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Landslides in Flysch terranes of Switzerland: Causal factors and climate change

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Key words: Flysch, landslides, Swiss Prealps, dendrochronology, C^{14} dating, causal factors, climate change

ABSTRACT

Landslide-prone areas in flysch sequences are widespread in Switzerland, covering approximately 1000 km^2. Mass movements can be caused by **ground conditions** inherited from geological or glacial history, by **preparing causal factors** linked to climate or human activities and by **triggering causal factors** related to weather, public works or earthquakes. We identified three periods of major crisis in unstable zones of flysch terranes during the past ten thousand years (Holocene), using dendrochronological analysis and C^{14} dating on fossil wood collected in landslides. We correlated these periods to other data (glacier fluctuation and timberline) and we underscore a strong relationship between climate change and landslide activity. Taking into account the latest predictions of the Intergovernmental Panel on Climate Change (IPCC 1996), the spatial distribution of landslides in flysch terranes will not change in the future but the unstable zones located between 1000 m and 1500 m will probably suffer from a marked increase in the rate of movements in landslides already active.

RESUME

Les mouvements de terrain sont très fréquents dans les séquences de flysch en Suisse et s'étendent sur une surperficie d'environ 1000 km^2. Les glissements sont causés par des **conditions intrinsèques** héritées de l'histoire géologique et glaciologique, par des **facteurs aggravants** liés au climat et aux activités humaines et par des **facteurs déclenchants** qui sont à mettre en relation avec la météorologie, les travaux dans les versants ou les tremblements de terre. Durant les dix mille dernières années (Holocène), nous avons identifié trois périodes distinctes de crise dans les versants instables grâce à des analyses de troncs récoltés dans les glissements par la dendrochronologie et les datations C^{14}. Nous comparons ces périodes avec d'autres données (glaciers et limite des forêts) en soulignant l'interaction entre les changements climatiques et l'activité des glissements. Sur la base des dernières prévisions de l'Intergovernmental Panel on Climate Change (IPCC 1996), la distribution spatiale des glissements en zone de flysch ne devrait pas subir de modifications importantes dans le futur mais les pentes instables situées à des altitudes comprises entre 1000 et 1500 mètres sont susceptibles de montrer une augmentation marquée des vitesses de mouvement dans des glissements actuellement actifs.

1. Landslide-prone areas in Flysch

Flysch is defined as a stratigraphic unit in the Alpine front ranges (Studer 1827). Flysch sequences are widespread in the Swiss Prealps where eight major flysch units are currently distinguished, based on geological setting, stratigraphy (from early Cretaceous to Late Eocene), sedimentology and petrography (Caron et al. 1989).

In the Swiss-German speaking Simmenthal, the local people used the word "flysch" to describe terranes susceptible to sliding. According to the project Geokarten 500 of the Swiss National Hydrological and Geological Survey (digital geological map at the scale 1 : 500'000) the flysch sequences cover 6% of Switzerland's territory. Schindler (1988) points out that flysch terranes are among the most sensitive to mass-movement problems in Switzerland.

As flysch sequences are very common in the Prealps and in the front range of the Alps, landslides constitute a real threat to the sustainable development of these regions. Recent mapping work in Adelboden (Canton of Bern) has shown that 30% of the slopes covering the very coarse Niesen Flysch are landslide-prone areas (Lateltin et al. 1997). In the region of Schwarzsee, near the city of Fribourg, on top of the marly sequence of the Gurnigel Flysch, more than 50 % of the slopes are unstable. In Switzerland, **landslide-prone areas in flysch** terranes cover approximately **1000 km^2**.

A project called "Landslides in flysch terranes and climate change" was initiated in 1991 by the Departement of Geology of the University of Fribourg, in the framework of the Swiss National Research Programme PNR 31 (Climate Change and Natural Disasters) to analyse the behaviour of slopes in the Swiss Prealps (Lateltin et al. 1997, Raetzo 1997). Some of the results of the project are presented in this paper.

