Westfjords Natural History Institute

Study of mass movement processes on slopes above man made structures in the Westfjord area.

Sponsored by Ísafjarðarbær

Thomas CHAREYRON

Supervision:
Þorsteinn SÆMUNDSSON
Nature Research Institute of Northwestern Iceland

Hafsteinn H. GUNNARSSON
Westfjords Natural History Institute

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Náttúrustofa Vestfjarða
Westfjords Natural History Institute
Adalstræti 21
415 Bolungarvik, Iceland

Tel:+354 4567005
Fax: +354 4567351

Id.No: 610397-2209
E-mail: nv@isholf.is
Homepage: http://www.snerpa.is/nv

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ABSTRACT

A study about the slope movements in the Ísafjörður area has been carried out between mid-may and mid august 2001. The aim is to study and map different types of slope movements, which occur on the slopes above the man-made structures in order to establish risk maps.

Six research areas were studied. All of them are situated within the Ísafjörður community. Three of them are situated within the Skutulsfjörður fjord area. The forth one is in Hnífsdalur valley area, the fifth one in the Önundarfjörður fjord and the sixth one in the Dýrafjörður fjord.

The first area is the slope extending between Kubbi and the residential quarter of Holtahverfi in the Skutulsfjörður fjord. This slope is characterised by a low activity and most of the rockfalls do not reach its foot. Moreover, snow avalanches or major rockfalls occur with a low frequency.

The second area is the inner part of the Eyrarhlíð slope in the Skutulsfjörður fjord. Snow avalanches and debris flows occur on this slope.

The third area is the outer part of Eyrarhlíð and covers the outermost sector of the Skutulsfjörður fjord. The slope is mainly affected by debris flow. Rockfalls and rock avalanches also occur. Thanks to the Gleiðarhjalli plateau that interrupts the slope, snow avalanches are of minor importance. However, where the plateau ends, the activity for both snow avalanches and debris flow is high, and the phenomena can be of large extend, down to the fjord.

The fourth area is situated on the northern side of the mouth of the Hnífsdalur valley and extends between a 647 meters high mountain and the Hnífsdalsá river. The slope is mainly affected by snow avalanches, but debris flows also occur.

The fifth area is situated at the north side of the Önundarfjörður head, between the Tannanes and Kirkjuból farms and up to the Kirkjubólsfjall mountain. The slope is affected by snow avalanches, debris flows and rockfalls.

The sixth area is the Lambadalshlið slope situated on the northern shore, close to the head of the Dyrafjörður fjord. The slope extends between the top of the Lambadalsfjall mountain and the fjord water. The slope is mainly affected by snow avalanches, but debris flows also occur.

These areas are different from each others and no general rules can be pointed out concerning the slope movements. Therefore a detailed study and mapping of these slope is essential.

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All pictures from Thomas Chareyron.

Aerial photo from Ísafjarðarbær.

1. INTRODUCTION

The Westfjords area, peninsula in northwestern Iceland, is characterised by steep mountains, which rush abruptly in deep fjords and valleys. The Westfjords' volcanic bedrock is composed of the oldest rocks found in Iceland, up to 13 millions years old. In the deep stratigraphic levels, some rocks reach about 16 millions years old. Tholeiitic lava and, intermediate and acid lava, genetically associated, spread out on vast, horizontal and plane plains since no erosion occurred during the tertiary period. The stratigraphy is quite regular with lava beds about 5 to 15 meters thick representing about 10.000 years each and alternating with thin clayey soil layers. Red to red brown, these soil layers contain traces of trees, leaves, bones that permitted an absolute datation. These layers would probably be airborne transported volcanic ashes, chemically altered (Sæmundsson, 1979).

During the Plio-Pleistocene, the conditions are different and glacial erosion starts to carve the basaltic plateau (Sæmundsson, 1979).

During the upper Pleistocene, erosion of these plateau, by that time far form the volcanic active areas, is going on very quickly. Valleys of 800 to 1000 meters deep have been carved in less than 1.8 million years (Sæmundsson, 1979).

The presence of zeolite in the air bubbles and fractures of the rock, without relationship to the stratigraphy of the lava pile, permits to estimate quantitatively this erosion. Zeolite facies is the lowest-temperature metamorphism. This regional burial metamorphism occurred in zones approximately parallel to the top of the lava pile at the time of zeolitization. Since zeolite is found up to the tops of the actual mountains, it has been estimated that at least 2000 meters of bedrock would have been eroded.

Towards the end of the last glaciation the sea level rose eustatically (Sæmundsson, 1979).

Today the landscape of the area shows obvious signs of their glacial origin and of the important erosion. Due to the ice cap erosion, the tops of the mountains are levelled, plateau-like, dominating deep valleys and fjords dug by outlet glaciers or valley glaciers. On the highest parts of the steep slopes, the planar lava beds appear clearly, tilting slightly, in the global trend, towards the rift centre, southeastwards. Scree and eventually depositional lobes cover the lowest part of these slopes. The soil and the vegetation cover is poor, limited in herbs and creeping bushes in non-active parts, whereas the active parts are simply bare. Some rare woods develop in some places, at the bottom of valleys, planted by man hands and replacing the forests he cut down along the history for his subsistence. The relatively plane lowland areas are scanty and scattered. The inhabitants of the area have always turned themselves towards the sea, supplying resources and lines of communication, settling down on sand shoals in the fjords or on narrow strips of land jammed between the coast and steep slopes. The latter are directly or indirectly threatened by landslides such as debris flows, rockfalls or snow avalanches. In addition to the topography and the weakness of the vegetation cover, climate plays a major role in the importance of the landslides. Expansion of the villages and other developments like roads, towards more vulnerable areas increases risks. The history, even recent, is ascertained by dramas. In 1910, a snow avalanche killed twenty persons in the Hnífsdalur valley. Sixteen habitations situated in the most snow avalanches threatened area have been bought by the state for destruction in 1995. In January and October 1995, two villages in the neighbourhoods of Ísafjörður, Súðavík and Flateyri, were struck by snow avalanches, causing death of 14 and 20 persons respectively, and damages on buildings

(Haraldsdóttir, 1998). The same day of this second avalanche, another avalanche in another fjord of the area provoked a wave, which reached the village of Suðureyri, situated on the opposite shore. In total 28 avalanches occurred in the period of 23rd to 26th of october 1995 (Haraldsdóttir, 1998). In 1981, a boulder fell upon a house of Suðureyri, went through the kitchen, miraculously sparing children that were inside (Pétursson, 1991). The roads are even more regularly affected. Some sectors in the Ísafjörður neighbourhood, administrative and economical centre of the Westfjords, are frequently struck by snow avalanches in winter and spring times and rockfalls occur almost daily in springtime. From time to time, it's a debris flow that damages the roads. If the accidents are relatively rare, it is due to the low traffic. These examples show the fact that nowadays, despite the improvement of the knowledge and technique, the buildings of protection, paravalanches and tunnels, the risk linked to the slopes movement is still high. The aim of this paper is to study and map diffrent types of slope movements, which occur above the man-made structures in the Ísafjörður area in order to establish risk maps (localisation Fig.1). After the presentation of the methods used for this study, the general descriptions of the different types of slope movements and of the research areas will be tackled. Then the different sectors will be studied, as well as the causes.

2. METHODS

The field study consists on a general description of the different sectors followed by a more detailed search for peculiar signs helping to determine the type of landslides which occur at a given place and the maximal extent reached. For example debris on the top of a boulder is typical for snow avalanches transport as well as boulder transported far at the foot of a slope. Erosive channels with levées are typical for debris flows. Both can create "debris horn" and "debris shadow" (Blikra & Nemec, 1998). Rockfalls present course grained debris, which usually do not reach the lower part of the slope. The different features will be described in the next chapter.

The mapping of Eyrarhlíð and Hnífsdalur is realised with help of aerial photography superimposed with contour lines, document supplied by the road administration. The mapping is then reported on a similar document on the computer by using the software Microstation.

Numbers have been attributed to the most remarkable gullies for the convenience of references in the text. The same number can refer to a gully, a track, a channel or a depositional cone, which are associated. The numbers are in order from 1 to 26 on Eyrarhlíð, from the head to the mouth of the Skutulsfjörður fjord. The numbers 27 to 29 refer to Hnífsdalur. Note that not every single gullies or tracks have been referenced by a number, but only the most remarkable ones and which are mentioned in the text.

Figure 1: Locality map of the study areas in northwestern Iceland; (1) Kubbi in Skutulsfjörður; (2) inner and (3) outer parts of Eyrarhlíð in Skutulsfjörður; (4) The Hnífsdalur valley area; (5) Kirkjubólsfjall mountain in Önundarfjörður; (6) Lambadalshlið slope in Dýrafjörður.

3. DEBRIS FLOW, SNOW AVALANCHE AND ROCKFALL

This chapter gives a general description and the characteristics of a debris flow, a rockfall and a snow avalanche in order to recognize and differentiate these phenomena's from each others.

3.1. Debris flow

A debris flow is a mixture of fine and coarse material, with a variable quantity of water, that form a muddy slurry which moves downslopes, usually in surge induced by gravity and the sudden collapse of bank material. A debris flow is composed by a source area, a main track, which follow a pre-existing drainage way and a depositional toe (lobe) which build up into a debris fan where the slope softens. A debris flow is triggered by water (melting water, heavy rain…) on mountainous area. In alpine environment, coarser material is involved since this coarser material falls into the source area by mechanical weathering. (Dikau *et al.*, 1996).

