The Collapse of Solifluction Lobes as a Factor in Vegetating Blockfields[1]

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ABSTRACT: The development of soil and vegetation in blockfields through normal processes is very slow. It is surprising, therefore, to find in the Ruby Mountains of southwest Yukon Territory, tongues and islands of vegetation occurring amidst certain blockfields. The collapse of solifluction lobes from upslope is suggested as the mechanism responsible. The lobes pass from the more gentle solifluction slope of the alb onto the steeper slope of the blockfields, and eventually become unable to maintain themselves because of: steeper slope, change in composition of vegetation, and deeper active layer. Once the lobes do collapse, they flow downslope carrying with them clumps of vegetation which may become established somewhere along the mud-flow channel or levee. In this way, small outposts of vegetation are created and speed up a process which would otherwise take indeterminately longer.

RÉSUMÉ. *L'effondrement de lobes de solifluxion, facteur de colonisation des champs de blocs par la végétation.* Selon les processus normaux, le développement du sol et de la végétation dans les champs de blocs est très lent. C'est pourquoi, dans les monts Ruby, dans le sud-ouest du territoire du Yukon, on est surpris de trouver des langues et des îlots de végétation au milieu de certains champs de blocs. On propose comme mécanisme responsable de ce phénomène l'effondrement des lobes de solifluxion des pentes voisines. En passant de la pente douce de l'alpe à celle, plus forte, des champs de blocs, les lobes ne peuvent plus se maintenir à cause de cette pente plus prononcée, du changement de composition de la végétation et de l'épaisseur plus grande du mollisol. En s'effondrant, les lobes fluent le long de la pente, entraînant des masses de végétation qui s'établissent quelque part le long du chenal de coulée ou sur ses levées. De cette façon, de petits avant-postes de végétation se créent et accélèrent ainsi le processus qui, autrement, serait interminablement plus long.

РЕЗЮМЕ. *Роль солифлюкции в развитии растительного покрова на валунных полях.* В обычных условиях развитие почвенного и растительного покрова на валунных полях. протекает весьма медленно. Поэтому было интересно отметить наличие островков растительности на некоторых валунных полях в горах Руби на юго-западе Юкона. Предполагается, что появление растительности является результатом разрушения солифлюкционных глыб, сползающих с вышележащих склонов. Попадая на валунное поле, отдельные обломки, покрытые растительностью, создают необходимые условия для более интенсивного развития растительного покрова.

For anyone who has spent time beyond treeline in alpine or arctic areas, felsenmeer or blockfields are a fairly common sight. They are slopes consisting of large and small angular blocks arrayed in chaotic fashion, usually believed to be the result of rapid mechanical weathering *in situ* of bedrock. They also occur in the Arctic on more nearly level areas, and they may include glacially transported

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materials as well (Bird 1967, pp. 168-71). The origin of these features is not of particular concern here except to point out that, where they occur in present periglacial climates, they are usually still active owing to frost activity. The more unstable areas are easily identified by the relative absence of lichens on surface rocks and, conversely, areas heavily lichen-covered are usually more stable. One quickly learns to take advantage of this fact when climbing on these rocky slopes.

As might be expected, even within the arctic or alpine context, blockfields are inhospitable environments. Several factors contribute to this condition including the lack of fines (and therefore the almost complete absence of soil), the lack of water near the surface, and the great diurnal extremes in temperature during the summer due to high conductivity of the bare rocks. Thus, it is surprising to find scattered strips of soil and vegetation occurring amidst this sea of rocks. The origin of these "islands" of vegetation is of considerable interest since they can be considered as forerunners in the process of vegetating the slope, a process which would otherwise take indeterminately longer. It is suggested that the collapse of solifluction lobes from upslope is in some areas responsible for the early development of a plant cover on these slopes. The purpose of this paper is to describe this phenomenon and discuss the processes involved.

The study area is in the Ruby Mountains of southwestern Yukon Territory, Canada, approximately 150 miles (241 km.) northwest of Whitehorse and about 35 miles (56 km.) north of mile 1050 on the Alaska Highway (Fig. 1). The specific study site is near the head of an east-west valley of recent glacial origin with paternoster lakes occupying the valley floor. The south side of the valley (north-facing) consists of a steep rock wall with a number of talus cones emerging onto the valley floor. There is little vegetation on this slope and the rocks are largely lichen-free suggesting considerable weathering activity and mass movement. The south-facing slope is not quite as high as the north-facing slope and consists mainly of felsenmeer or blockfields. The rocks are lichen-covered, and occasionally interspersing the blockfields are tongues of soil and vegetation (Fig. 2).