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2. Ground conditions

We studied selected landslides in different flysch sequences, in different structural and geomorphological settings and according to shape and state of activity of mass movements. We performed detailed hazard mapping in several areas to understand the spatial distribution and the intensity of the different processes (fall, slide or flow) in the flysch terranes.

We monitored recent displacements at the surface of the landslides using networks of geodetic points established with a survey by GPS and theodolites. We detected slip surfaces by inclinometer readings in boreholes or by geophysical soundings (Raetzo et al. 1995).

2.1 Lithology

From 1974 to 1985, a research project at the University of Fribourg focused on the flysch of the Alpine front ranges (Caron et al. 1989). This study provided a in-depth understanding of the sedimentology, petrography, diagenesis and structural setting of these flysch sequences.

From the point of view of landslide susceptibility, three flysch sequences (Tab. 1) are proposed (Lateltin et al. 1997).

Tab. 1. Types of process related to flysch sequences

Type of process	*Pebbly-sandstone Flysch*	*Marly-sandstone Flysch*	*Argillaceous Flysch*
First movement	**Fall**	**Debris flow**	**Rotational slide**
Secondary movement	**Rockslide**	**Translational slide**	**Debris flow**
Other movement	Flow Landslide	Fall	Translational slide
Landslide prone areas	**30 %**	**50 %**	**50 %**
Flysch units	*Niesen*	*Gurnigel Schlieren*	*Wildflysch*

Pebbly-sandstone sequences (e.g. Niesen) display a predominance of rockfalls in very steep cliffs. Associated with these superficial phenomena, coarse grained flysch usually develops rockslides with slip surfaces that can be 30 meters deep. Several examples of rockslides are visible in the Niesen flysch of the Ormonts region (Aigremont, Le Lavanchy, La Rite; Lateltin et al. 1997) or near Adelboden (Raufligrat, Galmschibe, Hengrich-Allmi; Bollinger & Noverraz 1996).

In the marly-sandstone sequence (e.g. Gurnigel, Schlieren) the weathering of sandstone beds on top of impermeable layers (marls) frequently gives rise to debris-flow events. Some unstable slopes can also evolve into deep translational slides. The cases of Falli-Hölli and Sörenberg are typical of such processes (Raetzo 1997).

For the argillaceous sequence (e.g. Wildflysch), landslide-prone areas commonly show some rotational slides of limited extension or debris-flow events in gullies.

2.2 Structural setting

The Swiss Prealps are the classic location of gravitational tectonics. Thin-skin thrust systems are now commonly invoked to explain the deformation and location of these units during the early Tertiary. The Prealps are formed by at least seven structural units and they constitute the complex hanging-wall of the frontal penninic thrust (Caron et al. 1989).

The structural setting and slope exposition are very important in relation to the percentage of landslide-prone areas and the depth of the slip surface.

In **dip-slope conditions**, the flysch terranes are much more sensitive to mass movement than in areas with **reverse dip**. For example, in the Niesen Flysch (pebbly-sandstone sequence) near Adelboden, 80 % of the slopes oriented towards the NW in dip slope condition (regional dip towards the NW) display deep seated landslides, rockslides (Fig. 1) or shallow landslides. In reverse bedding conditions, slopes oriented towards the SE display a small amount of landslides (20%) with shallow slip surfaces (Lateltin et al. 1997).

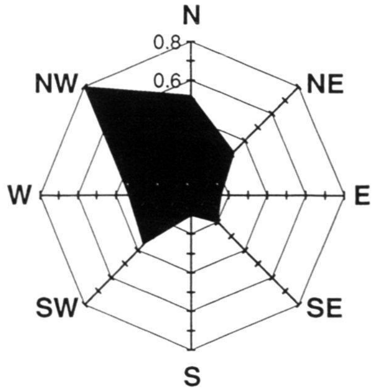

Fig. 1. Percentage of landslides related to the slope exposition in the Niesen Flysch. Dip slope towards the NW.

