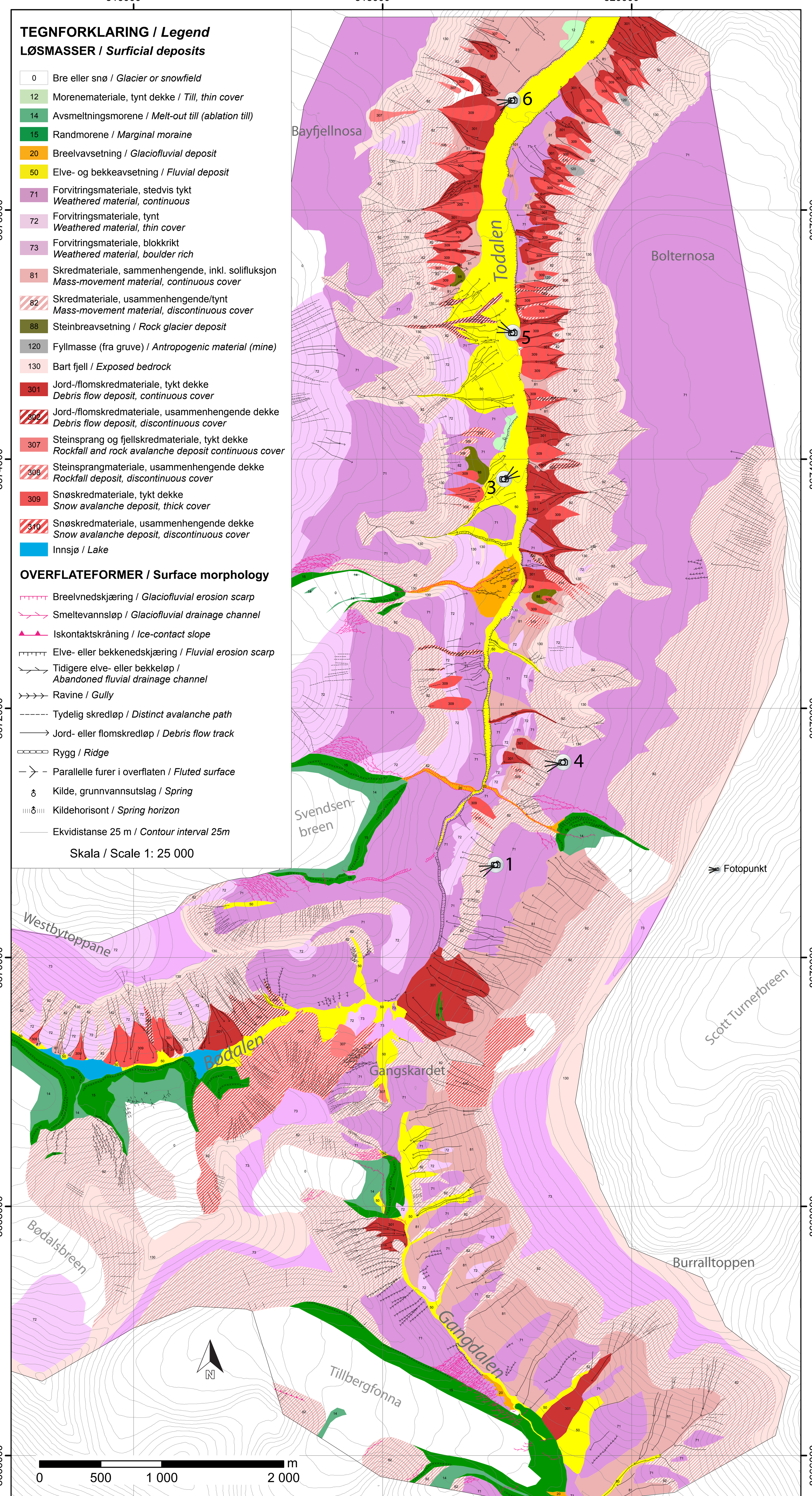
Map projection; Transvers Mercator. Geodetisk dato; WGS 1984, UTM 33N.



Who made this map, and why ?