A high-viscosity debris flow is responsible for matrix-rich to clast-supported gravel deposits, whereas a low-viscosity debris flow deposit typically includes an erosive, furrow-like track with levées and a highly elongated, coarse-fronted lobe in the down slope depositional zone (Blikra & Nemec, 1998).

The absence of vegetation cover characterises the area actively involved by the debris flow. The beds of the depositional toe are poorly sorted and matrix supported, except if the matrix has been washed away. The boulders may concentrate at the top and the front of the deposit and their long and intermediate axis is orientated parallel to the outer edges of the lobe. The frequency of debris flows is related to the rate of accumulation of material in the source area or in the channels and the recurrence of climatic triggering events. (Dikau *et al.*, 1996).

A debris flow can accumulate debris on the upslope side of boulders creating "debris horns" (Blikra & Nemec, 1998).

The water content within a debris flow varies greatly, and the flow viscosity is as higher as this water content is low. The flush and/or snow involved in debris flow also act on the viscosity. Slush reduces it whereas dense drier snow will increase it. (Blikra & Nemec, 1998).

3.2. Rockfall

Rockfall is a rapid and fully or partially free movement of rocks falling from a steep wall or slope. Rocks break away from the slope along the discontinuities depending on their dimensions, direction of the fractures and the ratio of their dip angle with the rock wall, and the mechanical characteristics of the rock. The movement undergoes deformations due to bounce, break-up, roll, slide or dry flow onto the slopes below and is influenced by the shape of the initial failure surface. A fall can be free all the way or with rebounds depending on the orientation and angle of the slope facet impacted, the size (weight) and the shape of the block, the angle at which it strikes the slope, the state and deformation of the rock, the gradient and roughness of the slope and absorption of the shock by any covering vegetation (Dikau *et al.*, 1996). The deposits are typically course grained, the runout distance varying with the size of the debris. Fine debris have short runout distances although coarse debris have longer runout distances. (Blikra & Nemec, 1998).

Repeated falls on a talus scree can build up a fan-shaped cone with a marked down slope coarsening. The down slope part of a rockfall deposit is typically openwork, composed of boulders with scattered large "outrunners" further down, whereas the upslope part is finer with gravel and sand. But boulders can have a large extend on the cone surface when series of rockfalls occurs along the same track since the effective runout of the successive events may be shortened. (Blikra & Nemec, 1998).

A fall is said primary if its movement is uninterrupted but secondary if the movement follow an interruption (Matznetter, 1956).

Rockfall avalanche deposits have usually a tongue shape with steep frontal lobes. They can extend over large area with a chaotic morphology when they occur on high slope (Blikra & Sæmundson, 1998)

3.3. Snow avalanche

Snow avalanche is a rapid movement of snow downhill. Hopfingers (1983) distinguish the dense snow avalanches and the powder snow avalanches. Snow avalanches can transport large amounts of debris such as debris accumulated on the snow pack due to rockfalls, airborne dust, debris picked up on the slope and in the proximal part of the colluvial fan during the flow (Blikra & Nemec, 1998). Dense and non-turbulent powder snow avalanches can carry large blocks such as boulders. Turbulent powder snow avalanches usually only carry fine debris but may also drag boulders on steep and relatively smooth or snow covered slopes (Blikra & Nemec, 1998).

Debris can be transported downhill as far as the valley bottom or in the fjord water and even uphill on the opposite hill. An avalanche dominated colluvial fan is regular, smooth and non dug by any channel.

The debris size has little importance on the distance it can be transported. The size and weight of these boulders can be impressively important. If the avalanche crosses a river it can even pick up boulders from the riverbed and so rounded boulders can be found away from the riverbed. In addition these boulders are just laid on the ground or on the vegetation. The surrounding vegetation cannot be damaged. The bigger ones form impact hollows as they bounce. The boulders can be covered by a layer of finer material transported by the avalanche and which settle down as the snow melts. Bushes and trees are typically broken and bended in the snow flow direction. Debris horn above a boulder and debris shadow below can be present (Blikra & Nemec, 1998).

It seems that a snow avalanche occurring early in the season is more able to pick up boulders because they may not be frozen to the slope and they are not protected by old and stable snow layers.

The Botnsá Valley, at the head of Dyrafjörður, shows a very good example of evidence for debris transported by snow avalanches (Saemundsson & Kristjánsdóttir, 1998).

4. RESEARCH AREAS

Six research areas were studied and are steep slopes dominating man made structure, i.e. habitations or roads. Three of them are situated in the Skutulsfjörður fjord, the three others are situated in the Hnífsdalur valley and in the Önundarfjörður and Dýrafjörður fjords (Fig. 1).

- The first area is situated at the head of the Skutulsfjörður fjord, at the entrance of the Dagverðardalur valley. The slope, facing north, extends between Kubbi (376 meters a.s.l.), northern end of the Hafrafell mountain (607 m.a.s.l.) and the residential quarter of Holtahverfi. Habitations lay right at the foot of the slope.

- The second area is the inner part of the Eyrarhlíð slope, situated along the northern shore of the Skutulsfjörður fjord between Holtahverfi and Ísafjörður. The slope, facing south-southeast, extends between the top of the Eyrarfjall mountain (724 m.a.s.l.) and the seashore. A road lay at the foot of this slope.

- The third area is the outer part of the Eyrarhlíð slope and covers the outermost sector of the Skutulsfjörður fjord. The slope, facing southeast, differs from the previous one by the presence of the Gleiðarhjalli plateau (about 450 m.a.s.l., up to 450 meters wide), which interrupts it. Habitations of Ísafjörður lay on the foot of the slope.

- The fourth area is situated on the northern side of the mouth of the Hnífsdalur valley. The slope, facing southeast, extends between a 647 meters high mountain and the Hnífsdalsá river. The village of Hnífsdalur lay on the foot of the slope.

- The fifth area is situated at the north side of the Önundarfjörður's head, between the Tannanes and Kirkjuból farms. The slope, facing south-southwest, extends between the Kirkjubólsfjall mountain (719 m.a.s.l.), part of the Kroppstaðafjall mountain (754 m.a.s.l.) and the shallow waters or bogs of the fjord's bottom. A road lay at the foot of this slope.

- The sixth area is the Lambadalshlið slope situated on the northern shore, close to the head of the Dyrafjörður fjord, between the Lambadalur and Hvallátradalur valleys. The slope, facing south-southeast, extends between the top of the Lambadalsfjall mountain (550 m.a.s.l.) and the fjord water. A road lay at the foot of this slope.

5. DESCRIPTION AND INTERPRETATION THE DIFFERENT AREAS

5.1. *The Holtahverfi area*

5.1.1. Description

The studied slope extends between Kubbi to the edge of the residential quarter. In the upper third of the slope, the bedrock appears and forms an irregular and eroded cliff with gullies (Fig. 1 & 2).

Figure 2: Overview of Kubbi and Holtahverfi. The slope is facing north.

On the southern side of the slope, two sub-horizontal layers of bedrock, slightly tilting towards northeast, occur. They appear as small cliffs ending chamfered towards northeast and with an increasing thickness towards southwest. On the highest southeastern part, bedrock creates small breaking up of the slope, tilting towards northeast. The low part is covered with scree and sometimes vegetated. The slope is regular except some shallow and vegetated channels on the lower and the southeast part of the slope. Vegetated lobes can be distinguished in the lower part. No channels are presented in the non-vegetated parts.

The main non-vegetated part of this slope is the central part underneath the gullies of the upper cliffs, but don't reach the foot of the slope. Buildings and houses lay just where the ground is flattening. Boulders are hung up on the slope underneath the upper small chamfered cliff, which is also non-vegetated. No habitation settles down there.

Boulders, mostly partially buried, sometimes laid upon the ground, are scattered at the foot of the slope down to the Ulfsá river.

5.1.2. Interpretation

The slope is characterised by a low activity and most of the rockfalls do not reach its foot. Moreover, snow avalanches or major rockfalls seem to occur with a low frequency. It is although difficult to determine if the boulders at the foot of the slope are snow avalanche transported or old glacial sediments, or even man displaced. Therefore it is difficult to determine which events occurred in the past and their extent.

5.2. *The inner part of the Eyrarhlíð slope*

5.2.1. Description

The inner part of the Eyrarhlíð slope extends above a very busy road which links the main part of Ísafjörður to the residential quarter of Holtahverfi but also Ísafjörður and Bolungarvík, respectively capital and second largest village of the Westfjords, to the rest of the area, e.g. Hólmavík eastwards, Patreksfjörður southwards and to the rest of Iceland (see Fig. 1).

The steep and regular slope coming down from Eyrarfjall is increasingly cut by tracks northeastwards. There is little scree on the flank between these tracks.

The south westernmost tracks (1 to 4) are slightly visible (see appendix, figure 26) The erosion signs are weak. No gully is present on the higher part of the slope and only the track 3 ends on a quite small colluvium, settled relatively high on the slope. One small colluvium is present. The slope is well vegetated with a continuous vegetation cover, except the scree covered higher part. Boulders are scattered far down in the slope, below the road going up to the old Ísafjörður ski centre.

Northeastwards, the slope shows signs of much stronger erosion. The tracks 5 to 9 deeply cut the slope (see appendix, figure 26). They start from gullies dug in the bedrocks at the top of the Eyrarfjall mountain. The tracks are associated downhill with large colluviums. These colluviums coalesce each others, particularly 7 and 8. They are all covered by vegetation and have a fairly regular shape. Only small portions generally situated on the sides of the colluviums are not vegetated and dug by erosive channels. Scattered boulders and stones appear on the surface these colluviums and far downslope, down to the fjord. However most of them have been cleared in the lowest part if the slope as a result of development of roads, buildings and fields. Some finer deposits and sometimes scars can be observed on remote large boulders put on the ground surface (Fig. 3).