In the Gurnigel Flysch (marly-sandstone sequence), the tectonic setting consists of several slice units of uncomplete flysch series. The massive beds (thick sandstone layers) of flysch control the geometry of the slip surface in reverse bedding conditions. A **staircase structure** of the slip surface can be observed in many sites (Fig. 2) with a rotational slide from the head scarp to the resistant beds and then an evolution towards a translational type or debris-flow downslope (Raetzo 1997).

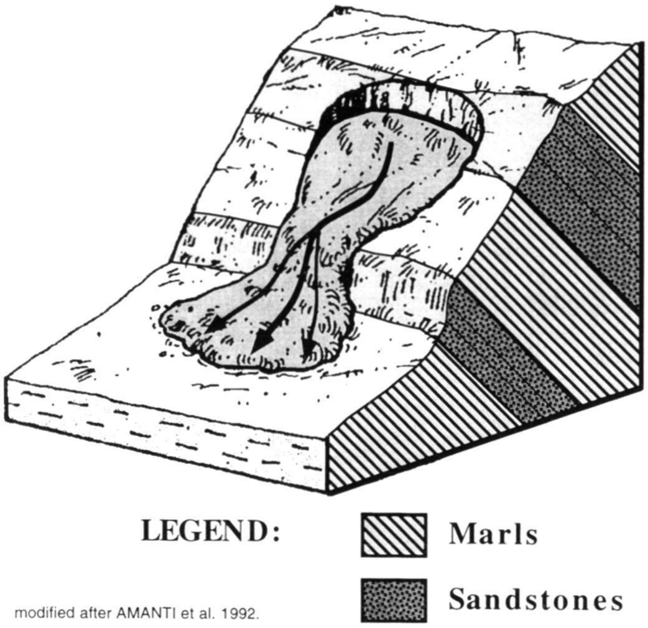

Fig. 2. Reverse bedding and resistant beds in the Gurnigel Flysch with a staircase structure of the slip surface.

2.4 Geotechnical parameter

The geotechnical parameters of the flysch area are characterized by large variability, due to the different mineralogical compositions of the flysch units inherited from their sedimentological history. Small scale tectonic structures are also responsible for great local variability in geotechnical properties of the flysch-rock. In the landslide-prone flysch terranes the geotechnical parameters of loose, unconsolidated and weathered soil are generally more important than the properties of the original rock.

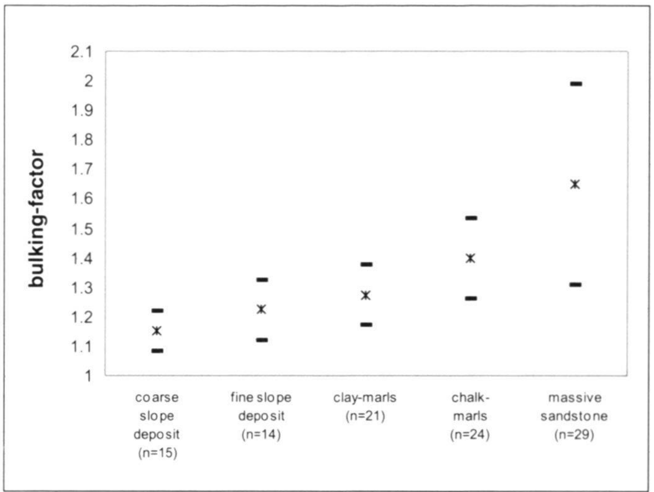

Fig. 3. Mean and standard-deviation of the bulking-factor in different lithologies of the flysch units.

Weathering, swelling of clay minerals and mass movements contribute to increase the total rock volume. The bulking-factor of the different flysch rocks is shown in figure 3. The maximum possible bulking-factor decreases with increasing weathered rock types (lithology).