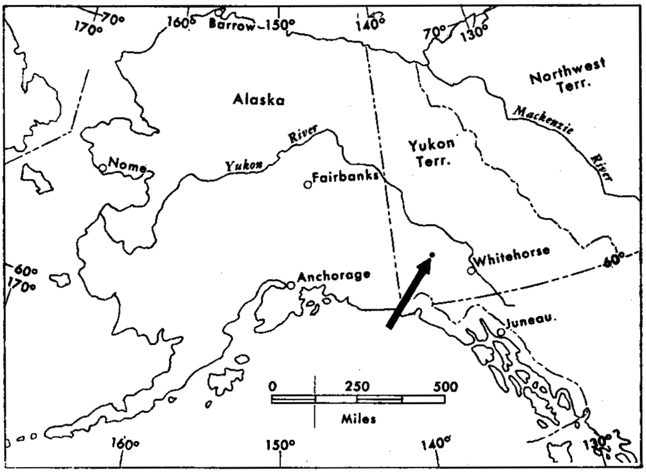

FIG. 1. Location of Study Area.

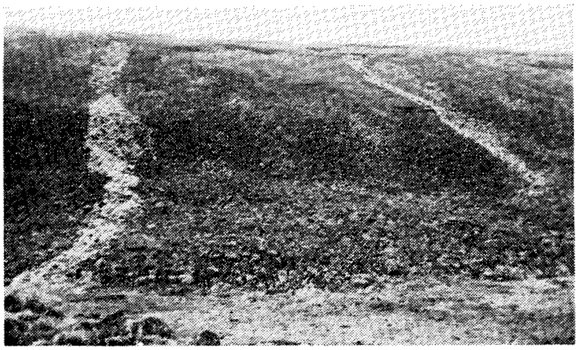

FIG. 2. South-facing slope showing two collapsed lobes which have moved downslope as mud-flows (light areas). The one on the left (No. 1) completely reaches the valley floor while the one on the right (No. 2) terminates ¾ the way down the slope. Solifluction lobes can be seen on the crest of the ridge as they pass onto the steeper blockfield below. Note the occasional tongues of soil and vegetation penetrating the blockfield.

The slope on which the blockfields are formed has an angle of 25° to 29°. Immediately above is an abrupt break in slope, marking the beginning of the alb of the glacial trough. The alb has a slope of 14° to 17°, and supports a relatively complete cover of tundra vegetation. There is no comparable alb on the north-facing slope where there is a very steep rock wall. The reason for this initial asymmetry is probably direction of ice movement and therefore more severe erosion on the south side of the valley (Gilbert 1904, pp. 579-88). Snow and ice patches still remain through the summer on this steep north-facing rock wall, and contemporary nivation along the rock wall has maintained its steepness, as well as contributing to the material of the talus cones below, which have formed since the valley was glaciated.

The entire area has been glaciated except for occasional peaks which remained as nunataks during glaciation, and it is probable that the upper slope was free of ice while the lower part of the valley was still occupied by valley glaciers (Muller 1967, pp. 9-16). Therefore, the upper slope has had more time for the accumulation of fines (through frost comminution), and the development of a soil and plant cover. This slope has also had more time to undergo mass wasting due to solifluction and frost creep.

Solifluction gives rise to several features, one of the most striking being solifluction lobes or terraces which are also known as soil runs, turf-banked terraces and detritus benches among other names (Taber 1943, p. 1461). These features are best developed where there is ample soil moisture (usually from late snow melt or from ground ice) and a good vegetation cover to act as a retarding agent to form the initial bulge which becomes the front of the lobe (Wilson 1952, pp. 251-52). Both of the above conditions are present in the study area and the lobes are well developed. They vary in height at the front from 1 to 6 feet (.3-1.8 m.), and occur as a series of scattered lobate tongues moving in the direction of greatest slope. Measurements made by the author at a nearby site (the results of which will be published separately) indicate a downslope surface movement on the order of ½ to 1 inch (1.3 to 2.5 cm.) per year. The lobes continue to retain their characteristic shape for several years even after passing over the abrupt break in slope between the alb and the lower valley slope. Eventually, however, they collapse and spill their contents downslope.

