 4,5 km.

Drop of Gotschnahang slide: from top of slope 1110 m; from top of sliding mass 630 m. Length of slide: 2 km.

- Rupture surfaces :

Landslide of Conters:

Rupture surface in Flysch layer, belonging partly to the dip slope type of movement. Depth of rupture surface: >200 m. The complex morphology displays many secondary and tertiary rupture surfaces. These secondary and tertiary rupture surfaces changed almost everywhere the morphology induced by the initial failure mechanism.

The initial rupture surface may have occured in postrissian or interglaciation period (see figure 6).

Landslide of Gotschnahang:

Depth of rupture surface: max 250 m. The rupture surface can be assumed as approximately rotational.

4.4 Landslide History

The Conters Landslide as a whole was unknown before the VERSINCLIM study of 1994. Its toe was the object of deep borings at the beginning of the 1980', in the frame of an abandoned project of modernization of the main A28 road, at present on the other side of the valley and entering the left side of the Prättigau valley in the small stable area between Conters and Gotschnahang landslide.

The Gotschnahang landslide has existed since the postrissian or interglaciation period. Its observation and its study began in 1930. The region was the subject of a thesis in 1954 (R.A. Gees, Geologie von Klosters). A detailed study began in the 1980's, during a project of modernization of the road A28 of Prättigau, one alternative of which was crossing the toe of the landslide. It is necessary to indicate that a railway line also crosses the landslide since 1890. A bridge had to be reconstructed in 1991 and a new tunnel was realized in 1996 to connect Klosters station with the new Vereina Tunnel. The movements are important enough to create problems in the infrastructures connecting Klosters station with the railway lines in the unstable slope, but no disaster has occurred yet.

5 LANDSLIDE INVESTIGATION, MONITORING AND MODELLING

5.1 Survey and monitoring of landslide activity

A series of 3rd and 4th order triangulation points on the landslide mass were laid out and measured since 1930 and 1937/1938, and redeterminated in 1972, 1975, 1980 and 1984/85.

The VERSINCLIM research project carried out a new determination of 54 official triangulation points in 1994 with GPS measurements, after checking all landmarks and reestablishing some of them. It was made by Bovay-Huguenin, official surveyors (Epalinges/Lausanne) 1994 and by the Institute of Geomatic of EPFL (Swiss Federal Institute of Technology of Lausanne) (see figure 10). 7 Leica S200 dual frequence GPS receivers were used. 7 measurement stations were organized, during which each point was determined twice in order to increase the reliability and ensure a connexion between the differente sessions.

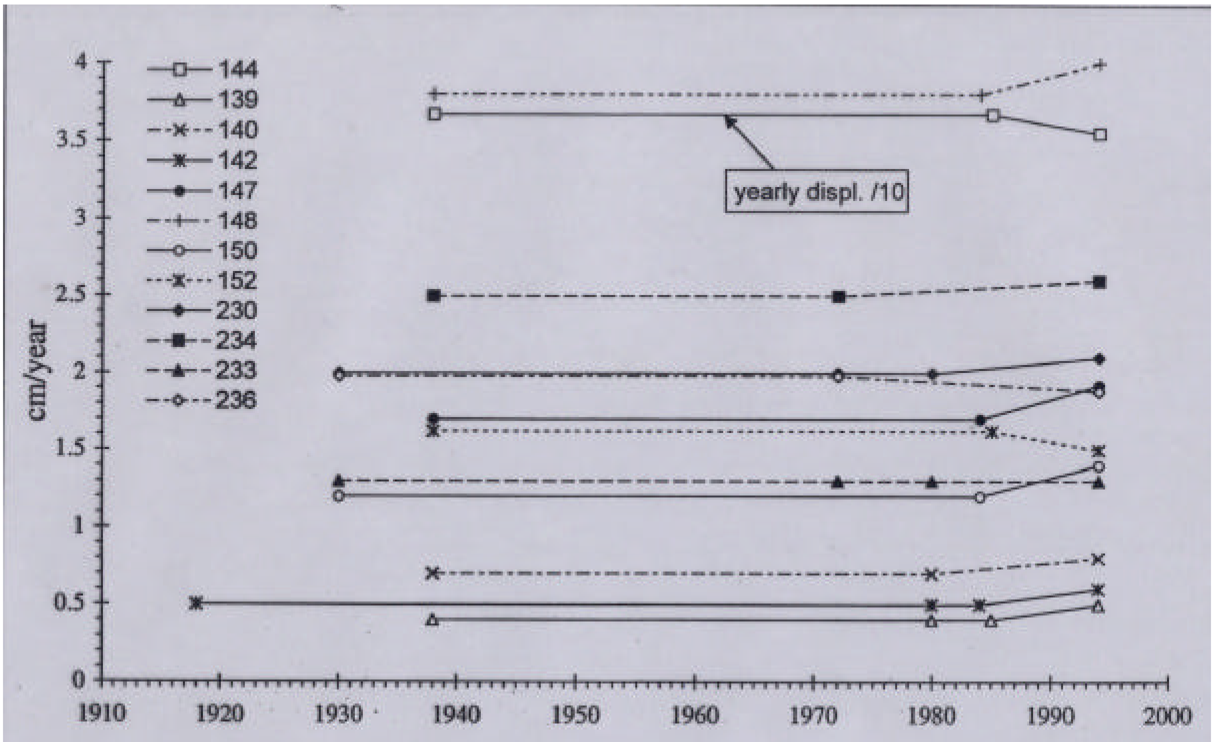

Fig. 6 : Evolution of average annual displacements of Conters-Gotschnahang Landslide, which displays a slight increase from 1980 on. Note that the Point No 144 for which the scale must be multiplied by 10 shows a slight reduction of velocity for the same period, probably due to some protection works in the adjacent river.