Mapping of landforms and sediments were made for the research project "CRYOSLOPE Svalbard" that ran between 2007 and 2009. The project compared monitoring data, mapping and modeling to understand how climatic variations may affect high arctic slopes, and thus affect transport in Svalbard. Monitoring of slope processes was carried out during the winter seasons. This map with description was developed by The Geological Survey of Norway (NGU) and The University Centre in Svalbard (UNIS) in cooperation, to spread some of the project results to the public. Fieldwork was done by Lena Rubensdotter and Knut Stalsberg (NGU) in 2008 and data was digitized based on aerial photos from 1990 (from Norwegian Polar Institute).

Svalbard environmental protection fund funded the printing of this map in 2011 and compilation of the text was made by Lena Rubensdotter in cooperation with Knut Stalsberg (NGU), Professor Hanne Christiansen and Markus Eckerstorfer (UNIS), and Priita Trøyen (Longyearbyen school).

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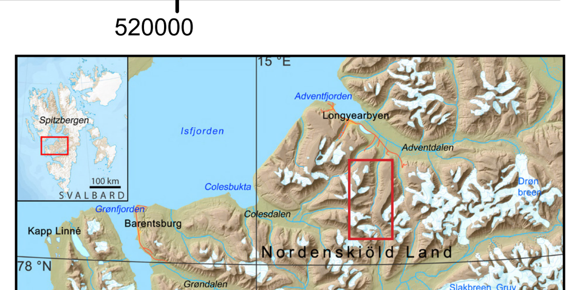
CRYOSLOPE Svalbard



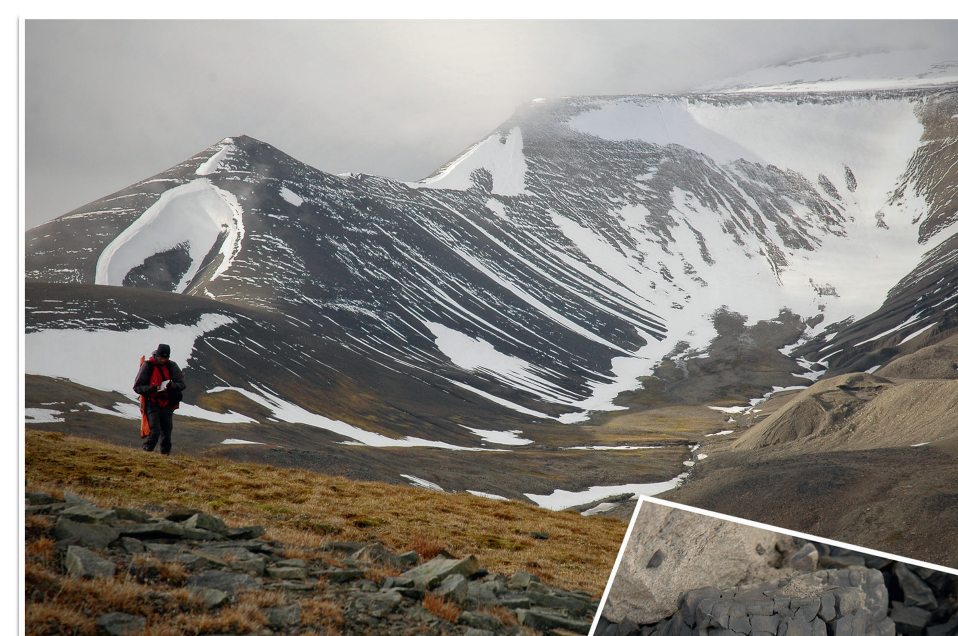
HOW TO INTERPRET THE COLORS ON THE MAP

The shades of green on the map symbolize till-deposits, which is a mix of sediment that has been eroded and transported by **glaciers**. Large portions of the landscape were draped with till during the melting of the last big ice sheet. Till ridges are called moraines and most of the moraines we find in front of glaciers in Svalbard were formed a hundred years ago during a cold spell called the Little Ice Age. Till is characterized by its unsorted grain-size distribution, from clay-size and up, as well as by the sharp angular shapes of the clasts.