During the summer of 1967, four freshly collapsed lobes were observed to occur in less than 1,000 feet (305 m.) along the study slope (Fig. 3). Arcuate-like tension cracks immediately upslope from the basins testify to the "stretching" that has taken place in the surface layer after the collapse of the lobe fronts. Small streamlets from late snow melt and ground ice keep these crevasses water-filled until the middle of July and the area above the basins is quite unstable.

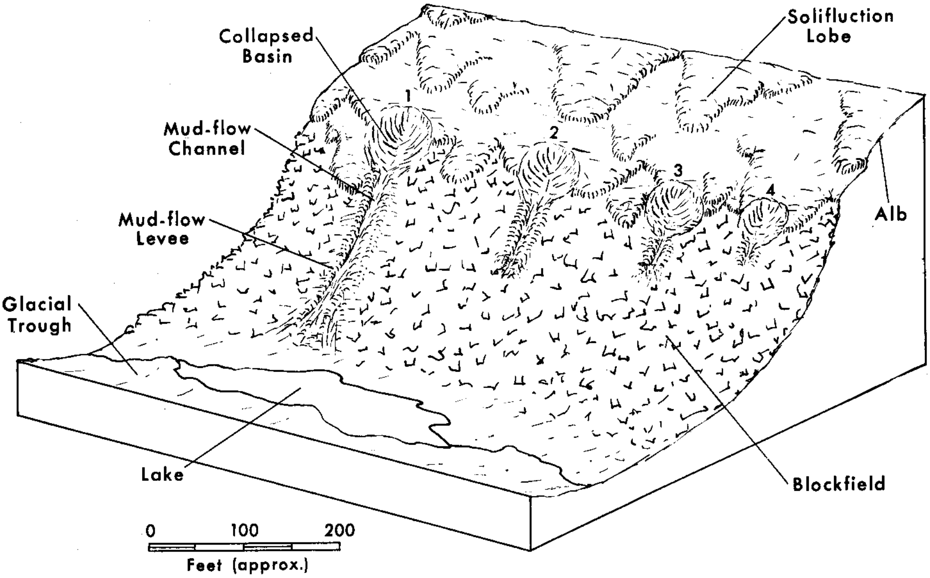

FIG. 3. Idealized block diagram of south-facing slope showing recently collapsed solifluction lobes and mud flows.

The largest collapsed basin (No. 1, Fig. 3) is the least active, as indicated by moss and lichens growing on the sides of the basin. The two smaller collapsed areas, Nos. 3 and 4, have fresh signs of movement including recently displaced mud, rocks, and clumps of vegetation. It is probable that these two sites will experience mud-flows in the near future, although not more than 1 or 2 feet (30 to 61 cm.) of material from the sides collapsed during 1967 and 1968. The most active of the four collapsed basins is No. 2. The collapsed area of the lobe was 65 feet (19.8 m.) wide and 95 feet (29 m.) long in the summer of 1967, but when we arrived for the 1968 field season, considerable collapse had taken place that spring and the basin was 73 feet (22 m.) across and 99 feet (30 m.) long. After a period of heavy rains in early August, the basin collapsed an additional 2 feet (61 cm.) headward and 4 feet 6 inches (1.4 m.) on the sides.

The most obvious reason why the lobes collapse after having passed the edge of the alb, is that the slope is 10° to 12° steeper. More specifically, it appears that once the lobes have passed the crest of the ridge onto the steeper part of the slope, collapse may be aided by a change which occurs in composition of the vegetation. This is supported by the fact that cotton-grass tussocks grow on the upper surfaces of the lobes occurring above the break in slope, but not on the lobes below the alb.

The tussocks are ball-like masses of plants and soil standing a few inches to 1 or 2 feet (30 to 61 cm.) above the poorly-drained surface. Principal species include *Salix pseudopolaris, Carex microchaeta, Salix reticulata,* and *Eriophorum angustifolium.* Mosses accumulate to a depth of 10 inches (25 cm.) or more around the rhizomes and adventitious roots of these plants, and provide excellent insulation helping to maintain the permafrost (tjaele) near the surface through the summer (Bliss 1956, p. 329). Reciprocally, the frozen layer maintains a high moisture content at the surface, which is necessary for the existence of the tussocks. The roots of tussocks are very intricate and well-developed, and several excavations showed live roots extending to a depth of 36 inches (91 cm.). Average depth, however, is about 20 inches (41 cm.). This well-developed root system acts as a binding agent and is largely responsible for maintaining the fronts of the solifluction lobes as virtual scarps up to 6 feet (1.8 m.) in height on the gentle upper slopes above the blockfields.