Strength properties and rheological behavior depend on friction angle, on cohesion and on plasticity parameters. Statistical data on more than 90 geotechnical tests in different flysch rocks of Switzerland show that strength parameters may vary due to the content of swelling clay minerals. The slope stability is mainly correlated to water pressure conditions.

Plasticity parameters of different flysch rocks are shown in figure 4 and 5. Plasticity index I_P is the difference between the liquid limit w_L and the plastic limit w_P.

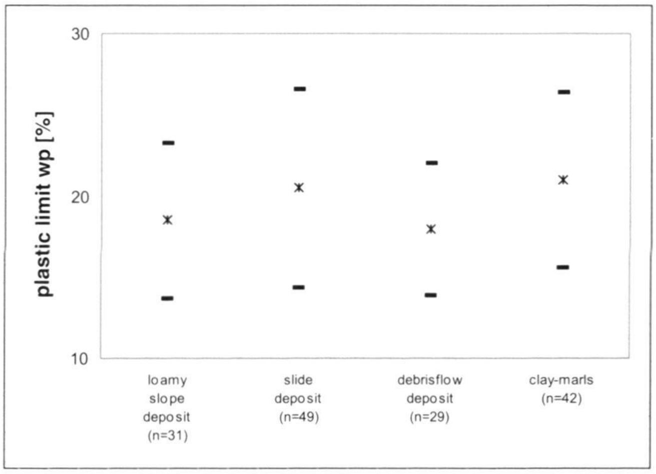

Fig. 4. Mean and standard-deviation of plastic limit in different lithologies of the flysch units.

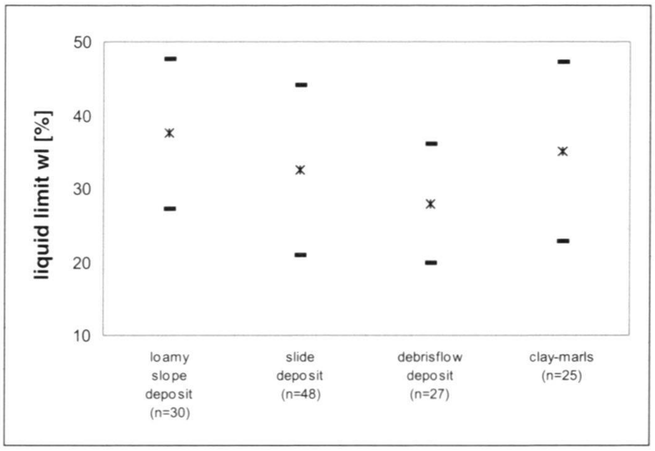

Fig. 5. Mean and standard-deviation of liquid limit in different lithologies of the flysch units.

The comparison of several geotechnical analyses on mass movements in flysch terranes shows a relationship between the liquidity index I_L and the type of slope movements (Tab. 2).

Tab. 2. Relationship between the liquidity index I_L and the type of slope movements in flysch terranes

liquidity index I_L	*type of slope movement*
0.25–0.5	landslide
0.2 –0.4	mostly deep-landslide
0.3 –0.6	mostly shallow-landslide
>0.5	debris flow

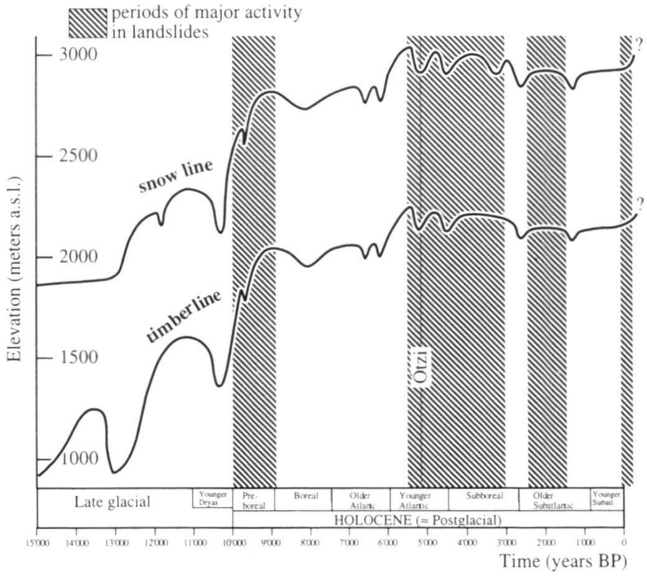

Fig. 6. Periods of major activity in the landslides of flysch terranes in Switzerland in relationship with the evolution of timberline and snowline during the Holocene (modified after Burga 1987).