The yellow and orange on the map represents fluvial and glaciofluvial deposits. These deposits consist of stone, gravel and sand that have been transported by running **water**. The sediments are sorted, often vertically layered, and the particles are rounded. The finest particles, clay and silt, were washed out and transported by water through the Adventdalen fluvial plains to the sea.

The 3 shades of lilac represent sediments formed by "on site" weathering of bedrock. We distinguish mechanical frost weathering from **chemical weathering**. The frost weathered material is composed of primarily of gravel, stones and boulders, with minor components of sand and clay. Weathered particles are often angular with sharp edges. Chemical weathering means that minerals in the rock are dissolved in water and later transported by surface water. This process is likely less significant in cold climates. Most of the frost weathered material is found on the plateaus and on gentle slopes.

The red and pink shades on the map represent material transported and deposited by gravitational **slope processes**. Slope processes can be purely gravitational (e.g. rock fall), or combined with water or snow. The latter two cause debris flow and snow avalanche deposits. Slope deposits were studied in detail in the CRYOSLOPE Svalbard project, which allows for the fine division of different slope deposits on the map: thick and thin sediment deposits from rock fall, snow avalanches and debris flows.



1. The black shale is present in several places in the mapped areas, notably around Gangskardet. Very susceptible to weathering, its presence in the landscape therefore creates "smooth" slope profiles. Photo: Lena Rubensdotter, NGU

2. Mechanical frost weathering is a very active process in Svalbard. At air temperature fluctuations around the freezing point ice is formed and expands in fissures and pore spaces in the rocks. The photo shows a black shale stone rapidly disintegrating into gravel. Photo: Lena Rubensdotter, NGU

The evolution of the landscape

The landscape of Svalbard is formed through a combination of tectonic uplift and subsequent denudation of the uplifted mountains. The sedimentary rocks that form the mountains were moved to their present places in the landscape through tectonic processes. Unconsolidated sediments are formed as the mountains are worn down (eroded) through weathering, river erosion and slope processes.

Valleys are one of the primary landscape features. Before the large-scale ice ages commenced ca 2.5 million years ago, river erosion was the process that formed the valleys. During the ice ages glaciers have moved through the valleys, widening them and giving them U-shaped profiles. The smaller V-shaped valleys seen today are either younger than the last ice age, or are positioned in a geographic direction which were protected from the linear erosion of the main ice-movement. When the last remnants of the major ice sheet melted away from Todalen more than 10000 years ago, it deposited till-sediments and glaciofluvial river sediments. Since that time small niche- and valley glaciers have left some moraines and glaciofluvial sediments in the valley bottoms.

Permafrost has been present in the Svalbard landscape since the last ice age, and so-called periglacial weathering and slope processes have dominated. The result of these processes is present in the vast areas of weathered sediments on top of the plateaus, as well as in the talus fans and rock-fall aprons on the valley slopes. The fan material originates as particles weathered out of the bedrock and transported down through rock-fall and snow avalanches. Slush-flows and debris flows have in many places eroded and redistributed the fan sediments further out on the valley floors. The different slope processes result in different types of slope fans with different types of sedimentology, geometry and grain size distribution.