Once the crest of the slope is passed, however, the angle of incidence of solar radiation changes substantially (Fig. 4). The surface temperature increases and the active layer becomes deeper (measurements made nearby indicate that the surface of the risers of the lobes are on the average 20° F. (11° C.) warmer than the treads). With the retreat of permafrost there is less surface moisture. The higher surface temperature also increases the rate of evaporation. The tussocks are therefore slowly replaced by other species, especially *Dryas octopetala, Festuca altaica, Polygonum viviparum,* and *Cassiope tetragona.* The root systems of these species are not so well-developed and there are very few associated mosses, so the vegetation is less able to maintain the surface material of the lobe.

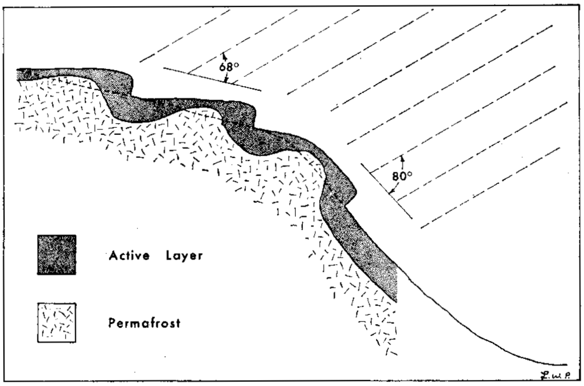

FIG. 4. Idealized cross section of south-facing slope showing depth of active layer on study slope. Variations in depths are largely in response to the insulating qualities of vegetation and the angle of incidence as discussed in text. Note the major difference in angle of incidence between the upper and lower slopes. These angles are calculated for slopes of 16° and 28°, respectively, at noon on summer solstice at 61° 30′ North Latitude.

In addition to the changes which take place in the composition of the vegetation, there is a corollary development in the level of permafrost as a result of varying vegetation and slope. The data for permafrost depths were gained by augering at 5-foot (1.5 m.) intervals in transects up the slope. A generalized picture of what occurs is shown in Fig. 4. As can be seen, on the upper slope the active layer is deeper near the front of the solifluction lobes. This is due to the greater angle of incidence of solar radiation and a vegetation cover having poor insulating qualities. The active layer becomes shallower both above and below the front because of tussock vegetation containing quantities of moss which is good insulation material. The lobes are apparently able to maintain themselves indefinitely under these conditions.

On the steeper slope, as shown in Fig. 4, the active layer below the last lobe does not arch upward as it did on the gentler slope because the insulating vegetation has disappeared for the reasons stated above. The entire area, then, is subject to movement due to gravity with no retardation to movement by the upward swell of permafrost below the lobe as exists on the gentler slope. The combination of factors 1) shallower root systems, 2) deeper active layer below the lobe, and 3) steeper slopes, all contribute to the collapse of the lobes.

In spring when melt occurs and the land is a well-saturated morass, the surface of the lobe moves slowly downhill due to solifluction. Permafrost is still relatively near the surface on the upper part of the lobe and is parallel to its outer surface. Movement takes place in the saturated zone above permafrost and pressure is built up against the vegetation retaining the front of the lobe. Eventually the front is not able to retain itself and collapses. The above conditions would be especially enhanced after two or three days of steady rain (Sharpe 1938, p. 55). This additional water adds a great deal of weight to the active layer above the permafrost, and exerts even more pressure in the downslope component. In addition, it acts as a lubricant and reduces the shear strength of the soil (Williams 1957, p. 52; Taber 1943, p. 1458).

All of the major movements (i.e., slumping and mudflow), that we observed during the summers of 1967-68, occurred during or soon after heavy rains. This, of course, is in addition to the movement to be expected during break-up and freeze-up in spring and fall. During a three-day period in late July, 1967, 2.86 inches (7.26 cm.) of rain fell, and on the third night, we were awakened by the rumble of falling rocks and debris caused by part of a slope giving way near our camp. In the local area, there were several scars on the landscape as a result of that particular rainfall. Although these disturbed areas were not all solifluction lobes, they nevertheless illustrate conditions under which collapse might be expected to take place. During the summer of 1968, 2 heavy rain periods occurred — one in early July with 1.70 inches (4.3 cm.) in 2 days, and the other in early August with 3.97 inches (10.1 cm.) in 7 days. Considerable fresh movement was observed on several of the disturbed areas after each rainfall, including that which took place on collapsed lobe No. 2, as previously mentioned.