3. Preparing causal factors

3.1 Three periods of crises in Holocene

The glaciation's footprints are often visible on the landscape. Deep erosion has occurred in many prealpine valleys. The first mass movements began with the retreat of ice sheets and during the **Preboreal period** (10'000 to 9'000 BP) many unstable zones started to move as **deep landslides** (Fig. 6).

In Austria, different rockslides and rock avalanches in the Ötztal were dated to the Preboreal age (Abele 1994). In the Prealps, some fossil trunks buried at the base of the slip surface have been dated by radiocarbon C^{14} at La Frasse (9'300 BP, Schoeneich 1990) near Leysin, at Villarbeney (10'190 BP, DUTI 1985) in the surroundings of Bulle or at the Hohberg near Schwarzsee (9'905 BP; Raetzo 1997). During that period, the timberline climbed from 1300 m to 2000 m (Fig. 6), in correlation to a drastic change in mean annual temperature from a late glacial to a temperated climate (Burga 1987).

During the period lasting from **mid Younger Atlantic to mid Subboreal** (5'500 to 3'200 BP), the climate became milder and drier. The timber-line went up to 2300 m (Fig. 6); Burga 1987. The permafrost belt followed this evolution and stayed above 2500 m.

As a consequence, many unstable zones in flysch terranes were reactivated as **deep landslides** in the Swiss Prealps (Fig. 6). The trunks dated by radiocarbon C^{14} (Lateltin et al. 1997, Raetzo 1997) at the base of the landslide of Falli-Hölli (5'000 BP) in the Berra/Lac-Noir Massif (Gurnigel flysch) are contemporaneous with the Iceman Ötzi discovered at Hauslabjoch in Austria (5'200 BP). In the Alps, Gamper (1985) described a peak in the solifluxion phases around 4'000 BP, based on 160 fossil trunks dated by radiocarbon C^{14}.

During the **Older Subatlantic** (2'500 to 1'500 BP), a third period of mass movement activities in the flysch terranes can be observed (Fig. 6). This cold and wet period (Haeberli 1995) was favourable to the development of **superficial events** (mud and debris flows) in the unstable zones of the Swiss Prealps. Some fossil wood found in the debris-flow deposits of Falli-Hölli (2'400 BP and 1'900 BP) and Hohberg (1'600 BP) were dated to this period (Lateltin et al. 1997, Raetzo 1997). Gamper (1985) also recorded another peak in the solifluxion phases of alpine slopes around 2'000 BP.

3.2 Anthropogenic influence since the Middle Age

The forest acts like an umbrella: The treetops retain 15 to 30 percent of the annual precipitation and part of the water evaporates back to the atmosphere. Trees consolidate the ground to a depth of about two meters, thus protecting it from superficial landslides.

The impact of human activity on forests in the Prealps is only perceptible since the late Middle Age. By the end of the 19th century, many areas were deforested, loosing up to 90% of their original forest cover (Zuffi 1993). In 1851, some severe landslides, debris-flows and floods occurred in the Sense watershed. In the early 20th century, the governement decided partly to reforest these bare slopes but not always the specific zones where landslides had occurred.

In the second half of the 20th century, the prealpine valleys were subjected to the intensive development of tourism and many landslide-prone areas in flysch terranes were used to build holiday residences. For example, the catastrophic event of Falli-Hölli of 1994 caused the damage and the destruction of 41 houses, (15 million US $ loss) in a touristic village (Raetzo & Lateltin 1996).