Figure 3: Fine grained deposits and scars on a remote large boulder put on the ground at the foot of the inner part of the Eyrarhlíð slope. The bigger boulder is about 2 m long. The picture is taken towards east. The Eyrarfjall mountain is on the right.

5.2.2. Interpretation

The scattered boulders on the ground at long runout distances presenting scars and fine debris on top indicate that the whole slope is affected by snow avalanches. These avalanches can cover long distances and sometimes reach the fjord.

The rockfall activity is very low. Some blocks can however punctually fall.

The tracks 1 to 4 do not show signs of significative erosion; they are shallow and the debris cone absent or pretty small. The debris flow activity in this sector is minor.

The tracks 5 to 9 have a quite different looking. They are much deeper and wider and are associated with colluvium of large extend travelled through by erosive channels, testifying of a much higher debris flow activity. The debris flows are expected to follow always the same well-defined path constituted by the tracks until they reach the top of the colluviums where the paths can diverge from one event to another in an unpredictable way.

5.3. *The outer part of the Eyrarhlíð slope*

5.3.1. Description

The slope of Eyrarhlíð is steep and is coming down from the levelled Eyrarfjall mountain (724 m.a.s.l.) and interrupted by the Gleiðarhjalli plateau (around 450 m.a.s.l.). See Fig. 1 & 4.

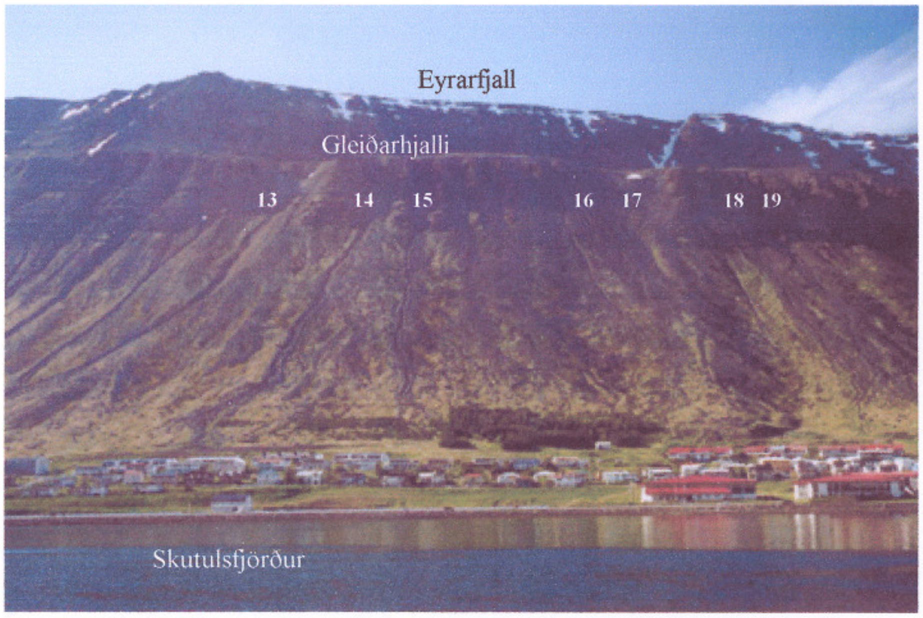

Figure 4: Overview of the inner part of the Eyrarhlíð slope interrupted by the Gleiðarhjalli plateau situated at about 450 m.a.s.l. In the background the top of the Eyrarfjall is at 724 m.a.s.l. Part of the Ísafjörður village lay along the fjord Skutulsfjörður. The picture is taken toward the northwest.

Numerous bowl-shaped source areas are cut into the edge of the plateau and covered by huge amount of loose and available material of all sizes, mainly instable sand and gravel covered by boulders (Fig. 5). In the most eroded parts, the boulders cover is manquant and boulders loosen due to erosion of the fine-grained matrix (Fig. 5). Under this source level, harder rockbed layers are thrown into relief but deeply dug by gullies beneath each source area, creating steep couloirs with striped ground and delimited on the sides by vertical walls. Some isolated instable rocks are present. The erosion of the relatively narrow soft soil beds leads to overhanging ends of rockbeds layers (Fig. 6).

Figure 5: Debris covered source area 18, in limit of the Gleiðarhjalli plateau. The picture is taken toward northeast.

Figure 6: Escarpments presenting overhanging rocks, which result from erosion of the soft soil layers. The picture is taken from the gully 17, towards northeast.

A vertical and regular cliff separates the levelled Eyrarfjall mountain from the plateau.

On the sides of the plateau, where it is the narrowest, scree from this cliffs reach the edge of the plateau (particularly the gullies 10 to 13) and are about to be involved again by landslides in the lower part of the slope due regressive erosion into the plateau, supplying important amount of large boulders (Fig. 7).

Figure 7: Western end of the Gleiðarhjalli plateau. Debris from the upper cliff extend down to the down slope limit of the plateau and can therefore be involved by landslides in the lower part of the slope by regressive erosion. The picture is taken towards southwest.

On the widest part of the plateau, just north of the source area of the gully 17, huge cone of debris with very large boulders (often meters long) is extending surprisingly far from the cliff related to its height but does not reach the edge of the plateau.

The rest of the slope itself presents different aspects. The westernmost part is travelled through by elongated tracks coming down from relatively short and wide gullies (10 to 16), some of them with lateral ridges or levées (Fig. 8). One even reaches the shield (ditch and debris-made wall) built along the upper inhabited limit. The debris lobes, when present, are smaller than the ones described for the inner part of Eyrarhlíð, without the plateau, in extend and in thickness alike. This part is relatively poor in scree and widely vegetation covered. The scree (particularly boulders) proportion increases eastwards where the non-affected, vegetated areas, are sparser, usually between the gullies axis. The vegetation cover gets more important as the distance from the source areas increases and the slope gets less steep. Scattered boulders sprawl at the foot of the slope. They are particularly sparse westernmost. They are numerous within and to the lower limit of a small forest situated at the lower part of the slope. The upper part of the forest shows signs of landslides effects (broken trees, areas lacking of tree opened on the upper forest limit…) but the rest of the forest is more or less undamaged, i.e. tall trees stand upstream of most of the boulders.

Figure 8: Erosive channel with levées downstream of the gully 15 on Eyrarhlíð.

Centrally the wide gully 17 dominates a slope covered by scree (Fig. 9), often of large size (boulders), all the way to the foot of the slope and therefore creating a small hill with a steep front. One the western side, there are some channels but they don't originate from the same gully and look small compared to the quantity of the debris present.

Figure 9: Source area of the gully 17 at the limit of the Gleiðarhjalli plateau. A large amount of boulders is present. The picture is taken toward southwest.

Then, northeastwards, the slope is quite similar that it was west of the gully 17 with a good proportion of vegetation-covered areas (Fig. 10). Large boulders are accumulated in some parts. The channel 20, with nice levées, reaches a shield protecting the houses (Fig. 10 & 11). Scattered boulders sprawl at the foot of the slope. One is encased in a print hollow.

Figure 10: Overview of the outer part of the Eyrarhlíð slope. The picture is taken towards northwest.

Figure 11: Source area and deep gully on the top of the lower part of the slope Eyrarhlíð. One can see the channel that reaches the shield along the upper houses of Ísafjörður. The picture is taken towards southeast.

The last portion of the slope, to the northeast, extends above the road to Hnífsdalur, which is laid along the shore and some buildings (houses, fish drier racks), and drops directly into the fjord water, except around 50 m.a.s.l. where the slope gentles before getting steeper again downhill. This slope portion, not as steep as seen previously, is characterised by four long and deep gullies (23 to 26) opening on four large debris fans. The parts of slope between the channels are covered with small sized scree and patches of vegetation. The debris fan 23 is different from the three others, developing upwards. It is much thicker but has a smaller extend and steep front and it is convex upwards like hung on the slope. The three last ones (24 to 26), concave upwards, have a larger extend. They develop on the gentler part of the slope, but are no as thick and not as steep than 23 (Fig. 12A). The vegetation cover is variable. The fans coalesce each others. They each present a non-vegetated channel with levées (Fig. 12B). Below the fan 26, a particularly deep and long erosive channel goes down to the road. Levées are well developed on each side all the way down and reach a fish drier wall (Fig. 12C). In addition of these levées at the ground level, other levées are sometimes present inside the channel itself, on one of the flank, whereas the opposite flank and even the levées at the ground level look newly re-eroded (Fig. 12D).

A

B

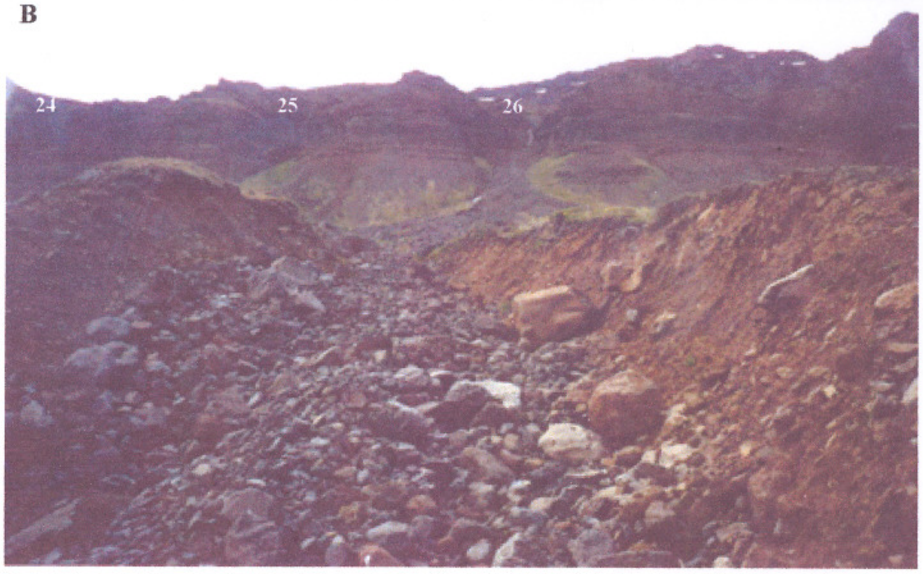

Figure 12: (A) Different morphological aspects between the convex upwards fan 23 and one of the concave upwards fans (24); (B) Large channel (4 m wide) below the forth colluvium 26; (C) Levées which had reached the road and a building downstream of the colluvium 26. The lower end of the roof is at about 2 m above the initial ground surface level and 50 cm above the new surface; (D) Several successive channels along the same track 26. The two large boulders are about 2 m long.