When the lobes do collapse, the movement appears to be fairly rapid, as suggested by the mud-flow channels and levees immediately downslope. These are of the same type as described by Sharp (1942, pp. 222-27), although his observations deal mainly with alluvial slopes. Basically, it is the downhill flowing of rocky detritus, including boulders two or three feet in diameter, in a saturated mass of mud. The material tends to move in spurts, the snout of the flow wedging its way along the leading edge, windrowing the material in snow-plow fashion on either side, giving rise to features similar to natural levees on a stream. Clumps of vegetation, broken loose from the upper surface of the lobe, are also carried down the mudflow channel and they are deposited helter-skelter on the levees (Fig. 5).

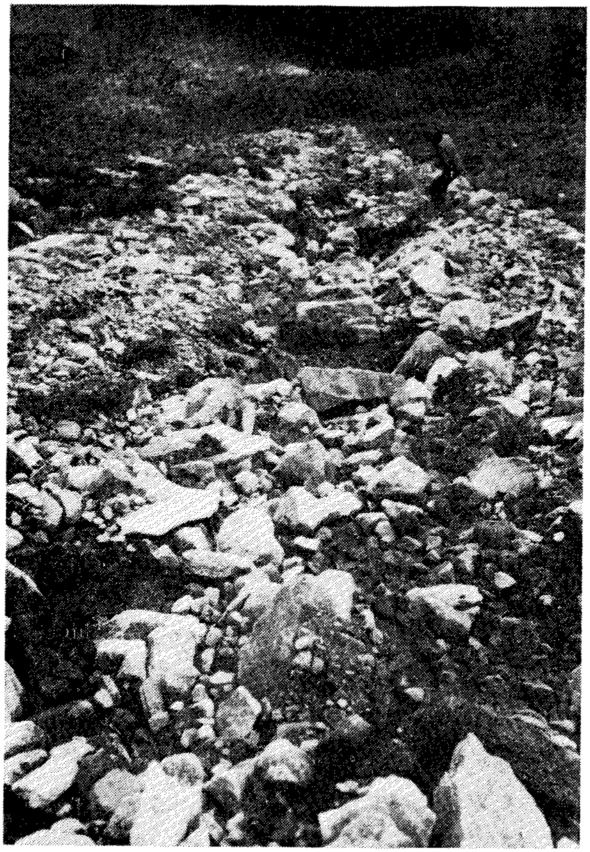

FIG. 5. Looking downslope at mud-flow channel immediately below collapsed basin of solifluction lobe. Note clumps of vegetation at the level where man is standing. Lake on valley floor is at top of photo. Even though this mud-flow channel is at least 9 years old, it still appears surprisingly fresh.

It is not surprising that these dislocated plants survive in their new habitat. Tundra vegetation in general exists because of its ability to live in an environment of constant flux. The particular adaptation with survival value in this case would be the ability to reproduce vegetatively. Nevertheless, if the plants are successful in becoming established before the fine material is carried away by erosion, a small island of vegetation is established. The amphitheater-like collapsed area of the lobe eventually becomes vegetated and the slope again appears to maintain some semblance of stability until another lobe from above moves downslope and collapses, and the process is repeated.

The foregoing is not meant to suggest that this process of developing a plant cover on blockfields is rapid. On the contrary, although the collapsed lobes appear very recent, they are present on airphotos taken by the Canadian Air Force in 1959. Collapsed basin No. 1 (see Fig. 3) is the oldest of those mentioned, and revegetation has partially begun. Its mud-flow channel has completely reached the valley floor and a similar prospect seems to be in store for the other collapsed lobe sites if current rates of movement continue. Evidence of former collapsed basins, and mud-flow channels and leeves, are present on the slope as well, and some may be several hundreds of years old. So, succession is very slow, but the process is directional and there is enough evidence on the slope representing different stages in its development, to suggest the central hypothesis of this paper: that the collapse of solifluction lobes is one way in which certain arctic and alpine slopes are vegetated more quickly than they would be otherwise.

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