4. Triggering causal factors

4.1 Extreme weather conditions

Debris flows and superficial landslides (less than 2 meters deep) are triggered by periods of heavy water supply to the soil by rainfall and snowmelt. Different climatic regions have different threshold values for rainfall intensities. Sandersen et al. (1996) suggested that the critical water supply (P) into the soil that trigger debris flows can be expressed as a percentage of mean annual precipitation and durations (D) in hours:

$$P\ (\%\ of\ annual\ precip.) = 1.2 * Duration\ (hrs)^{0.6}$$

For a region with annual precipitation of 2000 mm, the critical 12 hours water supply will be 106 mm.

For example, in February 1990 a heavy rainfall event of more than 300 mm in three days in the cantons of Valais (Tissières & Medico 1993) and Vaud (Schoeneich 1991) initiated many debris flows.

In Switzerland, 3 heavy rainfall events of at least **70 mm/day** occur yearly in Switzerland over an area of 500 km^2 (Bader 1996). This critical value of water supply triggers many superficial landslides or debris flows in flysch terranes.

4.2 Recent trends for temperature and precipitation

Unlike debris flows, **rockfalls/rockslides** and **deep landslides** need several days, months or years of weather impact before ground failure. In these cases, the triggering factors are not always very clear even though two elements should be mentioned in the recent reactivation of landslides in swiss flysch terranes.

First, a major increase (10 to 20%) of the mean annual precipitation was recorded in the Préalpes Romandes since 1977 in respect to the long term annual average (1901–1960). This increase is marked during the winter period and has a clear impact on groundwater-conditions. It has made active ancient landslides that were dormant.

Second, there were exceptionally warm winters each year between 1988 and 1995. During that period, many snowmelt episodes occurred in the course of a single winter. For regions located at an elevation between 1000 m and 1500 m, these mild winters with temperatures sometimes above 0 °C for many weeks between December and May, are responsible for the massive infiltration of meltwater into the ground that induced a major rise of the groundwater table in unstable zones. Therefore, heavy rainfall events on already saturated terranes caused by mild winters can explain the sudden reactivation of many ancient landslides in flysch terranes since 1990.

4.3 Works and earthquakes

One of the consequences of decreasing land ressource for development and increasing lifestyles on heavy infrastructure is that there are more and more building activities even in landslide-prone areas of the flysch terranes. Because the safety factor F_S of several flysch slopes is nearly equal to 1, the latter are very sensitive to changes in physical conditions. Overloading and discharging of unstable slopes by excavation for roads and forest-ways accelerate the mass movements.

Recent cases have shown that the improper layout and construction of drainage-systems often cause an acceleration of mass movements. Another example of man-made influence on the stability of slopes is the artificial lake of Wägital: many movements in the area are strongly correlated with the level and the speed of level changes of the lake.

Earthquakes may also reactivate mass movements. Methods of analysis that allow the calculation of earthquake-triggered mass movements are: the pseudo-static approach, methods based on a simplified evaluation of permanent displacements which all resort to a Newmark-type analysis and the finite-element method based on more sophisticated modelling of the material constitutive behavior. The application of these methods on flysch terranes in Switzerland (Lateltin et al. 1997) shows that the probability of occurrence of the critical acceleration for landslides is 1000 years in the Wägital, 350 years in the Schlieren-Flysch region and 200 years in the Niesen-Flysch area.