The slope presents also some smoothed and vegetated channel tracks, which are converging in small gullies in the lower steeper part. Some of these channels are followed by streams. In these small gullies above the fish drier racks, vegetation (mosses) covers blocks, except in some patches where the blocks remain visible.

A large number of scattered boulders, sometimes very big, occur all the way down, even to the fjord water in the axis of the small gullies. However these boulders are more dispersed especially as the distance from the source area increases. Smaller debris lie on some of the boulders and some boulders present scars. A triangular deposit of debris "debris horn" lies above a small boulder (Fig. 13 A & B).

Figure 13: (A) Boulder on the ground and covered by finer debris, between the tracks 25 and 26; (B) "Debris horn" above of a boulder. On the two pictures, the photo film box on top of the boulder is 5 cm long.

5.3.2. Interpretation

The materials involved in slope movement in this lower outer part of Eyrarhlíd come from the layer of loose debris covering the massive bedrock bank on the Gleiðarhjalli plateau. They include a wide range of grain sizes, from sand to boulders. In the extremities of the plateau, in particular the inner one, the supply of material is enhanced by coarse debris deposited close to the edge of the plateau as a result of slope movements on the upper cliff.

The westernmost part of the slope (gullies 10 to 16) is dominated by debris flows. Most of the gullies present a channel with levées, sometimes very recent. These debris flows are able to reach the inhabited lower part of the slope, fortunately protected nowadays, as observed recently below the gullies 14 and 20. From the source area, or at least at the opening of the gullies, high on the slope, the path followed by the debris flow can change from an event to another one. The snow avalanche activity seems to be low but some avalanche-transported boulders can be observed.

The slope portion between the gullies 15 and 16 (smaller gullies are present) seems not to be affected by debris flows but rather by rockfalls and snow avalanches. Indeed above the forest, course grained deposits are induced by rockfalls and boulders in the lower part of the forest and the damage on it results from snow avalanches.

The gully 17, which present important amount of debris, mainly boulders, all the way to the foot of the slope with a steep fronted tongue, results mainly from a large rockfall avalanche, which probably occurred as a single event.

Similarly the accumulation of large boulders dowhill of the gullies 21 and 22 may result from small rockfall avalanches.

Some rockfalls of minor importance can occur anywhere due to the weathering of the bedrock layers. Overhanging beds resulting from the erosion of the soft soil layers, isolated blocks with unstable looking and fractures are widespread. The material may eventually fall and settle in a debris flow or snow avalanche path and so be liable to be reactivated and therefore increase the supply of material involved.

The northernmost portion of the slope (gullies 23 to 26) seems to be very active. The erosive channels are recent and large. Boulders transported by snow avalanches are numerous, often big and remote. Some associated features such as debris horn or fine debris on top of boulders are observable. Both snow avalanches and debris flows occur widely and can be powerful. Both can reach the foot of the slope and even all the way to the fjord. Rockfalls are predominant for the building up of the convex above colluvium 23 but snow avalanches and debris flows are predominant for the concave above colluviums 24, 25 and 26.

5.4. *The Hnífsdalur valley area*

5.4.1. Description

The slope is regular and with three elongated tracks each opening on a colluvium (Fig. 14).

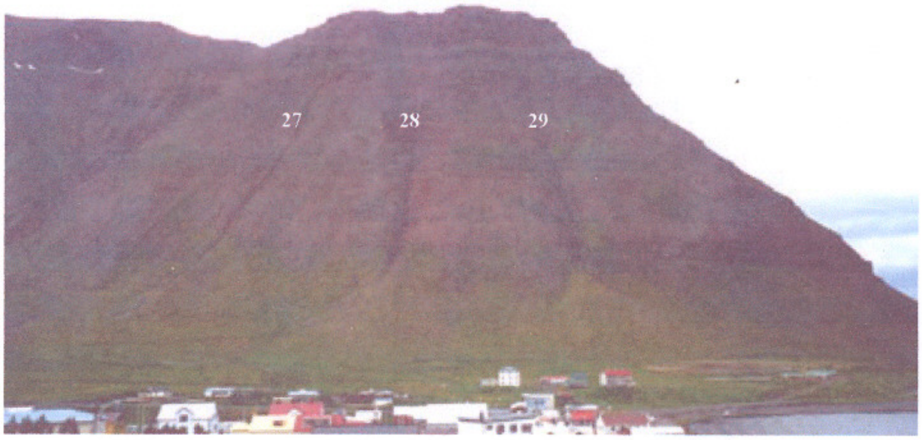

Figure 14: Overview of the south-facing slope above Hnífsdalur. The top of the mountain is at an altitude of 647 meters and the sea appears in the right-low corner.

The westernmost track and colluvium are of smaller importance than the two others. The channel is less deep; there is no real source area. This small colluvium is vegetated and presents traces of channels from debris flow but no recent one. No boulder is present on top of the colluvium or below it.

The slope between the first and the second track is mainly bare, covered by a thin layer of small sized scree. Two sub horizontal rocky escarpments present loose blocks. The lower part of the steep slope is vegetated. Some boulders are present right at the foot of the steep slope but they don't extend on the gentler part.

The second colluvium is much bigger and extends much further down. It is at the opening of a long V-shaped track (Fig. 15A). It is relatively regular, smooth but surface shows undulations, which are traces of old debris flow channels. The colluvium is well vegetated but bare with stones on the higher parts. No boulder is present on the colluvium but they are numerous and relatively small downhill (Fig. 15A). Some small debris (stones, gravel) is also there. In the proximal part but along the outer limit, a boulder presents debris its upper faces (Fig. 15 B & C). In the centre, one of the channel is clearly more recent than others but not very recent (presence of vegetation, faded out relief).

A

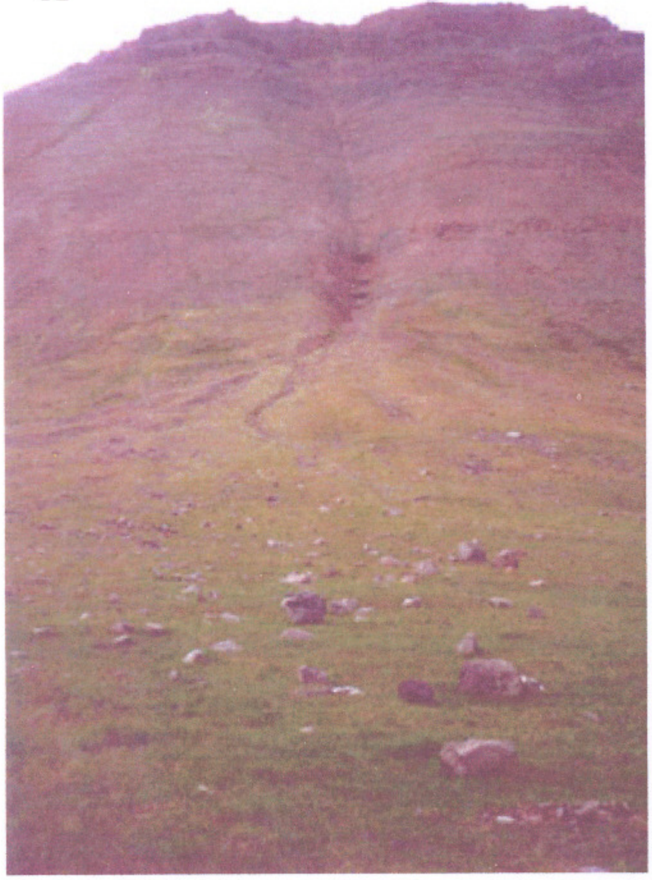

Figure 15: Colluvium 28 in Hnífsdalur (A) Track and smooth colluvium with stones on the surface.