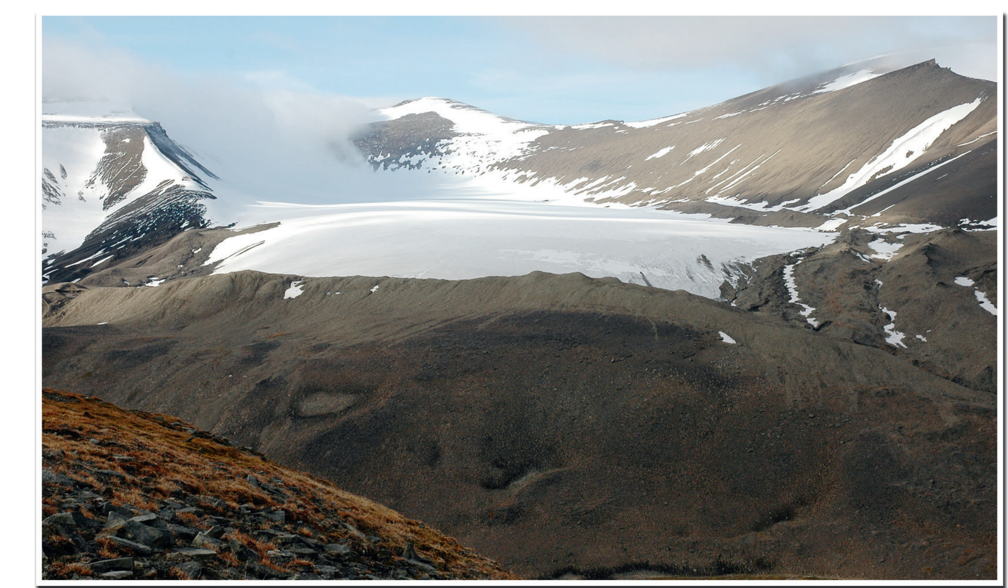
3. Intense frost weathering produces lots of loose rock material that is transported down the slopes by snow avalanches, and later deposited in large talus cones on the valley sides. Photo: Lena Rubensdotter, NGU

Glaciers in the landscape

The map shows a few relatively small glaciers and permanent snow patches together with numerous geomorphologic traces of snow and ice driven processes. All three valleys have U-shaped cross profiles that were carved out when the glaciers were much larger. In the southern "upper" part of Todalen valley we see the valley's largest glacier; the Svendsenbreen glacier, which is 1.5 km long. The smaller glacier on the east side of Todalen has melted back significantly and is today primarily a snow-path. In the northern part of Gangdalen we see the Tillbergfonna glacier that stretches its snout down to the valley bottom, and in the upper end of Bødalen we also find glaciers down into the valley, where their moraines dam small lakes.

Most of these glaciers are a mix of cirque and valley glaciers. Cirque glaciers are formed in round depressions in the upper parts of slopes, where snowdrift is trapped during the winters and where the high altitude prevents full snow melting in the summer. Over time this causes the snow layer to thicken, compact, and transform into glacier ice. When the ice is thick and heavy enough it will start to deform and slide downward. In front of today's glaciers we find frontal moraines formed at the last glacier advance period; the "Little Ice Age", which ended 100 years ago. This cold period caused the cirque glaciers to grow and expand down into the valleys. The moraine ridges have a high internal ice content, which today is melting rapidly and collapsing, reshaping the ridges year by year. The permafrost in the ground delays this process so that only the uppermost 1-2 m is affected every year.

Perennial snow patches are found in the three valleys, on the leeward side, where snowdrifts accumulate and in the shadowed north facing sides, where permanent snow patches tend to form. Melt water from the snow patches in the summer shape the sediment slopes in front of them. The constant presence of water throughout the summer results in a kind of "stone-pavement" where all the finer particles have been removed by the water. Over longer time a snow patch may thus "erode" backward into the slope (nivation process), and unique combination of lichens and plants grow in the snow patch forelands.

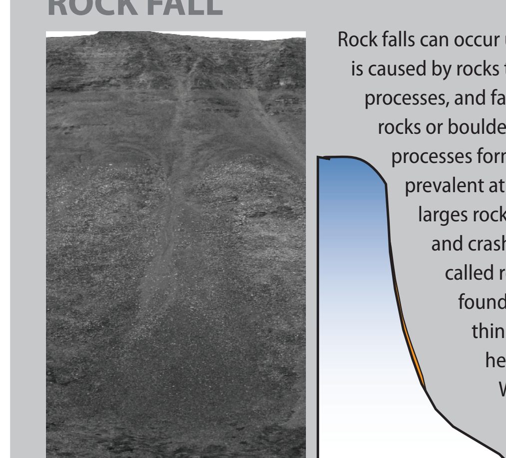


4. The Svendsenbreen glacier has well defined frontal moraines that were deposited during the "Little Ice Age" period that ended ca 100 years ago in Svalbard. Photo: Lena Rubensdotter, NGU