5. Climate Change

5.1 IPCC scenarios

According to the Intergovernmental Panel on Climate Change, man-made global warming will lead to a dramatic increase in temperatures of 1 to 4 °C, within one century. Based on the scenario "Business as usual" of the IPCC 1992, the NRP 31

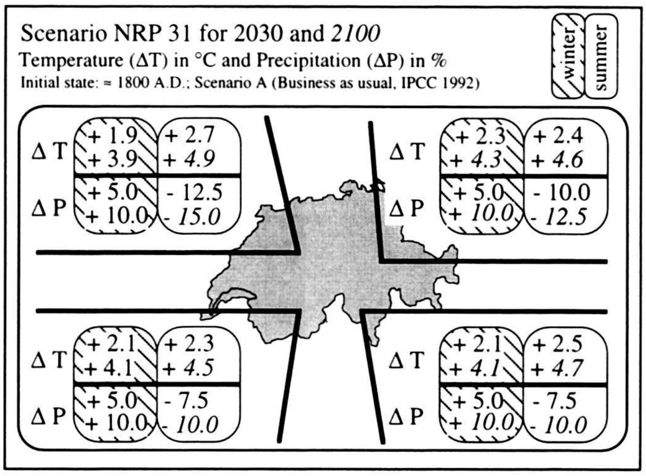

Fig. 7. NRP 31 prevision of temperature and precipitation (2030 and 2100) in Switzerland, according to the scenario "Business as usual" of the IPCC (1992).

Programme on "Climate Change and Natural Disasters" proposed some projections of temperature and precipitation for the years 2030 and 2100 in Switzerland (Fig. 7).

For the landslide-prone areas in flysch terranes of western Switzerland, we assume that the following parameters can be retained for 2050 (comparison with the year 1800):

- Increase of mean annual temperature (+ 2 °C)
- Increase of mean winter precipitation (+ 20%) and diminution of mean summer precipitation (– 10%)
- Increase of the occurrence of heavy rain periods: 3 events per year with precipitation of more than 70 mm/day on areas larger than 500 km^2.

5.2 *Impacts on landslide-prone areas*

The present evolution of climate towards mild and wet winters will affect the unstable slopes of the region located at an elevation between 1000 m and 1500 m in the Prealps, but the spatial distribution of landslides will not change drastically in the future.

The impact of a general elevation of both mean annual temperature and winter precipitations will probably cause a marked increase of the rate of movements in flysch terranes landslides. For some regions, the annual rate of displacement (intensity) can change from centimeters/year to decimeters/year and cause damage to roads and buildings.

Furthermore, some potentially unstable zones presently without movement will become active in the future. With the increase of heavy rainfall events (more than 70 mm/day), the initiation of debris flows and superficial slides can also be expected on critical slopes.

6. Concluding remarks

The flysch terranes are among the most sensitive to mass-movement problems in Switzerland and landslides constitute a real threat to the sustainable development of these regions.

Since 1990, the initiation or the sudden reactivation of deep landslides in prealpine regions located under 1500 meters seems to be related with periods of exceptionally warm winters, responsible for the massive infiltration of meltwater into the ground. We have identified two periods of crisis (Preboreal and Younger Atlantic/Subboreal) on unstable zones in flysch terranes in milder and drier conditions. We underscore a relationship between climate change and landslide activity. Further work should investigate the impact of a general elevation of mean annual temperature on landslides in the Swiss Prealps.

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REFERENCES

ABELE G. 1994: Felsgleitung im Hochgebirge und ihr Gefahrenpotential. Geogr. Rundschau 7–8, 414–420.

AMANTI M., CASTALDO G., MARCHIONNA G. & PECCI M. 1992: Proposta di una nova classificazione dei fenomeni franosi, ai fini del rilevamento geologico-tecnico e della corretta prevenzione del dissesto del territorio. Bolletino del Servizio Geologico d'Italia, Vol. CXI, Roma, 3–20.

BADER St. 1996: Projektionen zum zukünftigen Alpenklima. Stand der Diskussion 1996. Document interne de la Direction FNPNR 31, 1–13.

BOLLINGER D. & NOVERRAZ F. 1996: Pilotstudie: Karte der Bodenbewegungsgefahren 1:25'000, Blatt 1247 Adelboden. Rapport géologiques no 20, Service hydrologique et géologique national (OFEFP) OCFIM 310.022d, 1–40.