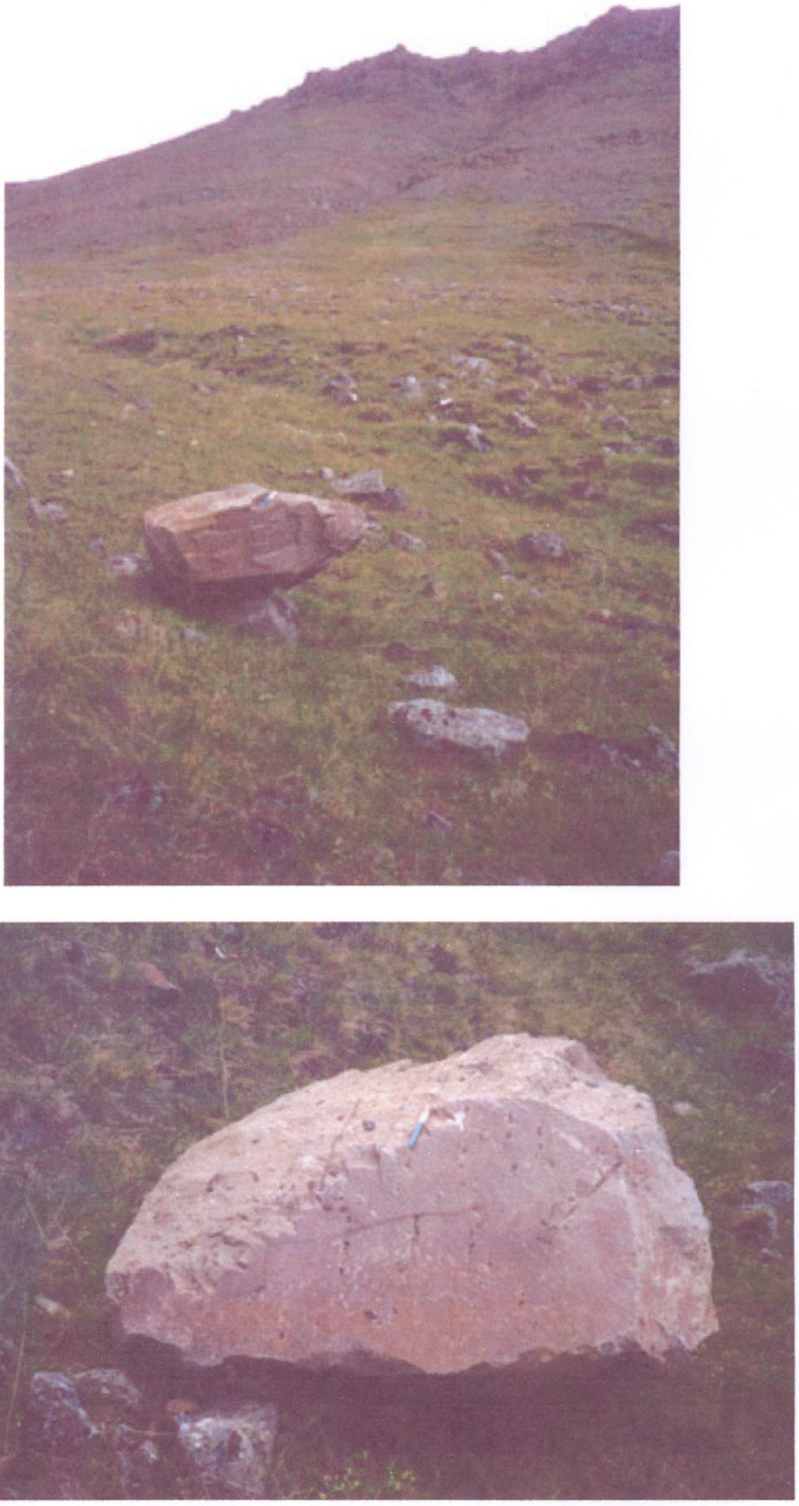

Figure 16, cont.: (B) Boulder along the outer limit. Pen for scale; (C) Close-up of the same boulder. Finer debris lay on its upper surfaces. Pen for scale.

The slope between the second and third tracks is quite similar to what it is between the first and second tracks. The lower rocky escarpment presents more loose blocks in this part of the slope. In the lower part of the steep slope, there are numerous boulders, usually of small size.

The third colluvium is well vegetated, very smooth with no trace of channel, on the inner part (Fig. 16A). There are very few boulders or stones. The outer part presents traces of channels, a "debris horn" (Fig. 16B) and one big, well-marked channel with levées (Fig. 16C) which reacher the road. It is relatively recent but with vegetation. Boulders are scattered downstream of the colluvium. This third colluvium is steeper than the two others.

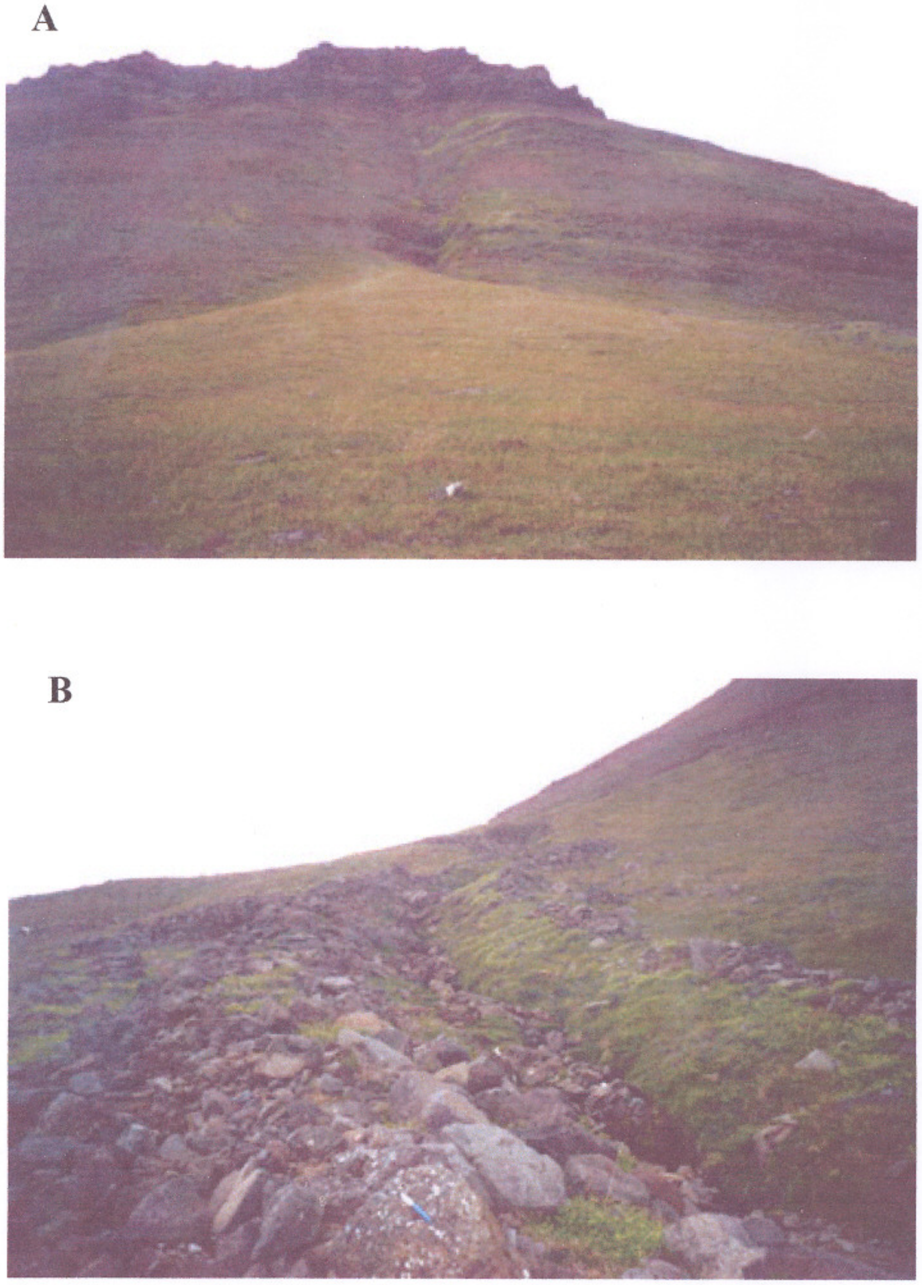

Figure 17: Colluvium 29 in Hnífsdalur; (A) The inner part of the colluvium is very smooth and well vegetated. Stones are very scarce; (B) Channel with levées along the outer limit. The picture is taken towards southwest. Pen for scale.

Figure 18, cont.: Colluvium 29 in Hnífsdalur; (C) "Debris horn" situated in the area of the colluvium presenting traces of channels. Pen for scale.

Boulders may have been removed from the fields downhill of the described area. Boulders are sometimes piled up along a field.

5.4.2. Interpretation

The small size of the colluvium and track 29 show that the activity is low. Snow avalanche is predominant. Debris flows occur, but with a low frequency and last event seems to be relatively old.

The slopes between the tracks are very little active since the activity concentrates in the tracks. However, some rockfalls occur from the rocky escarpments.

The two last colluviums and tracks appear to be more active than the first one, in intensity as well as in frequency. Their smooth surfaces with debris spread on it, boulders far below result from snow avalanches. The channels with levées or the traces and the "debris horn" come from debris flows. If they seem to occur with a somehow low frequency, they can be of high intensity, as the last one which reached the road.

5.5. Kirkjubólsfjall in Önundarfjörður

5.5.1. Description

The studied slope in the Önundarfjörður fjord can be divided in five different sectors presenting various features (from I to V in Fig. 17).

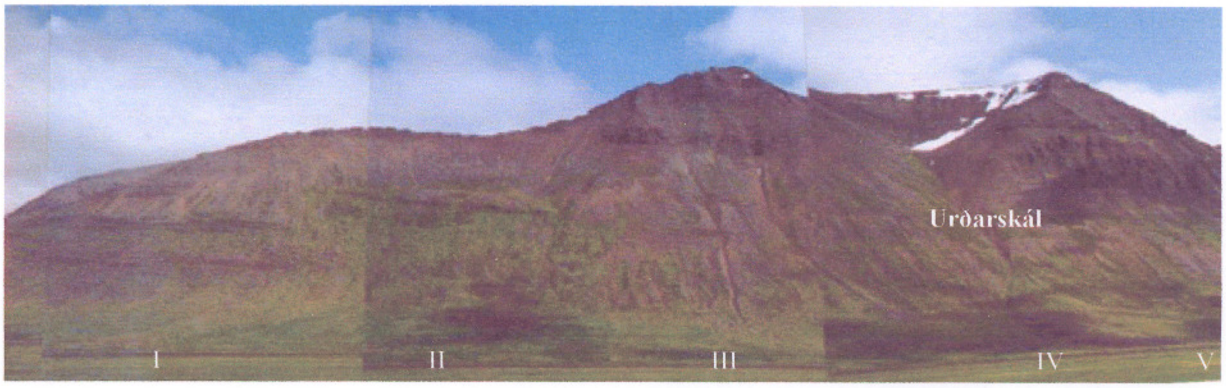

Figure 19: Overview of the Kirkjubólsfjall mountain. The numbers refer to the different sectors. The picture is taken towards east-northeast.