Permafrost and frost landforms

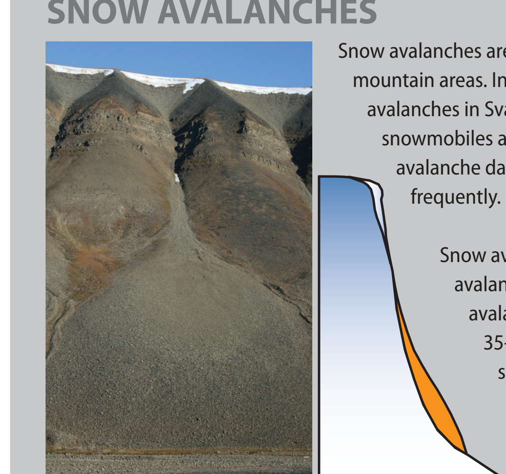
Permafrost is permanent frozen ground or bedrock for at least 2 consecutive years, and is found in the ground of all non-glaciated parts of Svalbard. Permafrost thickness varies from a few meters, when found close to major rivers, lakes and sea-shores, to several hundred meters in higher mountainous terrain. The uppermost 1-2 m of ground is called the active layer, which thaws during summer and refreezes in the winter. Repeated freezing and thawing will make particles of different sizes move differently in the soil column. Over time these movements in the uppermost soils will cause a sorting of particles on the surface, resulting in patterns of rings and polygons on flat ground and different stripes or lobes on slopes. Frost activity also causes a continuous creep of material down slopes, called solifluction. In this area we most frequently see frost-driven landforms on the plateaus and gentle slopes, but they are not mapped here due to their small scale.

ROCK FALL



Rock falls can occur under all rock scarps steeper than 40-45 degrees. It is caused by rocks that detach from the bedrock through weathering processes, and fall, jump and roll down the slope. The larger the rocks or boulders, the longer out from the cliff they fall. Rock fall processes form the steep talus fans or cones, which are so prevalent at the foot of the slopes in Svalbard. Occasionally larges rock sections or big parts of the mountain sides detach and crash down with huge force. Medium size events are called rock-avalanches and deposits from one such event is found in the north eastern part of Todalen (code 308 – thin rock fall deposit). A small rock-nose came down here in one event, sometimes during the last 22 years. We know this since it is still visible on aerial photos from1990. Really large rock avalanches can cross valleys and run up on the opposite side.

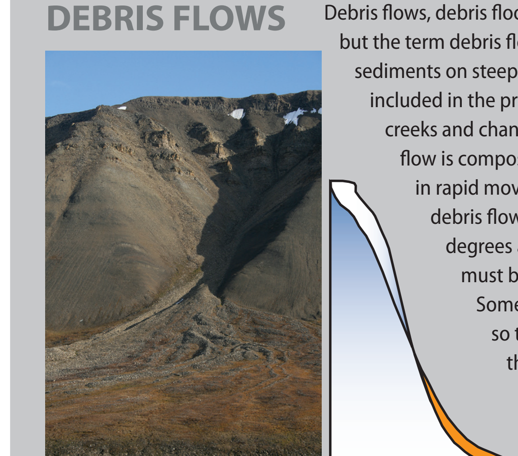
SNOW AVALANCHES



Snow avalanches are a common slope process in snow covered mountain areas. In the last 12 years, 5 people were killed by snow avalanches in Svalbard. Especially winter recreationists on skis, snowmobiles and dog sledges expose themselves to snow avalanche danger, but also infrastructure is threatened frequently.

Snow avalanches are divided into loose snow and slab avalanches, occurring both in dry and wet snow. Snow avalanches usually release at a slope angle between 35-50 degrees, mostly during or shortly after snowstorms. A special type of snow avalanche occurring frequently in Svalbard is cornice (snow overhang) fall avalanches. Cornices build up on the plateau edges and frequently collapse, producing large snow avalanches.

DEBRIS FLOWS



Debris flows, debris floods and earth slides are partly overlapping terms but the term debris flow is specifically used to describe slope collapses in sediments on steep slopes. However, if there is a high volume of water included in the process, which can be the case in smaller and larges creeks and channels, it is better described a debris floods. A debris flow is composed of a mix of stones, gravel, sand, soils and water in rapid movement. Three conditions must be fulfilled for a debris flow to occur: 1. It must be steep enough (usually > 30 degrees angle of slope, but less for debris floods). 2. There must be loose sediments available on the slope. 3. Something must make the sediments unstable enough so that gravity can pull them downslope and initiate the flow. This factor is often elevated pore water pressure due to snow melt or large precipitation events.