BURGA C. 1987: Vegetationsgeschichte seit der Späteiszeit. Das Quartär der Schweiz seit den letzten 18'000 Jahren. Geographica Helvetica 2/42, 71–76.

CARON CH., HOMEWOOD P. & WILDI W. 1989: The original Swiss flysch: a reapparaisal of the type deposits in the Swiss Prealps. Earth-Science Reviews 26, Elsevier Science Publishers, Amsterdam.

DUTI 1985: Projet d'Ecole Détection et Utilisation des Terrains Instables. Rapport final, Ecole Polytechnique Fédérale de Lausanne, 1–229.

GAMPER M. 1985: Morphologische Untersuchungen an Solifluktionszungen, Moränen und Schwemmkegeln in den Schweizer Alpen. Geogr. Inst. Univ. Zürich 17, 1–115.

HAEBERLI W. 1995: Climate change impacts on Glaciers and Permafrost. In Potential ecological impacts of climate change in the Alps and Fennoscandian mountains (Ed. by GUISAN, HOLTEN, SPICHIGER & TESSIER). Conserv. Jard. Bot. Genève, 97–104.

IPCC 1992: Climate change. The IPCC scientific assessment. Cambridge University Press, 1–365.

IPCC 1996: Climate change 1995. The science of climate change. Cambridge University Press.

LATELTIN O., BEER CH., RAETZO H. & CARON CH. 1997: Instabilités de pente en terrain de flysch et changements climatiques. Rapport final PNR 31, project no 4031–33429, 1–161, Vdf (in press).

PNR 31 1992: Mögliche Szenarien als Grundlage für die Forschungsarbeiten im Rahmen des NFP 31. Internes Arbeitspapier, 1–14.

RAETZO H. 1997: Massenbewegungen im Gurnigelflysch und Einfluss der Klimaänderungen. Diss. Universität Freiburg, 1–244.

RAETZO H. & LATELTIN O. 1996: The landslide of Falli Hölli, an extraordinary event ? Int. Symp. Interpraevent 1996 Garmisch-Partenkirchen, 129–140.

RAETZO H., LATELTIN O., PUGIN A., STIEFELHAGEN W. & MUELLER I. 1995: Geophysikalische Messungen zur Beurteilung von Rutschungen. Schweizer Ingenieur und Architekt 48, 9–11.

SANDERSEN F., BAKKEHOI S., HESTNES E. & LIED K. 1996: The influence of meteorological factors on the initiation of debris flows, rockfalls, rockslides and rockmass stability. Proc. Int. Symp. Landslides, Trondheim, Senneset (ed.), Balkema, Vol. 1, 97–114.

SCHINDLER C. 1988: Zones instables en Suisse – Conférence spéciale Proc. Int. Symp. Landslides, Lausanne, vol 2 Bonnard (ed.), Balkema, 1293–1299.

SCHOENEICH PH. 1990: Datation de glissements de terrain et de sédiments fluviatiles et lacustres dans la vallée des Ormonts. Rapport scientifique pour le Fonds du 450e. Inst. Géogr. Univ. Lausanne, 1–30.

– 1991: Effets des intempéries des 14 et 15 février 1990 aux Ormonts, Alpes vaudoises. Bull. Soc. Vaud Sc. nat. 80/3, 279–297.

STUDER B. 1827: Remarques géognostiques sur quelques parties de la chaîne septentrionale des Alpes. Ann. Sci. Nat. Paris, 11, 1–47.

TISSIÈRES P. & MEDICO J. 1993: Ecoulement de boue à Champéry, Val d'Illiez, mécanismes de rupture, stabilisation et impact sur l'aménagement du territoire. Symposium SIA/FEANI/IDNDR Lausanne, Documentation D 0110 SIA, 135–148.

ZUFFI D. 1993: Reboisements en Haute-Singine (Fribourg) 100 ans de lutte contre les effets de l'érosion et des forces de la nature. Symposium SIA/FEANI/IDNDR Lausanne, Documentation D 0110 SIA, 369–376.

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