In the first sector, the top gets lower and lower towards northwest. The higher part is covered by scree and some layers of rockbed are visible. Below this, strips of scree alternate with steep bedrock outcrops more or less continous, showing sub-horizontal beds that create rocky escarpments. Patches of vegetations are numerous. Small channels with small-vegetated lobes are present, but none of them is recent. The lower half is regular, well vegetated and quite smooth with some tracks of channels. Some boulders lie at the foot, but few around the abandoned Tannanes farm.

In the second sector, the slope is interrupted at about a quarter of the way by a narrow and almost flat strip underlined by a massive layer of rockbed tilting southeastwards. This sector is the most vegetated of the five. The vegetation covers the lower three quarters of the slope, expanding high on the slope up to the massive layer and also above the flat strip even if this part is mainly covered with scree and smooth. On the lower part of the slope, one can distinguish some small-vegetated tracks. The lowest part of the slope is steeper than it is at the same level in the other sectors due to debris which are however well vegetated (greener than anywhere else). At the foot of the slope boulders are scattered and some of them, sometimes big, lie in the water far in the lowlands (Fig. 18).

Figure 20: Boulders on flat land, in the water downhill of the forth sector. The picture is taken towards southwest.

The third sector has a triangle shaped top. The top of the slope is much higher, above 720 m.a.s.l. The highest third is dominated by sub-horizontal beds, slightly tilting towards southwest with scree. The lower bed is particularly thick and massive. The lower two thirds are mainly scree strips and vegetation. Some beds of bedrock, tilting southeastwards, appear. Two major tracks with their small source areas starting at the top, and smaller tracks travel through the slope. Only the easternmost major channel ends on a lobe, which is bare proximally, vegetated distally. Boulders lie on the slope, down to the foot on the east side but not on the west side where boulders are present only until the slope gets less steep. The foot of the slope is vegetated.

The forth sector, Urðarskál, is a bowl-shaped source area with a lot of material (stones, boulders) when it gets narrower, and an open channel presenting one large undulation (Fig. 19). The western side is particularly open and is vegetated. The large lobe ends progressively eastwards with vegetation whereas it ends with steeper "front" westwards with boulders. The channel follows the outer edge and is vegetated. The lobe reaches the lower part of the slope, almost flat, close to the fjord water. It extend is large compared to its thickness. The slope is about the same as it would be without the lobe. No visible channel is near but a small old and vegetated track is visible on the eastern side. Its surface is regular and smooth with boulders on it. There are more boulders in the distal part, some are quite big (2 metres). The limits are sharp with accumulation of a lot of boulders ending abruptly, even if a couple of boulders lay further down on flat land.

Figure 21: Urðarskál. Bowl-shaped source area and large lobe, which end progressively eastwards with vegetation whereas it ends with steeper "front" westwards with boulders. The picture is taken towards northeast.

The fifth sector is a slope ending also at the top as a triangle, culminating at 719 m.a.s.l. The first higher quarter is covered by scree and some beds are visible. The second quarter consists of steep bedrock showing sub-horizontal beds and shallow gullies. The lower half is regular and quite smooth, with some tracks of channels. Some parts (especially the lowest ones) are vegetated, others are covered by scree, and some parts are eroded on the surface. Numerous boulders are scattered on the lower third of the slope. The easternmost track is erosive and ends on a lobe that is quite vegetated but some channels are relatively recent. Boulders are present at the foot of the slope. Another track is associated with a small lobe that is vegetated and presents boulders. Some other well-vegetated small lobes can be distinguished with small, vegetated tracks (streams) starting in the lower half of the slope. Lots of boulders are present where the slope gets gentler.

5.5.2. Interpretation

The first sector does not show sign of high activity. Despite the low altitudinal range, snow avalanches occur, hence the boulders at the foot of the slope. These boulders are probably mainly picked up from the bedrock outcrops. Debris flows can occur with a low frequency in the vegetated tracks and colluvium. Rockfalls probably also occur with a very low frequency from the bedrock.

The second sector is also dominated by snow avalanches which can spread out over large distance, as showed by the boulders in the water. Large quantities of material are present at the foot of the slope. This is probably debris transported by snow avalanches since this accumulation is regular and smooth all over the wideness of the sector. Debris flow may occur with a very low frequency along the tracks in the lower part of the slope.

In the third sector the eastern part is more active than the western one. Only the eastern part shows signs of snow avalanche occurrences, such as boulders at the foot of the slope. Moreover only the easternmost debris flow channel presents a colluvium. The boulders with short runout result from rockfalls from the bedrock outcrops. The eastern part is affected by snow avalanches, debris flows and rockfalls, although the western one is only affected by a lower activity of debris flow and rockfalls, unable to build up a colluvium.

The forth sector, the colluvium, which is characterised by a large extend and a low thickness may have been built by processes with a high water content. It results from snow avalanches (boulders on the surface of a smooth colluvium and on the flat land) and debris flows (channel on the more chaotic eastern side of the colluvium).

The fifth sector, which presents some recent channels, is dominated by debris flow. The rockfall activity seems also relatively high, inducing numerous boulders with short runout from the bedrock outcrops.

5.6. The Lambadalshlíð slope in Dýrafjörður

5.6.1. Description

The Lambadalshlíð slope, facing south southeast, is coming from the mountain Lambadalsfjall (957 m.a.s.l.) with a very gentle slope down to about 550 m.a.s.l., then with a steep slope down to the fjord's water (Fig. 20). Only the lower steep half will be studied, from the west to the east.

The westernmost sector shows a sharp contrast between the densely vegetated lower part and the bare higher part.

Figure 22: Overview of the westernmost sector of the Lambadalshlíð slope between the edge of the Lambadalsfjall (550 m.a.s.l.) and the Dýrafjörður fjord. The picture is taken towards the northeast.

The lower third of the slope is covered by a thick vegetation (low bushes) and cut by channels, some of them reach the fjord water and are associated with small colluviums. The distal part of these colluviums is in the water.

On the highest part of the slope, the bedrock is observed with beds slightly tilting eastwards in the middle part of the slope and westwards on the higher third. The first ones are not always visible, alternating with scree, whereas the second ones are visible regularly up to the top. This bedrock is dug by shallow gullies.

In the west, a V-shaped, open and erosive channel goes through the road down to the fjord. Stones lie on its bottom and to the sides but vegetation returns to the channel. A big amount of stones has accumulated in the track just above the road. Below the road, the channel is more undulating and presents big levées and ends on the small cone which prograde into the fjord.

Westwards, another channel is undulating down to the fjord and presents levées with some small boulders.

Between the channels and particularly to the west, some small boulders are present in the vegetation and sometimes in the fjord water.

Eastwards, the second sector presents a valley that deeply cut the slope (Fig. 21). In the lower part, the river flows in a canyon. The bowl-shaped valley presents steep walls, scree in the lower part and bedrock in the higher part. Quite a lot of snow is still present in mid-July. On the west side of the canyon, the topography is undulating.

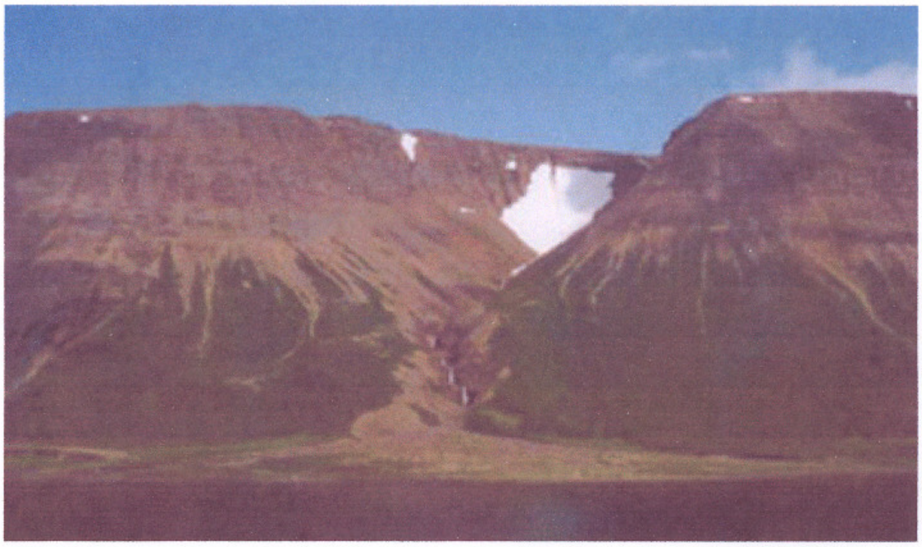

Figure 23: Overview of the valley cutting the Lambadalshlíð slope and associated large colluvium prograding in the fjord. The picture is taken towards the northeast.