Figure 10 : Evolution of the velocity of several topographic points on Conters-Gotschnahang Landslide over the period 1917-1994.

Some measurements points were also determinated in 1968 and 1980 on Grotschnahang slide, during the project, construction and control of a cablecar line above Klosters.

The project of a new road (Prättigauerstrasse A28a) to bypass Klosters and the development of the railway line RhB (Rhätischen Bahnen) Landquart-Davos-Tiefencastel to connect it to the Vereina tunnel lead to some surface and inclinometer measurements. 13 survey boreholes were made between 1979 and 1983. Oblique inclinometer measurements in boreholes using a Trivec equipment were also carried out.

Several points of Conters- Gotschnahang landslide display mainly constant long-term velocities from 4 to 15 mm/year. Some specific points on tertiary slides experiment velocities which are ten times larger (see figure 10).

5.2 Monitoring of meteorological and hydraulic conditions

There are some ISM rain gauge stations in Klosters, Weissfluhjoch and Schiers, all on duty since 1934. The rainfall pattern does not display a clear trend in its evolution, but nevertheless a regular slight increase for Kloster-station. Some very humid and dry years can be pointed out, but without relation with main instability phenomenon.

There are snow gauge stations too, (MS, IMIS, ENET, ANETZ) and climatological stations in Klosters, Davos and Weissfluhjoch, on duty since 1937

6 MODELLING

In the area, no modelling activities have been carried out up to now, but the applicable mechanical model should be a translational slide for Conters and a rotational slide for Gotschnahang.

7 STABILISATION/PROTECTION WORKS AND LEGAL FRAMEWORK

No specific stabilisation works have been undertaken on both slides, but some protection works have been built either along the Landquart river to reduce erosion at the toe of the slide, or along some perpendicular streams on Conters slide which were subject to large debris flows. The last works seem to be very efficient and not only on erosion phenomenon, as they reduce also the tertiary slide movements. As far as the legal framework is concerned, the touristic resort of Kloster does not extend on the toe of Gotschnahang slide, but only infrastructure works (roads, railway, cablecar) are concerned. At Conters, the village of the same name extends on the slide, but no specific measures have been taken in local land planning.

8 LAND USE AND RISK ASSESSMENT/MANAGEMENT

8.1 Land Use

The landslides concern essentially a region of pastures, meadows and forest. However, the railway line Landquart-Davos as well as a cablecar line cross the Gotschnahang landslide. Furthermore, zones strongly inhabited, particulary the touristic resort of Klosters, and the main road Landquart-Davos are directly threatened by the zone in movement of Gotschnahang slide as its toe is just facing the village and the railway station, on the other side of the Prättigau river.

8.2 Elements at Risk

Some villages are concerned by this active landslide zone. Conters is situated inside this zone (see figure 11). Klosters, an important touristic and ski resort is situated just under the Gotschnahang landslide. The villages of Küblis and Serneus are situated at the toe of this zone too. The railway line Landquart-Davos as well as a cablecar line cross the landslide. The road Landquart-Davos is directly threatened by the zone in movement in several strechtes.

Figure 11 : The village of Conters is clearly located in a slowly moving zone of the landslide.

9 FIRST HYPOTHESIS AND SCENARIOS

Due to the extremely large extension of Conters-Gotschnahang landslide, it is most improbable that the whole sliding mass will significantly accelerate in the future. The observation of the long-term displacements since 1930 which occur at a nearly constant velocity despite of increasing rainfall conditions confirm such prediction.

Nevertheless, a certain risk of damming the Landquart river has to be considered, in particular by both most active zones facing each other, namely the very active tertiary slide on Conters landslide extending over approximately 1 km^2 where the velocity of some points reaches 37 cm/an (20 m since 1938), and the active Heimweld slide on the right bank of the Prättigau valley, the movements of which vary between 5 and 10 cm/year. In such a situation, it would be possible to see the build-up of a fairly high dam, at least 20 to 30 m high, inducing then the risk of overtopping by the river flow and breaking up the dam in a very short period due to its fragile Flysch material. Thus the villages downstream, first of all Küblis near the toe of Conters landslide, and then the city of Landquart, would be seriously threatened, because they extend in flood plains near the riverbed.

In this scenario, the main communication network leading in particular to the major touristic resorts of Klosters, Davos and the villages of the lower Engadina valley would be directly affected, as both the private Rhätische Bahnen railway line and the A28 national road pass at several points quite near to the riverbed of the Landquart river. The indirect consequences of such an event would be catastrophic for the whole economy.

Another possible similar scenario would be the occurrence of a large debris flow in one of the torrents flowing on Conters landslide, as it has already happened in the past. Due to the remoulded material of the sliding mass, the erosion pattern in these torrents is very marked and the volume of the corresponding debris flows may exceed 50'000 m3. Therefore, some protection works have been built in the most critical areas like the Schwarzbach torrent, but they might not be sufficient or maintained inadequately in the long term. The effect of a debris flow would also be the damming of the Landquart river, but to a lesser extent than considered in the first scenario. If the discharge of the main river is sufficient, the destruction of the dam caused by the debris flow may be progressive and avoid the formation of a large reservoir upstream of the dam.

The last scenario to be considered for Gotschnahang Landslide is a reactivation of the movements which would not cause any major damage to the touristic resort of Klosters itself, but affect both railway lines to Davos and Vereinatunnel that cross the toe of the slide in two different tunnels. The bridge connecting Klosters railway station, on the right margin of Landquart river, to the two tunnels, has been reconstructed twice in the past; it is now an extremely rigid concrete structure that could be able to resist to an important thrust. However, differential movements near the railway tunnel portals may always occur and affect the rail alignments, causing a major traffic disruption.

10 REFERENCES

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