Debris flows often follow a channel or path down the slope, but occasionally wide zones of slope sediments can move down simultaneously. Along the outer edges of the debris flow elongated ridges, so-called levèes, are deposited. The debris flow material is deposited as lobes or tongues on the lower slope or valley bottom, and if frequently re-occurring, can develop into large debris flow fans.

LANDFORMS AND SEDIMENTS

in Todalen and upper Gangdalen and Bødalen

The landscape story told on this map is the result of geology, geomorphology and climate driven processes in high arctic Svalbard. The map informs about the landscape we see today and also gives information about hazards and challenges we face when traveling in it.

Photo: Lena Rubensdotter, NGU

SVALBARD ENVIRONMENTAL PROTECTION FUND

LONGYEARBYEN LOKALSTYRE OPPVEKST KF

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5. Slush avalanches run on top of fluvial- and slope fans far out in the valley. Dry-snow avalanches formed the steep snow-avalanche fans (right in the photo). Photo: Marcus Eckerstorfer, UNIS

When traveling in the landscape

Some slope processes may pose a direct danger to travelers, while some deposits are less suitable for people traversing by foot.

6. Slush avalanche deposit. The snowmobile in the foreground indicates the size of the deposit. Photo: Marcus Eckerstorfer, UNIS

Winter

While there is snow cover, skiers and snowmobile users need to be aware of different types of snow avalanches. Snow avalanches occur on a regular basis over the snowmobile tracks in both Todalen and Bødalen (See figure 7, monitored snow avalanches in 2010-11). The sediment colors on the map show thick snow avalanche deposits that form fans in both valleys. It is however impossible to know the precise route of the next snow avalanche, because this depends on seasonal snow and wind conditions. Some avalanches may bring just snow, and although hazardous to travelers, do not deposit any visible rock debris that can be mapped. It is therefore important to use common sense and carefully observe while you pass snowy slopes. A rule of thumbs is to stay away from steep slopes and not to venture out directly after a snow storm, when the avalanche hazard is the greatest. Sometimes, steep slopes or so-called terrain traps (e.g. gullies in the southernmost part of Todalen, or by the large glacier moraines in Bødalen) cannot be avoided, but should be passed with high attention on the slopes.

During the snow melting season or after heavy precipitation, slush flows or different types of debris flows can occur. These slope processes have extreme runouts and deposit large masses of coarse debris. This occurred in Todalen in 2010 and 2011. Several large debris flow events have occurred since 1990, particularly on the east slope of this valley, which is seen as large masses of coarse rock debris tongues on the valley floor.

Summer

The map can also be of use when walking in the summer. The cold Svalbard climate favors continuous frost weathering of the rocks on the steep slopes. The released rocks fall down and form deposits that then may be re-eroded by debris flows. Increased rock fall and debris flow activity are often seen after heavy rains, so stay clear of the steepest slopes and protruding rock noses.

The large debris flow deposits in Todalen can be difficult to traverse because they consist primarily of angular rocks and stones. However, walking is even more difficult on the pure snow avalanche deposits. Here, all particles, from sand to boulder sizes, are piled randomly on top of each other wherever they happened to melt out of the snow. Sometimes large boulders balance precariously, making the entire surface very unstable.

The moraine ridges in front of the glaciers may also be unsuitable for traveling, because in the summer they are affected by melting of internal ice, resulting in slumping and unstable slopes. A small meltwater lake is dammed between two moraine ridges in Bødalen and is not indicated on regular topographical maps. Such dammed meltwater lakes can form rapidly, even over a season, and may prevail over several seasons. These temporary lakes may either be drained slowly over time as the internal ice in the moraines melts, or it can be released through a dam-break. If the latter occurs it may cause a dangerous debris flow with water and sediment rushing down central Bødalen valley.