The colluvium in Valseyri is very large and progrades far into the fjord with a very gently slope, forming a large half disc prograding in the fjord (Fig. 21). Some parts are vegetated and boulders are present on the surface. The more proximal part of the colluvium is covered by large stones and looks like a secondary lobe (Fig. 22D). The river flows along the eastern edge, eroding the material from the slope (Fig. 22A). Levées are deposited along the inner side of the river. Then towards the west, the colluvium surface is bumpy, presenting old and vegetated tracks of channels and levées with stones (on the right on Fig. 22B). The relief is fading out but is still obvious. No boulder is present. Then the colluvium is smooth and vegetated by mosses and herbs (on the left on Fig. 22B). No boulder and even no stone is visible. In the central part, some more recent channels form a web less dense than the previously described (Fig. 22C). Some of the channels go through the road all the way to the fjord. Stones are present on the levées and in the bottom of the channels. On the western half of the colluvium, first no channel is present but bushes and boulders are (Fig. 22D), and then in the outer part, channels with levées of stones occur again but vegetation returns the area and boulders are absent. Vegetation around consists of mosses, bushes and herbs. Boulders and stones are put on the surface. Some of the boulders are quite large (2 meters) and far on this very gentle slope.

Figure 24: Different aspects of the large Valseyri colluvium. From the East to the West: (A) river along the western edge of the colluvium with levées and erosion from the slope. The picture is taken towards northwest; (B) Transition between an area with old and vegetated tracks of channels and levées (right) and a smooth and well a vegetated area (left). The picture is taken towards north-northwest.

Figure 25, cont.: Different aspects of the large Valseyri colluvium. (C) Central part with a web of channels more recent but not as dense as on (B left). The picture is taken towards north; (D) Smooth and well vegetated area with large boulders. The notebook is 20 cm high. The picture is taken towards northeast.

The third sector looks like the first one but the vegetation goes higher on the slope, up to half way (Fig. 23). Channels here are few and short. They get more and more frequent eastwards and are the widest centrally. In the high part of the slope the beds tilting eastwards are less visible and are present only in the highest part (smooth scree covering the slope go higher).

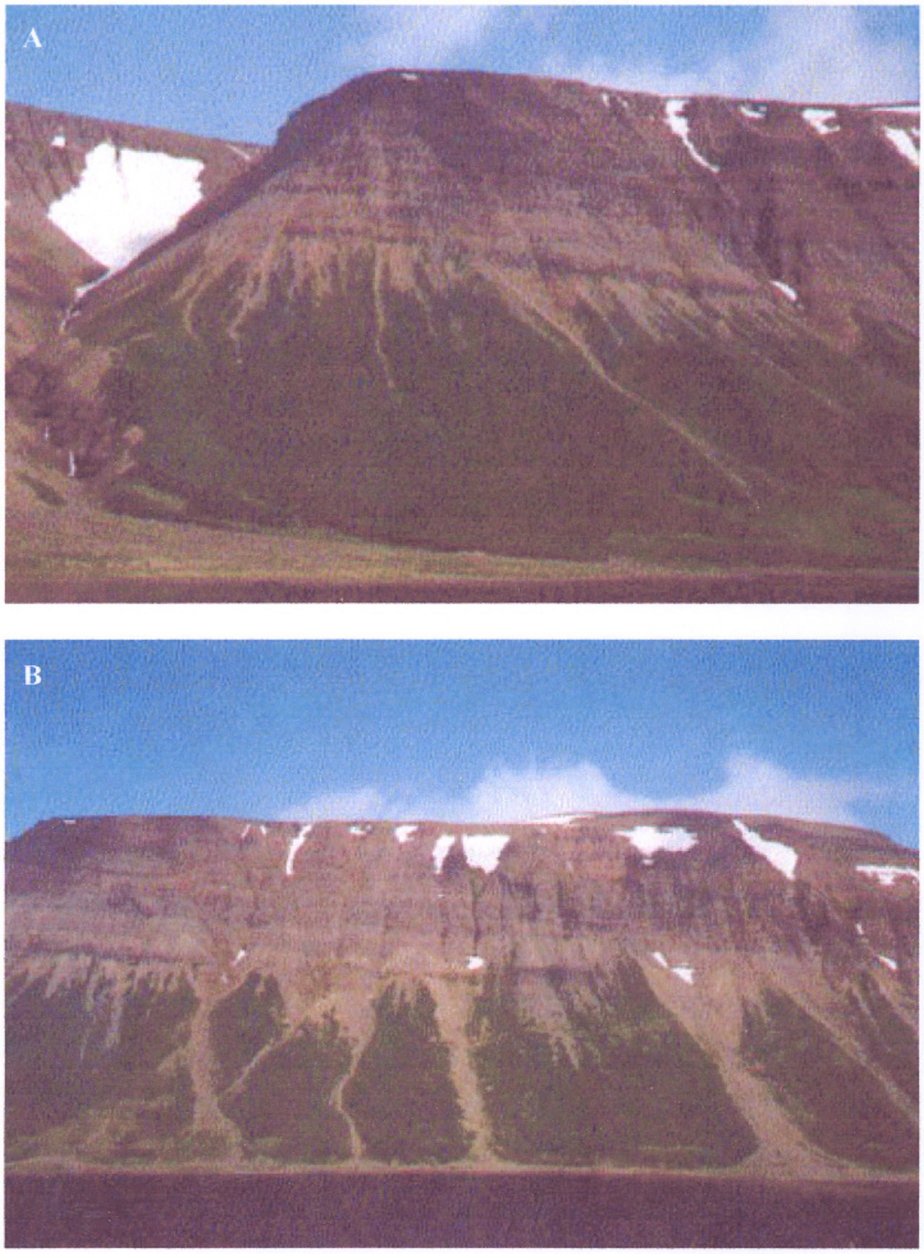

Figure 26: Overview of the third sector of the Lambadalshlíð slope slope, from the West (A) to the East (C). The channels get more and more frequent eastwards and are the widest centrally. The picture is taken towards northeast (A and C) and north-northeast (B).

Figure 27, cont.: Overview of the third sector of the Lambadalshlíð slope, from the West (A) to the East (C). The channels get more and more frequent eastwards and are the widest centrally. The picture is taken towards northeast (A and C) and north-northeast (B).

The first track of the sector, undulating and erosive, does not reach the road.

A very large track with piles of big stones and boulders is present, and then a deeper channel with a lobe.

Channels, with very variable width but in the mean quite wide, are scree covered and associated with small lobes slightly prograding onto the fjord. Boulders are scattered, sometimes in the fjord water. Above the fjord is one lobe with stones and vegetation. In the tracks the stones show impact scars. Vegetation is present. Some kind of levées of fine debris and undulating channels filled with stones are observable (Fig. 24).

Figure 28: Detail of the low part of a track in the third sector of the Lambadalshlíð slope. Note the prograding lobes in the fjord. The picture is taken towards southeast.

Some boulders are scattered between the tracks in the vegetation. Some of them are put on recent bushes (Fig. 25A). Older higher shrubs going beyond the others bushes have their upslope branches broken and the others are tilting downhill (Fig. 25B). They do not have any secondary branches (the main branches are striped).

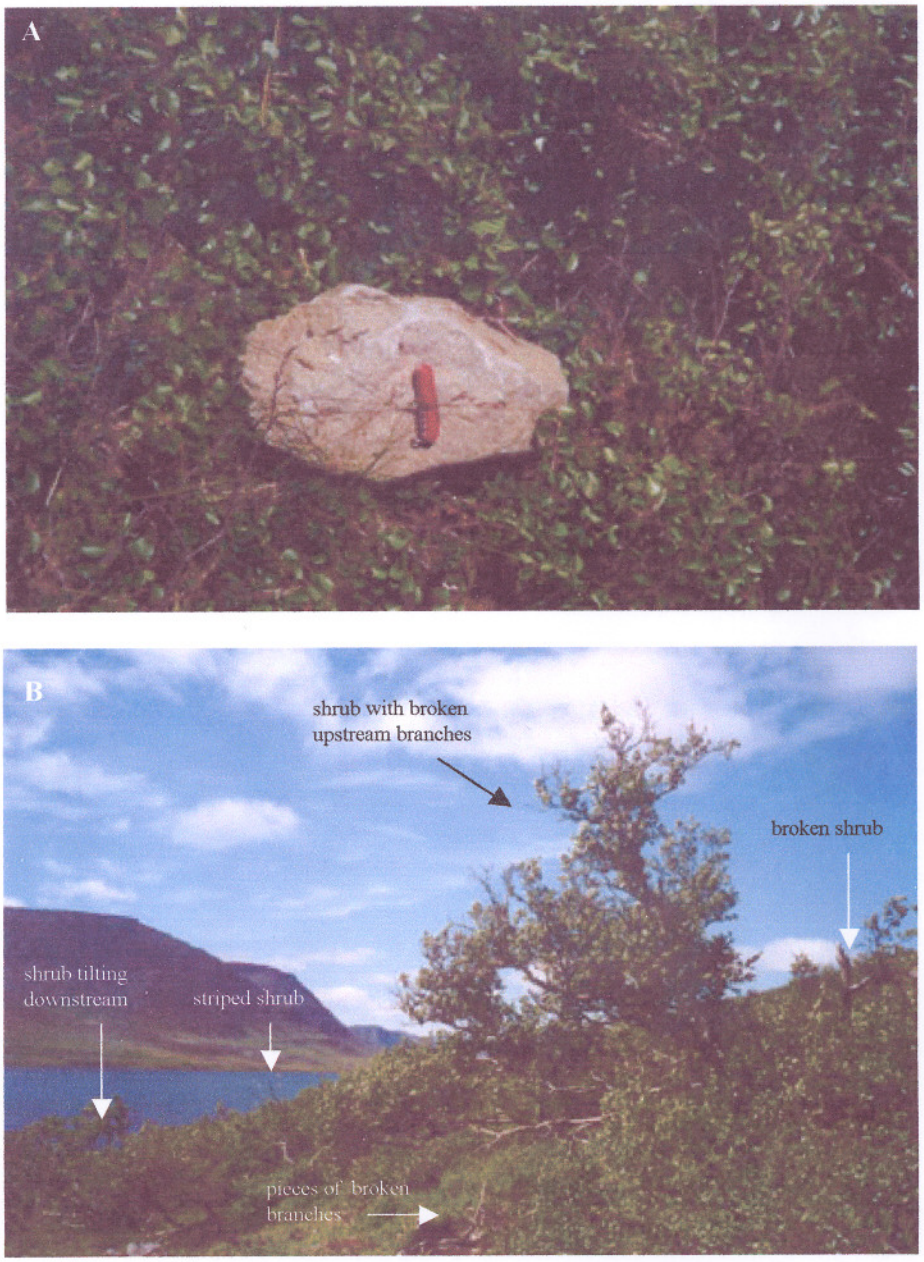

Figure 29: Details of features of the third sector of the Lambadalshlíð slope. (A) Boulders put on bushes. Knife for scale; (B) Damaged shrubs. The picture is taken towards northeast.

The central channels are wide and slightly bumpy lobes of debris (stones and gravel) active on its western side. One of the colluvium (steep) downhill of several gullies coalescing

5.6.2. Interpretation

The first sector is affected by snow avalanches, as showed by the boulders on bushes or in the fjord and broken trees. The tracks result from debris flows, which go across the road down to the fjord where the colluvium is. Rockfalls can occur from the bedrock on the upper part of the slope.

The debris fan in Valseyri, which is of large extent but small in thickness with a very gentle surface slope, is an alluvial fan formed by debris flows and waterflows. However the boulders in the central part indicate that snow avalanches also occur in the axis of the track.

The third sector is quite similar as the first one, but with a higher activity. The erosive undulating channels are also resulting from debris flows. The kind of levées of fine debris and undulating channels filled with stones may result from snow avalanches removing material from debris flow, dragging the coarser debris from the exposed levées to the more sheltered channels. Snow avalanches also occur between the tracks, therefore break and deform the shrubs and leave stones and boulders on the vegetation.

6. CAUSES OF LANDSLIDES

6.1. *Environmental factors*

The Westfjords area is characterised by basaltic bedrock very sensitive to weathering, especially as a harsh climate (high frequency of freeze-thaw cycles, presence of water) works on this bare ground. Little or none vegetation can stabilize the slopes. Moreover the vegetation could, if present, promote the infiltration of water and so decrease the surface runoff and local gulling. The effect of the concentration of the stress by local gulling may be more serious there rather than the increase in the local groundwater by infiltration (Schuster, 1978). The vegetation could also reduce the water content in the ground by transpiration.

In addition the morphology presents everywhere steep and long slopes, as a result of glacial erosion. The deglaciation led to a rapid unloading by glaciers. Landslides can result from the removal of the lateral support from a slope, due e.g. to the erosion by streams and rivers, sea and sub aerial weathering, wetting or drying, frost action, or due to the creation of a new slope after a previous landslide or by human activity (Schuster, 1978).

6.2. *Triggering mechanisms*

Landslides triggering are generally related to the normal climatic conditions. First of all it leads the input of water, large but intermittent: heavy rains, intense melting snow (itself depending on the air temperature, the air humidity, the wind speed, the albedo of the snow cover). The water supply in the period previously of the triggering event is also very important (Sandersen, 1996).

Water can sometimes be supplied by glacier or river outburst. The response time is quite variable, from a couple of hours to several hours (Sandersen, 1996).

Mechanical (freeze-thaw cycles) and chemical weathering and roots prying weakens the soil and rocks. The mechanical properties, the structure and texture of the soil and rocks play also an important role. Human activity can trigger landslides by changing the natural drainage system and by excavating the foot of a slope. Seismis activity often triggers landslides.

However the triggering mechanisms change between debris flows, rockfalls and snow avalanches.

6.2.1. Debris flows

Debris flows are mainly triggered by supply of water: heavy rainfall, intense snowmelt or a combination of both (Dikau et al, 1996). The antecedent moisture content in the soil also plays a role since it reduces the threshold values of rainfall or snowmelt intensities necessary. The response time is short (several hours) after the input of water (Sandersen, 1996).

6.2.2. Rockfalls

The water and ice pressure in the joint system leads the occurrence of rockfalls. Water supply over a long period seems to be more important than water supply the last day (Sandersen, 1996).

The frequency of rockfalls is often considerated to increase in spring and autumn whereas the freeze-thaw cycles are frequent. Moreover these seasons are of high snow melting (spring) and high precipitation (autumn). In summertime, heavy rainfalls and in some cases rock expansion can trigger rockfalls. The activity is small in wintertime when the joints are frozen. (Sandersen, 1996).

6.2.3. Snow avalanches

Local slope conditions and climate factors lead the occurrence of snow avalanches.

These slopes conditions include local morphology, topographic gradients, slopes aspects, altitudinal range, debris characteristics, the type and disintegration pattern of local bedrock, etc. Aspect of the source area, its orientation relative to the prevailing wind direction and the altitudinal range are determinant factors for the incidence and frequency of snow avalanches. (Blikra & Selvik, 1998).

The climatic factors leading to snow avalanche occurrences are high snowfalls, wind effects, sudden changes of conditions (sudden warming), and history of the climatic conditions on the snow cover.

7. DISCUSSION

The slope below Kubbi is mainly affected by a low activity of rockfalls, probably originating from the upper cliff due to mechanical weathering. The low altitudinal range and the northern orientation, face to the prevailing wintry winds probably avoids sufficient snow accumulation for avalanches. For the same reason the water supply from snowmelting is limited. Moreover the gullies are too steep to permit consequent deposit of debris. These two latter reasons can explain the lackness of debris flow occurrence.

On the Eyrarhlíð slope, the Gleiðarhjalli plateau which interrupt it at around 450 m.a.s.l. plays a major role. Indeed, where it is present, it cuts the slope into two independent slopes and so the avalanches triggered on the upper part are stopped by the plateau and do not affect the lower part. Therefore the avalanches occurring on the lower slope are of less importance since the area involved is smaller and has a small altitudinal range. This does not mean that there is no risk. Unfortunately, because of the presence of the town, it is virtually impossible to observe pieces of evidence for eventual large snow avalanche occurrences, e.g. boulders with long runout distances. If such pieces of evidence had been there, men would have cleared them. It is interesting to point out that boulders transported by snow avalanches are laid in a non-inhabited area with fields, downhill of the gully 19, area surrounded by houses. One can guess that no one would have settled in this upper part of the town if there would be a high activity of large snow avalanches. But events in some others places, for example Flateyri in 1995, sadly showed that men could have a short memory and that snow avalanches may have a long return period (Haraldsdóttir, 1998). Investigations following the accident in Flateyri pointed out that, in the past, there were no records of avalanche occurrences, except cases of accident or damage. (Haraldsdóttir, 1998). Pétursson & Sæmundson (1999) had tackled to list the old landslides that occurred in Ísafjörður between 1797 and 1999. It comes up from their work that landslides regularly caused damage. The records of snow avalanches have not been included. Eventually, it is important to note that inhabited areas have been sprawling in the last decades, therefore extending on previously non-inhabited areas where the risk can be expected to be higher, e.g. extension of the town upslope.

The northernmost studied portion of the Eyrarhlíð slope, where the Gleiðarhjalli plateau is not present or is narrow as it is close to the extremities, the snow avalanche activity is strong and dramatic avalanches can occur and reach the fjord since they can trigger at the top of the slope and rush down, accumulation energy end material all along the steep part. Rockfalls, resulting from mechanical weathering is not of major importance but can supply debris to the others processes (debris flows, snow avalanches).

The studied slope in the Hnífsdalur valley is facing southeast and therefore liable to accumulate important amount of snow under conditions of prevailing wintry wind, even if the accumulation areas are narrow. Therefore snow avalanche activity is high on this slope where debris flows also occur.

The studied slopes in Önundarfjörður and Dýrafjörður, facing south-southwest, can accumulate snow during the prevailing wintry wind. They present each a small valley with bowl-shaped source area, Urðarsklál and above Valseyri respectively, particularly disposed for it. As a result, snow avalanches occur as shown by the boulders far in the water fjord. Debris flows also occur due to the heavy melting that can take place since these slopes are well exposed to the sun. The lobe below Urðarskál is dominated by snow avalanches on the east side, where it progressively ends with vegetation whereas it is dominated by debris flow on its west side where it ends with a steeper “front”.

One can expect the slopes facing southwards to be more exposed to the risk related to the observed slopes movement. They can accumulate snow due to the regional prevailing wintry winds, i.e. from north, leading to snow avalanches. They are exposed to the sun, and/or warm southern wind in spingtime, and therefore heavy melting can takes place and possibly triggering debris flows. Due to this exposition to the sun during the day, the number of freeze thaw cycles is probably higher as it is on a north facing slope with less thawing days. As a result the mechanical weatering is stronger leading to higher rockfall activity, a potential direct risk or a source of available material able to be reactivated by types of slope movements, e.g. snow avalanches or debris flows. However local conditions can be different from the regional ones, e.g. the prevailing wintry wind direction can be different due to the topography, and therefore need to be attentively studied. Moreover one should keep in mind that exceptional climatic events may occur.

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